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Rebeca da Silva Nascimento Pereira (DESIGN - UFSC)

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CONTATO
lisiane.librelotto@ufsc.br
ferroli@cce.ufsc.br

DIREITOS DE PUBLICAÇÃO
Lisiane Ilha Librelotto, Dra. (UFSC)
Paulo Cesar Machado Ferroli, Dr. (UFSC)
UFSC | Universidade Federal de Santa Catarina
CTC | Centro Tecnológico
CCE | Centro de Comunicação e Expressão
VirtuHab
Campus Reitor João David Ferreira Lima
Florianópolis - SC | CEP 88040-900
Fones: (48) 3721-2540
(48) 3721-4971
Capa por: Guilherme Thielen em Bio Diversity 4 All.

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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.

ARQUIVAMENTO

Esta revista utiliza o sistema LOCKSS para criar um sistema de arquivo distribuído entre as bibliotecas participantes e permite às mesmas criar arquivos permanentes da revista para a preservação e restauração.

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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.
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MIX SUSTENTÁVEL VOL. 10 N. 3 – EDIÇÃO REGULAR

TRAJETÓRIA: DE 2014 A 2024, 10 ANOS DIVULGANDO A PESQUISA EM SUSTENTABILIDADE

Em 02 de Dezembro de 2015 publicamos o primeiro número da MIX Sustentável. Essa publicação foi o resultado do projeto de extensão denominado "Proposta de Periódico – MIX Sustentável", submetido ao edital Probolsas de 2014 da UFSC, que neste mês completa 10 anos.

A partir de uma conversa de lanchonete, no intervalo das aulas na universidade onde trabalhávamos, nasceu o evento ENSUS – Encontro de Sustentabilidade em Projeto, que em 2007 teve a sua primeira edição. Em seguida, para ampliarmos o alcance do evento e premiarmos os melhores artigos, modificamos uma revista comercial de nome MIG editada por um amigo, para que ela se tornasse um periódico científico e com ela publicamos duas edições do evento em 2008 e 2009.

Em 2009 e 2010 migramos de uma instituição privada para a pública e demoramos para entender os caminhos para continuar com as nossas ações. Após um intervalo de 5 anos, retomamos o evento ENSUS e criamos a revista Mix Sustentável. Nessa trajetória, entre buscar recursos nos editais próbolsas, atrair artigos para as edições regulares, buscar pelo apoio que não encontramos no portal de periódicos da UFSC, cadastrar o periódico em bases de dados, diretórios de buscas, indexadores, entender sozinhos todos os meandros da publicação científica, dos critérios de avaliação QUALIS e até implorar pelo envio de artigos (e por vezes ter de rejeitá-los depois) para fecharmos as edições e assegurarmos a qualidade, não foi uma tarefa muito fácil.

Estas iniciativas partiram de uma abordagem de integração dos pilares da sustentabilidade, tendo muita influência das trajetórias acadêmicas dos editores. A MIX surgiu como uma alternativa para os pesquisadores que não encontravam um periódico cuja característica principal fosse a abordagem da sustentabilidade no projeto, procurando um meio de interligação entre as áreas da arquitetura, design e engenharias. Aproximar essas áreas, que por características da formação possuem diferentes níveis de abstração foi muito importante para trazer o olhar inter e transdisciplinar, complementares, para a solução de um problema tão complexo quanto a (in)sustentabilidade, de onde surgiu a base dessa ciência. Esse mesmo princípio norteia o evento ENSUS, assim como todas as pesquisas e atividades desenvolvidas no contexto do grupo de pesquisa VirtuHab.

Durante estes 10 anos a MIX passou a ser conhecida e reconhecida e hoje comemoramos mais um número lançado, cuja diversidade dos temas, instituições e regiões permite que se tenha um diagnóstico das pesquisas na área da sustentabilidade no contexto nacional. Seu Qualis A3 e a quantidade de artigos que estamos recebendo, além do importante trabalho dos revisores, só mostra o quão longe foi o nosso alcance.

Dividiremos esse editorial nas áreas da revista, comentando inicialmente os artigos relacionados à Arquitetura.

O artigo **The contribution of the psychology of religion and spirituality to the development of sustainability in smart cities**, oriundo da Universidade Estadual do Centro-Oeste (UNICENTRO), traz uma reflexão conceitual com foco no ODS 3, e expões de que modo a espiritualidade pode desempenhar um papel crucial na formação de cidades inteligentes, oferecendo caminhos para que a sustentabilidade seja alcançada.

Da Universidade Federal de Mato Grosso do Sul (UFMS) com contribuição da Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), vem o artigo **Green Infrastructure Multifunctional Networks and Water-Ocused Approach: A Literature Analysis** que analisou 4.395 artigos no período entre 2013 e 2023, sobre como a Infraestrutura Verde (IV) ascendeu como um elemento fundamental no fomento de iniciativas urbanas sustentáveis.

O artigo **Tools for Assessing the Financial Sustainability of Integrated Management Systems of Urban Solid Waste**, de pesquisadores da Universidade Federal do Espírito Santo (UFES) e da Universidade Federal de Santa Catarina (UFSC), tem como principal objetivo trazer contribuições para pesquisas futuras e para o planejamento do GIRSU (Gerenciamento Integrado de Resíduos Sólidos Urbanos).

Da Universidade de Pernambuco (UPE), o artigo **Economic-Financial Feasibility Analysis of Projects in Historic Sites: Case of Engenho Monjope** apresenta um estudo de viabilidade econômico-financeira do patrimônio histórico-cultural do Engenho Monjope, construído em meados de 1.600 e sendo tombado em 1986, pelo Governo do Pernambuco, como Patrimônio Histórico Estadual.

Na área da engenharia nas suas várias ênfases, os artigos deste volume são:

Artigo **Technical feasibility study of a CCW recycling plant in Juazeiro do Norte-CE**, trabalho conjunto que reuniu pesquisadores da Universidade Norte do Paraná (UNOPAR), Universidade Federal do Cariri (UFCA) e Universidade Federal do Tocantins (UFT), e que tratou da análise da viabilidade técnica da implantação de uma usina de reciclagem de resíduos da construção civil em Juazeiro do Norte.

O artigo **Use of Calcium Carbonate sludge as filler in hot mix asphalt concrete sludge**, é assinado por pesquisadores da Universidade do Vale do Rio dos Sinos (UNISINOS), com contribuição da Universidade Federal do Rio Grande do Sul (UFRGS), e apresenta uma pesquisa voltada a materiais na construção civil, especificamente visando a redução do cimento asfáltico petrolífero na composição das misturas, com potencial utilização deste resíduo como carga em concretos asfálticos usinados a quente.

Pesquisadores da Universidade Federal de Ouro Preto (UFOP), Universidade Federal de São João del-Rei (UFSJ), Centro Universitário Presidente Antônio Carlos (UNIPAC) e Universidade Federal de Minas Gerais (UFMG) apresentam o artigo **Feasibility Study of the use of Iron ore Tailings as Pigment in Polypropylene Resins**, que procura respostas ao problema dos grandes volumes de rejeitos durante o processo de beneficiamento dos minérios, resultando em impactos ambientais severos.

Também da Universidade do Vale do Rio dos Sinos (UNISINOS), o artigo **Characterization and Processing, by Mechanical Processing, of Printed Circuit Boards of Post-Consumer Smartphones** apresenta um estudo em 87 smartphones, concluindo que as técnicas de processamento mecânico mostradas são eficientes para a concentração de metais e ligas, especialmente o cobre, e que podem trazer benefícios econômicos e ambientais.

Da Universidade Federal do Mato Grosso (UFMT), o artigo **Investigation of Ground Temperatures for the Implementation of Geothermal Systems in Historical and Future Periods** apresenta uma investigação sobre as variações nas temperaturas do solo em quatro cidades de Mato Grosso, cuja ênfase foi na necessidade de implementar estratégias de resfriamento passivo em edifícios, especialmente em regiões quentes, para se adaptar às condições futuras no cenário de mudanças climáticas.

O artigo **The Role Of Renewable Hydrogen in Achieving Sustainable Urban Transportation**, oriundo da Universidade Federal do Rio de Janeiro (UFRJ), trato da adoção de um sistema de produção e distribuição de hidrogênio, atualmente em destaque global, impulsionada por seu menor impacto ambiental em comparação com os combustíveis fósseis.

Da Universidade Federal de Santa Maria (UFSM), os pesquisadores assinam o artigo intitulado **Assessment of The Mechanical and Environmental Properties of Concretes With High Levels of Lime Filler and Fly Ash**, cujas conclusões mostram ser possível a obtenção de Concretos de Alta Resistência com fck de até 80 MPa e baixas emissões de CO2, com o emprego de elevados teores de adições minerais.

Para finalizar os artigos a seguir são relacionados ao design e conscientização/educação ambiental:

Da Universidade Federal do Paraná (UFPR), o artigo **The Future of Work In Fashion in Light of Emerging Technologies: Preliminary Study**, objetiva trazer os primeiros resultados de uma pesquisa elaborada em prol de obter diretrizes para o trabalho remoto na moda, no formato distribuído, auxiliado pelas tecnologias digitais emergentes.

O artigo **Greenwashing and Boycott: Critical Appreciation of Academic Production** é resultado do trabalho de pesquisadores da Universidade Federal de São Paulo (UNIFFESP), e aborda a questão da falta de regulamentação efetiva, que tem contribuído para a proliferação da prática de greenwashing, relegando a responsabilidade de identificação, diferenciação e proteção aos consumidores.

Analysis of Consumers' Willingness to Adopt Sustainable Practices When Changing Automotive Lubricating Oils, é um artigo proveniente de um grupo de pesquisadores da Universidade Estadual do Oeste do Paraná (UNIOESTE), e apresenta como contribuição a confirmação da disposição dos usuários para pagamento adicional por práticas ecológicas, destacando a importância da conscientização ambiental na tomada de decisões.

O artigo **Reinvent: a Project Composite Sustainable**, proveniente da Universidade Tecnológica Federal do Paraná (UTFPR), apresenta um novo compósito, que mostrou-se um excelente material alternativo a ser utilizado na criação de projetos de bioengenharia e design de interiores, combinando aspectos de inovação e meio ambiente.

A revista ainda traz cinco resumos, quatro de dissertações de mestrado e um de iniciação científica. Desejamos a todos uma ótima leitura.

Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli – editores.

TECHNICAL FEASIBILITY STUDY OF A CCW RECYCLING PLANT IN JUAZEIRO DO NORTE-CE

ESTUDO DE VIABILIDADETÉCNICA DE USINA DE RECICLAGEM DE RCC EM JUAZEIRO DO NORTE-CE

ESTUDIO TÉCNICO DE FACTIBILIDAD DE PLANTA DE RECICLAJE DE RCC EN JUAZEIRO DO NORTE-CE

MATHEUS SOUZA DE LEITE | UNOPAR – Universidade Norte do Paraná, Brasil
MARCUS VINICIUS DE OLVEIRA BRASIL, Dr.| UFCA – Universidade Federal do Cariri, Brasil
MARIA GORETHE DE SOUSA LIMA BRITA, Dra.| UFCA – Universidade Federal do Cariri, Brasil
GABRIELA AGUIAR REZENDE | UFT – Universidade Federal do Tocantins, Brasil

ABSTRACT
The objective of the article is to analyze the technical feasibility of implementing a construction waste recycling plant in Juazeiro do Norte, for this purpose initially studying the feasibility in terms of demand for the plant by surveying the annual volume of waste recyclable materials from class A civil construction in the municipality of Juazeiro do Norte, which would host this hypothetical plant. In a second step, the path to be taken by the waste from its generation to its destination was studied under the local legislative perspective. Studies were also carried out on the national scenario of construction waste recycling plants to point out possible characteristics that the local plant should have to meet the intrinsic needs of Juazeiro. In this way, it was possible to observe that the municipality provides sufficient demand for a waste recycling plant, in addition to the fact that local legislation still lacks greater regulation for the sector, but with a more encouraging scenario with the study process and the implementation of a consortium intermunicipal project to deal with urban solid waste.

KEYWORDS
Environmental impacts; public policy; Generation profile; Cariri.

RESUMO
O objetivo do artigo é analisar a viabilidade técnica da implantação de uma usina de reciclagem de resíduos da construção civil em Juazeiro do Norte, para tanto inicialmente estudou-se a viabilidade em termos de demanda para a usina por meio do levantamento do volume anual de resíduos recicláveis da construção civil de classe A no município de Juazeiro do Norte, ao qual sediaria esta usina hipotética. Em um segundo momento foi estudado o caminho a ser realizado pelo resíduo desde sua geração até sua destinação final sob o olhar legislativo local. Foram também realizados estudos quanto ao cenário nacional das usinas de reciclagem de resíduos da construção civil para apontar possíveis características que a usina local deveria ter para atender as necessidades intrínsecas a Juazeiro. Desta forma pôde se observar que o município fornece demanda suficiente para uma usina de reciclagem de resíduos, além de que a legislação local ainda carece de maior regulação para o setor, porém com um cenário mais animador com o processo de estudo a implantação de um consórcio intermunicipal para tratar dos resíduos sólidos urbanos.

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PALAVRAS-CHAVE

Impactos ambientais; políticas públicas; geração de resíduos sólidos; Cariri.

RESUMEN

El objetivo del artículo es analizar la viabilidad técnica de implementar una planta de reciclaje de residuos de construcción en Juazeiro do Norte, para ello se estudia inicialmente la viabilidad en términos de demanda de la planta, mediante el levantamiento del volumen anual de residuos de materiales reciclables de clase A civil. construcción en el municipio de Juazeiro do Norte, que albergaría esta hipotética planta. En un segundo paso, se estudió el camino que seguirán los residuos desde su generación hasta su destino final bajo la perspectiva legislativa local. También se realizaron estudios sobre el escenario nacional de las plantas de reciclaje de residuos de la construcción para señalar posibles características que debería tener la planta local para satisfacer las necesidades intrínsecas de Juazeiro. De esta manera, se pudo observar que el municipio brinda suficiente demanda para una planta de reciclaje de residuos, además de que aún falta en la legislación local una mayor regulación para el sector, pero con un escenario más alentador con el proceso de estudio y la implementación. de un consorcio intermunicipal para abordar los residuos sólidos urbanos.

PALABRAS CLAVE

Impactos ambientales; políticas públicas; generación de residuos sólidos; Cariri.

1. INTRODUCTION

Nowadays, the city of Juazeiro do Norte, which is the largest in terms of population in the Cariri region of Ceará, generates tons of Civil Construction Waste (CCW) that are discarded of in landfills or at collection points called "bota-fora" (AMAJU, 2016).

Demonstration of leadership of the civil construction in this scenario is described by Evangelista (2010), when he mentions that in the sectors that have the most impact on the environment, the main generator of solid waste in a society are those from civil construction. and in relation to the impacts of the irregular disposal of construction waste, the Brazilian Association for Recycling of Civil Construction and Demolition Waste - ABRECON (2015), states that its irregular disposal can result in drainage problems, floods and pollution that result in more disease vectors, and also providing an increase in public expenditure. thus, in addition to avoiding social and environmental constraints, actions to inhibit this inappropriate disposal generate savings for the State.

For many years, the civil construction industry generated not so good impacts on the environment, causing scarcity and degradation of natural resources, so that it was necessary to instigate the way that environmental issues are thought and treated at the end of the 20th century (Klepa *et al*., 2019). To prove the environmentally appropriate destination of solid waste Bessa (2019), reports that an institution needs to prepare a management plan, which must fit the decisions adopted in the process of collection, transport and final disposal in order to give them a correct destination and sustainable management.

The civil construction industry and inadequate waste disposal have a high potential for degradation and are influenced by human activities amplified due to exacerbated consumption, resulting in damage to the environment (Silva; Fucale; Ferreira, 2020). Francisco et al. (2020), explains that the final disposal of waste in an appropriate way, leads to a healthy, clean and profitable environment for businesses, and also avoiding the propitiation of natural disasters and fines.

Law 1235/2010, which deals with the National Solid Waste Policy - NSWP, mentions these problems, opening the way for good solutions by encouraging the fight against waste generation, bringing reusable waste back to the production chain and depositing waste in appropriate places.

Vergani (2024) highlights the importance of higher education institutions in implementing the circular economy, contributing to the dissemination of information to future citizens.

In this way, the present work has the objective of analyzing the technical viability of implementing a recycling plant for civil construction waste in Juazeiro do Norte, using data about the legal cycle of recyclable waste from civil construction, as well as estimating the annual volume of recyclable waste from Class A civil construction in the municipality of Juazeiro do Norte, and the discussion of the national scenario of civil construction recycling plants and the local context for a hypothetical plant.

2. THEORETICAL FRAMES

2.1 Relevant legislation

The definition of construction waste is given by Brazil (2010) as waste arising from construction, renovations, repairs, demolitions, excavation and land preparation for civil works.

According to (Brazil, 2002), the National Council for the Environment (CONAMA), in its Art. 3 describes civil construction waste through classification, based on its characteristics, which are:

> I - Class A - are reusable or recyclable waste as aggregates, such as:
> a) construction, demolition, renovations and repairs of paving and other infrastructure works, including soil from earthworks;
> b) construction, demolition, renovations and repairs of buildings: ceramic components (bricks, blocks, tiles, cladding boards, etc.), mortar and concrete;
> c) manufacturing and/or demolition process of precast concrete parts (blocks, tubes, curbs, etc.) produced at construction sites;
> (Brazil, 2002, p. 95-96).

According to Souza (2021), the average gravimetry of these wastes for Class A corresponds to 87.7%, thus demonstrating their propensity for recycling and reuse.

And about the relationship between human beings and the environment Brazil (1988), guarantees in its Art. 225 that everyone has the right to an ecologically balanced environment and, to ensure this right, the principle of shared responsibility was established.

The goal of sustainable development can be achieved through the implementation of city solutions and technologies, thus contributing to improved efficiency and economic growth (Sharifi, 2024).

According to Brazileiro and Matos (2015), CONAMA Resolution No. 307/2002 was the first national initiative to establish guidelines, criteria and procedures in the management of civil construction waste. CONAMA Resolution No. 348/2004 (Brazil, 2004) promoted the inclusion of asbestos as Class D, considering it a hazardous waste, while Resolutions No. 431/2011 (Brazil, 2011) and No. 469/2015 (Brazil, 2015) promoted, respectively, the inclusion of plaster and paint packaging in class B, making them recyclable and consequently allowing their reinsertion in the production chain.

After all, Resolution nº 448/2012 (Brazil, 2012) updated the CONAMA resolutions bringing guidelines from Law 12.305/2010 that deals with the National Policy on Solid Waste, such as the responsibilities of the generator and the introduction of the objective of reusing this CCW.

In Chapter II, art. 3, item X of the national solid waste policy cited by Brazil (2010), it is evident the need to contemplate the municipal solid waste plan or the solid waste management plan to delimit actions directly or indirectly in waste management.

Regarding the current legislation in Juazeiro do Norte, we can mention Complementary Law nº 10/2016, which establishes the Code of Posture and mentions that the property owners are responsible for cleaning, and can be fined if they do not follow the rules. (Juazeiro do Norte, 2016). In addition to this, we have Law No. 3689/2010, which establishes the Integrated Plan for Civil Construction Waste Management (IPCCWM) and the Sustainable Management System for Civil Construction Waste (SGSR-CC).

This law punishes all generators, transporters and receivers of waste and disposes the waste by the name of rubble, understanding that it is a heterogeneous material from civil construction (Juazeiro do Norte, 2010).

The complementary Law nº 85/2012 promoted the creation of the Juazeiro do Norte Municipal Environmental Authority, an important milestone in environmental management related to the characteristic of promoting environmental licensing, still having the power of environmental control and inspection (Juazeiro do Norte, 2012).

The decree nº 219/2015 established the municipal sanitation plan that defined goals that will always be followed in this area, such as registration of solid waste transporters, study of the implementation of an intermunicipal consortium and continuous supervision of the management and disposal of solid waste (Juazeiro do Norte, 2015).

The decree No. 226/2016 developed improvements in aspects of Law No. 3,689 in relation to the regulation of the collection, storage, transport and disposal of construction waste that were not included in the regular collection, also including details to regulate registration and authorization of companies specializing in waste collection (Juazeiro do Norte, 2016).

2.2 Definitions of construction waste elements

The definition of civil construction waste generators is given by Brazil (2002), as being the public or private persons of a physical or legal nature responsible for the generation of waste. For Francisco et al. (2020), the actions and models of disposal and non-reuse of waste produced in civil construction are influenced by the priority criterion on environmental issues and the financial view of builders.

According to Brazil (2002), the carriers are responsible for collecting and transporting construction waste from origin to final destination and may be individuals or legal entities.

Han (2024) reports that strategies such as the use of BIM can help in the management of solid demolition waste, contributing to the environment, in addition to contributing to financial efficiency.

Municipal Law No. 3689 of 2010 reports that the dimensions of stationary buckets must have a capacity of 7 m^3, and the waste cannot overflow the edge, its transport must be carried out by buckets with specific colors according to the company, legible name, telephone number, number of the bucket, and a notice stating that it is forbidden to put domestic garbage (Juazeiro do Norte, 2010).

This same law also states that all transport must be carried out after printing a waste transport order (WTO) indicating information pertinent to the identification of the company, as well as the origin and destination of the material. As soon as the bucket is removed from the site, the company is obliged to clean it, this place being preferably inside the work and protected by fences, and as a last resort, placed on a public road (Juazeiro do Norte, 2010).

Brazil (2002) states that the area for transshipment and sorting of civil construction waste is a space whose function is sorting and temporary storage for a subsequent transition to the final destination that respect operational standards.

But the environmentally appropriate destination was given by Brazil (2010), which defines it as those who are

able to reuse, recycle or dispose the waste following the current regulations, ensuring safety and preserving the environment. The destination is in charge of the indication of the municipal autarchy of the environment of Juazeiro do Norte since it is responsible for the management and inspection of the residues (Juazeiro do Norte, 2010).

2.3 Public Policies

In 2010, the NSWP was approved through Law nº 12.305 of 2010, being a legislative advance in the subject that uses the principle of shared responsibility and its implications set out in article 3 - item XVII, dealing with the disposal of waste produced (Brazil, 2010).

Concerning the legislation at states level, Ceará (2016) through Law No. 16.032/2016, instituted the State Policy on Solid Waste (SPSW) which brings together a range of guidelines, objects, principles and goals in line with the NSWP. However, adapting the particularities that are required due to the nature of the service.

This state legislation also encourages public-private partnership, promoting it in inter-municipal cooperation in the search for new solutions in the management of solid waste. In addition, it also provides for the formulation of what would become the state waste plan, as well as the need for a municipal plan for the integrated management of solid waste in force for an indefinite period and horizon of every 20 years, being updated in at least, every four years.

By Law No. 3689 of Juazeiro do Norte (2010), the generator has a series of responsibilities through the production of construction waste, and must be careful not to dispose of it in a public environment or inappropriate place. In addition, it is also up to the generator the removal of this material, being able to transport it or hiring another company to do it.

Those responsible for the waste must have a permit from the city hall, which will also indicate the designated place for the correct disposal of the material. In the aforementioned law, through Article 5 in § 1, the law also gives the possibility of using material of a mineral nature, provided that it is suitable for application as a landfill (Moura, 2018).

The municipal waste management policy was further detailed through Decree No. 226 of Juazeiro do Norte (2016), which included the Juazeiro do Norte Municipal Environmental Authority (AMAJU) in the process of controlling and inspecting transporters. In addition, it also included new regulatory aspects for transport companies specializing in construction waste in their registration, authorization and operation.

A recent positive environmental inspection action according to Juazeiro do Norte (2021) was the creation of a group to combat inappropriate disposal at clandestine accumulation points in the municipality, initially having an educational character, but with the possibility of applying the legislation.

2.4 Recycling Plants

According to Brazil (2010), recycling is the process of changing the physical, physio-chemical and biological properties that aim to create a new material that can be reinserted into the production chain, provided it meets the minimum standards required. In this way, construction waste can be considered as recycled products.

Klepa *et al*. (2019), reports that civil construction has a high potential for generating job and business opportunities, contributing substantially to the gross national product, thus being a great promoter in the economy. Technological innovation and inputs in the civil construction industry, motivated by sustainability, can generate alternatives to the problem of reducing the availability of resources available in nature (Marques *et al*., 2020).

In this context, for Paschoalin (2019), recycling plants reduce the environmental impact and have a high potential for contributing to the circular economy of waste management. However, they still have difficulties in controlling processes and products.

2.4.1 Profile of recycling plants in Brazil

The recycling plants come to contribute with a sustainable gain. In order to become viable, an amount is charged per cubic meter of waste received, which according to ABRECON (2015), ranged from R$10.00 to R$20.00 (quotation made in Brazilian currency, reais) per meter cubic received, which is much cheaper when compared to values practiced in Europe when converting currencies.

For Lima (2013), it is common to observe, within an international experience, charging the value of waste based on established content. Heterogeneity is considered to avoid contaminating elements that could damage the equipment or disrupt recycling. A good example of this way of working is a container that is considered as homogeneously containing concrete in Spain must have 95% of this material to be accepted, while in Germany the minimum admissible value rises to 99% to be accepted.

For Lino (2023), waste can no longer be seen as valueless materials, given their embedded economic, social, and environmental potential.

Even though they don't charge for material content when recycled, their products don't usually go through very rigorous quality control processing. Considering that, according to ABRECON (2015), 23% of recycling plants do not or have never carried out technical testing of products; 25% only perform when requested, in addition to the fact that just over a quarter of these plants are implemented in cities with up to 200 thousand inhabitants; and 60% of recycling plants in the country employ only 5 to 10 employees, demonstrating that it is possible to implement them in small and medium-sized cities and with low cost in terms of labor.

Francisco *et al*. (2020), states that the scenario with the existence of proper disposal of this waste can provide profitability and sustainability, in addition to avoiding fines. This fact is confirmed, since, according to ABRECON (2015), most Brazilian recycling plants are managed by the private sector, in addition to the fact that construction companies are also their biggest customers, followed by the public authorities. However, the main difficulties in selling recycled waste from civil construction, according to those responsible for the plants, are due to the high tax rates, the lack of knowledge of the market and the absence of legislation that encourages consumption.

According to ABRECON (2018), most recycling plants are concentrated in the Southeast, more precisely in São Paulo, demonstrating a great potential for expansion in the sector in other states, with a national growth rate of 10.5 plants per year.

2.4.2 Regulatory rules for recycling plants in Brazil

The NBR 15112 contributes to the temporary and environmental preservation of the transshipment areas that receive the material, performing first the sorting and then the destination of the rejects to an appropriate landfill that follows the NBR 15113 molds. However, the recyclable portion will pass to the step of recycling that is designated by NBR 15114, making the material re-applicable in society along with reusable waste that, in case of application in road paving and non-structural concrete, will follow the descriptions said by NBR 15116.

2.4.3 Classifications of recycling plants in Brazil

The recycling of construction waste can be classified according to mobility, which can be classified as fixed, mobile and semi-mobile (Damasceno, 2019).

Another possible classification for the plants is the occurrence of a simple screening until it promotes the complete removal of contaminants from the material, which can be designated as first, second or third generation (Sobral, 2012).

Stationary recycling plants have, according to Damasceno (2019), positive characteristics, such as plants that present higher quality of their products and have more robust equipment, being able to obtain a higher production than the others.

For Damasceno (2019), the mobile recycling plant, on the other hand, has the advantage of not needing to be fixed in a certain location and not having costs associated with the assembly and disassembly of the equipment. In his work, Sobral (2012) reported that mobile recycling plants are common in undertakings with constant movement such as the construction of highways, and may be transported using special trailers.

The semi-mobile recycling plant, on the other hand, has the practicality of allowing its displacement, but at the same time presents a cost associated with its mobilization and demobilization, as exposed by Damasceno (2019). The use of this type of recycling plant is intended for businesses that have a specific installation period, such as the construction of hydroelectric plants, and it is also common to have their bases in metallic structure to facilitate assembly and disassembly.

Comparatively, when observing ABRECON (2015), it is noticed that fixed plants have priority, compared to the others and followed by the mobile plant, which showed growth in the period between 2013 and 2015. This is due to the flexibility of use and greater economic viability due to the economy of transporting waste containers to the recycling plant.

Table 1 systematically shows the types of plants mentioned above, as well as their application and their advantages and disadvantages.

According to Sobral (2012), plants can also be classified as first, second and third generation. The first type is when there is a removal through machinery such as electromagnets, the second presents a greater sophistication in the cleaning and sorting processes guaranteeing a greater removal of impurities and the third presents the complete removal of these impurities being often associated with dry or wet aggregate separation processes, and sometimes the combination of both.

For Fogliarini (2018), the first generation is the simplest, containing conventional crushing equipment

Type of plant	Applicability	Advantages	Disadvantages
Mobile	Works that require constant movement	Easy mobility	Low volume recycled compared to other
Semi-mobile	Works with a defined term and that are large enough to demand a plant	Can be moved and tend to recycle more material than the mobile	cost of mobilization
Fixed	Receiving a large volume of waste	highest potential volume to be recycled	High implementation cost

Table 1: Summary table of civil construction recycling plants aspects in terms of mobility.
Source : The researchers (2024)

and magnetic magnets, as being responsible for the separation of contained metallic elements. The second generation are comparable to the first in terms of design simplicity, however they include greater sophistication compared to the first in terms of separation, sometimes material can be removed, in addition to the use of electromagnets. Finally, the third generation aims at the almost complete removal of impurities based on dry, wet or thermal processes, or even a combination of them.

According to Sobral (2012), recycling plants can also be classified as first, second and third generation. The first type is when there is a removal through machinery such as electromagnets, the second presents a greater sophistication in the cleaning and sorting processes guaranteeing a greater removal of impurities and the third presents the complete removal of these impurities being often associated with dry or wet aggregate separation processes, and sometimes the combination of both.

The equipment for such use can range from magnetic separators for the removal of ferrous and metallic elements, floatation purification tanks aimed at separating materials by their density, and furthermore the equipment for wet processes such as water jets and immersion of waste.

2.5 Civil Construction Waste Recycling Stages

For Oliveira (2020), the process begins with the collection of material so that a content screening can be initiated. After this stage, the content is processed to be sieved and distributed according to the granulometry, and only then to be sold. Figure 1 illustrates this path through a flowchart.

For Lima (2013), initially a separation and collection of materials is carried out, to then feed the crusher. The remaining metallic and ferrous residues would be segregated by the magnetic separator and, based on their granulometry, the sieves would divide the materials, generating products such as running spout and splitting. Figure 2 elucidates the idea cited by Lima (2013).

Already observing a more complex circuit, one can observe the European experience that, according to Lima

Figure 1: Construction waste recycling flowchart.
Source : Adapted from Oliveira (2020, p. 4)

(2013), uses more specific devices for the operation, such as the Wind Shifter, which is a pneumatic classifier, and the Jigue, which is a classifier that guarantees a very low portion of organic matter. As shown in Figure 3.

The feeder places the material in the system and transports it through the conveyor belt, which is previously sorted to allow the removal of the identified waste. Subsequently, a primary crusher is used to reduce the material to a maximum granulometry.

The crushed material is placed on the magnetic

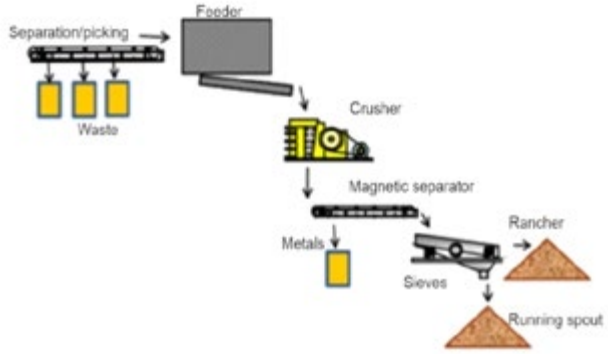

Figure 2: Typical circuits of the emerging recycling industry in countries like Brazil and China
Source : Lima (2013, p. 38)- adapted by the author

conveyor belt to remove metallic and ferrous elements. The Wind Shifter and the Jigue together promote the removal of contaminants, while the sieves are responsible for the separation of recycled products.

2.6 Construction waste processing equipment

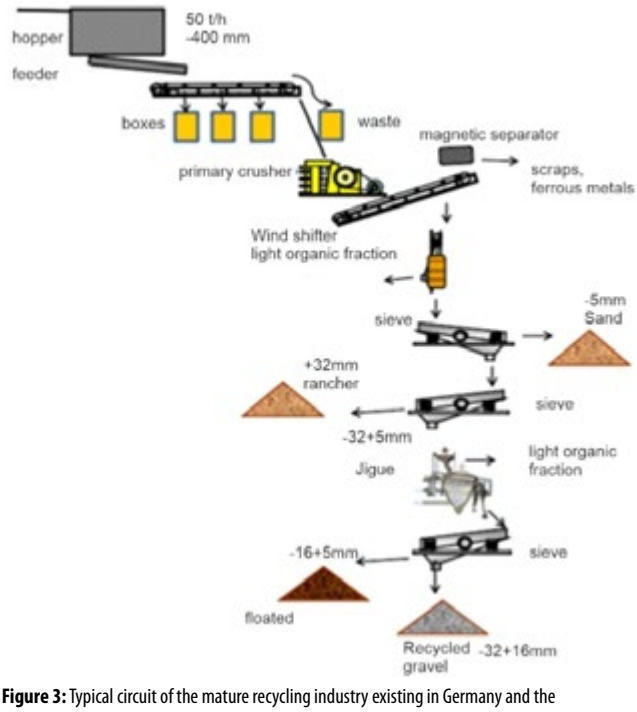

Figure 3: Typical circuit of the mature recycling industry existing in Germany and the Netherlands to obtain concrete gravel.
Source : Adapted by Lima (2013) Usina VAR in Angulo et al. (2009)- adapted by the author

According to Fogliarini (2018), the equipment used in a recycling plant is diverse, from vibrating feeders, crushers, vibrating sieves and conveyor belts.

The use of technologies for decision-making processes in waste management for Al Awadh (2023) can contribute to a cleaner and more sustainable future worldwide, in addition to allowing automation.

The vibrating feeder is, according to Fogliarini (2018), a reinforced metallic funnel that promotes the separation of the material while promoting feeding through a directed vibrating system. The last one is carried out through a metal table with springs, moved by an eccentric shaft.

For equipment sales company Odebraz, he reports that the insertion of the vibrating feeder, shown in Figure 4, helps to facilitate waste handling and reduces maintenance costs, making it important to insert it before the primary crusher (Odebraz, 2021).

The crusher is responsible for the civil construction waste, and transforming it into aggregates of different granulometries, which may be, according to Odebraz (2021), jaw, conical or impact type.

For the Brazilian Association of Public Cleaning and Special Waste Companies (2020), the jaw crusher is the most common in Brazil being used in plants in the national territory. It is usually allocated as a primary crusher for having a cheaper price and lower maintenance cost, however, the crushed product tends to have a more lamellar characteristic than the others. Impact crushers, on the other hand, generally tend to be allocated in a secondary position because they have a higher acquisition and maintenance cost, in addition to the possibility of generating aggregate with better characteristics. As for

Figure 4: Vibrating feeder
Source : YLS (2024, https://www.yls.net.br/trituradores2.html)

the cone crusher, it is also used as a secondary or tertiary crusher because it has characteristics depending on the characteristics of the aggregate to be recycled.

The conveyor belt is used, according to Odebraz (2021), to promote the automated transport of waste to the next recycling stages to be carried out in a more practical and automated way, as seen in Figure 5.

The magnetic separator (Figure 6), for the company Metal Detector, is used for the removal of metals, and

can be replaced by electromagnets, and its operating principle is the generation of a magnetic field that attracts metallic and ferrous elements (Metal Detecor, 2021).

The vibrating sieve, as seen in Figure 07 and Odebraz (2021) understanding, is the equipment responsible for segregating each crushed product according to granulometry, in addition to the vibration process also contributing to the elimination of remaining impurities.

Figure 7: Vibrating Sieve
Source: ODEBRAZ (2024, https://www.odebraz.com.br/peneira-vibratoria-a-venda)

For Lima (2013) Jigues can be inserted, as seen in Figure 8, which are equipment for use to generate coarse

Figure 5: Conveyor belt
Source : Odebraz (2024, https://www.odebraz.com.br/transportador-continuo-correia)

aggregates with low concentration of organic matter and is a gravity concentration equipment.

2.7 Products obtained from recycling

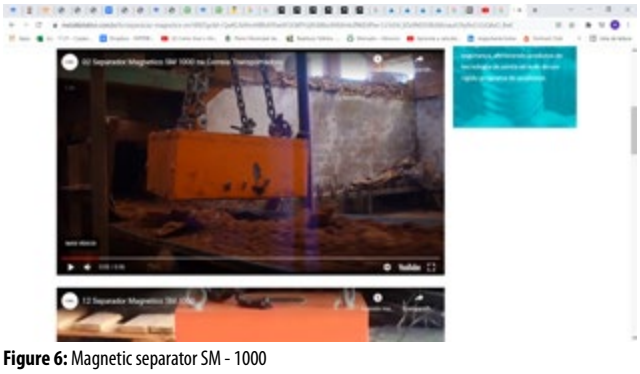

Figure 6: Magnetic separator SM - 1000
Source : Metal Detector (2024, https://metaldetektor.com.br/br/separacao-magnetica-sm1000)

Interest in the circular economy in the context of Latin America is still in its early stages, with a greater volume of publications starting in 2017, therefore it is necessary to develop further studies on this multidisciplinary topic to better mature the theme and find paths for its development practical (Ospina-Mateus, 2023).

For Möslinger (2023), solid waste management and the circular economy are essential for promoting a sustainable environment, as they are intelligent alternatives to solving the problem of inadequate disposal.

According to Salomão (2019), the products obtained after the recycling of waste from Class A civil construction

Figure 8: Jigs from Deisl-Beton, Salzburg, Austria
Source: Lima (2013, p. 36)

can vary greatly, depending on the function and granulometry, which can be:

a) recycled sand, material with maximum dimensions of less than 4.8 mm and derived from recycling concrete and blocks, and application can be carried out from the production of masonry laying mortar without structural function to subfloors.

b) recycled gravel, a material with a maximum dimension of 6.3 mm and with applications in concrete artifacts such as benches and tables in the square, in addition to being able to also be used in sewage pipes.

c) recycled gravel, a material with a maximum dimension of 39 mm, commonly used in drainage works and in the manufacture of non-structural concrete.

d) running spout, material with a maximum dimension of 63 mm, whose use ranges from subgrade reinforcement, and sub-base for paving to regularization of the ground level in topographic terms.

e) recycled stone or cracked stone is a material from recycling that contains a maximum dimension of 150 mm, and is more common in paving, drainage, in addition to the possibility of use in earthworks.

The cost compared by Damasceno (2019) demonstrates the disparity in values between natural and recycled aggregate.

For Marques *et al*. (2020), products from recycling have similar characteristics to the natural ones, but at a lower cost, thus making the material more attractive from a practical point of view.

Akter (2024) describes that the use of artificial intelligence in the service of environmental management is of substantial impact, in addition to the fact that its use can also be used on market performance determination of recycled inputs.

3. METHOD

For Severino (2014), bibliographical research is the one made from previous research such as books, articles, theses, and documental research is that which is based on objects without analytical treatment. In this way, a bibliographical and documentary research was carried out using articles, monographs, laws, diagnosis, overview and information from associations, being necessary to carry out the study of a quantitative approach, which for the same cited author, is the one whose relationship of cause and effect are described under mathematical function, and yet the qualitative approach is one that focuses on epistemological foundations.

Product	Natural R$/m³	Recyclable R$/m³
Thin sand	80,00	35,00
Medium sand	80,00	35,00
Thick sand	80,00	35,00
Gravel #2	100,00	35,00
Gravel #3	100,00	35,00
Ranch	56,75	35,00

Table 2: Price comparison of natural and recyclable products from recycling plant
Source: Damasceno (2019, p. 9)

The field of study was delimited, in addition to documentary and bibliographical research to understand the flow of recyclable construction waste from a normative Perspective. An estimate of recyclable waste from civil construction was also made, as well as its corresponding analysis, and discussion on the national scenario of recycling plants.

3.1 Delimitation of the field of study

The object of study of this work is the municipality of Juazeiro do Norte-CE, located in the region of Cariri, with coordinates with Latitude: -7.23718, and with Longitude: -39.3222, as shown in Figure 15, which according to the Brazilian Institute of Geography and Statistics – IBGE (2021) has a population of 276.264 inhabitants, the largest in the Cariri region in terms of population. Still under the same source, the development of the city also stands out in the Cariri region, since its Gross Domestic Product (GDP) per capita is in the order of R$ 17.725.62, the highest in the region. As civil construction takes place more intensely in cities whose economy is growing, this justifies that this municipality is a parameter for this present study.

Research stage	Activity
Beginning of the Research	Delimitation of the field of study
Bibliographic research	Search in monographs, studies, articles and books that deal with the matter
Documentary Research	Search through legislation, agency data government and consortia
Data analysis	Annual estimate of construction waste from class A in the municipality
Conclusion	Response to the problem

Table 3: Framework of Research
Source: The researchers (2024)

The municipality still has a territory of 258.788 km², which is one of the smallest in the region, in addition to having the highest percentage of inhabitants living in urban areas, thus facilitating the transport of waste to an area eventually chosen in the municipality.

3.2 Research approaches

In a qualitative approach to waste in the study municipality, a bibliographical review was carried out using scientific articles, reports, diagnoses, overviews on solid waste

from civil construction, its classification, environmental impacts and regulation of the subject.

The current legislation is very important to understand this theme, because public policies are established from it, where various pertinent information can be found, such as the definition of solid construction waste, or the classification. Its occurrence goes from the national, state and ends in municipal terms. Similarly, the public policies created by these laws will also be analyzed. The legal flow of waste was determined, covering the legal aspects foreseen from the generation of the waste to its destination.

Law 12.305/2010 was responsible for establishing the National Solid Waste Policy (NSWP) and presenting a range of guidelines in national terms. At the state level, it is possible to highlight Law No. 16.032/2016, which constitutes the State Policy on Solid Waste, and in municipal terms, Law No. 3.689/2010 deals with the Integrated Plan for the Management of Civil Construction Waste and the Management System Sustainable Development of Civil Construction Waste (CEARÁ, 2016), as detailed in Figure 09.

Other municipal laws used were: Complementary Law No. 85 of May 10, 2012, which promoted the creation of the Municipal Environmental Authority of Juazeiro do Norte (AMAJU), which is responsible for environmental management, licensing and inspection; and Decree No. 226 of January 21, 2016, which updates the provision of Law 12.305/2010 regulating the collection, storage, transport and disposal of construction waste not included in the regular collection.

Giving more focus to the municipal sphere, one documentary research was done, and later another bibliographical research using articles that had an analytical treatment. Subsequently, it was specified how the flow of civil construction waste should happen, from its generation to disposal as described in this legislation.

In a quantitative approach to civil construction waste, an annual estimate of its class A volume was calculated, based on secondary data. To calculate the estimate of the recyclable mass of CCW, seeking to understand the scenario set in the municipality, the per capita collection index of collected civil construction waste was taken from the Brazilian Association of Public Cleaning Companies and Special Waste (2020). in Brazilian municipalities it is 213.5 kg/inhabitant/year. As reported by the Brazilian Institute of Geography and Statistics (2021), the estimated population for 2021 in the municipality of Juazeiro do Norte is 276.264 thousand. Thus, the annual mass of construction and civil waste generation in Juazeiro do Norte can be estimated using Equation 1:

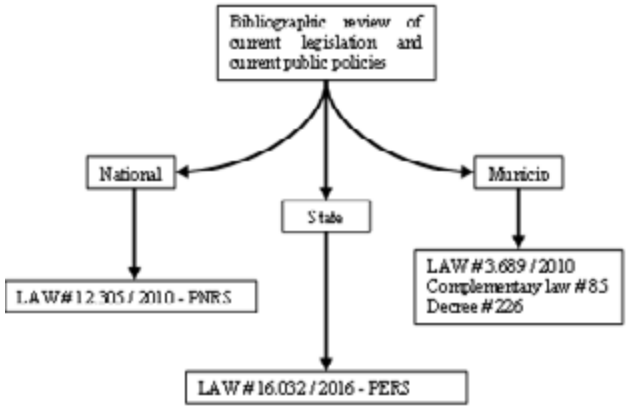

Figure 9: Bibliographic review of current legislation and policies
Source: The Searchers (2024)

$$\text{Estimated total mass} = \text{Population and CDW per capita Collection index} \quad (1)$$

According to Souza (2021), the average recyclable portion of class A construction waste is 87,7%, to estimate the total recyclable mass, Equation 2 was used:

$$\text{Total estimated recyclable mass} = \text{Total estimated mass x average recyclable mass} \quad (2)$$

However, it is common in the literature to use values in volume to quantify the size of plants. Therefore, it was necessary to use the specific density calculated by the diagnosis of waste in the municipality, to estimate the volume of recyclable waste from civil construction in the city with a value of 760 kg/m^3 (AMAJU, 2016). To estimate the total recyclable volume, Equation 3 was used.

$$\text{Estimated total recyclable volume} = \frac{\text{Total estimated recyclable mass}}{\text{Apparent density}} \quad (3)$$

Figure 10 describes the methodology for calculating the estimate of CCW in the municipality that was carried out in the methodology.

4. RESULTS AND DISCUSSIONS

The environmental problems arising from the improper disposal of construction waste require society's intervention. Initiatives such as the use of a specialized recycling plant to process this product is an alternative for its reinsertion into the production chain, providing what, according to Paschoalin (2019), would reflect in the

reduction of environmental impacts and in the generation of jobs and income for the population.

To enable the implementation of this experience in Juazeiro do Norte city, a survey was carried out on the legal flow of waste, observing how the recycling plant would fit into the current policy and the quantification of the volume of waste to be placed in the local context and frame the power plant that would best meet the demand.

4.1 Legal flow of construction waste

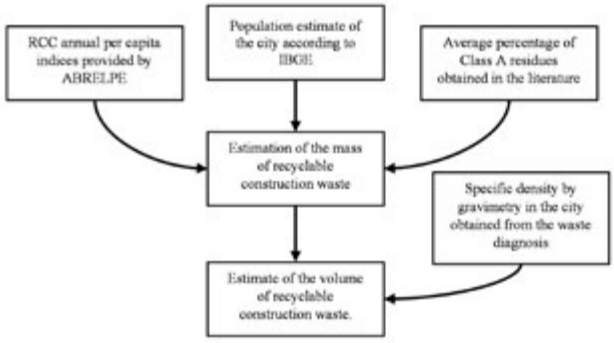

Figure 10: Calculation methodology for estimating the volume of CCW in the municipality.
Source: The researchers (2024)

The municipality of Juazeiro do Norte has the Law nº 3.689/2010 that deals with the Integrated Plan for the Management of Civil Construction Waste and the Sustainable Management System of Civil Construction Waste. In this law, the waste generator is obliged to properly dispose of the material and is subject to a fine in case of non-compliance.

Decree No. 226 of January 21, 2016 was also used to analyze the collection, transport and disposal of construction waste. In addition, there was an analysis of Complementary Law No. 85 of May 10, 2012, which establishes the disciplinary and licensing function of AMAJU for waste management, also providing for the need to encourage recycling in the municipality (Juazeiro do Norte, 2016).

To use the disposal, the generator should hire companies specialized in the transport of waste. These are responsible for the collection and regulated transport of waste between the source and its destination, the entire flow will be registered by means of a Waste Transport Order (WTO), however, after Ordinance number 280 of June 29, 2020 of the journal union official, the necessary document is the Waste Transport Manifest (MTR) through the National Information System on Solid Waste Management (SINIR).

For Juazeiro do Norte (2016), the transported material is taken to the municipal controlled landfill or receivers, which are discharge points authorized and regulated by the Municipal Environmental Authority of Juazeiro do Norte, and reuse in private areas may also occur through the detailed study of the implications of using real estate for this purpose. Another destination foreseen by Law nº 3.689/2010, are those of receivers who are operators of registered and authorized waste management enterprises for this purpose, in addition to opening up the possibility of reuse of CCW in sanitary landfills for the purposes of internal services to the landfill. In this way, the plant would be cataloged as a receiver. Although, according to Moura (2018), Law nº 3.689/2010 does not provide any incentive for recycling construction waste in the municipality.

Legally, Complementary Law No. 85, of May 10, 2012 presumes the incentive to recycling to make the National Solid Waste Policy effective, however it does not directly expose how this incentive would occur. However, Figure 11 demonstrates the legal flow of construction waste in the city of Juazeiro do Norte in Brazil that was previously described.

Currently, the city has a controlled municipal landfill, which Moura (2018) reports to be a municipal dump in use, and two others. The first one is made by the company Construrban Logística Ambiental LTDA, with a total area of 150,000.00m^2, and the second is made by Revert - Soluções Ambientais LTDA, with an area of 455,380m^2, all three located near Horto.

According to Juazeiro do Norte (2016), 90% of the collected construction waste is sent to a controlled landfill, while 10% is sent to a landfill in private buildings and for city hall works. However, the legislation still does not directly regulate the disposal of construction waste to recycling plants.

4.2 Estimate of the volume of recyclable waste in the municipality

To study the volume of recyclable waste in the city, demographic characteristics and construction waste generation were taken to determine the volume of construction waste generated. Then, taking the average of class A waste generated in Brazil, an estimate of waste of this class generated by the municipality was made in terms of mass and volume corresponding to taking the

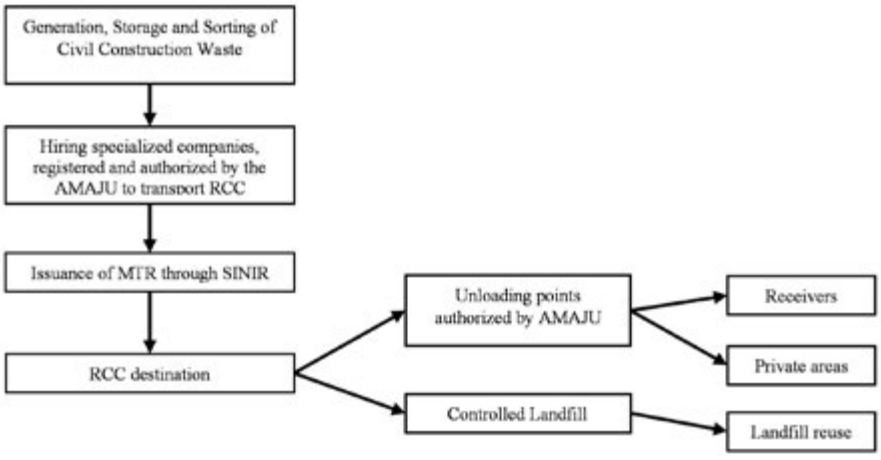

Figure 11: Fluxo legal dos resíduos de reciclagem em Juazeiro do Norte.
Source: The Searchers (2024)

specific density of municipal waste.

So that Equation 1 found the estimated total mass considering the population of the municipality and the per capita collection index:

Estimated total mass =
276.264 x 213,5kg/hab/year

Estimated total mass = 58.982.364Kg/
year or 58.982t/year

According to Equation 2, the total recyclable mass estimated through the estimated mass, and the average percentage of the amount of Class A waste, or recyclables:

Estimated total mass=
58.982.364 kg/year x 87,7%

Estimated total mass=
51.727.533 kg/year or 51.727 t/year

Taking the results of gravimetry in transitory points of AMAJU (2016), 19.823,75 tons of waste were found, which represented a volume of 26.076,78 m^3, thus inferring that its specific density of 760 kg/m^3, value within the specific density range reported by Vasconcelos et al. (2015), whose upper and lower limits are 916,67 and 629,33 kg/m^3.

By Equation 3, the estimated recyclable volume was obtained by the estimated total recyclable mass, and by the specific density of the municipal waste:

Estimated total recycable volume =
51.727.533 kg/year = 68.062 m3/year
760kg/m3

The mass values of recyclable civil construction waste in the municipality are 51,727 ton/year, and in volume are 68,062 m^3, contrasting with the 37.27 tons that were collected by private transport companies according to data from (Juazeiro do Norte, 2016) in a previous period with a smaller population, in addition to the fact that this total only accounts for the portion transported by companies regulated by the municipality, and not the total generated.

4.3 Reflection of the scenario of Brazilian CCW recycling plants and the scenario in Juazeiro do Norte for a hypothetical recycling plant

According to ABRECON (2015), there are several experiences in force in the country of civil construction recycling plants in cities similar to or smaller than Juazeiro do Norte, representing 27% of the total number of plants.

In terms of potential nominal capacity, when analyzing the data mentioned so far, the annual volume of waste is in the order of 68,062 m^3/year or 5,666 m^3/month which, when compared to the national average, would be in the range of up to 10,000 m^3/month which corresponds to 70% of the total national nominal capacity. The municipality does not have a public policy or specific legislation to encourage the recycling of civil construction waste, also accompanying the difficulties addressed by the sector in national terms, on the other hand, state legislation provides for public-private partnerships to contribute to the development of this sector.

The municipal sanitation plan foresees, until 2021, an evaluation of the destination of civil construction waste, in addition to an evaluation and implementation

of the intermunicipal consortium that deals with solid urban waste that until the present moment is still being processed by the municipal council. For Araújo (2020), the implementation of an intermunicipal consortium will not contribute to the reduction of costs in the management of urban solid waste.

Another aspect that can also be addressed in future work is the receptiveness of companies and professionals towards recycled products in civil construction, understanding the inherent market aspects, and thus also enabling an economic feasibility study of a recycling plant, thus validating methodological form of its implementation.

5. CONCLUSIONS

The construction industry is historically linked to environmental degradation. The processes generate impacts on the environment and, therefore, must be disciplined.

In this scenario, the recycling plant as a management tool is essential, as it contributes to the processing of waste that would otherwise be discarded, thus resuming its economic importance. In cases of cities with treatment that is still not very advanced in the matter, as is the case of Juazeiro do Norte, this disposal can represent great damage in terms of sustainability.

The recycling plant, from the perspective of municipal legislation, would be characterized as a receiver, requiring registration and authorization to receive construction waste. On the other hand, it does not provide an in-depth treatment explaining how the implementation and operation of the enterprise would be regulated.

In this sense, public policies could contribute by offering information to guide the recycling plant, also foreseeing the possibility of a management model based on public-private partnership or inclusion of this theme in the intermunicipal consortium, thus seeking economy for the public power and efficiency in the processes. The national legislation still sets precedent for differentiated scores in public tenders in the case of the use of sustainable materials, thus being able to be inserted in the municipal context.

The results of estimating the volume of recyclable waste from civil construction demonstrate that the municipality has sufficient demand for the implementation of the plant when compared to other realities of Brazilian plants.

Subsequently, in other works, the author intends to conduct an interview with those responsible for the companies regulated by the city that carry out the transport of waste, in order to understand what would be the position of each one in the face of a new scenario generated by the recycling plant in the city, the which was unfeasible due to the short research time that was further reduced due to the pandemic period.

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AUTHORS

ORCID: 0000-0002-9902-4920
MATHEUS SOUZA LEITE | Mestrando em Engenharia Ambiental Professor contratado da Universidade Norte do Paraná (UNOPAR)| Curso de Agronômia, polo Santana do Araguaia | Av. Albino Malzoni, 688 - Bel Recanto, Santana do Araguaia - PA, 68560-000 | e-mail: math96leite@gmail.com

ORCID: 0000-0001-6525-9257
MARCUS VINICIUS DE OLIVEIRA BRASIL | Doutor em Administração | Professor Associado da Universidade Federal do Cariri (UFCA) | Curso de Administração, CCSA |Professor dos mestrados: PPGB, PRODER e PPGA | Rua Cel. Antonio Fernades, 271, Pirajá, Cep 630134-120, Juazeiro do Norte-CE |
e-mail: marcus.brasil@ufca.edu.br
ORCID: 0000-0001-8977-1116
MARIA GORETHE DE SOUSA LIMA BRITO | Doutora em Engenharia de Processos | Professora Associada da Universidade Federal do Cariri (UFCA) | Curso de Engenharia Civil, CCT | Professora do mestrado: PRODER | Rua Odete Matos de Alencar, 1071, Lagoa Seca, Cep 63040-255, Juazeiro do Norte-CE | E-mail: gorethe.lima@ufca.edu.br

ORCID: 0000-0003-3291-5371
GABRIELA AGUIAR REZENDE | Mestranda em Engenharia Ambiental | Professora voluntária da Universidade Federal do Tocantins (UFT) | Curso de Arquitetura, CAMPUS PALMAS | Quadra 109 Norte, Av. NS 15, ALCNO-14. Plano diretor Norte / 77001-090 Palmas/TO
E-mail: gabrielarezendearq@gmail.com

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USE OF CALCIUM CARBONATE SLUDGE AS FILLER IN HOT MIX ASPHALT CONCRETE SLUDGE

UTILIZAÇÃO DE LAMA DE CARBONATO DE CÁLCIO COMO FÍLER EM CONCRETO ASFÁLTICO USINADO A QUENTE

USO DE LODO DE CARBONATO DE CALCIO COMO FILTRANTE EN HORMIGÓN ASFÁLTICO MECANIZADO EN CALIENTE

KIDNER ANGELINO PRÓSPERO, Me. | UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil
FRANCISCO ROGER CARNEIRO RIBEIRO, Me.| UFRGS – Universidade Federal do Rio Grande do Sul, Brasil
CARLOS ALBERTO MENDES MORAES, Dr.| UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil
REGINA CÉLIA ESPINOSA MODOLO, Dra. | UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil

ABSTRACT

Using industrial solid waste in the composition of asphalt mixtures can provide economic and environmental gains for the generating sector and civil construction. This work evaluated the feasibility of using calcium carbonate sludge as a filler material in producing hot-mix asphalt concrete. The methodology was based on current standards, using a reference trace based on the Marshall dosage to measure the ideal content of petroleum asphalt cement and replacing three levels (2%, 3% and 4%) of stone dust with carbonate calcium sludge in the mixtures. The stability and creep parameters results did not show a statistically significant difference despite the increase in resistance (1394.41 kgf) and lower deformation (3.48 mm) using 3% residue compared to the reference mixture. On the other hand, the values for the percentage of voids and the bitumen-void ratio showed statistical differences, reaching values of 5.29% and 69.86%, respectively, with the incorporation of 3% of the sludge. It was concluded that there is a possibility of reducing petroleum asphalt cement in the composition of the mixtures and a potential for using this residue as a filler in hot-mix asphalt concrete.

KEYWORDS

Industrial solid waste; Calcium carbonate sludge; Hot mix asphalt concrete; Asphalt paving.

RESUMO

A utilização de resíduos sólidos industriais na composição de misturas asfálticas pode proporcionar ganhos econômicos e ambientais para o setor gerador e para a construção civil. Este trabalho avaliou a viabilidade do uso de lama de carbonato de cálcio como material de enchimento na produção de concreto asfáltico misturado a quente. A metodologia foi baseada nas normas vigentes, utilizando um traço de referência baseado na dosagem Marshall para medir o teor ideal de cimento asfáltico de petróleo e substituindo três níveis (2%, 3% e 4%) de pó de pedra por lama de carbonato de cálcio nas misturas. Os resultados dos parâmetros de estabilidade e fluência não apresentaram diferença estatisticamente significativa apesar do aumento na resistência (1394,41 kgf) e menor deformação (3,48 mm) utilizando 3% de resíduo em relação à mistura de referência. Por outro lado, os valores da percentagem de vazios e da relação betume-vazio apresentaram diferenças estatísticas, atingindo valores de 5,29% e 69,86%, respetivamente, com a incorporação de 3% de lama. Concluiu-se que existe possibilidade de redução do cimento asfáltico petrolífero na composição das misturas e potencial de utilização deste resíduo como carga em concretos asfálticos usinados a quente.

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PALAVRAS-CHAVE

Resíduo sólido industrial; Lama de carbonato de cálcio; Concreto asfáltico usinado à quente; Pavimento asfáltico.

RESUMEN

El uso de residuos sólidos industriales en la composición de mezclas asfálticas puede proporcionar ganancias económicas y ambientales para el sector generador y la construcción civil. Este trabajo evaluó la factibilidad de utilizar lodo de carbonato de calcio como material de relleno en la producción de concreto asfáltico de mezcla en caliente. La metodología se basó en las normas vigentes, utilizando una traza de referencia basada en la dosificación Marshall para medir el contenido ideal de cemento asfáltico de petróleo y reemplazando tres niveles (2%, 3% y 4%) de polvo de piedra por lodo de carbonato de calcio en el mezclas. Los resultados de los parámetros de estabilidad y fluencia no mostraron una diferencia estadísticamente significativa a pesar del aumento de la resistencia (1394,41 kgf) y la menor deformación (3,48 mm) utilizando un 3% de residuo con relación a la mezcla de referencia. Por otro lado, los valores para el porcentaje de huecos y la relación betún-huecos mostraron diferencias estadísticas, alcanzando valores de 5,29% y 69,86%, respectivamente, con la incorporación de un 3% de lodo. Se concluyó que existe la posibilidad de reducir el cemento asfáltico a base de petróleo en la composición de las mezclas y el potencial de utilizar este residuo como relleno en concreto asfáltico maquinado en caliente.

PALABRAS CLAVE

Residuos sólidos industriales; Lodo de carbonato de calcio; Hormigón asfáltico mecanizado en caliente; Pavimento asfáltico.

1. INTRODUCTION

Asphalt pavements are essential for users' daily lives in developing and developed countries. Due to the increase in traffic volume, there is an increasing number of road construction projects, thus requiring large quantities of natural construction materials.

Hot mix asphalt production requires 90 to 95% by mass of aggregates (KHASAWNEH; ALSHEYAB, 2020; TAHMOORIAN; SAMALI, 2018). Around 1.36 trillion tons of asphalt are used annually to pave roads and airports (DEVULAPALLI; KOTHANDARAMAN; SARANG, 2019). This non-renewable material causes severe environmental problems (DYER; DE LIMA, 2022).

Mining activities are associated with the extraction of aggregates, causing soil erosion, loss of biodiversity, destruction of fauna and flora, geological risks, geomorphological changes, and soil, air and water contamination. Inyim et al. (2016) estimate that 50% of total greenhouse gas emissions from pavement construction are linked to the extraction of natural resources. Considering these undesirable scenarios, developing new, more sustainable paving technologies is elementary. To this end, the reuse of industrial solid waste in the incorporation or partial replacement of these materials in hot asphalt mixes can be considered one of the alternatives to reduce the extraction of non-renewable natural resources, the cost of building roads, and the generation of carbon dioxide emissions.

Several research have been conducted on using industrial solid waste in asphalt pavements as filler materials of different particle sizes. Among which, we can mention the use of dregs and grits (MODOLO *et al*., 2010), iron powder residue (ARABANI; MIRABDOLAZIMI, 2011), andesite residue (UZUN; TERZI, 2012), biomass ash (MELOTTI *et al*., 2013), ceramic tile waste (SILVESTRE *et al*., 2013), glass waste (SHAFABAKHSH; SAJED, 2014), plastic waste (KÖFTECI; AHMEDZADE; KULTAYEV, 2014), coal waste (MODARRES; RAHMANZADEH; AYAR, 2015), fly ash biomass (PASANDÍN *et al*., 2016), tire rubber waste (PASANDÍN; PÉREZ, 2017), silicon-manganese iron slag (OLIVEIRA *et al*., 2017), construction and demolition waste (AL-BAYATI; TIGHE; ACHEBE, 2018; ARTUSO; LUKIANTCHUKI, 2019), red sludge (ZHANG *et al*., 2019), calcium carbide residue (DULAIMI *et al*., 2020), ferronickel slag (COSME; FERNANDES; FERNANDES, 2021), ash of incinerated acid sludge (SHISHEHBORAN *et al*., 2021), graphite (PEREIRA; LACERDA; MODOLO, 2021), sugarcane residue (LE, 2021), water treatment plant sludge (HASAN *et al*., 2022), sludge from the processing of ornamental rocks (FACHIN *et al*., 2022) and scheelite residues (SOUZA *et al*., 2023). Following this perspective, another potential waste is calcium carbonate sludge (CCS) from the cellulose and paper industry.

In 2022, Brazilian cellulose production totaled approximately 25 million tons, and Brazilian paper production reached 11 million tons (IBÁ, 2022). This production scenario highlights the generation of large volumes of waste, with the amount generated depending on the technology used and the type of paper to produce (HAQ; RAJ, 2020; MODOLO *et al*., 2010). At all stages of the production process, these residues of organic and inorganic origin have different compositions and moisture levels.

The Kraft process is the most widespread and used paper production method in the world. It differs from the others by presenting numerous advantages, such as preserving the strength of the fibers, shorter cooking cycles with lower temperatures, and a more efficient reagent recovery system. In its last production stage, calcium carbonate sludge, or lime sludge, is generated. It is an inorganic solid residue, white, rich in calcium carbonate, with an estimated generation of 20 to 30 kg (dry basis) per ton of cellulose processed in Brazil (RIBEIRO *et al*., 2022).

Based on this context, this research aimed to investigate the possibility of using calcium carbonate sludge as a filler, replacing natural aggregates in hot mix asphalt concrete mixtures, and contributing to an adequate disposal of this waste in civil construction.

2. MATERIALS AND METHODS

Calcium carbonate sludge was made available by a partner company. The determination of the particle size distribution was carried out using the laser particle size test using the Microtac equipment, model S3500. The specific mass was determined by helium gas pycnometry using the Pycnometer equipment, model AccuPyc II 1340 from Micromeritics. The specific surface area by nitrogen adsorption (BET) was determined using the Micromeritics TriStar II Plus equipment. Chemical characterization was determined using a PANalytical equipment, model Epsilon 1. The morphology was observed using the Scanning Electron Microscope (SEM), model EVO MA 15. The mineralogical determinations were carried out by X-ray diffraction (XRD), using diffractometer equipment

from the Panalytical brand, model Empyrean.

The coarse aggregates of granitic origin had a maximum characteristic diameter (MCD) of 9.5 and 19 mm. Stone dust (passed through a 200 mesh sieve), also of granite origin, was used as fine aggregate. The petroleum asphalt cement (PAC) used as a binder was 50/70, acquired by a partner industry.

The granulometric analysis of the aggregates was carried out to comply with the rules inherent to the working ranges determined by the DNIT 031 standard (DNIT, 2006), and the physical properties were found by NBR 16917 (ABNT, 2021). The specific mass of the stone powder was carried out per the DNER – ME 084 standard (DNER, 1995), and the company provided the specific mass of the PAC. The results obtained from the analyses above are presented in Table 1.

Physical Properties	Dry Specific Mass (g/cm³)	Specific mass in saturated condition with dry surface (g/cm³)	Apparent Specific Mass (g/cm³)	Water absorption (%)
Coarse aggregate (MCD = 9.5 mm)	2.878	2.752	2.684	2.505
Coarse aggregate (MCD = 19 mm)	2.856	2.792	2.757	1.265
Stone Dust (MCD = 4.8 mm)	2.796	-	-	-
Petroleum Asphalt Cement (PAC)	1.045	-	-	-

Table 01: Physical characterization of aggregates and PAC.
Source: Authors

Based on the characterization results and granulometric composition of the aggregates, it was observed that the most suitable pavement range is range B, established in the DNIT 031 standard (DNIT, 2006). Then, the replacement levels of stone dust with CCS were defined at 0% (REF mixture), 2% CCS (CCS2%), 3% CCS (CCS3%), and 4% CCS (CCS4%) to compose the concrete asphalt, checking its adequacy to the pre-established limits as can be seen in Figure 1. Although the projected curve appears outside the range specified on the 200 mesh sieve, it is still within the tolerance range of ± 2% as per regulations. After this step and with the results of the specific mass of the aggregates and the binder, the theoretical density of each mixture was calculated according to the regulations of DNIT 428 (DNIT, 2020) and Pinto; Pinto (2015), which can be seen in Table 2.

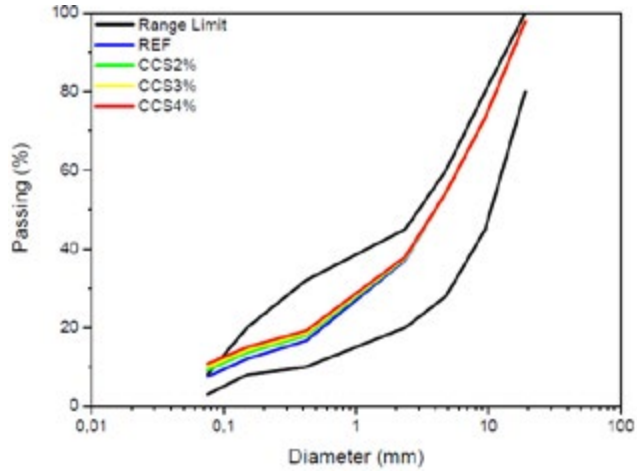

Figure 01: Granulometric distribution of asphalt mixtures without addition of PAC.
Source: Authors

Materials / Mixtures	Coarse aggregate (MCD = 9.5 mm)	Coarse aggregate (MCD = 19 mm)	Stone Dust (MCD = 4.8 mm)	CCS	Theoretical Density
REF	27	27	46	0	2.6027
CCS2%	27	27	44	2	2.5994
CCS3%	27	27	43	3	2.5977
CCS4%	27	27	42	4	2.5961

Table 2: Composition of asphalt mixtures without addition of PAC and respective theoretical densities (m.s. = dry mass).
Source: Authors

The determination of the ideal asphalt cement content was obtained by the Marshall method using the reference mix, without adding residue, varying in 4.5% PAC, 5.0% PAC, 5.5% PAC, and 6.0% PAC about the mass of the mixture, according to Figure 2.

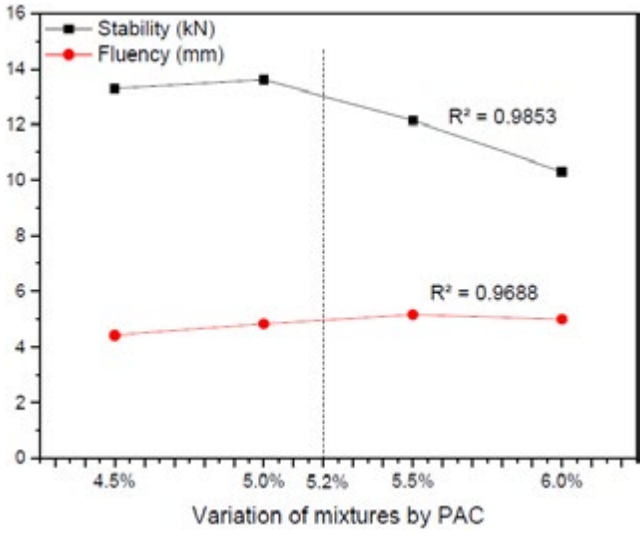

Figure 02: Intersection between the chosen PAC percentage and the corresponding stability and creep values.

Source: Authors

After defining the optimal PAC content, it was set at 5.2% for all traits. The composition of the materials presented in Table 2 was reformulated. Table 3 summarizes the final quantity of materials for each trace investigated. 4 specimens were produced for each CCS variation. The DNIT 178 standard (DNIT, 2018) recommends that for each specimen of ø100 mm and 60 mm in height, 1200 grams of asphalt mixture is required.

Materials / Mixtures	MCD = 9.5 mm (g)	MCD = 19 mm (g)	Stone Dust (g)	CCS (g)	PAC (g)	Total
REF	307.15	307.15	523.30	0.00	62.40	1200
CCS2%	307.15	307.15	512.83	10.47	62.40	1200
CCS3%	307.15	307.15	507.60	15.70	62.40	1200
CCS4%	307.15	307.15	502.36	20.94	62.40	1200

Table 3: Composition of asphalt mixtures with addition of PAC.

Source: Authors

The stability and creep of the specimens were determined using the Marshall method. These tests measure the maximum resistance to radial compression and total deformation, respectively (DNER, 1995b).

To calculate the percentage of voids, it is necessary to use the apparent and theoretical densities of the mixtures by the DNER – ME 043 standard (1995b). Thus, using the values of theoretical densities combined with information on the masses obtained by hydrostatic weighing, the apparent densities were calculated, and finally, the percentages of voids were calculated for each specimen.

To calculate the Bitumen Void ratio, the percentage of voids occupied by the CAP binder and the percentage of voids in the mineral aggregate were used. The DNER describes the method for carrying out this calculation – ME 043 standard (1995b).

Statistical analyses were also conducted to detect patterns and trends in the results obtained using the SISVAR software. Next, an analysis of variance (ANOVA) was performed using the Tukey test to determine whether the mean results of all measured parameters presented a statistically significant difference as the percentage of CCS varied. The significance level adopted for this test was 5%.

3. ANALYSIS AND DISCUSSION OF RESULTS

The chemical and physical composition of the residue is shown in Table 4. It can be seen that the calcium carbonate sludge (CaCO3) is rich in calcium oxide (CaO) and has a high fire loss due to the release of carbon dioxide. (CO2) through the decarbonation process. Using stoichiometry, it is possible to estimate the amount of CaCO3 present in this sludge, considering 0.56 g/mol of CaO molar mass and the presence of 55.49% of CaO on a dry basis. Thus, it is possible to assess the presence of 99.09% calcium carbonate. It can be seen in the literature that CaO is the typical constituent of CCS (MODOLO *et al*., 2014; MODOLO *et al*., 2010). As for the particle size of this waste, its particles are in the range of 2 to 105 µm but predominantly below 75 µm, which can be used as inert materials (particle packaging).

Chemical Composition (%)	CCS
SiO_2	ND
Al_2O_3	0.36
Fe_2O_3	0.04
CaO	55.49
MgO	0.71
SO_3	0.05
Na_2O	0.56
K_2O	0.01
TiO_2	0.01
P_2O_5	ND
MnO	0.01
SrO	0.25
Loss of Ignition (LOI)	42.51
Physical Properties	
Specific Mass (g/cm³)	2.59
Specific Surface Area BET (m²/g)	1.26
D_{10} (µm)	8.41
D_{50} (µm)	20.47
D_{90} (µm)	43.96
Dm (µm)	22.70

Table 4: Physicochemical characterization of CCS.

Source: Authors

Figure 3 presents the morphological and mineralogical characteristics of the CCS. It is evident that the sludge particles are agglomerated and irregular, possibly due to their generation by precipitation in industry. Analyzing the diffractogram, predominant calcite peaks are observed, corroborating the XRF results.

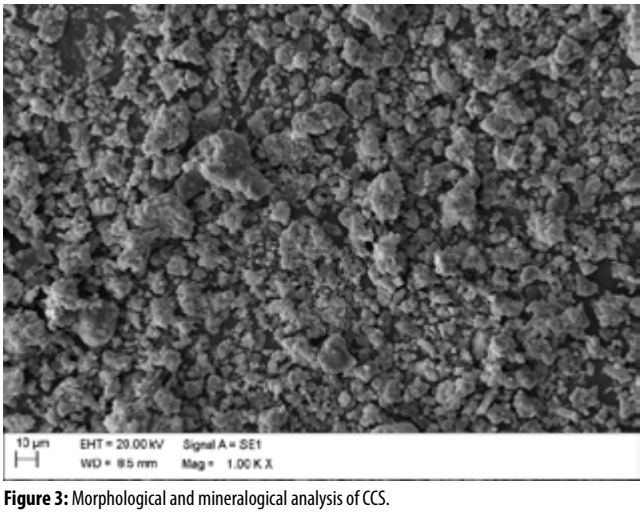

Figure 3: Morphological and mineralogical analysis of CCS.

Source: Authors

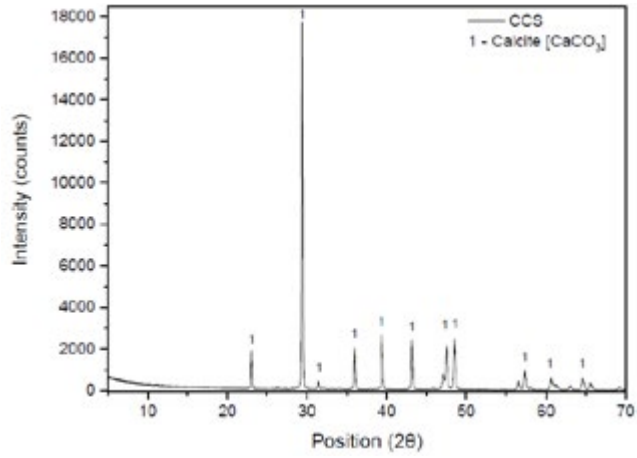

Figure 3: Morphological and mineralogical analysis of CCS.

Source: Authors

Other authors state that CCS waste can be classified as non-hazardous and, in some cases, inert according to the results of the environmental characterization by Buruberri; Seabra; Labrincha (2015), according to Decree-Law nº 152/2002, as well as Simão *et al.* (2017) and Milak *et al.* (2019) according to NBR 10004 (ABNT), 2004).

Figure 4 presents the results obtained in the Marshall test for stability and creep in the specimens of each mixture investigated. The DNIT 031 standard (DNIT), 2006) establishes a minimum value of 500 kgf for acceptable stability and a range of 2 to 4.6 mm for acceptable creep in the adopted range B. About the reference, 2% and 4% mixtures showed a reduction in the stability value of 2.88% and 12.79%. On the other hand, the mixture with 3% CCS slightly increased this criterion by 0.51%. Regarding the performance of the mixtures in the creep analysis, all formulations showed lower deformations than the REF mixture, 23.55% with 2% CCS, 25.48% with 3% CCS, and 17.99% with 4% CCS, but within limits recommended by the regulations Brazilian.

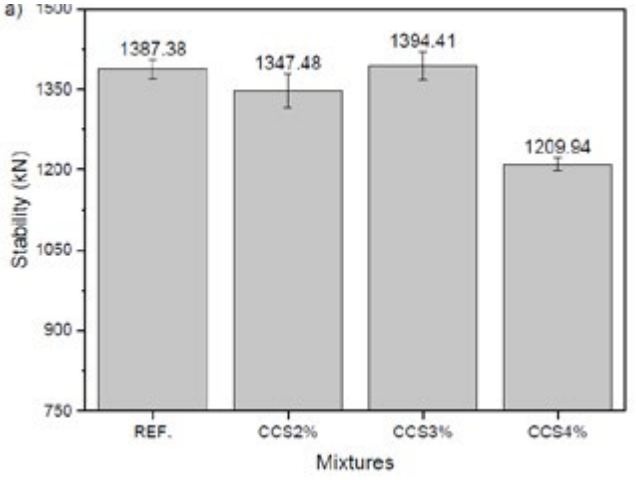

Figure 4: Averages obtained from the mixtures by the Marshall test: a) stability and b) fluency.

Source: Authors

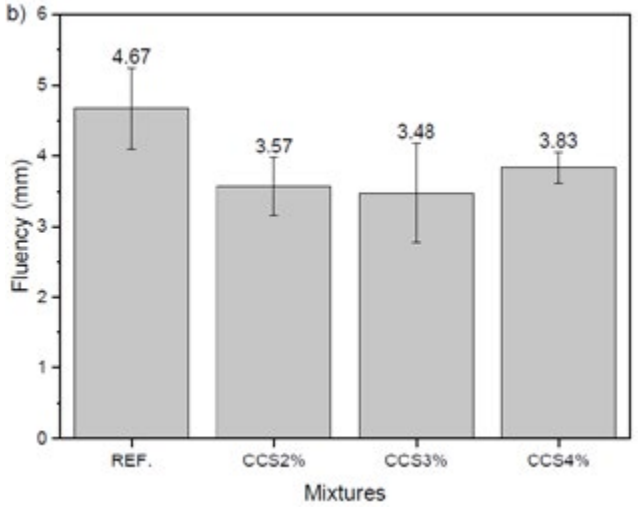

Figure 4: Averages obtained from the mixtures by the Marshall test: a) stability and b) fluency.
Source: Authors

The values for both parameters were within the norm in all variations of calcium carbonate sludge. However, the stability value with 4% CCS demonstrated a downward trend. This fact was also observed by Bardini; Klinsky; Fernandes (2010), realizing that the higher the percentage of material passing through the 75µm sieve, the voids in the granular skeleton reduced, the granular gradation is improved, and the workability of the asphalt mixture is increased, to a certain extent. Above this point, the higher the percentage passing through the 75µm sieve, the more fines impair the stability of the mixture, reducing contact between coarse particles and altering the compaction capacity. According to Arabani; Tahami (2017), stability indicates the resistance of the asphalt mixture to horizontal tension, pressure, and shear due to compression load.

Modolo et al. (MODOLO *et al*., 2010) evaluated the effect of replacing natural aggregates with dregs and grits from the cellulose and paper industry in bituminous mixtures. The authors achieved stability values of 1142 kgf and 1080 kgf using 5% dregs and 5% grits, respectively. Lins (2019) investigated the production of asphalt binder modified with lignin from the cellulose and paper industry. The author showed better stability results with 4% lignin addition, reaching values of approximately 1100 kgf. Fachin *et al.* (2022) obtained values of 1079.78 kgf using 4% sludge from processing ornamental rocks in asphalt mixtures.

In the analysis of variance for stability, according to Table 5, the p-value was 0.5010, demonstrating insufficient evidence to state a significant difference between the means obtained in each percentage of CCS used. Even without demonstrating this difference, the test still demonstrates that the experiment presented acceptable variability since the coefficient of variation was 14.08%, which is 20% lower. All means were grouped into the same group, "a1", confirming that the experiments presented statistically equal means.

Coefficient of variation	GL	SQ	Fc	Pr > Fc
14.08	3	88275.608525	0.833	0.5010
Treatments	**Average**	**Results**		
CCS4%	1209.94	a1		
CCS2%	1347.49	a1		
REF	1387.38	a1		
CCS3%	1394.41	a1		

Table 5: ANOVA for the stability variable.
Source: Authors

In the fluency requirement, Modolo *et al.* (2010) achieved 2.5 mm and 2.9 mm values when using 5% dregs and 5% grits in bituminous mixtures, respectively. Fachin *et al.* (2022) achieved results of 4.27 mm when using 4% of the sludge from processing ornamental rocks in asphalt binders.

For this parameter, it was also observed that the ANOVA test did not identify sufficient evidence to show variation in the results as the increase in residue in the formulations investigated, according to Table 6. The results indicate a p-value of 0.1437, demonstrating insufficient evidence to affirm a significant difference between the averages obtained for fluency in each percentage of CCS used. Even without demonstrating this statistical difference, the test still demonstrates that the experiment presented acceptable variability since the coefficient of variation was 18.96%, less than 20%. All means were grouped into the same group, "a1", confirming that the experiments presented statistically equal means.

Coefficient of variation	GL	SQ	Fc	Pr > Fc
18.96	3	3.546750	2.177	0.1437
Treatments	**Average**	**Results**		
CCS3%	3.48	a1		
CCS2%	3.57	a1		
CCS4%	3.83	a1		
REF	4.67	a1		

Table 6: ANOVA for the fluency variable.
Source: Authors

Figure 5 shows the results obtained in the Marshall test for the parameter percentage of voids in the mixture. The DNIT 031 standard (DNIT, 2006) establishes the 4% and 6% percentages as an acceptable range for the connection layer, range B. All formulations investigated presented parameters within this range.

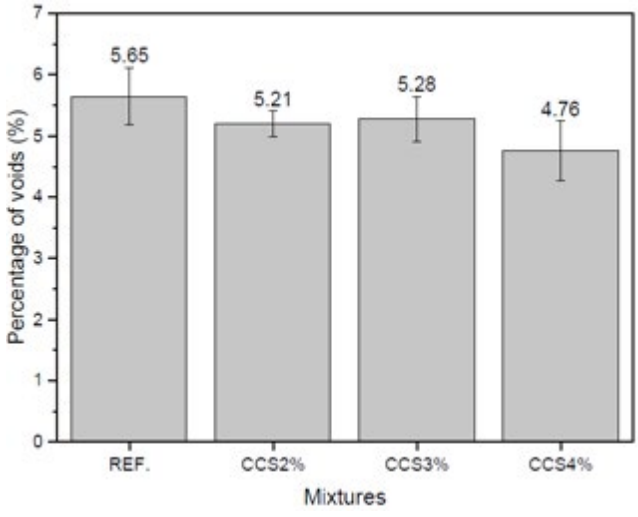

Figure 5: Percentage of voids in the asphalt mixtures investigated.
Source: Authors

As seen in Figure 5 and according to the CCS granulometry in Table 4, this residue provided a filling effect in the asphalt mixtures, thus reducing the percentage of the number of voids. Comparing these results with the literature, considering inert waste, Modolo et al. (2010) achieved a percentage of voids in asphalt mixtures of 3.8% using 5% grits and 4.9% using 5% dregs. Fachin *et al*. (2022) obtained values of 5.85% using 4% of the sludge from processing ornamental rocks in asphalt binders. Therefore, all these residues provided a filler effect.

The Rigden void index, modified by Anderson, is a method capable of analyzing the effect of the filler in the asphalt mixture, determined under standardized conditions, since the voids in the filler-asphalt binder mixture result in maximum densification of the filler (BARDINI; KLINSKY; FERNANDES, 2010). When the amount of binder increases beyond the Rigden void ratio, the particles lose contact, and the additional amount of binder causes lubrication between the particles. On the other hand, when the free amount of binder decreases, the stiffness of the mixture increases. Therefore, the thinner the filler, the lower the filler-binder ratio must be, considering that the free volume of binder causes the increase in the coating thickness of the aggregate particles.

Therefore, the higher the volumetric concentration of the filler-binder system, the aggregate particles in the mixture are closer together, and the pore volume will be smaller. Consequently, the mixtures will have greater rigidity, corroborated in stability tests.

In the analysis of variance for the percentage of voids, as shown in Table 7, the p-value was 0.5076, slightly greater than 0.05, implying that there may be some significant statistical difference between the means for the different CCS percentages. The difference between the groups is observed because the test separated the results into two groups, "a1" and "a2". The REF trace results differed significantly from those obtained when 4% CCS was added. In the case of 2% and 3% CCS, the test presented a conflict, making the statement that these mixtures differ from the others uncertain and could be statistically equal to the REF and differ from the mixture with 4% CCS or be equal to the last formulation and differ from REF.

Coefficient of variation	GL	SQ	Fc	Pr > Fc
7.68	3	1.595937	3.302	0.0576
Treatments	**Average**	**Results**		
CCS4%	4.76	a1		
CCS2%	5.21	a1	a2	
CCS3%	5.29	a1	a2	
REF	5.65		a2	

Table 7: ANOVA for the variable percentage of voids.
Source: Authors

Figure 6 shows the values obtained when calculating the bitumen/voids ratio. The DNIT 031 standard (DNIT), 2006) establishes an acceptable 65% to 72% range for the band B bonding layer. All formulations investigated presented parameters within this range despite the mixture with 4% CCS being at the upper limit.

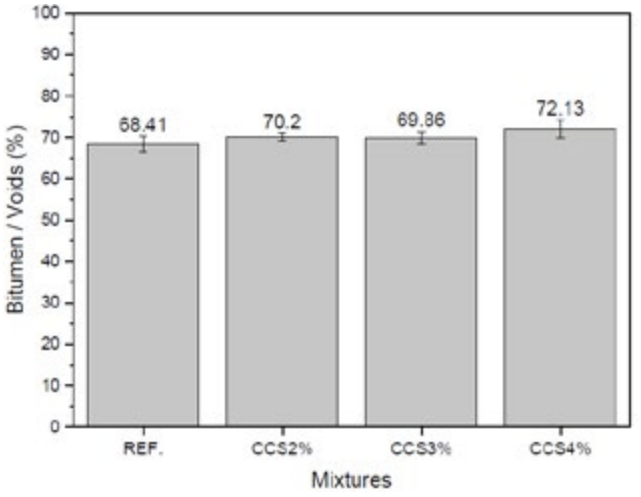

Figure 6: Bitumen/void ratio in the investigated mixtures.
Source: Authors

The bitumen-void ratio indicates the percentage of aggregate voids filled by the binder (PINTO; PINTO, 2015). Thus, for a ratio of 0%, we have a mixture without asphalt. For a ratio of 100%, it indicates that all voids are filled with asphalt. In previous studies, Fachin *et al*. (2022) achieved results of 65.16% using 4% of the sludge from the processing of ornamental rocks. It is essential to highlight that when noticing an increase in the bitumen/voids ratio as the percentage of CCS in the mixture increases, care must be taken not to exceed the limit recommended in the standard, as excess can cause cracking and reduce life—usefulness of the asphalt mixture.

In the analysis of variance for the bitumen/voids relationship, as shown in Table 8, the p-value was 0.0618, slightly greater than 0.05, implying that there may be some significant statistical difference between the means for the different CCS percentages. The difference between the groups is observed because the test separated the results into two groups, "a1" and "a2". The REF trace results differed significantly from those obtained when 4% CCS was added. If the bitumen-void ratio increases, this means a reduction in PAC consumption in the mixture, as the residue fills the voids and improves the absorption of the binder by the mixture. In the case of 2% and 3% CCS, the test presented a conflict, making the statement that these mixtures differ from the others uncertain and could be statistically equal to the REF and differ from the mixture with 4% CCS or be equal to the last formulation and differ from REF.

Coefficient of variation	GL	SQ	Fc	Pr>Fc
2.44	3	28.135365	3.209	0.0618
Treatments	**Average**	**Results**		
REF	68.41	a1		
CCS3%	69.86	a1	a2	
CCS2%	70.20	a1	a2	
CCS2%	72.13		a2	

Table 8: ANOVA for the bitumen/void ratio variable.
Source: Authors

4. CONCLUSIONS

In this work, the use of calcium carbonate sludge in the production of hot mix asphalt mixtures was investigated. With the experimental results, it was possible to conclude that:

- The PAC content of 5.2% was well suited to the mixtures produced since the tested mixtures showed stability parameters, creep, percentage of voids, and bitumen/void ratio within the normative ranges;
- In stability and creep analyses, the 3% CCS provided an improvement in strength by 0.51% and a decrease in deformation by 25.48%, respectively, compared to the reference mixture;
- In terms of the percentage of voids, all formulations achieved lower values compared to the reference mixture, being a good indication of the filling effect provided by the residue to bituminous concretes;
- It was verified in the bitumen/void ratio that as CCS is inserted into the mix, there is a surplus of binder, indicating the possibility of adjusting the mixture to a lower PAC value and, therefore, reducing the production cost of these asphalt mixtures.

Therefore, this study demonstrates that replacing stone dust with CCS can contribute to the preservation of the environment, minimize the environmental impacts of inadequate disposal of this waste in uncontrolled landfills, reduce the extraction of non-renewable natural resources, and add less value economical in the production of hot mix asphalt mixtures.

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AUTHORS

ORCID: 0009-0006-4249-3255
KIDNER ANGELINO PRÓSPERO | Me. em Engenharia Civil | Universidade do Vale do Rio dos Sinos (UNISINOS-RS) | PPG em Engenharia Civil | São Leopoldo, RS, Brasil | Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750 | email: prospero.k@gmail.com

ORCID: 0000-0001-8790-3023
FRANCISCO ROGER CARNEIRO RIBEIRO | Me. em Engenharia Civil | Universidade Federal do Rio Grande do Sul (UFRGS-RS) | PPG em Engenharia Civil/ Porto Alegre, RS, Brasil | Av. Osvaldo Aranha, 99, 90035-190, Porto Alegre – RS | email: roger.ribeiro_@hotmail.com

ORCID: 0000-0001-7295-2826
CARLOS ALBERTO MENDES MORAES | Dr. em Ciência dos Materiais | Universidade do Vale do Rio dos Sinos (UNISINOS-RS) | PPG's em Engenharia Civil e Engenharia Mecânica | São Leopoldo, RS, Brasil | Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750 | email: cmoraes@unisinos.br

ORCID: 0000-0001-7088-2502
REGINA CÉLIA ESPINOSA MODOLO | Dra. em Ciências e Engenharia do Ambiente | Universidade do Vale do Rio dos Sinos (UNISINOS-RS) | PPG's em Engenharia Civil e Engenharia Mecânica | São Leopoldo, RS, Brasil | Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750 | email: reginaem@unisinos.br

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FRCR: curadoria de dados, análise formal, validação, visualização, escrita - rascunho original, escrita - revisão e edição.

CAMM: aquisição de financiamento, supervisão, escrita - revisão e edição.

RCEM: conceituação, aquisição de financiamento, investigação, metodologia, administração de projetos, supervisão, escrita - revisão e edição.

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THE CONTRIBUTION OF THE PSYCHOLOGY OF RELIGION AND SPIRITUALITY TO THE DEVELOPMENT OF SUSTAINABILITY IN SMART CITIES

A CONTRIBUIÇÃO DA PSICOLOGIA DA RELIGIÃO E DA ESPIRITUALIDADE NO DESENVOLVIMENTO DA SUSTENTABILIDADE EM CIDADES INTELIGENTES

LA CONTRIBUCIÓN DE LA PSICOLOGÍA DE LA RELIGIÓN Y DE LA ESPIRITUALIDAD EN EL DESARROLLO DE LA SOSTENIBILIDAD EN CIUDADES INTELIGENTES

GUSTAVO BIANCHINI PORFÍRIO, Me. | UNICENTRO – Universidade Estadual do Centro-Oeste, Brasil
SILVIO ROBERTO STEFANI, Dr.| UNICENTRO – Universidade Estadual do Centro-Oeste, Brasil
RONALDO FERREIRA MAGANHOTTO, Dr.| UNICENTRO – Universidade Estadual do Centro-Oeste, Brasil

ABSTRACT
Considering religion and spirituality as essential components of human experience and also associated with better mental health, this study discusses their impact on the development of sustainability in Smart Cities. The main objective of the study is to identify the application of the Psychology of Religion and Spirituality for aligning these areas with the Sustainable Development Goal 3 (SDG-3) proposal for cities. An integrative review methodology was used on 23 relevant studies that promote discussion on the Psychology of Religion and Spirituality in the context of smart and sustainable cities. These studies were selected based on pre-defined inclusion and exclusion criteria, with data collection for subsequent analysis. The main findings observed that aspects such as interconnection, values, ethics, and health and well-being are facets of religion and spirituality that can be integrated into the construction of smart cities. The paper concludes that religion and spirituality can play a crucial role in shaping smart cities, and offer pathways for achieving sustainability. Further studies on the topic and its application in smart city development projects could better explore this interaction.

KEYWORDS
Psychology; Sustainable Cities; Smart Cities; Mental Health.

RESUMO
Considerando a religião e a espiritualidade como componentes essenciais da experiência humana e também associadas com melhor saúde mental, realiza-se a discussão sobre o seu impacto para o desenvolvimento da sustentabilidade em Cidades Inteligentes. O objetivo do estudo é identificar a aplicação da Psicologia da Religião e da Espiritualidade para o alinhamento das áreas com a proposta da ODS-3 para as Cidades. Foi utilizada a metodologia de revisão integrativa em 23 estudos relevantes que promovem discussão sobre a Psicologia da Religião e da Espiritualidade no contexto de cidades inteligentes e sustentáveis. Esses estudos foram selecionados com base em critérios pré-definidos de inclusão e exclusão, com coleta de dados para posterior análise. Como principais resultados foi observado que aspectos como interconexão, valores, ética, e a saúde e o bem-estar são aspectos da religião e da espiritualidade que podem ser integrados na construção de cidades inteligentes. O trabalho conclui que a religião e a espiritualidade possam desempenhar um papel crucial na formação de cidades inteligentes, e oferecem caminhos para que a sustentabilidade seja alcançada. Mais estudos sobre

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o tema e sua aplicação em projetos de desenvolvimento de cidades inteligentes podem explorar melhor essa interação.

PALAVRAS-CHAVE
Psicologia; Cidades Sustentáveis; Cidades Inteligentes; Saúde Mental.

RESUMEN
Considerando la religión y la espiritualidad como componentes esenciales de la experiencia humana y también asociadas con una mejor salud mental, se realiza la discusión sobre su impacto en el desarrollo de la sostenibilidad en las Ciudades Inteligentes. El objetivo del estudio es identificar la aplicación de la Psicología de la Religión y de la Espiritualidad para el alineamiento de las áreas con la propuesta de los ODS-3 para las Ciudades. Se utilizó la metodología de revisión integrativa en 23 estudios relevantes que promueven la discusión sobre la Psicología de la Religión y de la Espiritualidad en el contexto de ciudades inteligentes y sostenibles. Estos estudios fueron seleccionados con base en criterios predefinidos de inclusión y exclusión, con recopilación de datos para su posterior análisis. Como principales resultados se observó que aspectos como la interconexión, los valores, la ética y la salud y el bienestar son aspectos de la religión y la espiritualidad que pueden integrarse en la construcción de ciudades inteligentes. El trabajo concluye que la religión y la espiritualidad pueden desempeñar un papel crucial en la formación de ciudades inteligentes y ofrecen caminos para que la sostenibilidad sea alcanzada. Más estudios sobre el tema y su aplicación en proyectos de desarrollo de ciudades inteligentes pueden explorar mejor esta interacción.

PALABRAS CLAVE
Psicología; Ciudades Sostenibles; Ciudades Inteligentes; Salud Mental.

1. INTRODUCTION

The Psychology of Religion and Spirituality is a recognized field of psychological and psychiatric research (MOREIRA-ALMEIDA; LUCCHETTI; KOENIG, 2014; SILVA et al., 2022). The World Health Organization (WHO) acknowledges the spiritual and religious dimension of humans as one of the determining aspects of the concept of quality of life (MACHADO; HOLANDA, 2016; PLAUTO et al., 2022). In addition to being associated with a lower prevalence of depression and anxiety, it is also found that religious participation in institutions fosters greater social connections and a decreased sense of isolation and loneliness (MOREIRA-ALMEIDA; LUCCHETTI, 2016; RONNEBERG et al., 2016).

Based on the ISO - International Organization for Standardization model, smart cities can be conceived from a certain number of indicators, among them: Mobility, safety, health, housing, among others (BENCKE; PEREZ, 2018; ABREU; MARCHIORI, 2023). Therefore, an integrative perspective on the scientific knowledge about the Psychology of Religion and Spirituality with the development of Smart Cities is essential for the construction of Sustainable Cities, aiming to realize the SDG 3 "Health and well-being" (SILVESTRE, 2016; SÁ; BENEVIDES, 2019).

The main objective of this study is to identify the application of the Psychology of Religion and Spirituality for the alignment of the areas with the proposal of SDG-3 for the Cities, seeking to answer the question: Can spirituality be a pathway to the development of sustainability in Smart Cities?

2. LITERATURE REVIEW

Current urbanization is associated with emerging mental health problems, influenced by social, economic, and environmental factors, such as social disparities, pollution, and lack of contact with nature (VENTRIGLIO et al., 2021). Mental disorders such as depression, psychotic experiences, and stress are also associated with the process of urbanization, especially in developing countries (LECIC-TOSEVSKI, 2019).

This mental health scenario may be associated with physical inactivity, urban design and planning, housing conditions, and the quality of city architecture (IRAVANI, 2020). Urban displacements observed in society can also be a factor when considered as reinforcing the status of surplus of certain groups, distancing them from access to employment, education, and care networks, directly impacting the mental health of these groups (GILLESPIE; HARDY; WATT, 2021).

In this environment of transformation experienced in the urban space where health is at serious risk, a new way of experiencing the territory has emerged: Smart Cities (LOPES, LEITE, 2021). Aiming to enhance the efficiency of public services with the advancement of technology, it is expected to also impact sustainability goals, promoting improvements in urban quality of life and greater resilience to urban centers, thus committing to environmental protection, social justice, and economic prosperity (CHIUSOLI; REZENDE, 2019; PROENÇA JUNIOR; DUENHAS, 2020; ANDRADE; FRANCESCHINI, 2017).

Observing the impacts on the mental health of populations in urban environments, it is evident that elements such as spirituality and religion can be beneficial in fostering discussions about possible interventions in this context. This is because spirituality/religiosity serve as significant coping resources in people's lives (MONTEIRO et al., 2020). This coping is described by Avezum et al. (2019) as either positive or negative, with the former associated with resilience and a better quality of life, and the latter with passive acceptance and psychological distress.

Considering religion as a constitutive element of human subjectivity and a giver of meaning to suffering, Dalgalarrondo (2008) argues that it holds a privileged position in the dialogue between health and mental disorders. Some organizations officially recognize its role in human health. Consequently, the Psychology of Religion and Spirituality is Division 36 of the APA (American Psychological Association). It also holds a prominent position in organizations such as the American College of Physicians, American Medical Association, American Nurses Association, World Psychiatric Association, American Psychiatric Association, and Royal College of Psychiatrists (MOREIRA-ALMEIDA; LUCCHETTI; KOENIG, 2014).

Recognized by the UN in September 2015 as one of the Sustainable Development Goals (SDG 3.4), mental health emerges as one of the priorities for global development over the next 15 years (VOTRUBA; THORNICROFT, 2016). To achieve the SDGs, interdisciplinary dialogue and debate are essential (LIEN, 2018). Therefore, considering spirituality and its influential role in mental health is fundamental in discussions promoting sustainable development.

3. METHODOLOGICAL PROCEDURES

For the study's execution, we will use an integrative research methodology (SOUZA; SILVA; CARVALHO, 2010) employing the descriptors a) "Psychology of Religion and Spirituality", b) "Smart and Sustainable Cities", and c) "Health and Well-being in Smart and Sustainable Cities". Literature will be explored for articles that, regardless of language or publication period, address the relationship between religion and society/community, as well as the role of smart and sustainable cities in the realm of health. Inclusion criteria will encompass texts that clearly and substantially discuss these themes, whether or not they establish an explicit connection between the two topics. Conversely, we will exclude works that, even if mentioning the subjects of interest, do not provide specific knowledge on the topic or lack scientific rigor. Following the selection of studies, we will undertake critical reading, extraction of relevant data, and the subsequent analysis and synthesis of the results.

4. ANALYSIS AND DISCUSSION OF RESULTS

The research involved the analysis of 23 scientific articles found using the descriptors. When evaluated based on the inclusion and exclusion criteria, 15 studies were found to be compatible with the analysis proposal and the research objectives. Among these, 7 were suited to descriptor a) "Psychology of Religion and Spirituality"; 10 matched descriptor b) "Smart and Sustainable Cities"; and 10 aligned with descriptor c) "Health and Well-being in Smart and Sustainable Cities". Following this, Table 1 will be presented, which will include the analyzed texts and the applied criteria.

The article by Gilbert and Parkers (2011) highlights the desire of mental health service users to have their spiritual dimension addressed by professionals. In the social dimension, the impact of spirituality is the creation of potential mobility in which the existence of something sacred creates a space in which different people can meet and relate (VEER [org.], 2015). In this encounter, these interlocutors are influenced in the construction of their value systems and behavioral repertoire (VLASENKO; IVANOVA, 2017; GHONIMI, 2021). This possibility of relationship and transformation offered by the spiritual dimension in contact with the social dimension paves the way for interdisciplinary discussion with the study on architecture, which, in dialogue with religiosity, is seen by Srivastava, Scriver, and Nash (2020) as an agent of construction and articulation of physical and social space, of engagement and coexistence, that can define and build symbolic identities of religious communities, developing in the relationship the strength and resources necessary for these communities. This can be complemented by the argument defended by Brennan (2020), which observes the great contemporary relevance of discussing religion in the public space, which, although subject to criticism, offers pathways for promoting a more inclusive and compassionate society.

Discussing this theme in public space, although relevant and challenging, requires great care on the part of planners. In India and Asia, insightful policies are designed to align proposals for sustainable urban development and planning with the religious aspects of the territory (NARAYANAN, 2014). Mahanjan and Mane (2023) advocate a lasting and complex history on the interrelation between spirituality and Indian architecture, so that for the authors there are great advantages to infusing spirituality in today's society, such as health improvement, cultural preservation, and community development. Considering future planning without taking into account this integration of proposals is unthinkable for Sandercock (2006), when considering both elements indivisible, the social system and architecture are thus marked by the religious/spiritual dimension (BECCI, BURCHARDT; GIORDA, 2017; MAHDNEJAD, AZEMATI; HABIBABAD, 2019). As an example of this relationship, there is the project of the Universal City Auroville, an ecovillage located in the south of India built with the spiritual perspective of human evolution through the practice of integral yoga, being conceived by its founders as a place of material and spiritual research for the sake of human union, which also integrates into its scope of activities sustainable practices that have proven their success in providing low-cost ecological solutions to the challenges of sustainability (VENKITARAMAN; JOSHI, 2022).

Zavratnik et al. (2020) and Keshavarzi, Yldirim, and Arefi (2021) are authors who argue that sustainability can only be effectively achieved through integrated communities, not just through the integration of technologies. Although IoT (Internet of Things) resources can promote mental health (VAHDAT-NEJAD et al., 2022), the unity of a community is the axiomatic axis for the realization of sustainability. An example of this relationship is described by Tabb (2016) in a case study on the Serenbe community in the United States of America, where he identified a society that incorporated a balance between the natural

and the urbanized with an emphasis on sustainability and a deep relationship with nature. Through a strong sense of community, they visualize and project a secular-sacred community in contemporary times. The intersection between life in integrated communities and sustainability can be seen from the philosophical perspective of Martin Buber presented by Benedikt (2016), who observes the sacredness emerging from interpersonal connections and facilitated by the built environments for this purpose, as they create space for ethical and creative actions among individuals. From this perspective, the author emphasizes that architecture can still evolve significantly by focusing more on the human being and the development of interpersonal relationships. In this way, the concept of "value-sensitive design" by Helbing et al. (2021) emerges as a pathway to this more human-centered vision and contemporary needs, particularly in building sustainability in cities by integrating ethics, law, and culture for a sustainable, global, and human-centered technological revolution, focused on complete human well-being. One possible foundation for constructing this ethic are the values found in the experience of spirituality, which, by aligning with sustainable management, are also associated with a deep sense of social responsibility (ZSOLNAI, 2015).

Finally, when considering SDG-3 "Health and Well-being," the research by Ferreira (2021) suggests that smart cities are moving towards a higher quality of life for citizens and are better employing health resources to control pandemics, such as COVID-19 (MÜLLER; SILVA, 2021; KHAYAL; FARID, 2017). This appropriate planning of resources, especially health resources, to reduce vulnerabilities through a systemic and complex vision of the city provides resilience for a city, as it values intersectoral actions focused on meeting needs and accessing opportunities for agents to intervene (SOTTO et al., 2019). As an example of discussion, Porfírio et al. (2022) argue that organizational religious practice is fundamental for maintaining good mental health but was the subject of much debate and uncertainty in the political scenario during the COVID-19 pandemic period, which questioned the resilience capacity of urban planning to intervene and assertively meet the immediate needs of citizens.

Therefore, smart cities have great potential for projection and execution in addressing social problems and achieving sustainability goals, creating more equitable and habitable environments (TRENCHER; KARVONEN, 2019), and a resilient infrastructure through the integration of architectural elements and urban planning that aim for the development of appropriate prevention and intervention strategies (AHMED; PARRACK, 2023). The transition to resilient planning requires a multi-scalar process in the city's sectors that can meet the speed, form, and characteristics of the necessary changes (CRANE et al., 2021), given that efforts that do not adopt a holistic, inter-scalar, and inter-level perspective encounter resistance from the other elements and scales of the system (KRUEGER et al., 2022). The study's conclusions are presented below.

Author/Year	Objectives	Results	Descriptor
P. Gilbert; M. Parkers / 2011	Describe the research program on spirituality and mental health of the Birmingham and Solihull Mental Health NHS Foundation Trust (BSMHFT).	Those who use mental health services increasingly claim they wish the spiritual dimension of their lives to be addressed by professionals.	a)
Irene Becci; M. Burchardt; M. Giorda / 2017	Discuss cities as post-secular and super-diverse elements.	Religious groups have shaped cities leaving lasting architectural marks on them.	a)
M. L. Di Silvestre / 2017	Identify new ways of environmental protection and waste reduction for a new eco-sustainable lifestyle.	The Eastern worldview offers a unifying perspective of science and religion by bridging the gap that emerged over time and reflected in many Western cultures and reverberated in many community development models.	b)
J. MahdiNejad; H. Azemati; A. Habibabad / 2019	Conduct interviews and a literature review on the role of religion in mental health related to architecture.	Religious beliefs and spiritual practices prevent spiritual and physical diseases, as well as mental diseases, while simultaneously reducing the recurrence of diseases and their symptoms.	a)
P. Veer (Org.) / 2015	The book seeks to highlight the creative and innovative role of urban aspirations in Asian cities.	In their potential and current mobility, the sacred creates a social space in which everyone can meet.	a)
L. Vlasenko; I. Ivanova / 2017	Analyze the formation of social values in young people from big cities.	The analysis confirmed that the value system held by young people is strongly influenced by the urban environment and the processes taking place within it.	b) c)
A. Ferreira / 2021	Identify the conceptual relationship between smart cities and citizens' quality of life.	Twelve key concepts were found that demonstrate how to relate a smart city and the quality of life of its citizens.	a) c)
L. Sandercock / 2006	Discuss the role of religiosity and faith in future planning.	The topic between faith and religiosity cannot be avoided by academics and should not be divided between spiritual and practical life.	a) c)
Y. Narayanan (Org.) / 2014	Explore the historical and ongoing influence of religion in urban planning, design, space utilization, urban identities, and communities.	The topic between faith and religiosity cannot be avoided by academics and should not be divided between spiritual and practical life.	a) b) c)
D. Helbing, et al. / 2021	Promote smart cities that value ethics, citizen participation, and sustainability, in addition to technological efficiency.	The text emphasizes the importance of integrating ethics, law, and culture into a digital design that promotes self-management and resilience, contributing to a global sustainable technological revolution.	b) c)

Author/Year	Objectives	Results	Descriptor
I. Ghonimi / 2021	Discover the existing correlation between people's familiarity with ICT and changing behavioral patterns.	Smart cities have significant implications in changing urban behavior patterns, city spatial structure, and urban social sustainability.	b)
G. Trencher; A. Karvonen / 2019	Explore how the pursuit of greater health and well-being has expanded smart city activities beyond technological innovation to directly impact residents' lifestyles and become more socially relevant.	Smart cities have great potential to be designed and implemented to address social issues and achieve more sustainable, equitable, and livable cities.	b) c)
M. Crane, et al. / 2021	Consider the possibility of how to frame and unpack the transformation at the city level towards synergistic benefits for urban health and environmental sustainability.	Urban transformation needs to be a multi-scalar process across city sectors to meet the scale, speed, and form of required change.	c)
I. S. Khayal; A. Farid / 2017	Answer the question of how to design smart cities taking into account the health and well-being of citizens.	Smart city initiatives can actively impact health, rather than passively waiting for it to happen.	b) c)
L. Müller; T. L. Silva / 2021	Analyze urban health indicators of Passo Fundo/RS, seeking to understand the interrelation of these indexes with the epidemiological data of COVID-19.	Cities that monitor health indicators and implement Smart City strategies showed better results in controlling the COVID-19 pandemic.	b) c)

Table 1 - Texts analyzed and considered for the research, showing authors, year of publication, objectives of the studies, results, and descriptors used.
Source: Authors.

5. CONCLUSION

The integrative review conducted in this study highlights the crucial role that the Psychology of Religion and Spirituality can play in the development of smart and sustainable cities. The studies reviewed show that religion and spirituality not only influence individual behavior and well-being but also have the potential to impact the way smart cities are designed and operated. Thus, it is understood that the objective of the study was achieved and discussed with the various works analyzed.

Interconnection and community, values and ethics, and health and well-being are all aspects of religion and spirituality that can be integrated into the construction of smart cities. These elements can help ensure that smart cities are not only efficient and offer a quality of life but also move with quality and assertiveness towards sustainable development. However, it is also important to recognize that the application of religion and spirituality in the context of smart cities can vary depending on the specific cultural and religious context. Therefore, it is up to urban planners and researchers to consider these differences when integrating religion and spirituality into the construction of smart cities.

Thus, three fundamental topics are highlighted in which religion and spirituality can be pathways for the development of sustainability in Smart Cities: 1) **Interconnection and Community**, by offering environments for learning and building values, in addition to fundamental social interaction for mental health. 2) **Values and ethics**, since religion and spirituality often provide a set of values and an ethical framework for individuals, which are reflected in their behaviors, practices, and future planning. 3) **Health and well-being (SDG-3**), a theme that is a major highlight of the proposal of smart cities and fundamental for achieving SDG-17 and which is associated with the practices of religiosity and spirituality in the population.

This study contributes to the existing literature by highlighting the importance of the Psychology of Religion and Spirituality in the formation of smart and sustainable cities. For the future, it will be necessary to explore which practices and planning in religion and spirituality are important for achieving sustainability in Smart Cities, alongside an assessment of the impact that the discussion of these themes in the training of managers and planners may have on their future constructions.

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AUTHORS

ORCID: 0000-0001-9770-3033

GUSTAVO BIANCHINI PORFÍRIO, Mestre em Desenvolvimento Comunitário pela UNICENTRO. | UNICENTRO | Programa de Pós-Graduação Interdisciplinar em Desenvolvimento Comunitário | Guarapuava, Paraná(PR) - Brasil | Correspondência para: Rua Professora Maria Roza Zanon de Almeida Bloco A 2º Piso Engenheiro - Gutierrez, Irati - PR, 84505-677 | E-mail: gbporfirio@unicentro.br

ORCID: 0000-0002-5871-8686

SILVIO ROBERTO STEFANI, Pós-Doutor em Gestão pela FEP - Universidade do Porto (2020-2021). | UNICENTRO | Programa de Pós-Graduação Interdisciplinar em Desenvolvimento Comunitário | Guarapuava, Paraná(PR) - Brasil | Correspondência para: Rua Professora Maria Roza Zanon de Almeida Bloco A 2º Piso Engenheiro - Gutierrez, Irati - PR, 84505-677 | E-mail: silviostefano@unicentro.br

ORCID: 0000-0003-0659-1481

RONALDO FERREIRA MAGANHOTTO, Doutor em Geografia pela Universidade Federal do Paraná (2013) | UNICENTRO | Programa de Pós-Graduação Interdisciplinar em Desenvolvimento Comunitário | Irati, Paraná(PR) - Brasil | Correspondência para: Rua Professora Maria Roza Zanon de Almeida Bloco A 2º Piso Engenheiro - Gutierrez, Irati - PR, 84505-677 | E-mail: rmaganhotto@unicentro.br

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THE FUTURE OF WORK IN FASHION IN LIGHT OF EMERGING TECHNOLOGIES: PRELIMINARY STUDY

O FUTURO DO TRABALHO NA MODA SOB O VIÉS DAS TECNOLOGIAS EMERGENTES: ESTUDO INICIAL

EL FUTURO DEL TRABAJO EN LA MODA BAJO EL SESGO DE LAS TECNOLOGÍAS EMERGENTES: ESTUDIO INICIAL

JANICE RODRIGUES | UFPR – Universidade Federal do Paraná, Brasil
AGUINALDO DOS SANTOS, Dr.| UFPR – Universidade Federal do Paraná, Brasil

ABSTRACT

Despite the relevance of the clothing industry worldwide, there is a need for changes in the current scenario, given that it is permeated with imbalances in environmental, social, and economic aspects. With the covid-19 pandemic and the impossibility of in-person work, another problem emerged: the production chain was affected by the work stoppages. The solution found to carry it out was remote work. Furthermore, the focus on changing the traditional work format has been intensified . Therefore, this article aims to present the initial results of a research project designed to obtain guidelines for remote work in the fashion industry, in a distributed format, aided by emerging digital technologies. The results were obtained through a multiple case study approach, based on six fashion brands in Curitiba (PR), conducive to assessing the situation of each brand in relation to the core subjects of this research: sustainable fashion, distributed economy, emerging technologies, and remote work. Among the findings to date, it is evident that there is already a significant movement towards a more sustainable approach in fashion designing, producing, and consuming.

KEYWORDS

Design; Fashion; Sustainability; Emerging technologies; Remote work.

RESUMO

Apesar da relevância que a indústria do vestuário possui no mundo, há a necessidade de mudanças no cenário atual, visto que ele é permeado de desequilíbrios nos aspectos ambientais, sociais e econômicos. Com a pandemia da covid-19, ocasionando a impossibilidade do trabalho presencial, houve o surgimento de mais um problema, ou seja, a cadeia de produção foi afetada pela paralisação do trabalho. A forma encontrada para o exercício dele foi o trabalho remoto. Além disso, o olhar para as mudanças no formato de trabalho tradicional foi intensificado. Assim, o presente artigo objetiva trazer os primeiros resultados de uma pesquisa elaborada em prol de obter diretrizes para o trabalho remoto na moda, no formato distribuído, auxiliado pelas tecnologias digitais emergentes. Os resultados obtidos foram, através de um estudo de casos múltiplos, tomando como base seis marcas de moda de Curitiba (PR), a fim de avaliar a situação de cada uma em relação aos assuntos base da presente pesquisa, ou seja, moda sustentável, economia distribuída, tecnologias emergentes e trabalho remoto. Dentre aquilo o que resultou, até o presente momento, compreende-se que já há uma movimentação relevante em prol de um projetar, produzir e consumir mais sustentáveis.

PALAVRAS-CHAVE

Design; Moda; Sustentabilidade; Tecnologias emergentes; Trabalho remoto.

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RESUMEN

A pesar de la relevancia que tiene la industria de la confección en el mundo, es necesario realizar cambios en el escenario actual, ya que está permeado de desequilibrios en aspectos ambientales, sociales y económicos. Con la pandemia del Covid 19, ante la imposibilidad del trabajo presencial, surgió otro problema, es decir, la cadena productiva se vio afectada por el paro laboral. La forma encontrada para llevarlo a cabo fue el trabajo remoto. Además, se intensificó la atención a los cambios en el formato de trabajo tradicional. Así, este artículo pretende traer los primeros resultados de una investigación diseñada para obtener pautas para el trabajo remoto en la moda, en un formato distribuido, ayudado por tecnologías digitales emergentes. Los resultados obtenidos se obtuvieron a través de un estudio de caso múltiple, basado en seis marcas de moda de Curitiba (PR), con el fin de evaluar la situación de cada una en relación con los temas básicos de esta investigación, es decir, la moda sostenible, la economía distribuida., tecnologías emergentes y trabajo remoto. Entre lo que ha resultado, hasta ahora, se entiende que ya existe un movimiento relevante hacia un diseño, producción y consumo más sostenibles.

PALABRAS CLAVE

Diseño; Moda; Sostenibilidad; Tecnologías emergentes; Trabajo remoto

1. INTRODUCTION

The fashion industry, more specifically, the clothing sector, is not only one of the most long-standing on the planet but it also represents 6% of global trade (Khajavi, 2021). Furthermore, it generates approximately 20 million formal jobs and 60 million informal jobs worldwide (Castaneda-Navarrete, Hauge, and López-Gómez, 2021).

Brazil is one of the few countries with a complete production chain for clothing production (ABIT, 2022). Moreover, it generated a financial turnover of around R$185.7 billion, as it was the case in 2021, with a production of 9.04 billion clothing items and 1.5 million workers involved in it. Despite all this relevance in its traditional format, this sector presents numerous problems.

In the social and economic spheres, these deficiencies are exemplified by the existence of poorly paid labor, which does not provide workers suitable conditions to live and support their families. Additionally, workers are often exposed to unhealthy and near-slavery conditions for more than twelve consecutive hours, with no real guarantee of labor rights. The existence of these practices is induced by the pressure to reduce production costs (Berlim, 2012). Concerning the environmental sphere, in addition to the use of chemical products in production, which are dumped into the environment, there is improper waste disposal and the environmental impact of product transportation and distribution in retail (Santos et al., 2021).

A type of work that has been suggested to address these and other problems for being more sustainable is remote work. This is possible because it can be done at a distance, by people connected to a network, sharing different information, materials, etc. (Perez, 2017). It also offers a higher quality of life, lower gas emissions (WRI BRASIL, 2020) due to the lack of commuting (SOBRATT, 2020), increased job retention (Nunes et al., 2019), and the maintenance of jobs (Zaman, 2021).

Remote work saw significant growth in practice during the Covid-19 pandemic (Durães, Bridi, and Dutra, 2015). In the fashion industry, this was driven by a 90% drop in fashion clothing production in 2020, which affected all other links in the textile chain (Gandra, 2020). Thus, there was a need for reinvention; that is, instead of producing clothing, the industry produced health items such as masks and aprons, as well as changing the design and sales of products.

The work in question can be done either at home or another location and it can be fully remote or partially remote (hybrid). Furthermore, it can be carried out by micro-entrepreneurs as well as workers in conventional companies (Moço, Lopes, and Soares, 2020).

Therefore, all the aspects mentioned are important for the deepening of this research, hence it addresses fundamental core aspects. Foremost, how the distributed economy can implement sustainability in fashion. Secondly, the implications of using various technologies for the distributed economy in the clothing sector. Finally, the implications of remote work for sustainability in the clothing sector, using emerging digital technologies.

Thus, the aim of this article is to present the initial results of a research project concerning the development of guidelines for sustainable fashion work in a remote format, based on the distributed economy and the use of emerging technologies, in order to provide parameters for those who intend to carry out this type of work, and also provide changes to the current prevailing fashion scenario, which is characterized by significant inequality.

2. GENERAL CONTEXT REGARDING THE FUTURE OF WORK

The following themes are part of the fundamental structure of the research and contribute to its elaboration, which are sustainability, distributed economy, emerging technologies, and remote work.

2.1 FASHION AND SUSTAINABILITY

Fashion, according to the Michaelis Dictionary, is defined as the manner or style of acting or dressing, as well as the system of collective uses or habits that characterize clothing, footwear, accessories, etc., at a certain moment (Michaelis, 2022). Aligned with this, Svendsen's (2010) words are, fashion, which strengthened in the 18th century, "began with rapid changes and a constant challenge to the individual to keep up with their time"; about this passing period, certain types of clothing and accessories are in evidence and, afterwards, give way to others. According to Lipovetsky (2009), ephemerality ended up consecrating fashion as a system, during modernity, because before, that is, in the time when the Roman Empire dominated several parts of the world, including the East, brief uses and excessive concern with adornments were not seen, i.e., aesthetic fantasy.

Thus, the link between clothing and fashion became quite relevant, considering that fashion, as a symbol, has clothing as the instrument for each individual to express their identity, as well as to manifest their own emotions (Fletcher, 2014). All this led to the emergence of fashion design, an area that can aggregate the material and the immaterial aspect. This means the union of raw materials, form, functionality, and quality with the emotional needs that people have (Berlim, 2012). In addition, design intrinsically enables, through the realization of an idea, the effective satisfaction of those who use the product and designers themselves, for being able to create and materialize useful solutions (Papanek, 1995). In fashion, this aspect is important because design managed to bring behavioral and aesthetic considerations into it, which were translated into artifacts through contact with disciplines such as psychology, anthropology, and sociology (Berlim, 2012).

Following the path of bringing products aiming to satisfy people's desires, design, through the union with marketing (advertising/publicity), has been used to provoke continued demand for artifacts with increasingly shorter life cycles (Pantaleão, Pinheiro, and Menezes, 2016). On the other hand, since around the 1960s, more strongly, Design and Designers have been responding to the call of environmentalists, starting to worry about designing artifacts and materializing them in a more conscious way. With an emphasis initially restricted to the environmental dimension, these efforts sought to reduce the impact caused to the environment (devastation of planet Earth) by consuming environmental resources above the planet's resilience levels. This began with ecodesign, seeking to avoid environmental impacts throughout the life cycle of fashion products (GWILT, 2014, P. 19). Currently, with the expanded focus of sustainable design, which also takes into account social and economic impacts, in order to adopt a holistic approach to sustainability, the designer projects with a view to production, use, repair, recycling and, when the latter is not possible, product disposal (Gwilt, 2014). Contemporarily, sustainable design, through approaches such as social innovation and product+service systems design, has sought to change lifestyles, business models, and consumption patterns in order to reduce consumption levels or, at least, promote a circular economy.

Therefore, it is necessary to better define what sustainability is, to understand its influence on design, which is possible through the definition introduced by the World Commission for Environment and Development Our Common Future (WCED), which emphasizes the environmental context and refers to:

> The systemic conditions according to which, at the regional and planetary levels, human activities should not interfere with the natural cycles on which everything the planet's resilience allows is based, and at the same time, should not deplete its natural capital, which will be passed onto future generations (MANZINI; VEZZOLI, 2016, P. 27).

To this concept, which refers to a physical perspective, it is important to associate an ethical perspective, that is, according to the principle of equity, the same amount of natural resources should be available to all people (Manzini and Vezzoli, 2016). Furthermore, it is also important to observe the economic and social aspects, in order to achieve real sustainability, because

> the eradication of poverty, the shift from unsustainable to sustainable consumption and production patterns, as well as the protection and management of natural resources, which underpin economic and social development, are fundamental objectives and essential requirements for sustainable development. (...) to achieve sustainable development, it is necessary to: promote sustained, inclusive and equitable economic growth; create greater opportunities for all; reduce inequalities; improve the basic living conditions; promote equitable social development for all; promote integrated and sustainable management of natural resources and ecosystems, which notably contributes to social and human development, without neglecting the protection, regeneration, restoration, and resilience of ecosystems in the face of challenges, whether new or existing (UNCSD, 2012, p. 3).

Taking into consideration not only the environmental aspect but also the social and economic aspects, or at least moving towards it, is sustainable fashion. It can be defined as one that pays attention to all phases of the clothing cycle and, by designing holistically and systematically, seeks to reduce negative impacts. In the social aspect, it improves working conditions and employment in fashion, favors the inclusion of everyone in fashion; improves social cohesion in fashion; values local resources and competencies; promotes education

in sustainability in fashion (Santos et al., 2019); promotes responsible consumption in fashion. In the economic aspect, it promotes local fashion entrepreneurship; values local infrastructure and culture; promotes economic equity among actors; promotes economic inclusion through fashion for the weak and marginalized; promotes network organizations; values the reintegration of fashion product waste; promotes education for sustainable economy (Nunes et al., 2019).

2.2 DISTRIBUTED ECONOMY

Distributed Economies, according to Santos et al. (2021), comprise units of added value, on a small scale, whether in manufacturing or services, in which the user and/or client have control over the activities. This happens because these units, organized in a network format, serve local needs. Such needs correspond to artifacts and services, concerning the product lifecycle and the business process. Therefore, these units are most capable of offering on-demand solutions and having real participation from various users, including when they take on the role of manufacturer or service provider. Additionally, they share products, resources, knowledge/information, and other types of services.

Within the distributed economy are distributed systems, which can be defined as those in which agents are connected both closely and more distantly, generating a global connection. Therefore, they are more flexible systems. They also "reduce environmental impacts related to product transportation; allow the local community to have greater control over the means of production; enable individuals to become aware of social and environmental issues" (PEREZ, 2017, P. 46). Two of these systems stand out and are relevant to the present work: Distributed Design (DD) and Distributed Production (DP) (Perez, 2017).

Distributed Design is conceptualized as an open design project, in which a small-scale design unit, i.e., one person or more, connects with others through the computer. This means that several individuals, small businesses, and/or local communities, networked together, work towards the development of artifacts (Perez, 2017), including those related to fashion, such as clothing and accessories.

On the other hand, distributed production, in system format, is conceptualized as a "small-scale production unit, at the point of use or nearby, in which users are the producers – whether individuals, small businesses, and/or a local community" (LeNSin, 2016, p. 7; Perez, 2017). This type of production signifies a significant change in traditional patterns of production and consumption, as it challenges this model, especially regarding large-scale artifact production in vast supply chains, economies of scale, and tendencies towards centralization (Perez, 2017).

Distributed production can occur in a sort of mini-factory connected to others in networks, with connections also between designers, producers, and users, in order to produce in smaller quantities using technology to meet local needs in a more sustainable manner (Perez, 2017).

It is possible to discuss digital manufacturing technologies for fashion within the context of distributed production, as they enable on-demand production, personalized products, do-it-yourself, surface design, connection with craftsmanship, and the consequent reduction of environmental impact (Santos et al, 2018). Therefore, emerging technologies will be discussed below as a way to exemplify those that can be used in the fashion sector.

2.3 DIGITAL FABRICATION AND EMERGING TECHNOLOGIES

Digital Fabrication is defined as a set of processes in which computer-monitored tools are used, meaning that these tools decode CAD (Computer-Aided Design) files for product printing. Moreover, there is the possibility for the manufacturing materials themselves to be digital, and object production can occur on demand, in the place and time it is needed (GERSHENFELD, 2012). Thus, the virtual context provides an environment that favors this new form of production, in which users/consumers have a greater role (Bastos, 2014).

In this production form, design and consumers collaborate, sharing ideas that are passed to the virtual environment, enabling interaction. Thus, co-design occurs using open design, meaning the product is realized with the aid of digital fabrication, and those who acquire them have the option to personalize them. The existence of the internet has made it easier for all interested parties in the context to access open design to produce in the quantity that suits them best (Bastos, 2014).

Regarding Fashion, some technologies for digital fabrication have already been used, often gathered in spaces called Fab labs or Fashion labs. In these places, conditions are provided for people, collaboratively and experimentally, to explore their creativity with the different available technologies, as it is a place open to

the entire community (Felippe et al., 2020).

Examples of emerging technologies that can be used in the fashion industry include Drawing and Modeling Software; Digital printing machines; Digital embroiderers; Laser cutters; Digital weaving machines; 3D printers; Vinyl cutters, and CNC milling machines.

Another type of current work that also makes use of emerging digital technologies is remote work. This work saw an acceleration with the Covid-19 pandemic, a situation that occurred even in Latin America, where this type of work increased almost tenfold compared to before the pandemic (Poder 360, 2021), due to the need to adapt labor forms to address this context.

2.4 REMOTE WORK

Remote work, or telecommuting, is defined as work that takes place outside the company's premises, and it can be carried out either at home or in another physical space connected to the company, through technological artifacts (Moço, Lopes, & Soares, 2020).

Regarding the fashion industry, with the pandemic context, stakeholders in this segment, especially those linked to garment manufacturing, needed to reinvent themselves. Fashion apparel production dropped by 90% in 2020, affecting all other links in the textile chain. This led to the production of other items, such as health items (masks and gowns), and changes in design and product commercialization methods.

Among the practices that emerged, there was an increase in remote work, with the use of platforms for digital marketing and e-commerce, including brand showrooms with virtual samples of pieces and the availability of co-creation for users of the space (customized and on-demand clothing production), such as the choice of fabric, color, and print of the pieces; avatar influencers for luxury brand promotion; online fashion shows; brand lookbooks featuring 3D clothing pieces to showcase all details virtually; WhatsApp as a sales tool; offering discounts and free shipping to boost sales; Google integration for better visibility; administrative staff working from home; and fully remote creation collectives, such as Fresco, created by fashion designer Ingrid Frederichi, composed of 5 fixed women and over 15 freelancers developing brands, products, fashion collections, prints, etc.

In the 3D context, it is worth highlighting the role of 3D software, which even before the Covid-19 pandemic was gaining prominence in garment manufacturing. With the current health crisis, these software gained even more relevance as they could be used from home computers. The primary goal of modeling with such software is to increase efficiency and precision without the need for physical materials, as everything is digitally manipulated. This type of modeling involves product simulation and visualization to minimize losses before production. An example of such software is CLO 3D, which allows users to realistically design clothes and avatars wearing them. It enables users to create pieces and showcase them in a virtual showroom for consumers, facilitating on-demand manufacturing.

Therefore, it is evident that the fashion industry has also incorporated technology in various aspects of its operations to enable remote work and thereby prevent greater human and/or economic losses. Reflecting on the decrease in production, driven by isolation and reduced purchases, even after the most challenging period of the pandemic, there is also an observed increase in consumer preference for sustainable and durable products, which is expected to continue growing in the years to come. These factors are important drivers for making the industry more sustainable. Additionally, remote work aligns with distributed economy principles, as it involves units connected in a network where people can work from different locations but remain connected, allowing for the sharing of information, services, resources, among others (Perez, 2017).

3. RESEARCH METHOD

The study in question is divided into six phases, which will culminate in the establishment of guidelines for sustainable fashion remote work. However, this section will address what was carried out in the first, second, and third phases, as the last three phases have not yet been completed. Therefore, the details of the highlighted phases are as follows:

3.1. PHASE 1: UNDERSTANDING THE PROBLEM

In this phase, the strategies used to understand the problem and obtain data to support the development of the research protocol, to be carried out in phase 2, were described. The strategies included a theoretical review conducted systematically and unsystematically in 2021,

aimed at providing theoretical grounding on sustainable fashion, remote work, and emerging technologies, the four main points of the research.

For the unsystematic review, texts (journals, conference proceedings, dissertations, etc.) were searched on Google Scholar. Physical books providing a general overview of the researched topics, as well as keywords and possible search strings, were also used. Subsequently, the systematic review was conducted according to the criteria proposed by Conforto, Amaral, and Silva (2011). This review consisted of three phases: input, processing, and output, aimed at selecting publications, archiving and cataloging them, and writing the text. Table 01 shows the respective criteria of the RBS.

Based on the coding, each case was individually

Data Collection Protocol for the State of the Art	
Question	What theory underpins sustainability in fashion? How are the themes of distributed economy, emerging technologies, and remote work related to it?
Research Objective	**General:** Develop the topics of fashion, sustainability, distributed economy, emerging technologies, and remote work; **Specific:** Identify details of the above context and, among them, define the dimensions of sustainability by bringing concepts and principles applied to fashion. Additionally, investigate the relationships between fashion, technology, distributed economy, and remote work.
Themes	Sustainable fashion, Distributed Economy, Remote Work, and Emerging Technologies.
Keywords	Fashion; Sustainability "Clothing Design"; Dimensions; SME; Textile; "Sustainable Development"; Technology; "Distributed economy".
Research Scope	Capes Journals Portal. Directs to databases containing relevant articles for the study.
Technical Aspects	Filter 1: Title, keywords, and abstract reading; Filter 2: Introduction and conclusion reading of the article; Filter 3: Complete article reading. Comparison with the theoretical framework of Silveira, Santos, and De Sampaio (2022).
Methodological Validity Criteria	The research is being conducted by the authors of the present study. Inclusion and exclusion criteria ensure that no relevant result is discarded. Furthermore, comparing the articles, after the filters in the technical aspects, with the theoretical framework of Silveira, Santos, and De Sampaio (2022), which addresses sustainability heuristics, will ensure a solid and coherent result.
Inclusion/ Exclusion Criteria	**Inclusion criteria:** Last 5 years, English language, peer-reviewed, journal articles, subject: sustainability. **Exclusion criteria:** Conference papers, articles on marketing, footwear.
Search Strings	Fashion AND Sustainability AND Dimensions; Fashion AND "Clothing Design" AND Sustainability; Fashion AND SME AND Sustainability; Fashion AND Textile AND "Sustainable Development"; Fashion AND technology AND Sustainability; Fashion AND Distributed economy" AND Sustainability.
Data Export	Personal hard drive of one of the authors.

Table 01: Criteria used in the initial phase of the State of the Art Review
Source: Based on Santos et al. (2018)

Only the articles that met the criteria presented were included, which were important for clarifying ideas and constructing the literature review in section 2 (General context of the future of work) of this article. Additionally, it was a preparatory stage for the field research (Santos et al., 2018).

It was also possible to observe the situation of the research problem in relation to what has been written about it.

3.2. PHASE 2: DEVELOPMENT OF THE DATA COLLECTION PROTOCOL

In this phase, the planning of the data collection protocol was described, that is, the delineation of brands to be studied, the data to be collected, and the subsequent data storage of the same.

Regarding the brand selection criteria for the case studies, the following were adopted (Table 02):

Criteria	Nature
At least one sustainable practice in at least one sphere of sustainability.	Mandatory
Digital technologies for fashion design and production, as well as facilitation of remote work	Desirable
Remote/Hybrid Work	Mandatory
Micro or small company, with no minimum time of existence	Mandatory
Location: Metropolitan Region of Curitiba	Mandatory
Distributed Economy (Work conducted in a network)	Mandatory
Apparel Industry	Mandatory

Table 02: Criteria considered for brand selection.
Source: Authors .

Data were obtained in the form of interviews, social networks and websites and images. As for their storage, an external HD and Google Docs were used.

3.2. PHASE 3: MULTIPLE CASE STUDY

The Multiple Case Study reports the collaboration that took place in Phase 2, which involved data collection, since these data are essential for the analysis of how sustainable fashion, distributed economy, remote work, and emerging technologies have been implemented with their advantages and disadvantages. Additionally, it quantifies the maturity level of these elements in the analyzed brands, and it identifies common factors, specificities, and barriers.

3.2.1. ANALYSIS AND VALIDATION STRATEGY

To analyze the field research data, the Nvivo software was used. This software was chosen for its practicality and greater reliability in the analysis. Initially, interviews, images, and information gathered from the internet (websites and Instagram) were coded. The coding considered the four main topics of the thesis, of which this report is a part: sustainability, distributed economy, emerging technologies, and remote work. These topics were selected as attributes (attribute coding) to classify the several data formats obtained, which enhanced the analysis and interpretation of the data. Furthermore, this approach was suitable for cross-case analysis with multiple participants (Miles, Huberman, and Saldaña, 2014), as seen in this research.

In addition to codes, subcodes were established within the primary codes in order to classify the information more specifically, that is, providing further detail or enrichment to the entries. This strategy is appropriate for content analysis, studies with multiple participants and sites, and studies with a wide variety of data formats (Miles, Huberman, and Saldaña, 2014), as is the case in this research.

Therefore, the selected codes and subcodes are presented in the following table (Table 03):

Sustainability
Lifecycle, Education, Inclusion, Slow fashion, Work time, Transparency, Social and environmental responsibility and Deficiencies_S.
Distributed Economy
Co-creation, Small producer, Networking, Local valorization and Deficiencies_DE.
Emerging Technologies
Types_ET, Advantages_ET and Disadvantages_ET.
Remote Work
Forms_RW, Advantages_RW and Disadvantages_RW.

Table 03: Established codes and subcodes,
Source: Author

Based on the coding, each case was individually analyzed using the Nvivo software. As a comparative parameter the content obtained in the theoretical review and tools were used to assess the level (from 1 to 5) of individual maturity (figures 01 to 03) of each one regarding sustainability, distributed economy, remote work, and emerging technologies, along with the theory obtained in the theoretical foundation. The first two tools were adapted from pre-existing ones (Paz, Frozza, and Kipper, 2015; Clear Word, 2023), and the last one, concerning emerging technologies, was created by the author of this document based on the knowledge acquired during the theoretical review conducted for the thesis. After all the previous steps, a cross-analysis was conducted among the data of each case to investigate connections, gaps, barriers and specific attributes.

Finally, a report was written, from which the results of the preliminary study were extracted, and a reflection on the study was included in the conclusions section. This report is to be presented to the brands for validation in the next phase.

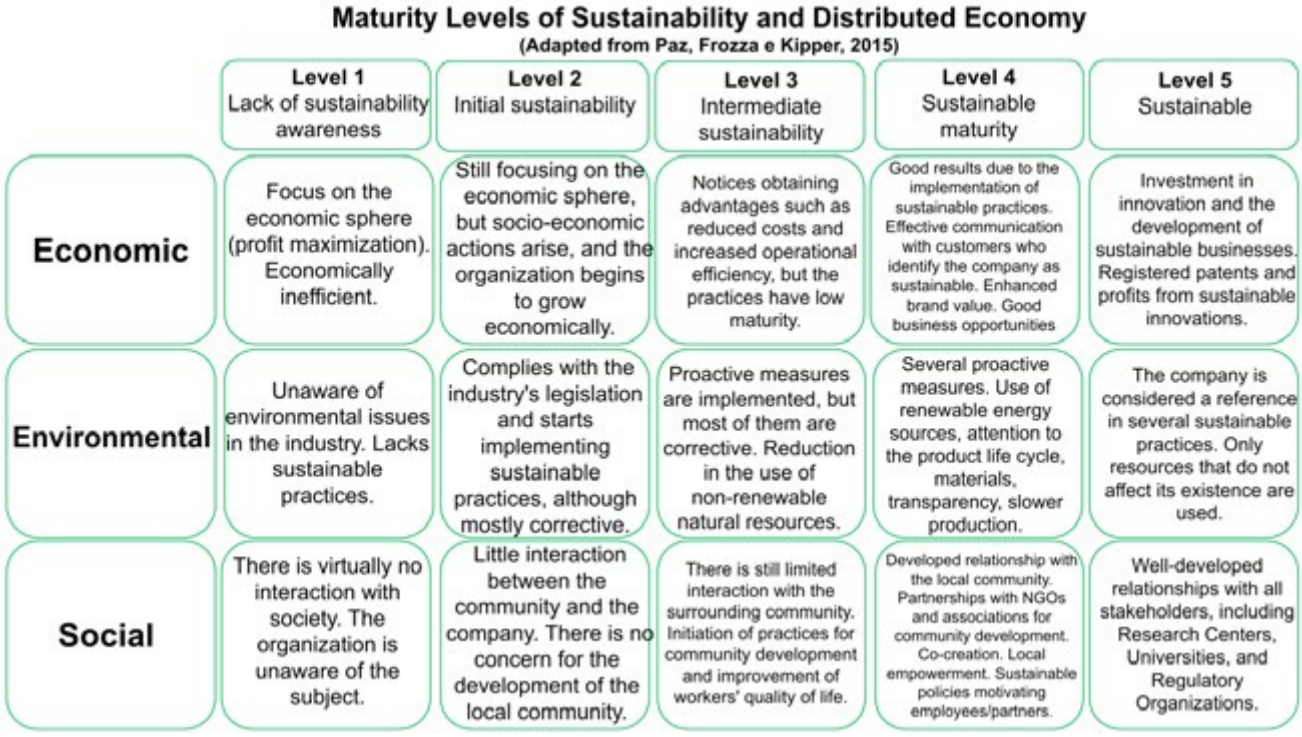

Figure 01: Assessment Tools for Sustainability and Distributed Economy Maturity Levels .
Source: Adapted from Paz, Frozza, and Kipper (2015).

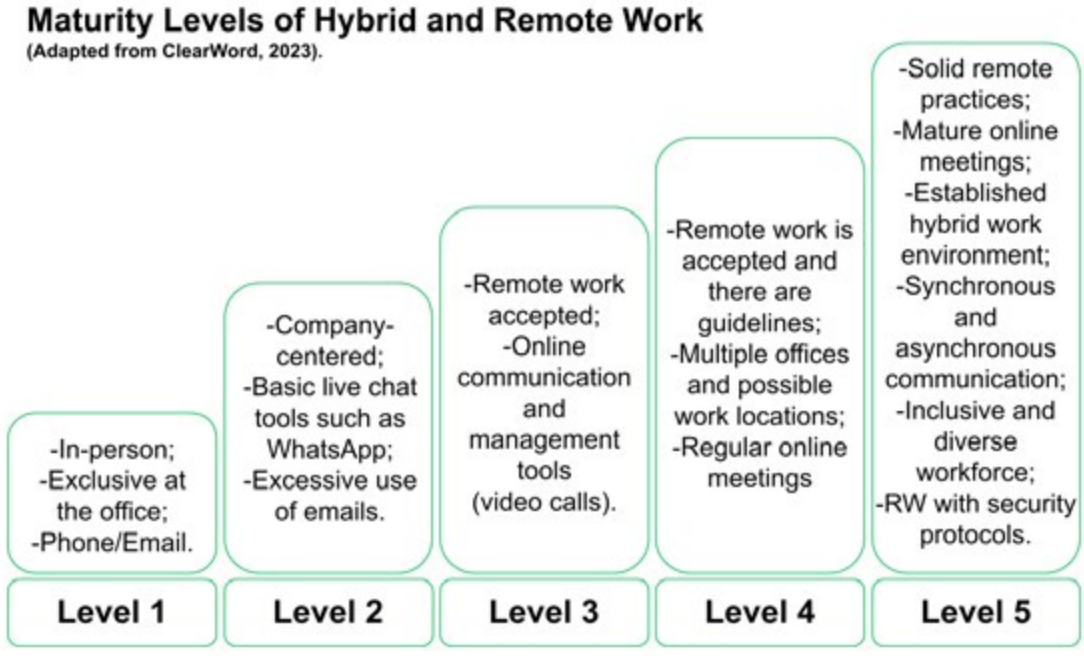

Figure 02: Assessment Tools for Maturity Levels of Hybrid and Remote Work.
Source: Adapted from Clear Word, (2023).

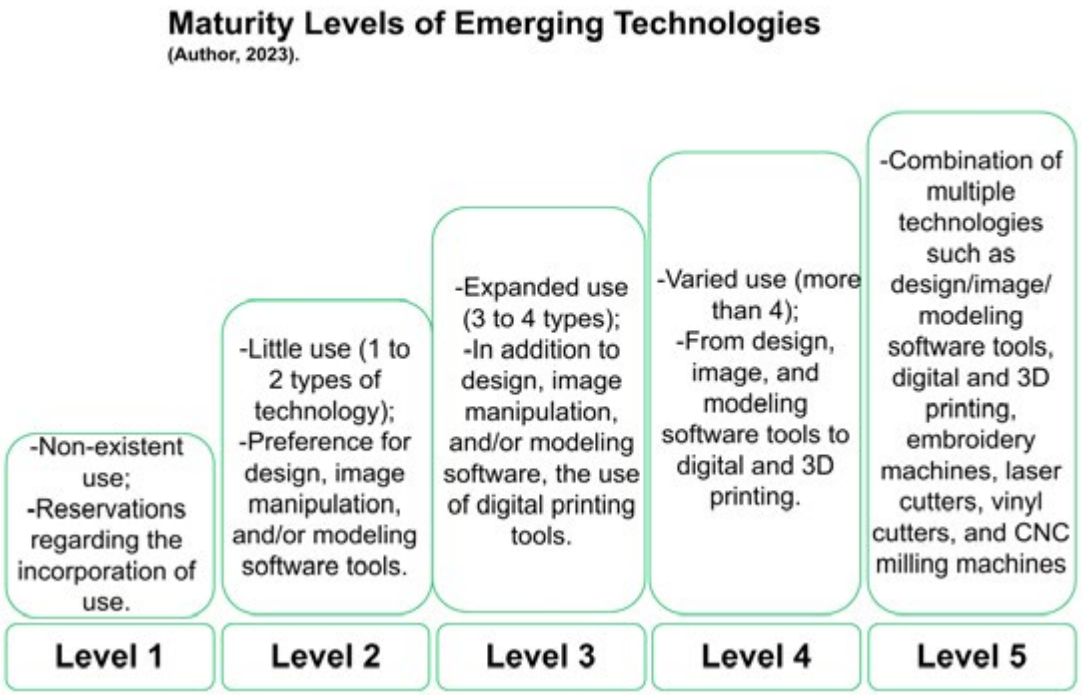

Figure 03: Assessment Tools for Maturity Levels of Emerging Technologies.
Source: Authors .

4. RESULTS

4.1. Phase 1 Results

In order to understand the research problem and identify authors, content, and knowledge, as well as to provide a basis for the theoretical review in item 2, an unsystematic review was conducted in conjunction with the systematic review.

Regarding the Systematic Review, Table 04 was created to show the results obtained with the search strings and, after their use, with the filters. Although several articles were found, only 17 were used in writing the thesis because the central theme of the current document is still underexplored. Additionally, articles focusing on remote work, after attempts to search using various strings such as Fashion AND Sustainability and Remote Work, Fashion AND Sustain* AND Remote Work, and Fashion AND Sustain* AND Hybrid Work, did not yield any results. This can be considered a gap but also an opportunity to explore the subject in this thesis through unsystematic review.

Search Strings	Results	Filter 1	Filter 2	Filter 3
Fashion AND Sustainability AND Dimensions	3	2	1	1
Fashion AND Clothing Design AND Sustainability	64	30	11	4
Fashion AND SME AND Sustainability	340	70	14	3
Fashion AND Textile AND Sustainable Development	50	20	13	3
Fashion AND Technology AND Sustainability	157	60	20	3
Fashion AND Distributed Economy AND Sustainability	600	150	40	3
Total	1214	332	99	17

Table 04: Results of the Systematic Literature Review
Source: Authors (2023).

Regarding the quantity of publications (Figure 04), after applying filter 2, an evolution of the publications over the last 5 years was observed. There was growth in 2018, fluctuation in 2019, and a significant increase in 2020, with 29 publications.

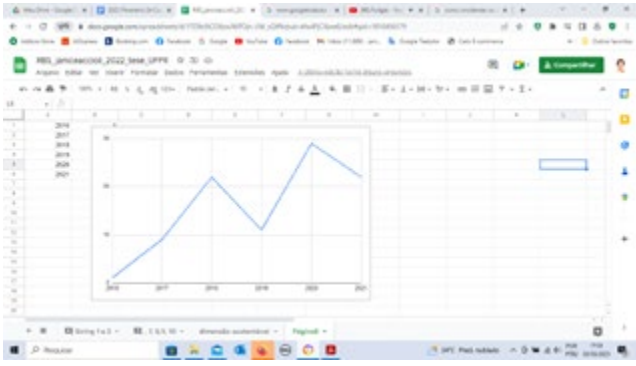

Figure 04: Timeline of Publications from the Systematic Review
Source: Authors (2023).

Despite the reasonable number of publications, the final result after filter 3 showed an insufficient amount of work to support the present research. Therefore, the importance of also conducting the unsystematic review is highlighted, as it provided theoretical support for this document through books, articles, theses, and dissertations.

4.2. Phase 2 Results

The data collection protocol began with the choice of six local brands, from the city of Curitiba, Paraná, which took into consideration the criteria outlined in section 3.1. These brands were initially selected through internet search, a SEBRAE Sustainable Fashion event attended by one of the research authors and also through the recommendation of experts. In order to maintain the confidentiality of the brand names, at this early stage of the research, they were referred to as Brand 1, Brand 2, Brand 3, Brand 4, Brand 5 and Brand 6. Their detailed profiles are described below:

a) Type 1 Cases: Remote Work with Distributed Economy and Emerging Digital Technologies (Brand 2 and Brand 3). Common characteristics include Sustainability (only in Brand 3), Digital Technologies, Remote/Hybrid Work, Micro/Small Business, Local, Distributed Economy, and Apparel;

b) Type 2 Cases: Remote Work with Sustainability and Emerging Digital Technologies (Brand 5 and Brand 6). Common characteristics include Sustainability, Digital Technologies, Remote/Hybrid Work, Micro/Small Business, Local, Distributed Economy, and Apparel;

c) Type 3 Cases: Remote Work and Sustainability (Brand 1 and Brand 4). Common characteristics include Sustainability, Remote/Hybrid Work, Micro/Small Business, Local, Distributed Economy, and Apparel.

Interviews were performed with the appropriate completion of Informed Consent and Clarification forms. The semi-structured format of these interviews allowed participants to express different perspectives, in addition to the questions that were asked. All interviews were recorded in audio format using a mobile phone and stored on an external hard drive owned by one of the authors. They were then transcribed using NVivo transcription software.

Data collection from the internet (information and images) including websites and social media platforms such as Instagram, aimed to facilitate data triangulation, which is a requirement in the case study method. This provided an overall overview of the brands in terms of sustainable fashion, actions taken in this regard, the use of emerging technologies, sustainable messaging to consumers, type of marketed apparel products, and the respective raw materials. The most relevant information was gathered and stored in a Google Docs spreadsheet.

Photographed images included clothing items, fabric samples, and packaging. Collected artifacts consisted of finished brand products or samples of raw materials used in products. This approach was taken to examine the artifacts produced by the brands in terms of raw materials, printing details, multifunctionality, timelessness, agenderness, artifacts produced from production waste, and upcycling. Each image was cataloged as a card in a Google Docs document, along with all possible details, and they were stored on an external hard drive owned by one of the authors.

Upon this scenario it was possible to set the foundation for the next phase, involving Multiple Case Study and the consequent data analysis.

4.3. Phase 3 Results

This analysis process began with the coding of interviews using NVivo software, as well as images (records from one of the research authors and social media) and information collected from the internet (websites and Instagram), totaling 166 files coded, and 1,116 coded references. The four main topics of the thesis, of which this report is a part of, were chosen as codes: sustainability (775), distributed economy (195), emerging technologies (83), and remote work (63).

The performed analysis was provided by the static grouping mechanism, present in NVivo Software, which allows the aggregation of elements for the research purposes (SOFTWARE SHOP, 2023). In virtue of this

grouping of data, triangulation is enabled, where the three types of data sources corresponding to each case were consolidated into separate folders. Triangulation consists in confirming information from different sources related to the research topic and highlights inconsistencies, errors, and conflicts, enabling the researcher to discover and explain properly why these discrepancies exist, which enhances the reliability of the analysis (Miles, Huberman, and Saldaña, 2014).

From the data grouping, the software analyzed the data and provided results regarding the presence of each code and subcode in the data..

Subsequently, the analysis involved examining individual cases to evaluate the four main aspects underpinning the research and conducting cross-case analysis using information from all interviewed brands. The results of both analyses will be presented in the following items.

4.3.1. Individual Analysis

4.3.1.1. Sustainability

Regarding sustainability, brand 1 is at **level 2**, indicating **initiation of sustainability** when comparing the data obtained with the maturity tool, in the highlighted aspect. This is because sustainability is already seen in the brand, but there are still deficiencies, such as the use of materials with two fibers and materials from more distant locations, lack of repair availability, among others, which would be important for facilitating the extension of the lifecycle of garments/materials (Vezzoli et al., 2022) and for reducing carbon emissions by preferring local resources (Gwilt, 2014). Some notable actions include the use of recycled materials, multifunctional pieces (Vezzoli et al., 2022), communication for consumer education (Santos et al., 2019), and the inclusion of diverse female body types (Gwilt, 2014), however, the brand needs to further enhance its sustainable character, particularly regarding the inclusion of marginalized groups (Santos et al., 2019). Additionally, the Social and Environmental Responsibility subcode was not identified in the analyzed sources due to this lack of action by the brand.

As for brand 2, it is at **level 1**, meaning **lack of sustainable awareness** when comparing the data obtained with the maturity tool regarding the highlighted aspect. This means that although the brand already has some sustainable practices, such as using local and biodegradable raw materials (Gwilt, 2014); producing in small quantities on-demand (Perez and Santos, 2018); and offering high-quality products (Nunes et al., 2019), so that they last longer; there is little awareness on the subject and many deficiencies. The latter include not using organic cotton, using materials with two fibers, no use of recycling in any way (Vezzoli et al, 2022), nor is there the inclusion of marginalized people (Santos et al., 2019). Besides, several subcodes related to sustainability were not found in the analyzed materials, which could be relevant for the brand's sustainable practices such as education for sustainability, social and environmental responsibility, and sustainability in work hours

Brand 3 is at **level 4**, that is, **sustainable maturity** when comparing the data obtained with the maturity tool for the highlighted aspect. Which means, despite a few deficiencies, such as the use of materials with two fiber types (Vezzoli et al, 2022) and PET itself (Redação Future Print, 2021) due to its maturity in other areas, it is well developed in terms of sustainability. The other aspects are the use of organic, recyclable, and recycled materials, zero waste practices, multifunctional items (Vezzoli et al, 2022), waste integration into production (Nunes et al, 2019), inclusion of marginalized groups and consumers (Santos et al., 2019), in the strong social and environmental responsibility that is actually present, covering all positive subcodes.

Brand 4 is at **level 3**, indicating **moderate sustainability** when comparing the data obtained with the maturity tool for the highlighted aspect. Besides some reservations, such as using raw materials that, despite being recycled, contain more than one fiber type in the composition (Vezzoli et al, 2022), waste is not reintroduced in the production (Nunes et al, 2019), there is a lack of initiatives in the area of social and environmental responsibility, which could engage continuous community involvement, and providing greater transparency on the website, specifically regarding partners responsible for clothing production (Bhamra et al, 2011).

Brand 5 is at **level 4**, which represents **sustainable maturity** when comparing the data obtained with the maturity tool for the highlighted aspect. Although it still has some deficiencies, including not accepting returns of items for raw materials lifecycle extension, waste management, and the use of recycled materials or modular/multifunctional pieces, some issues are being addressed, such as transitioning from paper to QR codes for minimizing material use (Vezzoli et al., 2022). Also, it is a brand that has been growing and improving in social and environmental efforts, and it complies with all

positive subcodes.

Brand 6 is at **level 3**, meaning **moderate sustainability** when comparing the data obtained with the maturity tool for the highlighted aspect. The company already has more sustainable practices, such as considering the design of clothing, not just the material, a point that it is very conscious of, being strongly selective about its materials (Vezzoli et al., 2022). However, points such as a lack of involvement in the development of the local community (Santos et al., 2019), to the point that social and environmental responsibility was an unmarked topic; more engagement with research organizations, as they are interested in new materials; the issue of waste management (Vezzoli et al, 2022), transparency (Bhamra, Lilley and Tang, 2011) are areas that need improvement to achieve a higher level of sustainability maturity.

4.3.1.2. Distributed Economy

Brand 1 is at **level 2,** indicating **limited interaction between the company and the community**, when comparing the data obtained using the maturity tool for the highlighted aspect. This is primarily due to the nearly non-existent engagement between the company and the community, which should be intensified (Santos et al., 2019), limited co-creation aspects for their products, and the absence of customized garments, which should be broader to enhance product personalization (Duarte and Santos, 2019).

Brand 2 is at **level 2**, denoting **limited interaction between the company and the community**, when comparing the data obtained using the maturity tool for the highlighted aspect. It is evident that the company's focus is more on economic aspects rather than on community development, which would be an essential aspect (Santos et al., 2019). This is supported by the total absence of the subcode "local valorization", which is crucial for establishing a deeper connection with the community and valuing local materials, knowledge, etc.

Brand 3 is at **level 4**, that is, a **well-developed relationship with the surrounding community**, among other factors, when comparing the data obtained using the maturity tool for the highlighted aspect. Besides the absence of deficiencies in the data, there is a considerable level of engagement with the community, aimed at its development and appreciation (Santos et al., 2019). What would make it truly sustainable and distributed is forming partnerships with universities and regulatory organizations.

Brand 4 is at **level 3**, implying a **somewhat limited relationship with the surrounding community**, when comparing the data obtained using the maturity tool for the highlighted aspect. While co-creation is one of the brand's strengths (Duarte and Santos, 2019), with numerous partnerships (Nunes et al., 2019), and deficiencies not being mentioned, it lacks involvement in projects aimed at community improvement (Santos et al., 2019), rather than just benefiting the brand.

Brand 5 is at **level 4**, meaning **partnerships with NGOs and associations for community development**, when comparing the data obtained using the maturity tool for the highlighted aspect. Despite having some deficiencies, particularly the absence of co-creation in pattern-making for all order quantities (Duarte and Santos, 2019) and not being able to confirm the existence of bonuses/incentives for individuals producing the garments to enhance working conditions in the fashion industry (Vezzoli 2007; 2010), the brand, overall, is progressing toward establishing itself as a sustainable business, featuring numerous positive aspects and is already recognized for it.

Brand 6 is at **level 3**, suggesting a **somewhat limited relationship with the surrounding community** when comparing the data obtained using the maturity tool for the highlighted aspect. Despite concerns about remuneration (Vezzoli 2007; 2010) and the valorization of local resources (people and raw materials) (Nunes et al., 2019), there is still insufficient community involvement, even as a means to have a more substantial social and environmental responsibility. Moreover, there is a lack of significant customer engagement in co-creating for the brand (Duarte and Santos, 2019), which would help create stronger emotional connections with people (Lilley, 2009; Santos et al., 2019).

4.3.1.3. Emerging Technologies

Brand 1 is at l**evel 1**, meaning there is **no use of emerging technologies** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The use of technology would improve the clothing design (software) and on-demand production, product personalization, and the integration of craftsmanship with technology (Perez and Santos, 2018).

Brand 2 is at **level 4**, indicating the **use of more than four types of integrated emerging technologies** when comparing the data obtained with the maturity tool regarding the highlighted aspect. These technologies include design software tools (Corel Draw and Adobe Illustrator), image manipulation software (Adobe

Photoshop), and digital printing technologies (DTF and Sublimation). The use of these technologies offers several advantages such as on-demand production in small quantities (Troncoso and Rustchiling, 2014), customization according to customer preferences (Perez and Santos, 2018), and efficiency, especially with DTF for printing labels and patterns, saving time and resources (Sanches et al., 2021).

Brand 3 is at **level 2**, meaning there is **limited use of technologies**, comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand uses two software tools for pattern modeling, which minimize waste generation (Lulitex, 2022; Molde. me, 2022). To optimize the production process even further, the incorporation of other software tools that cover the entire production process, such as Audaces and Lectra, would be more efficient (Lectra, 2022; Audaces, 2022). The limited use of more technologies is due to the unavailability of inks made from more sustainable materials for digital printing, such as materials made from reclaimed resources, which would contribute to sustainability by using biodegradable and reused materials from other production processes (Vezzoli et al., 2022).

Brand 4 is at **level 2**, indicating **limited use of technologies** when comparing the data obtained with the maturity tool regarding the highlighted aspect. Despite some forays into the 3D realm, the brand's use of technology is limited to two software tools for graphic design purposes, like brochures. Even with the strong artisanal appeal of the brand, greater utilization of 3D printing for buttons and other accessories, the design of unique pieces similar to handcrafted products (Gonçalves, Teofilo, and Campos, 2017) with zero waste (Pasricha and Greeninger, 2018) and other software tools covering the entire production process, such as Audaces and Lectra (Lectra, 2022; Audaces, 2022), would enhance the overall efficiency.

Brand 5 is at **level 3**, meaning **use of three types of technologies** when comparing the data obtained with the maturity tool regarding the highlighted aspect. These technologies include DTF, DTG, and Adobe Illustrator. Notably, DTF allows for the printing of smaller quantities, or on-demand production (Troncoso and Rustchiling, 2014), and does not use water in the printing process, conserving resources, and DTG has a less toxic composition, reducing health hazards (Vezzoli et al., 2022).

Brand 6 is at **level 5**, with the **use of several technologies and software tools** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand employs two types of digital printing, laser cutting, and three software tools for design and image manipulation. Although, the incorporation of a comprehensive software tool like Audaces 360 (Audaces, 2020), which covers the entire process of creating pieces, would certainly further enhance waste reduction, time and energy savings (Vezzoli et al., 2022).

4.3.1.4. Remote Work

Brand 1 is at **level 3**, meaning **remote work is accepted** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand's designer and owner creates and produces clothes at home, sells them, and meets with clients at Casa 102, in addition to online sales (a hybrid approach) (NYC, 2022), and there is also a person who works with her remotely (home office) (SOBRATT, 2020).

Brand 2 is at **level 3**, meaning **remote work is accepted** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The company owner works from home or in a co-working space and sells online (a hybrid approach) (NYU, 2022), their partners work from their respective locations, and communication is mainly conducted via technologies, especially through WhatsApp. They are not always physically present, but the work processes proceed as usual.

Brand 3 is at **level 5**, indicating **solid remote work practices** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand predominantly follows a hybrid work model (NYU, 2022), with people working remotely in collaboration with the brand, using technology for communication. No deficiencies were detected in the data, and remote work functions exceptionally well in the company, as demonstrated by the high-quality production that benefits all involved, without the need to be physically present together.

Brand 4 is at **level 4**, meaning **several acceptable work locations** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand's designer and owner works in a hybrid manner (NYU, 2022), creating pieces at home while their production occurs in the brand's own studio. Additionally, there is a network of partners who work from different locations, including their homes and locations outside the state. Communication is facilitated through internet-connected technology, primarily WhatsApp.

Brand 5 is at **level 4**, indicating **several acceptable work locations** when comparing the data obtained with

the maturity tool regarding the highlighted aspect. Part of the work is done from the brand owner's residence (for creation and marketing), sales are conducted at the Acampar store and online (a hybrid approach) (NYU, 2022). Production takes place in other locations, across four partner hubs, and there are partners for prints design who reside outside of Brazil.

Brand 6 is at **level 3**, meaning **remote work is accepted** when comparing the data obtained with the maturity tool regarding the highlighted aspect. The brand's designers and owners often work from home (for design and managing social media) and interact with clients at the studio (a hybrid approach) (NYU, 2022). Communication is facilitated through internet-connected technology, primarily WhatsApp. The work also involves collaboration with other professionals (production and print design).

4.3.2. Cross Analysis

With the purpose of comparing the results of the brands, it was necessary to cross-reference them, starting with the maturity levels concerning the four main aspects that underpin the research.

The graphs (Figures 05 and 06) verify that two companies (brands 3 and 5) have a level 4 of sustainable maturity and the distributed economy maturity level, being followed by brands 4 and 6 (3), brand 1 (2), and brand 2, with no points concerning sustainability and 2 concerning the distributed economy.

This is due to the fact that the brands have nearly the same level of development between these two items, meaning there is a greater balance.

Regarding emerging technologies (Figure 07), two brands stand out (brand 6 and brand 2) with 5 and 4 points, respectively, as they make more extensive use of these technologies. Brand 5 comes next (3), then brand 4 (2), and only one (brand 1) still does not use any technology.

This situation is due to the working methods chosen by some brands, such as artisanal production, due to the high cost of using technological machinery and the lack

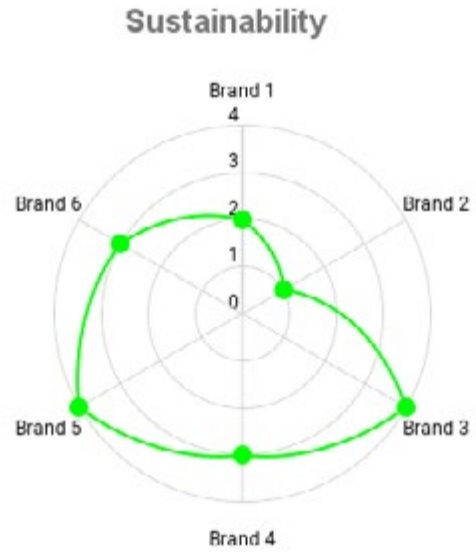

Figure 05: Graph showing brand maturity in terms of sustainability.
Source: Authors.

of greater sustainability in their methods, which does not drive all brands to invest in these technologies.

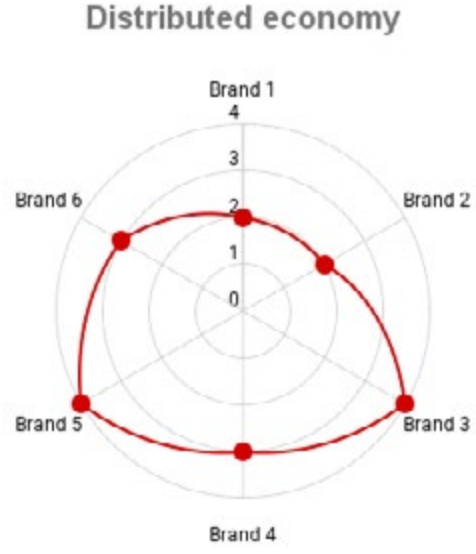

Figure 06: Graph showing brand maturity in terms of the distributed economy.
Source: Authors.

Regarding remote work (Figure 08), all of them make use of this type of work because it provides usefulness. However, three brands do so with a greater number of partnerships and, consequently, more places to work, which are brand 3 (5) and brands 4 and 5 (4).

Next, a word cloud was generated using Nvivo software (Figure 09). It displays the 94 most common words from

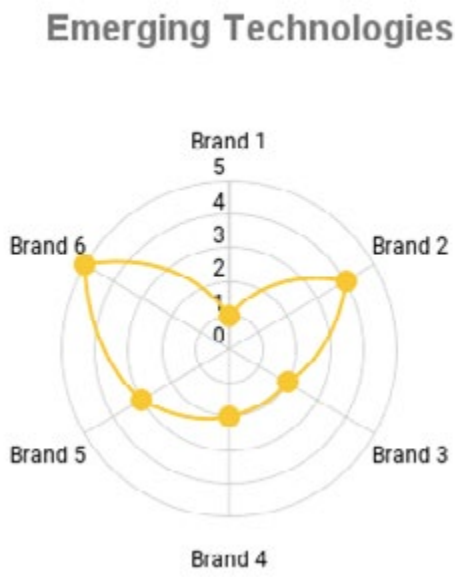

Figure 07 : Graph showing brand maturity in terms of Emerging Technologies.
Source: Authors .

interviews, online data, and images, which was important for identifying common points among the companies.

From the word cloud, these findings could be searched in the report, along with other points of interest, in order to organize the results and present them in a way that makes them understandable. Therefore, a table was created to group the characteristics found for the purpose of identifying connections (4 to 6 markings: most companies have them), gaps (0 to 3 markings: most companies do not have them), barriers (having these characteristics is an obstacle to the business), and specific attributes (specific characteristics of one or more brands). This grouping is a way to conduct cross-analysis, aiming to determine which groups the cases fall into and which configurations are common (Miles, Huberman, and Saldaña, 2014).

The data obtained were placed in another table,

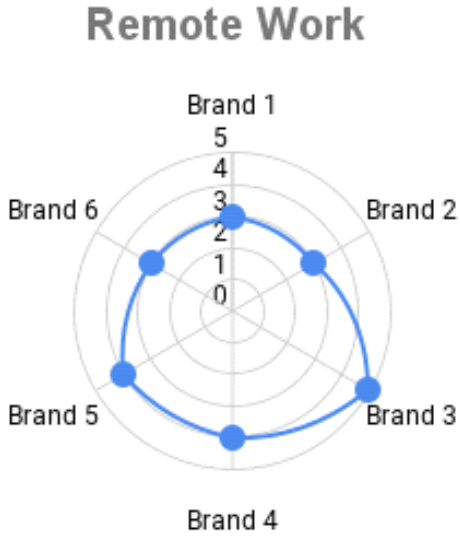

Figure 08: Graph showing brand maturity in terms of Remote Work.
Source: Authors.

Figure 09: Word cloud with the 94 most common words among the files (interviews, images, and online information).
Source: Authors .

which was divided into two (Tables 05 and 06) to specify the results and make them more visually comprehensible.

After all the procedures were completed, it was observed that the number of gaps and connections, in terms of numbers, are almost equal, with few barriers and some peculiarities. In terms of connections, the standout feature is that most brands are Slow Fashion, which already contributes to the existence of several other common characteristics such as the use of biodegradable and quality materials, garment life extension, concern about the product life cycle, etc. As for the gaps, it is notable that not all brands use organic biodegradable materials, partly due to issues related to traditional cotton culture and the use of upcycled materials. The latter would be more sustainable as it involves using existing materials and not extracting more resources from nature to create

Connections	Gaps
-Slow Fashion - Biodegradable materials - Does not use PET fabrics - Sustainable education - Inclusion (consumer) - Garment lifespan extension (maintenance care) - Multifunctionality - Certified materials - Production on demand - Recycled and recyclable packaging - Networking - Local valorization (materials and partnerships) - Local valorization (ancestral knowledge) - Co-creation (partners) - Co-creation (consumer) - Small-scale producer - The business is the sole source of income - Emerging technologies - Remote work - Partners working from home - WhatsApp is the primary means of communication	- Biodegradable and organic materials - Concern for post-disposal - Use of recycled/upcycled materials - Garment lifespan extension (repair) - They communicate to the consumer, in some way, the meaning of symbols for garment care - Transparency - Inclusion (LGBTQIAP+ individuals, black individuals) as models or in the production chain - Inclusion (production chain, models, or social causes) of Persons with Disabilities (PCDs) - Use of fabrics with more than one fiber - Suppliers and materials from longer distances - Custom-made garments - Social and environmental responsibility - Incentives for employees - Garment lifespan extension (rental) - Modularity - Certified brands and/or labels attesting to sustainability - Use of inks based on waste reuse

Table 05: Results related to connections and gaps
Source: Authors.

Barriers	Specific Attributes
- Higher price compared to a conventional product - They do not use or would like to use more sustainable practices, but do not do it due to the high cost, uncertainty about the positive aspects of sustainability, or not knowing how to use them - Receives clients in a shared location because they lack the infrastructure at home	- T-shirts are the primary product in their production - They use natural dyes - The designer's main workplace is their home - Use of emerging technologies (up to 3) - Use of emerging technologies (4 or more)

Table 06: Results related to barriers and specific attributes
Source: Authors.

new clothing items.

Financial incentives for partners/employees are not a common characteristic for all brands, and the concept of clothing rental as a form of extending the life of garments is present in only one brand. Regarding barriers, the cost of more sustainable materials and technological processes is a significant obstacle, reported by almost all brands, as well as the lack of infrastructure for receiving customers at home. As for particularities, working from home is the main workspace for the brands, and the use of technologies is specific to each brand since, despite the commonality of remote work and technology use, each brand uses these tools in a way that best suits its work.

Therefore, it was possible to obtain a general and concrete understanding of the situation of fashion brands, their relationships with sustainability, remote work, new technologies, and areas where they can improve and innovate (barriers and gaps).

5. CONCLUSION

After conducting Multiple Case Study, some reflections were carried out regarding the planning and execution of the latter, the consistency of the results, and whether, in their current state, these results could be validated by the companies to proceed to the next steps required by the present research.

Regarding the planning and the process, both the software used (NVivo) and the chosen data for analysis were crucial for a more accurate study of the current context.

This is stated because a purely manual analysis was not used; instead, a tool traditionally employed in various fields

for qualitative research brought more reliability to the diverse data collected. This data included the experiences and opinions of the brands, details of the work they perform, their communication with consumers, supported initiatives, and samples of products and raw materials, all of which were recorded by the authors of this research.

Regarding the results, it was noticed that the analyzed brands, even those with limited knowledge of sustainability, such as Brand 1, and the need for improvement in almost all of them, particularly in waste management, have initiatives related to this theme. In some brands, this is more evident, such as Brand 3 and Brand 5, but it is clear that, at the local level, efforts to have sustainable standards encompassing at least a substantial portion of the life cycle of a garment are already a concrete reality in most cases. As for other aspects, there is also a need for improvement, especially in terms of greater involvement with the local community for development, collaboration with organizations like universities to apply research results in the fashion market, and granting consumers greater freedom for co-creation to establish a real bond with clothing items. Additionally, it is necessary to further utilize and lower the costs of emerging technologies to make them more accessible. There is also room for more partners to work from home to establish it as an achievable working environment.

However, when analyzing the questions and responses, even though they were more comprehensive and robust than expected, as they provided details that were not directly asked for, it is clear that a new round of questioning is necessary. This will be conducted to address the research question fully, that is, to understand aspects related to: the integration of local culture into the project and manufacturing, the ergonomics of working from home, sharing resources/machinery with other local producers, future plans, and other relevant factors.

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AUTHORS

ORCID: 0000-0003-0634-1343
JANICE ACCIOLI RAMOS RODRIGUES | Doutoranda | UFPR| Design| Curitiba, PR- BR | Correspondência para: Rua General Carneiro, 460. E-mail: janiceaccioli@ufpr.br

ORCID: 0000-0002-8645-6919
AGUINALDO DOS SANTOS | Doutor | UFPR| Design| Curitiba, PR- BR | Correspondência para: Rua General Carneiro, 460. E-mail: asantos@ufpr.br

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FEASIBILITY STUDY OF THE USE OF IRON ORE TAILINGS AS PIGMENT IN POLYPROPYLENE RESINS

ESTUDO DA VIABILIDADE DA UTILIZAÇÃO DE REJEITO DE MINÉRIO DE FERRO COMO PIGMENTO EM RESINAS DE POLIPROPILENO

ESTUDIO DE VIABILIDAD DEL USO DE RESIDUOS DE MINERAL DE HIERRO COMO PIGMENTO EN RESINAS DE POLIPROPILENO

ANDERSON RAVIK DOS SANTOS, Msc.| UFOP – Universidade Federal de Ouro Preto, Brasil
GUSTAVO LUIZ ALVES | UFSJ – Universidade Federal de São João del-Rei, Brasil
EWERTON DE CASTRO TEIXEIRA | UFSJ – Universidade Federal de São João del-Rei, Brasil
RIVELINO NERI SILVA | UNIPAC - Centro Universitário Presidente Antônio Carlos, Brasil
PATRÍCIA SANTIAGO DE OLIVEIRA PATRICIO, Dra.| UFMG – Universidade Federal de Minas Gerais, Brasil

ABSTRACT

The Brazilian mining industry plays a significant role in the country's economy. However, it also generates large volumes of waste during the ore beneficiation process, resulting in severe environmental impacts. Recent researches have explored the potential of iron ore tailings as a raw material in the manufacturing of construction materials, aiming to reduce environmental impact. The distinctive coloring acquired by the produced materials can contribute to their application in certain segments where aesthetic factors are relevant. This study aimed to evaluate the feasibility of iron ore tailings, derived from the dam breach in Mariana-MG, as a pigment for polypropylene, widely used as a polymer matrix for composites, especially wood-plastic composites. Samples with different polypropylene and iron ore tailing contents, ranging from 1 to 10 % by mass, were developed using thermokinetic mixing, milling, extrusion, pelletization and hot compression processes. The produced specimens were analyzed for their appearance and evaluated for their mechanical performance. The results showed that the tailings presented high pigmentation power when incorporated into polypropylene, without compromising its mechanical properties and even providing a gain in flexural strength. However, the proportion between the amount of residual material used and the total volume of waste discarded in nature is very low, indicating limited potential for material reuse. This situation can be modified by using the tailings in the production of wood-plastic composites, where, in addition to acting as pigment, they can also act as reinforcing filer. This approach would allow the utilization of a considerable larger portion of the residual material.

KEYWORDS

Iron ore tailings, Pigmentation, Civil Engineering, Polymeric matrix.

RESUMO

A indústria mineradora brasileira desempenha um papel significativo na economia do país, no entanto, ela também gera grandes volumes de rejeitos durante o processo de beneficiamento dos minérios, resultando em impactos ambientais severos. Pesquisas recentes têm explorado o potencial do rejeito de minério de ferro como matéria-prima na fabricação de materiais de construção, com o objetivo de promover a redução do impacto ambiental. A coloração característica adquirida pelos materiais produzidos pode contribuir na sua aplicação em alguns

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segmentos, onde o fator estético é relevante. Neste estudo, buscou-se avaliar a aplicabilidade do rejeito de minério de ferro, proveniente do rompimento de barragem ocorrido em Mariana-MG, como pigmento do polipropileno, amplamente utilizado como matriz polimérica de compósitos, em especial de madeiras plásticas. Foram desenvolvidas amostras com diferentes teores de polipropileno e rejeito de minério de ferro, este variando de 1 a 10 % em massa, a partir dos processos de mistura termocinética, moagem, extrusão, peletização e compressão a quente. Os corpos de prova produzidos foram analisados quanto à sua aparência, e avaliados quanto ao seu desempenho mecânico. Os resultados obtidos demonstram que o rejeito possui alto poder de pigmentação quando incorporado ao polipropileno, além de não comprometer sua performance quanto às propriedades mecânicas, proporcionando inclusive ganho de resistência à flexão. No entanto, a proporção entre a quantidade de material residual utilizada e o volume total de rejeito descartado na natureza é muito baixa, sugerindo limitado potencial de reaproveitamento do material. Essa situação pode ser modificada ao empregar o rejeito na fabricação de madeira plástica, onde além de desempenhar a função de pigmento, ele pode também atuar como carga de reforço. Essa abordagem permitiria a utilização de uma parcela consideravelmente maior do material residual.

PALAVRAS-CHAVE

Rejeitos de minério de ferro, Pigmentação, Engenharia Civil, Matriz polimérica.

RESUMEN

La industria minera brasileña desempeña un papel significativo en la economía del país. Sin embargo, también genera grandes volúmenes de residuos durante el proceso de beneficio del mineral, lo que resulta en graves impactos ambientales. Investigaciones recientes han explorado el potencial de los residuos de mineral de hierro como materia prima en la fabricación de materiales de construcción, con el objetivo de reducir el impacto ambiental. La coloración distintiva adquirida por los materiales producidos puede contribuir a su aplicación en ciertos segmentos donde los factores estéticos son relevantes. Este estudio tuvo como objetivo evaluar la viabilidad de los residuos de mineral de hierro, derivados del colapso de la represa en Mariana-MG, como pigmento para el polipropileno, ampliamente utilizado como matriz polimérica para compuestos, especialmente compuestos de madera y plástico. Se desarrollaron muestras con diferentes contenidos de polipropileno y residuos de mineral de hierro, que varían del 1 al 10% en masa, utilizando procesos de mezcla termocinética, molienda, extrusión, peletización y compresión en caliente. Los especímenes producidos se analizaron en cuanto a su apariencia y se evaluaron en cuanto a su rendimiento mecánico. Los resultados mostraron que los residuos presentaron un alto poder de pigmentación cuando se incorporaron al polipropileno, sin comprometer sus propiedades mecánicas e incluso proporcionando una ganancia en la resistencia a la flexión. Sin embargo, la proporción entre la cantidad de material residual utilizado y el volumen total de residuos descartados en la naturaleza es muy baja, lo que indica un potencial limitado para la reutilización del material. Esta situación puede modificarse mediante el uso de los residuos en la producción de compuestos de madera y plástico, donde, además de actuar como pigmento, también pueden actuar como material de refuerzo. Este enfoque permitiría la utilización de una porción considerablemente mayor del material residual.

PALABRAS CLAVE

Residuos de mineral de hierro, Pigmentación, Ingeniería Civil, Matriz polimérica.

1. INTRODUCTION

The Brazilian mining industry holds a strategic position in the country's economy, notably due to its significant contribution to iron ore production, representing approximately 1.4% of Brazil's Gross Domestic Product (GDP), according to data from IBRAM (2019). Although it has a crucial role in economic development, this industrial activity is also a source of considerable environmental impacts, particularly due to the generation of large volumes of waste during the ore beneficiation process. The growing global demand for iron ore has led to the exploitation of lower grade deposits, which has resulted in an increase in waste generation, requiring increasingly larger tailings dams for containment (CARNEIRO, 2020). According to the National Mining Agency (ANM, 2023), iron ore production reached approximately 430 billion tons in 2022, and the Institute for Technological Research (IPT, 2016) estimates that each ton of processed ore results in 0.4 tons of tailings, indicating the production of around 172 million tons of iron ore tailings (IOT) that year alone.

The challenges related to mining and tailings management became particularly evident after the disaster with the IOT dam in Mariana-MG, in November 2015, which resulted in severe environmental and social impacts (COURA, 2018). Approximately 40 million cubic meters of tailings were released, affecting 663 kilometers of watercourses and 1,469 hectares of vegetation (CARNEIRO, 2020), in addition to directly impacting about 2 thousand people, including casualties, injuries, illness, homeless, displaced and missing, as indicated by the Mariana Task Force report (2016).

Recently, researches have focused on the reuse of the IOT from the Mariana disaster as a raw material in the construction industry, aiming to transform this environmental liability into a resource. Studies indicate that the tailings can be incorporated into various construction materials, such as ceramic tiles (RUY, 2022), asphaltic mixtures (MORAES, 2022) and ceramic blocks (MENDES, 2019). In addition to enhancing certain properties, the characteristic coloring acquired by the materials when incorporating the tailings can favor their application in specific segments where aesthetic appeal is a significant differentiator.

Particularly, Moraes (2022) explored the use of IOT as a substitute for stone powder in asphalt mixtures, observing significant improvements in reflectance and reduction of surface temperature, which can mitigate the urban heat island phenomenon. Nascimento (2019) evaluated the use of IOT as pigment in concretes, noting not only an aesthetic alteration with the acquisition of a reddish color but also improvements in mechanical strength and durability of the material.

Another innovative application of IOT is in the wood-plastic composites, which are formed by a polymeric matrix and a reinforcement phase, both organic and inorganic (BRASKEM, 2016). In this application, IOT acts both as an inorganic reinforcing filler and as a pigment, a fundamental component for these composites. Santos *et al.* (2022) emphasize that the visual aspect of wood-plastic composites, which should resemble natural wood, is essential to valorize the material and promote its acceptance in the market as an alternative to tree species. The relevance of inorganic pigments, such as IOT, also lies in their thermal resistance, which is especially useful as many polymers require molding temperatures above 200 ºC (JAFELICCI, 2019). Studies by Bressiani *et al.* (2021) and Coura (2018) show that the addition of IOT in polymeric matrices improves both the aesthetic characteristics and the mechanical and thermal properties of the composites.

In the composition of wood-plastic composites, thermoplastic polymers are often preferred, and amongst these, Polypropylene (PP) stands out due to its mechanical strength, lightweight, transparency, ease of recycling and high processing capability (MONSORES *et al.*, 2017). Thus, this study aims to explore the impact and feasibility of using IOT, derived from the tragic collapse of the Fundão dam in Mariana-MG, as a pigment agent in PP. This investigation seeks to expand the applicability of PP not only as a substrate for wood-plastic composites but also in other composites where aesthetic value is important. Furthermore, this study proposes to analyze how IOT affects the mechanical properties of PP, varying according to the amount of tailings incorporated into the composition.

2. METHODOLOGY

2.1 Preparation of testing specimen

In this study, the materials used were Iron Ore Tailings (IOT) and virgin Polypropylene (vPP). The IOT, collected after the dam's collapse in Mariana-MG, was acquired already processed by a mining company located in Congonhas-MG, dried and without agglomerations. The vPP, provided by Braskem, has a flow index of 3.5 g/10 min and density of 0.905 g/cm^3 (BRASKEM, 2020).

For the production of the specimens, the vPP and IOT were thermokinetically homogenized, enhancing the dispersion of IOT and vPP. For this purpose, a laboratory homogenizer (model MH-100, MH Equipments) was used. Initially, the proportion of IOT ranged from 1 to 5%, aiming to highlight its function as a pigment instead of acting as a reinforcement filler. Moreover, samples were prepared with 10% of IOT to evaluate its influence on the mechanical properties. Additional samples with 2% of IOT incorporated with Industrial Black recycled Polypropylene (IBrPP) and Laboratory Blue recycled Polypropylene (LBrPP), from Nonwoven fabric (NW) from masks, were also produced to analyze the IOT's pigment capability to cover the recycled polymers' colors. The samples' composition is described in Table 1.

Sample	PP Mass (g)	IOT Mass (g)	PP (%m)	IOT (%m)
100vPP	180	0.00	100	0
99vPP1IOT	180	1.82	99	1
98vPP2IOT	180	3.67	98	2
97vPP3IOT	180	5.57	97	3
95vPP5IOT	180	9.47	95	5
90vPP10IOT	180	20.00	90	10
98IBrPP2IOT	180	3.67	98	2
98LBrPP2IOT	180	3.67	98	2

Table 1 – Composition of the samples used

As mentioned, the procedure involved a thermokinetic mixer, where the fusion and homogenization of the polymer with the IOT were obtained by the heat generated by friction and rotation. The resulting product was then cooled and ground in a knife mill (Marconi, model MA 580) to obtain smaller particles. These particles were subsequently extruded in a single-screw extruder (Thermo Scientific, HAAKE Polylab), set at 175 ºC in three heating zones and a speed of 45 rpm. The extruded material, with an average diameter of 3.40 mm, was cut into pellets approximately 3.70 mm in length using a pelletizer (AX Gran, AXPlástico). Finally, the pellets were molded into plates of 150 mm x 100 mm x 1 mm, using a heated hydraulic press (SOLAB, model SL11) at 180 ºC under a pressure of 25 MPa for 5 minutes. The plates, after pressing and cooling, were cut into test specimens with dimensions of 10 mm x 13 mm x 1 mm for subsequent analyses. The experimental procedures are outlined in the flowchart in Figure 1.

Figure 1: Flowchart of raw materials and experimental procedures.

2.2 Mechanical Characterization

The mechanical characterization of the samples was performed following standardized procedures. For the tensile tests, six specimens of each composition, including the control sample (100% vPP) and the blends with IBrPP and LBrPP, were tested in a universal testing machine (Instron, model EMIC 23-20) at a speed of 50 mm/min, according to ASTM D638 (2014) standard. The results represent the average of the six tests performed. Flexural strength was determined using the same testing machine, operating at a speed of 30 mm/min in alignment with ASTM D790 (2007) standard. Four specimens of each composition were subjected to the test, and the results obtained are the arithmetic mean of these measurements.

3. RESULTS AND DISCUSSION

3.1 Sample Analysis

The visual analysis of the specimens, as illustrated in Figure 2, reveals the influence of the Iron Ore Tailings (IOT) on the coloration of the Polypropylene (PP), with variations proportional to the amount of IOT incorporated. The designation of the specimens reflects their specific compositions, for example, the sample 99vPP1IOT consists of 99% by mass of virgin Polypropylene (vPP) and 1% by mass of IOT. Control samples were prepared using only pure resin (100vPP), and comparative samples were prepared using Industrial Black recycled PP (98IBrPP2IOT) and Laboratory Blue recycled PP (98LBrPP2IOT).

It was observed that the IOT provided a distinctive coloration to the PP, demonstrating its effectiveness as a pigment even at low concentrations. In the specimens produced with vPP (transparent), the intensification of the

hue was notable with increasing IOT content, although the samples with 3, 5 and 10% IOT presented indistinctive colors when observed under the same ambient light. This observation is consistent with Chen et al. (2016), who highlighted the effectiveness of inorganic pigments in imparting color to light-toned polymers, maintaining thermal stability even at low concentrations.

Samples containing recycled PP exhibited distinctive behaviors regarding coloration. The 98IBrPP2IOT sample did not show significant color change due to its original dark hue. On the other hand, adding IOT to the LBrPP resulted in a greenish coloration, indicating that the polymer base decisively influences the final coloration of the specimens.

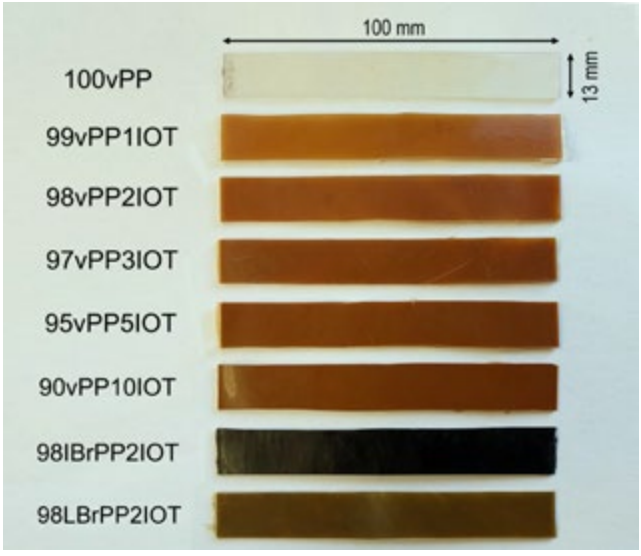

Figure 2: Samples' testing specimen.

The prevalence of a red-ochre hue in the samples indicates the presence of hematite (Fe2O3) in the tailings (BRANCO, 2015). This composition was confirmed by Coura (2018), who characterized a sample of IOT from the same origin through X-ray fluorescence analysis and found a predominance of 58.1% of iron oxide. The same hue was verified in the study conducted by Galvão et al. (2018), in which IOT was used as a base to reddish pigments in the production of sustainable paints.

When examining the resulting plates under direct light (Figure 3), a clearer differentiation between the samples was observed, highlighting the influence of the IOT content on coloration and opacity. The vPP, due to its translucent nature, when combined with IOT, a material of high opacity, especially when compared to organic pigments (TORRES, 2018), resulted in specimens with noticeable variations in transparency and color.

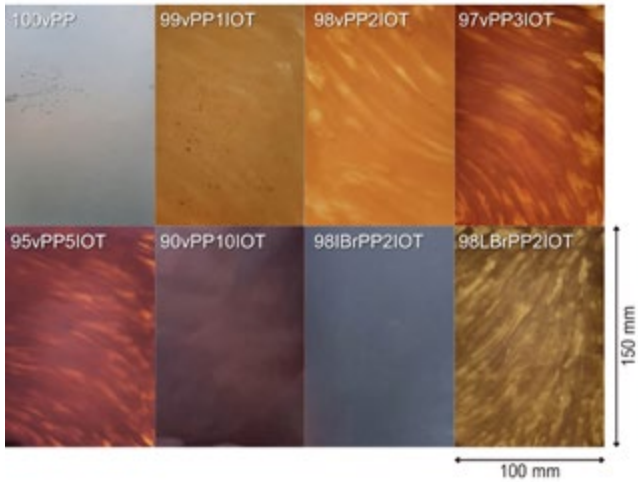

Figure 3: Samples' plates against light.

While the images of the specimens (Figure 2) initially suggest a seemingly homogeneous mixture of the samples, the analysis of the plates under direct light (Figure 3) reveals areas with varied transparency in samples containing up to 5% of IOT. This heterogeneity is less pronounced in the sample with only 1% of tailings. Such variation in coloration and opacity across the same plates suggests that the pelletized IOT grains exhibit a diversity in pigment intensity, resulting in a non-uniform color distribution. This phenomenon indicates a possible loss of homogeneity in the mixture, believed to have occurred during the extrusion process. During this processing phase, it is likely that the unintentional introduction of additional vPP, used in cleaning the extruder before and after extrusion, contributed to the observed variation, subtly modifying the proportion of the mixture. Notably, the sample containing 10% IOT stands out significantly for the increased opacity compared to the other samples made from vPP, reinforcing the influence of IOT concentration on the optical properties of the material.

In addition to coloration, the effectiveness of a pigment is highly affected by the average particle size and its granulometric distribution, as emphasized by Buxbaum and Pfaff (2005). In this context, IOT emerges as a raw material with promising potential. This is because, for the efficient applicability of a residue rich in iron oxide as a pigment, it is essential that the raw material possess a granulometric distribution concentrated in ranges of smaller particle sizes. This characteristic is essential, as it can directly affect the hue manifested by hematite, ranging from red to intense violet (TAVARES, 2012; MONTEDO et al., 2004). A granulometric analysis of the IOT conducted by Coura (2018) revealed that the particles of the materials used in the present work are

distributed in a range from 0.01 to 70 µm, with about 50% of the material having a diameter smaller than 8.16 µm. These values are comfortably within the limits considered ideal for pigments, which are between 0.01 and 10 µm, as described by Buxbaum and Pfaff (2005).

3.2 Mechanical resistance

Figures 4 and 5 show the Stress/Strain curves and the average values of the modulus of elasticity, respectively, obtained by the tensile strength tests.

In general, the addition of IOT resulted in a decrease in the tensile strength of the vPP. However, this behavior

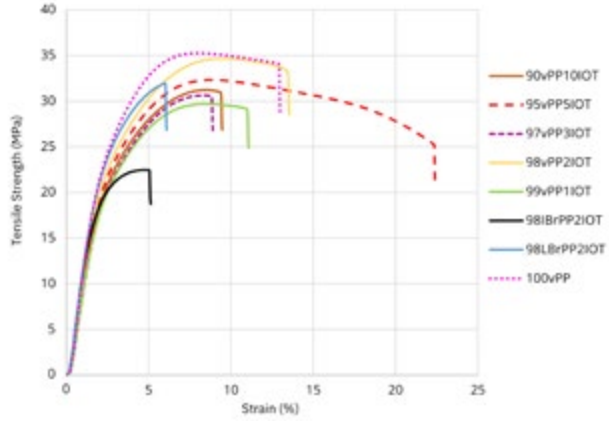

Figure 4: Tensile strength and strain of the samples.

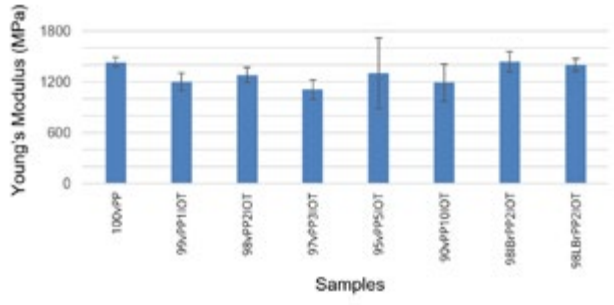

Figure 5 – Tensile modulus of elasticity of the samples.

was not linear. For example, when compared to the control sample (100vPP), the addition of 1% IOT resulted in a 15.80% loss of strength, while the addition of 2% IOT presented a reduction of only 1.67%. Samples produced with a recycled PP matrix also showed inferior performance compared to the vPP, specially the 98IBrPP2IOT sample standing out for having the lowest tensile strength. However, all samples, except for the latter mentioned, achieved tensile strengths superior or very close to the expected values for vPP, according to the literature: from 31 to 41.4 MPa (CALISTER; RETHWISCH, 2012), indicating that the incorporation of IOT at low levels does not significantly compromise the performance of PP in this property.

The analysis of the modulus of elasticity graphs reveals that the addition of tailings did not result in an increase in this property, unlike what was observed by Coura (2018), who found a gradual increase in the value of the modulus of elasticity in composites with 20% IOT. It is worth remembering that Coura (2018) produced composites with 20% IOT so that the tailings would act as reinforcement filler, unlike the present study in which the focus is the pigmentation of PP. With lower IOT contents, a variation in the modulus of elasticity was observed, with only the comparison sample 98IBrPP2IOT exceeding the average value achieved by the vPP. However, all the samples presented stiffness values within the expected range for PP, according to Calister and Rethwisch (2012): 1140 to 1550 MPa, indicating that the pigmentation of PP with IOT does not pose risks to its stiffness.

Figures 6 and 7 present the Stress/Strain curves and the average values of the modulus of elasticity, respectively, obtained by the flexural strength tests.

In contrast to the tensile strength tests, an improvement in the performance of vPP was observed with the addition

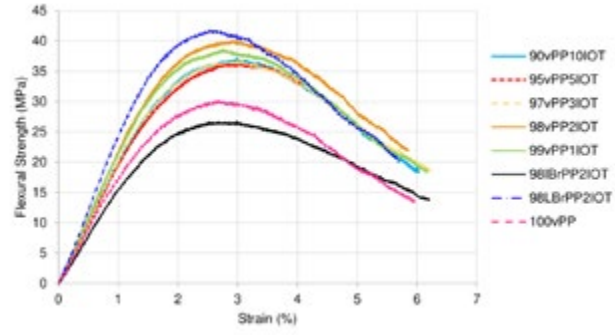

Figure 6 – Flexural strength and strain of the samples.

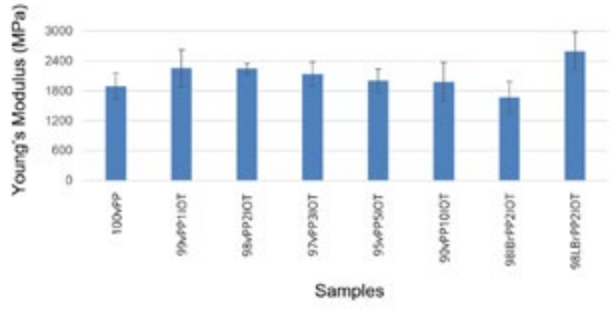

Figure 7 – Flexural modulus of elasticity of the samples.

of IOT regarding flexural strength and stiffness. The sample with addition of 2% IOT even presented a 28% gain compared to vPP. The two comparison samples exhibited extreme performances, with 98IBrPP2IOT showing the worst strength while 98LBrPP2IOT achieved the highest. Although a progressive decrease in the stiffness of the specimens with the increase o IOT content was observed, all exceeded the modulus of elasticity of the vPP. The PP recycled from NW fabric also stood out regarding stiffness, possibly due to the matrix used. Thus, the addition of IOT did not compromise the behavior of vPP regarding flexion, enhancing its resistance, which is advantageous in applications such as decks in civil construction, one of the main applications of wood-plastic composites.

4. CONCLUSION

Based on the results obtained and the analysis performed, this study demonstrates that the Iron Ore Tailings (IOT) from the collapse of the Fundão dam in Mariana-MG can be effectively used as a pigment agent in the coloration of polymers, particularly Polypropylene (PP). The significant coloration achieved with minimal additions of IOT, and its proportional intensification with increasing concentrations of IOT in the samples, highlight its efficiency as a pigment. Despite small reductions in the tensile strength of virgin PP (vPP) due to the addition of IOT, the values remained close to those expected for vPP, as described in the literature. Regarding flexural properties, an increase up to 28% in material strength was observed with the addition of IOT.

It is noteworthy that the pigmentation is often achieved with low levels of pigment material, resulting in a low volume of IOT reused compared to the generated waste, raising questions about the environmental efficiency of this technique. However, the results of this study demonstrate the promising potential of mining waste as a highly efficient and economic viable option for the pigment industry. Moreover, they contribute to the valorization of industrial by-products and the reduction of the environmental impacts associated with improper disposal of these residues.

In addition to the results achieved, it is important to highlight that the shades obtained in this study evoke familiar tones, with an appearance capable of eliciting affective memories associated with natural wood. This aspect makes IOT a promising option for coloring wood-plastic composites, providing an attractive and familiar aesthetic to the final products. For future research in this field, it is recommended to conduct a wider variety of tests, especially those aimed at evaluating the performance of IOT as a pigment in different scenarios. This includes darkness and accelerated weathering tests, aiming to optimize the efficiency of IOT as a pigment and explore its potential contribution to sustainability.

It is also critical to evaluate tests with wood-plastic composites, both with and without the presence of IOT, to understand how this would affect the production volume of the composite. Even though there are doubts about the potential reuse of IOT solely for coloring pure polymers, its use in the wood-plastic composite production offers a different perspective. In this case, the residual material does not only act as a pigment but also serve as reinforcement, allowing for the utilization of a substantially larger volume of waste.

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AUTHORS

ORCID: 0000-0001-5047-7630
ANDERSON RAVIK DOS SANTOS, Mestrado | Universidade Federal de Ouro Preto | Engenharia Civil | Ouro Preto, Minas Gerais (MG) - Brasil | Correspondência para: Av. Mariza de Souza Mendes, 681, Apto. 301 - Siderurgia, Ouro Branco - MG, 36492-183 | E-maill: anderson.ravik@gmail.com

ORCID: 0009-0000-0351-3723
GUSTAVO LUIZ ALVES, Bacharelado | Universidade Federal de São João del-Rey | Engenharia Civil | Ouro Branco, Minas Gerais (MG) - Brasil | Correspondência para: R. C, 84 - Bairro Machado, Itabira - MG, 35901-017 |
E-mail: gustavoluisalves@hotmail.com

ORCID: 0009-0005-6111-6837
EWERTON DE CASTRO TEIXEIRA, Bacharelado | Universidade Federal de São João del-Rey | Engenharia Civil | Ouro Branco, Minas Gerais (MG) - Brasil | Correspondência para: R. São Vicente de Paulo, 103 - Bairro Andaraí, Barbacena - MG, 36204-000 |E-mail: ewertonct94@gmail.com
ORCID: 0000-0001-9383-137X
RIVELINO NERI SILVA, Bacharelado | Centro Universitário Presidente Antônio Carlos | Engenharia Civil | Barbacena, Minas Gerais (MG) - Brasil | Correspondência para:
R. Costa Sena, 1615, Apto. 403 - Padre Eustáquio, Belo Horizonte - MG, 30720-496
Email: rivelino.silva@aluno.ufop.edu.br

ORCID: 0000-0002-1681-9091
PATRÍCIA SANTIAGO DE OLIVEIRA PATRICIO, Doutorado | Universidade Federal de Minas Gerais | Química | Belo Horizonte, Minas Gerais (MG) - Brasil | Correspondência para: Av. Amazonas, 5855, Gameleira, Belo Horizonte - MG, 30510-000 | E-mail:patricia@cefetmg.br

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GREEN INFRASTRUCTURE MULTIFUNCTIONAL NETWORKS AND WATER-FOCUSED APPROACH: A LITERATURE ANALYSIS

INFRAESTRUTURA VERDE REDES MULTIFUNCIONAIS E ENFOQUE HÍDRICO: UMA ÁNALISE DE LITERATURA

INFRAESTRUCTURA VERDE REDES MULTIFUNCIONALES Y ENFOQUE HÍDRICO: UN ANÁLISIS DE LA LITERATURA

ANTONIO DE JESUS NAZARETH NETO | UFMS – Universidade Federal de Mato Grosso do Sul, Brasil
ADEMIR FONTANA, Dr.| EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária, Brasil
ELIANE GUARALDO, Dra.| UFMS– Universidade Federal de Mato Grosso do Sul, Brasil

ABSTRACT

Between 2013 and 2023, Green Infrastructure (GI) emerged as a key component in promoting sustainable urban initiatives. Its rise was marked by an interdisciplinary approach that fostered the integration of diverse fields, establishing it as a foundational element in sustainable urban projects. GI aimed at creating resilient and sustainable cities by enhancing biodiversity, improving environmental quality, and contributing to climate change mitigation. This study aimed to analyze trends in GI, indicating that its scope extended beyond water-related issues to encompass multifunctional green networks. The research was conducted in two phases. Initially, a survey was carried out using the keyword "green infrastructure." Subsequently, two sets of research were outlined, with the first focusing on water-related terms: "Drainage," "Stormwater," "Rain-Garden," while the second focused on multifunctional green networks: "Landscape," "Nature-based solutions," "Urban Forest," "Implantation." The research, across both phases, reviewed 4,395 articles by country, highlighting the diversity and evolution in the definitions and applications of GI, varying by the year of publication. Of the reviewed articles, 1,545 focused on GI and multifunctional green networks, while 2,073 examined water-related issues. The research on GI grew from 2013 to 2023, especially in the USA, China, and Europe.

KEYWORDS

Nature-Based Solutions; Sustainable Cities, Interdisciplinarity; Urban Forest.

RESUMO

No período entre 2013 e 2023, a Infraestrutura Verde (IV) ascendeu como um elemento fundamental no fomento de iniciativas urbanas sustentáveis. Essa ascensão foi notável pela sua abordagem interdisciplinar, que promoveu a integração de campos diversificados, tornando-se um pilar essencial em projetos urbanos sustentáveis. A IV visou cidades resilientes e sustentáveis, promovendo biodiversidade, melhorando a qualidade ambiental e contribuindo para mitigar mudanças climáticas. Este estudo objetivou analisar tendências na IV, mostrando que seu escopo foi além de questões hídricas, abrangendo redes verdes multifuncionais. A pesquisa foi conduzida em duas fases. Na primeira etapa, procedeu-se a um levantamento utilizando a palavra-chave "green infrastructure". Na segunda etapa, dois conjuntos de pesquisa foram delineados, com o primeiro focando em termos ligados a questões hídricas: "Drainage",

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“Stormwater”, “Rain-Garden”, enquanto o segundo concentrou-se em redes verdes multifuncionais: “Landscape”, “Nature-based solutions”, “Urban Forest”, “Implantation”. A pesquisa, com suas duas fases, avaliou 4.395 artigos por país, destacando a diversidade e evolução nas definições e aplicações da IV, variando conforme o ano de publicação. Dos artigos revisados, 1.545 focaram em IV e redes verdes multifuncionais, enquanto 2.073 examinaram questões hídricas. A pesquisa sobre IV cresceu de 2013 a 2023, especialmente nos EUA, China e Europa.

PALAVRAS-CHAVE

Soluções Baseadas na Natureza; Cidades Sustentáveis; Interdisciplinaridade; Floresta Urbana.

RESUMEN

Entre 2013 y 2023, la infraestructura verde (IV) emergió como un componente clave en la promoción de iniciativas urbanas sostenibles. Su ascenso estuvo marcado por un enfoque interdisciplinario que fomentó la integración de campos diversos, estableciéndola como un elemento fundamental en proyectos urbanos sostenibles. la IV tuvo como objetivo crear ciudades resilientes y sostenibles mediante la mejora de la biodiversidad, la mejora de la calidad ambiental y la contribución a la mitigación del cambio climático. Este estudio tuvo como objetivo analizar las tendencias en la IV, indicando que su alcance se extendió más allá de los problemas relacionados con el agua para abarcar redes verdes multifuncionales. La investigación se llevó a cabo en dos fases. Inicialmente, se realizó una encuesta utilizando la palabra clave "infraestructura verde". Posteriormente, se delinearon dos conjuntos de investigaciones, con el primero enfocado en términos relacionados con el agua: "drenaje", "aguas pluviales", "jardín de lluvia", mientras que el segundo se centró en redes verdes multifuncionales: "paisaje", "soluciones basadas en la naturaleza", "bosque urbano", "implantación". La investigación, en ambas fases, revisó 4,395 artículos por país, destacando la diversidad y evolución en las definiciones y aplicaciones de la IV, variando por el año de publicación. de los artículos revisados, 1,545 se centraron en la iv y redes verdes multifuncionales, mientras que 2,073 examinaron problemas relacionados con el agua. La investigación sobre la iv creció de 2013 a 2023, especialmente en los EUA, China y Europa.

PALABRAS CLAVE

Soluciones Basadas en la Naturaleza; Ciudades Sostenibles; Interdisciplinariedad; Bosque Urbano.

1. INTRODUCTION

Green Infrastructure (GI) has emerged as an interdisciplinary field of research over the past few decades, spanning areas such as Architecture, Urban Planning, Engineering, Ecology, Economics, Humanities, and Social Sciences. This approach aimed to create resilient and sustainable cities by promoting biodiversity, improving air and water quality, providing recreational spaces, and contributing to climate change mitigation.

Given the growing concern over climate change and sustainable development, the management of stormwater and sustainable urban practices have driven the adoption of concepts such as sustainable drainage and rain gardens, making GI a promising solution to address these challenges.

The fundamental principles of GI permeated various aspects, from the interconnectivity between green areas to the meticulous assessment of the existing infrastructure in the specific context of its implementation. This focus, outlined by Benedict e McMahon (2002), was characterized by a long-term commitment, marked by careful consideration of local dynamics and the need to fully respect the interests and properties of those involved. The scientific approach underlying such concepts emphasized the importance of careful and sustainable implementation of Green Infrastructure, aiming to maximize its environmental and social benefits.

The GI approach proposed the preservation and utilization of environmental services inherent to natural functioning, encompassing various typologies for the creation of multifunctional landscapes that integrated into the conventional urbanization system, as outlined by Schutzer (2014). This focus sought not only to incorporate nature into the urban environment but also to establish more balanced and healthy urban spaces, where the active presence and participation of nature played a fundamental role in the configuration and sustainability of the city's infrastructure.

Achieving the outlined objectives required the participation of professionals from different disciplinary areas in the projects, given the heterogeneous scope of GI, which ranged from recreational spaces, such as parks and green areas, to integrated systems for sustainable water and transport management. The diversity of interpretations and perspectives attributed to GI by these professionals required an inclusive approach, aiming for a holistic understanding of its elements and the maximization of the desired outcomes.

The synergistic integration of diverse specialties not only enriched the design and execution of projects but also promoted a broader and more effective understanding of GI, fostering the effectiveness of the proposed solutions and optimizing their socio-environmental impact.

Research related to the global and multi-scalar vision of GI as multifunctional networks, embedded in urbanism and landscape and reaching urban and territorial planning policies, has seen a significant increase in interest, indicating a greater diversity of fronts for GI as a sustainability tool beyond the water system.

The study of the concepts and applications of GI at an international level required a comprehensive analysis of existing publications in the countries in question, such as Brazil, USA, China, and the United Kingdom. The approach consisted of mapping the current scenario through a systematic review of articles, seeking to understand emerging trends and dominant topics in discussions about GI in these contexts. This article aimed to provide an in-depth view of the scientific and technical perspectives adopted by these countries, facilitating the identification of strategic directions and research gaps in the area of GI on a global scale.

In this context, the present research aimed to present an overview of current publications on GI, comparing terms related to water-related concepts and multifunctional green networks, while highlighting the expansion of the scope of application of GI beyond water issues, also encompassing areas related to multifunctional green networks. This approach aimed to elucidate both the trends and relevant themes in the field of GI as well as demonstrate its interdisciplinary applicability.

2. MATERIAL AND METHODS

Through conducting a bibliographic research of a quantitative nature, this study facilitated the analysis of terminologies associated with Green Infrastructure (GI) on a global scale. Relevant documents were located using the Scopus database due to its breadth, being considered the largest database of abstracts and citations of peer-reviewed literature. (COLODETTI SUELA; ROCHA MORETO; RANDOW DE FREITAS, 2021).

The search on the GI theme was carried out in the following countries which presented the highest numbers of published articles: Brazil, United States, China, Germany, Italy, United Kingdom, Spain, Sweden, Australia, Poland, Netherlands, Canada, Portugal, Austria, France,

Finland, Switzerland, Norway, Belgium, and South Korea.

The aim was to identify the occurrence of the term "Green Infrastructure" and its association with the following keywords: "Landscape OR Nature-based solutions OR Urban Forest OR Implantation OR Drainage OR Stormwater OR Rain-Garden." The data collection was conducted in November 2023, covering the period from 2013 to 2023. This temporal selection was intended to collect the most updated production on the theme, while also obtaining a significant volume of data for analysis.

In the first stage, articles containing the term "Green Infrastructure" were identified. The analysis used the raw results of this term's survey in the period 2013-2023. This initial stage was crucial for establishing a preliminary database, using the results obtained through a comprehensive search for this specific term. This procedure allowed the capture of a broad spectrum of research related to GI and facilitated the subsequent filtering and detailed analysis of the data.

In the second stage, the analysis was divided into two distinct segments, aiming for a more refined categorization of the themes addressed in the identified publications. To this end, two groups of keywords were defined for the search:

- Group 1: Included the combination of "Green Infrastructure" with "Landscape OR Nature-based solutions OR Urban Forest OR Implantation," explicitly excluding any works associated with the terms "Drainage OR Stormwater OR Rain-Garden." This group aimed to isolate studies focusing on more comprehensive aspects of GI, such as nature-based solutions, urban forests, and their implementation, avoiding the predominance of themes related to stormwater management.

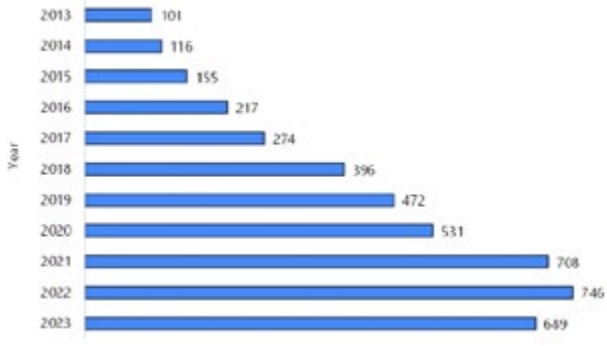
- Group 2: Focused on "Green Infrastructure" associated with "drainage OR stormwater OR rain-garden," directing the analysis towards studies addressing GI primarily from the perspective of urban stormwater management and control.

The distinction and analysis of these two groups aimed to identify the predominant discussion axes within the GI field, starting from the initial hypothesis that the theme related to stormwater management could be a significant focus in research. However, by segmenting the studies in this way, the study also sought to reveal other dimensions and approaches to GI that may be present in the global scientific production, contributing to a more holistic and diversified understanding of the theme. This method allowed a quantitative analysis of the articles and a qualitative assessment of the trends, themes, and predominant approaches in the study of GI over the last decade.

3. RESULTS AND DISCUSSION

3.1 Overall volume of articles

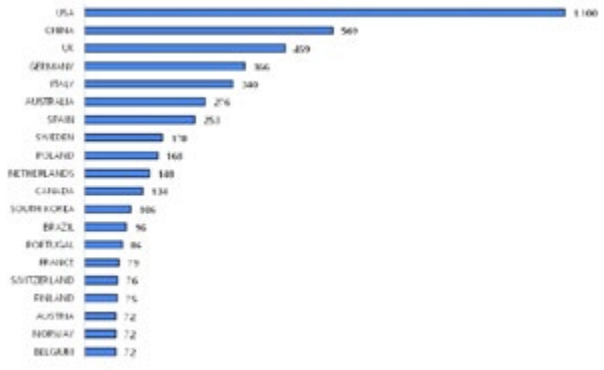
In the initial data mining phase, a total of 4,395 articles were identified that included the term 'green infrastructure'. Of these, 1,545 articles met the inclusion criteria "Landscape OR Nature-based solutions OR Urban Forest OR Implantation", while 2,073 articles were associated with the terms “Green Infrastructure and drainage OR stormwater OR rain-garden”.



Graph 01: Publications in the period from 2013-2023 with the term green infrastructure.
Source: Scopus, adapted by the authors (2023)

Graph 1 showed a significant increase in the volume of articles over the research period, from 101 in 2013 to 689 in 2023 (January to November). It was also noted that, from 2016 to 2021, there was an acceleration in this volume, demonstrating an average annual growth rate of 26.26%, indicating the growing interest in the topic as a subject of research. In 2013, the volume of articles constituted 2.29% of the total value, and in 2023, this figure rose to 15.64%.

Comparing terms related to Multifunctional Green Networks and Drainage found in the green infrastructure articles showed that the selected search terms led to diverse research focuses, with varying emphases on the topics discussed.



Graph 02: Countries with most publications in the period from 2013 – 2023 using the term green infrastructure
Source: Scopus, adapted by the authors (2023)

It was noted that, except for the United States, which occupied the first position, the countries with the highest scientific production in green infrastructure (GI) were located in Europe, indicating that in recent years European countries have advanced in research and implementation of green infrastructure strategies, probably as a consequence of the publication of the European Parliament Resolution, on September 17, 2020, which emphasized GI as a tool to achieve more green city planning.

The deliberate exclusion of terms associated with drainage and stormwater management was intended to focus specifically on elements that exclude the approach to GI merely related to stormwater management. This decision suggests a particular interest in addressing aspects of green infrastructure that do not directly relate to water issues.

By avoiding specific water-related terms, the focus seems to be directed at features and functionalities of green infrastructure that transcend conventional stormwater management, indicating a broader interest in other dimensions and benefits of this type of urban infrastructure.

When the distribution by countries was analyzed (Graph 2), the United States led in number with a total of 1,100 articles, which amounted to 24.97% of the total publications for the period. Following, China contributed 569 articles, representing 12.91% of the publications and about half of the United States' output. Brazil occupied the 14th position, having published 96 articles, which accounted for 2.17% of the total publications in this period.

The year 2022 stood out for the highest number of publications, totaling 746 articles indexed in journals; this increase could be associated with the holding of the United Nations Climate Change Conference (COP 26), held on November 12, 2021, in Glasgow, Scotland.

3.2 Publications on green infrastructure related to multifunctional green networks

In stage 2, group 1, a comprehensive research was conducted on articles related to the field of landscaping and multifunctional green networks as demonstrated by the studies of Herzog (2016); Lovell; Taylor (2013); Scott et al. (2016); Siehr; Sun; Aranda Nucamendi (2022); Verdú-Vázquez et al. (2021). Our goal was to identify materials that specifically addressed the integration of green infrastructures, highlighting the importance of GI in this context.

The results regarding the volume of scientific productions revealed prominence for the United States, China, Germany, Italy, and the United Kingdom. Brazil appeared in the 14th position (Chart 3).

Graph 03: The top 10 countries with the most publications using terms related to green infrastructure and multifunctional green networks.
Source: Scopus, adapted by the authors (2023)

The publications presented a diversity of themes, ranging from the development of strategies for the creation of open spaces to the promotion of approaches based on natural elements in the urban context.

The surveyed works provided a panoramic view of the central themes addressed in the literature related to multifunctional green networks. The generated word cloud offered a refined view of the predominant topics in the analyzed articles (Figure 1). This visual representation emphasized the concepts and specific terminologies that were central in the scope of green infrastructure and multifunctional green networks. Terms such as "biodiversity," "ecology," and "sustainability" emerged as focal points, reflecting the relevance of these themes in contemporary research. The occurrence of words like "management" and "planning" suggested an approach aimed at the effective application of green infrastructure concepts in urban environments. Furthermore,

the presence of terms related to "ecosystems" and "urbanization" highlighted the growing interest in the interaction between natural and built spaces. This visual synthesis served as a useful tool for identifying the main areas of interest and emerging trends in research on multifunctional green networks and their role in cities.

Figure 1: Word cloud of green infrastructure articles related to multifunctional green netwoks
Source: Authors (2023)

It has been observed a steady increase in publications over the years in the United States, reaching a peak in 2021. Green Infrastructure (GI) was considered a holistic approach to incorporating natural elements and ecological systems into urban spaces, regardless of scale, to provide environmental, social, and economic benefits (VAN DER JAGT et al., 2019). GI aimed to improve the quality of life in cities, making them more sustainable and resilient (PARKER, 2023).

China showed significant growth in publications, with a notable increase starting in 2019. This could reflect the country's increasing commitment to sustainable practices and Nature-Based Solutions. This fact was related to the challenge faced by China, resulting from its rapid urban growth, climate change, air and water pollution, loss of biodiversity, and environmental degradation (LI et al., 2021).

GI in Chinese production referred to the use of natural elements, such as urban parks, green areas, bodies of water, green belts, green roofs, and squares with vegetation, as a strategy to deal with various urban problems, such as air quality, urban heat islands, sustainable water management, and promoting biodiversity in urban areas (YAO et al., 2022).

GI played a key role in transforming Chinese cities into more sustainable, resilient, and pleasant environments for their inhabitants, in addition to contributing to the preservation of the environment in a highly urbanized, industrialized, and rapidly growing country (LI et al., 2018).

The steady volume of publications over the years in countries like Germany, Italy, and the United Kingdom indicated that these countries were interested in and regularly involved in the GI theme, possibly incorporating it into territorial urban planning and management of urban spaces. This could be observed in the conceptualization of GI as an essential element of urban and regional planning through goals and implementation initiatives. Some developments of the concept into planning actions were highlighted, as mentioned in the scientific production in these countries.

- Improving Quality of Life: Green Infrastructure (GI) was perceived as a means to enhance the quality of life for citizens. This involved access to green spaces for recreation, leisure, and outdoor activities, in addition to promoting mental and physical health (STURIALE; SCUDERI, 2019).

- Environmental Resilience: GI was seen as an element that played a vital role in mitigating the impacts of climate change, such as heatwaves. It contributed to reducing air pollution and preserving local biodiversity (ALLAM; JONES; THONDOO, 2020).

- Biodiversity and Conservation: The promotion of biodiversity was clearly a fundamental component of GI in these countries. Urban green spaces and natural areas were carefully planned and managed to support the integrity of local flora and fauna.

- Connectivity and Ecological Corridors: The creation of ecological corridors that connected green areas was essential to facilitate the movement of species and their adaptation to changing environmental conditions (JONES et al., 2022).

- Community Engagement: Community participation was encouraged in both the development and maintenance of GI. This could include the creation of community gardens, tree planting programs, and other activities (ANGUELOVSKI et al., 2022).

- Policies and Incentives: In the countries researched, there was the implementation of policies and incentives to promote GI, such as the promotion of green roofs, green walls, and urban green spaces (BURSZTA-ADAMIAK; FIAŁKIEWICZ, 2019).

- Sustainable Urban Planning: The integration of GI into urban planning was fundamental to building more sustainable and pleasant cities (MELL; CLEMENT, 2020). This included the creation of green zones in cities, the promotion of public transport, and the planning of accessible public spaces.

In this context, these European countries and China explored green infrastructure as interconnected multifunctional networks, aiming to enhance air quality, plan resilient spaces to preserve biodiversity through the implementation of ecological corridors. Moreover, they sought to actively involve the community in executing these initiatives, with the goal of promoting more sustainable urban planning.

Brazil, ranked 14th, showed a lower volume of productions compared to the countries mentioned previously. Nonetheless, a notable increase was observed from 2019, gaining importance as concerns over sustainable urban development and the mitigation of environmental impacts became more pressing. Green Infrastructure (GI), often referred to as "urban GI" or "green urbanism," is an approach that, here, as observed in the countries already mentioned, is perceived as an element promoting the integration of natural elements and ecological systems in urban areas.

Ecological systems are understood as natural systems that encompass biotic and abiotic components interacting in a specific environment. As mentioned by Marques (2020), it aimed not only to improve the quality of life in cities but also to address extreme events resulting from climate change, mitigating damages and adapting the city when possible to avoid harm.

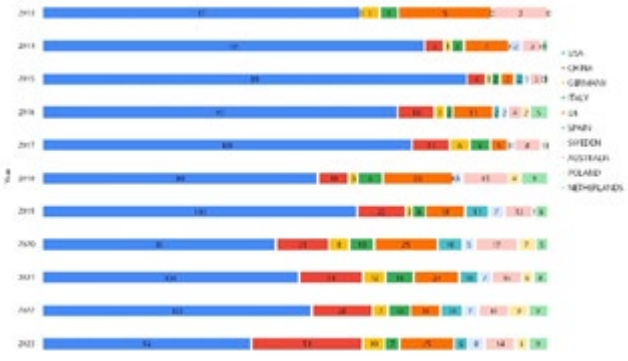
GI in Brazil encompassed a range of strategies and practices aimed at making cities resilient. The adoption of GI played a fundamental role in promoting sustainable urban development and improving the quality of life for urban inhabitants.

The deliberate exclusion of terms associated with stormwater drainage and management was intended to specifically focus on elements not directly linked to stormwater management. This decision suggests a particular interest in addressing aspects of green infrastructure that do not directly relate to water issues.

By avoiding specific water-related terms, the focus seemed to be directed at characteristics and functionalities of green infrastructure that transcend conventional stormwater management, indicating a broader interest in other dimensions and benefits of this type of urban infrastructure.

3.3 Indexed articles on green infrastructure related to water issues

A search was conducted in articles specialized in the field of water-related aspects of green infrastructure, aiming to identify research that focused particularly on the integration of green infrastructures within the water domain, with special emphasis on stormwater management as highlighted by Diep; Dodman; Parikh (2019; Lovell; Taylor (2013); Nguyen et al. (2019); Radinja; Atanasova; Lamovšek (2021). This analysis covered scientific works that explored the intersections between green infrastructure and issues related to the sustainable management of stormwater in urban environments (Figure 4).



Graph 1: The top 10 countries with the most publications on green infrastructure terms relatd to water issues.
Source: Scopus, adapted by the authors.

A word cloud, generated from the surveyed works on green infrastructure related to water issues, provided a panoramic view of the predominant themes. This graphical representation highlighted frequently used terms, indicating research focuses and areas of interest (Figure 2). Words like "ecosystem," "management," "sustainability," and "water" were prominent, reflecting the emphasis on the intersection between ecology and water resources. The frequency of terms "urban" and "development" suggested a concentration on challenges and solutions in urban contexts. Terms such as "modeling" and "analysis" indicated the methodologies applied, while "policies" and "strategies" pointed to planning and implementation approaches. This keyword analysis offered a comprehensive understanding of current trends, research directions, and core concerns in the interaction between green infrastructure and water resource management.

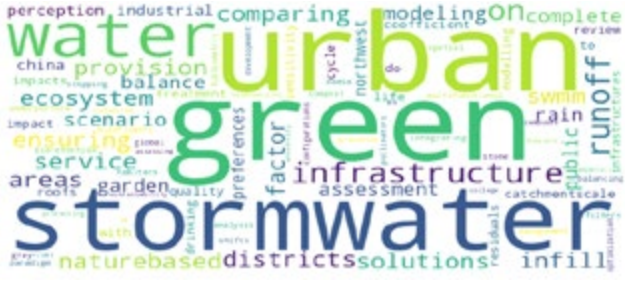


Figure 2: Word cloud from articles on green infrastructure related to water issues.
Source: Authors (2023).

As demonstrated in Graph 4, the United States led the research scene on Green Infrastructure (GI) related to water issues, with an increasing trend over the years. Emphasis was placed on integrating nature-based solutions, such as bioretention and permeable pavements, into the effective management of urban stormwater (STADDON et al., 2018).

China showed significant growth in article production in the context of drainage with GI . The strategies adopted in Chinese cities to cope with rapid urban development and the challenges associated with stormwater management through the implementation of green roofs and permeable pavements stood out as an integral part of GI (CHESHMEHZANGI, 2022).

In European countries, research showed variations over the years. The policies and practices adopted in Europe to promote green infrastructure as a viable solution for stormwater management were highlighted by Mell and Clement (2020).

In these countries, a detailed approach to green infrastructure was adopted to tackle water challenges, focusing on improving urban drainage and planning urban spaces that are functional and resilient. This involved the implementation of innovative solutions to promote sustainable practices in stormwater management, highlighting the importance of urban green spaces in effectively dealing with water issues (LIU; JENSEN, 2018).

The bibliometric analysis revealed an upward trend of interest in GI towards drainage solutions, reflecting a pressing global need to adopt sustainable approaches in the management of urban stormwater. The specialized literature demonstrated that various countries offered unique perspectives to address both local and global challenges associated with stormwater management.

These studies emphasized the importance of incorporating sustainable practices in stormwater management as an integral component of sustainable urban development (MINKS, 2013). The sustainable approach not only addressed environmental concerns but also contributed to the enhancement of urban resilience in the face of extreme weather events (HANNES, 2019).

A deeper understanding of these practices, coming from different parts of the world, provided a solid foundation for formulating adaptable and contextually relevant strategies at the local level (CANTON, 2013). Therefore, by incorporating lessons learned from successful initiatives in different contexts, it was possible to develop and implement innovative and effective solutions for sustainable stormwater management in urban areas.

This holistic approach not only met the immediate needs of urban communities but also contributed to building more resilient and sustainable cities in the long term.

4. CONCLUSION

This study explored the increasingly broad conceptual scope and trends of the subject, showing that green infrastructure (GI) has transcended water-related issues. The analysis of articles highlighted the diversity of definitions and their applications, reflecting its interdisciplinary nature and geographical variation.

There was a significant increase in the publication of articles on GI from 2013 to 2023, with emphasis on the United States, China, and European countries. This trend underscored the global recognition of the subject as a tool for the development of resilient and sustainable cities. The research revealed two main lines of focus: one oriented towards general aspects of GI, including landscaping and nature-based solutions, and another focused on water issues, both with a growing trend of publications.

In the USA and China, studies emphasized the integration of natural solutions in urban settings, aiming to improve quality of life and environmental resilience. In Europe, GI was approached in urban policies and practices, standing out in stormwater management and in the construction of sustainable cities.

It was concluded that GI is an expanding field, crucial for sustainable urban planning. With its multifunctional and interdisciplinary approach, it offered solutions to urban challenges such as climate change, environmental quality, and biodiversity. The results reinforced the importance of continuing to explore and implement GI in different contexts, promoting healthier, more resilient, and sustainable cities.

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AUTHORS

ORCID: 0000-0002-2032-8594
ANTONIO DE JESUS NAZARETH NETO | Mestrando em Recursos Naturais UFMS - Campo Grande, MS, Brasil - Rua Alegrete, 923, Bloco 3, Apartamento 13 - Bairro Coronel Antonino, Campo Grande - MS, CEP: 79010-800.
E-mail: nazareth_antonio@ufms.br

ORCID: 0000-0001-7624-8676
ADEMIR FONTANA, Doutor | Agronomia-Ciência do Solo Embrapa Solos, Campo Grande, MS, Brasil - Av. Rádio Maia, 830 - Vila Popular, Campo Grande - MS, CEP: 79106-550.
E-mail: ademir.fontana@embrapa.br

ORCID: 0000-0003-2526-1293
ELIANE GUARALDO, Doutora | Estruturas Ambientais Laboratório da Paisagem, UFMS, Campo Grande, MS, Brasil Herbert Moses, 297 - Jardim Paulista, Campo Grande - MS, CEP: 79050-150.
E-mail: eliane.guaraldo@ufms.br

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AF: writing -review & editing

EG: writing - review & editing

Conflict declaration: nothing has been declared.

TOOLS FOR ASSESSING THE FINANCIAL SUSTAINABILITY OF INTEGRATED MANAGEMENT SYSTEMS OF URBAN SOLID WASTE

FERRAMENTAS PARA AVALIAÇÃO DA SUSTENTABILIDADE FINANCEIRA DE SISTEMAS DE GERENCIAMENTO INTEGRADO DE RESÍDUOS SÓLIDOS URBANOS

HERRAMIENTAS PARA EVALUAR LA SOSTENIBILIDAD FINANCIERA DE SISTEMAS INTEGRADOS DE GESTIÓN DE RESIDUOS SÓLIDOS URBANOS

DAYANE VALENTINA BRUMATTI, Msc. | UFES – Universidade Federal do Espírito Santo, Brasil
GISELE DE LORENA DINIZ CHAVES, Dra.| UFSC – Universidade Federal de Santa Catarina, Brasil
RENATO RIBEIRO SIMAN, Dr.| UFSC – Universidade Federal de Santa Catarina, Brasil

ABSTRACT
The integrated management of urban solid waste (IMUSW) is considered a challenging task due to the multiple dimensions that make up the system, its changes over time and the fragility of financial sustainability in the sector. Knowing the tools that enable the analysis of this complex system is important to help decision makers in waste management. Thus, this article aims to present the tools, and indicate the most suitable ones to be used to analyze the behavior and interrelation of the elements that affect the financial sustainability of municipalities in the IMUSW over time. As a result, when considering IMUSW systems, System Dynamics (SD) presented advantages over other static tools and methods of operational research due to their complex, changeable and recognizable nature from real world elements. This study provides important contributions for future research and IMUSW management planning, as it provides information on the most relevant and current tools for the development of studies focused on waste management and the financial sustainability of the system.

KEYWORDS
Solid waste management; Financial sustainability; Evaluation methods.

RESUMO
O gerenciamento integrado de resíduos sólidos urbanos (GIRSU) é considerado uma tarefa desafiadora devido às múltiplas dimensões que compõem o sistema, às suas mudanças ao longo do tempo e à fragilidade da sustentabilidade financeira no setor. Conhecer as ferramentas que possibilitam a análise desse complexo sistema é importante para auxiliar os tomadores de decisão no gerenciamento dos resíduos. Desta forma, este artigo tem como objetivo apresentar as ferramentas, e indicar a mais adequada, que podem ser utilizadas para análise do comportamento e inter-relação dos elementos que afetam a sustentabilidade financeira dos municípios no GIRSU, ao longo do tempo. Como resultado, a Dinâmica de Sistemas (DS) apresentou vantagens sobre as outras ferramentas e métodos estáticos de pesquisa operacional, quando se considera os sistemas de GIRSU, por sua natureza complexa, mutável e reconhecível dos elementos do mundo real. Esse estudo fornece importantes contribuições para pesquisas futuras e para o planejamento do GIRSU, pois traz informações sobre as ferramentas mais relevantes e atuais para o desenvolvimento de estudos voltados para o gerenciamento de resíduos e a sustentabilidade financeira do sistema.

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PALAVRAS-CHAVE

Gerenciamento de resíduos sólidos; Sustentabilidade financeira; Métodos de avaliação.

RESUMEN

La gestión integrada de los residuos sólidos urbanos (GIRSU) se considera una tarea desafiante debido a las múltiples dimensiones que componen el sistema, sus cambios en el tiempo y la fragilidad de la sostenibilidad financiera del sector. Conocer las herramientas que permiten el análisis de este complejo sistema es importante para ayudar a los tomadores de decisiones en la gestión de residuos. Por lo tanto, este artículo tiene como objetivo presentar las herramientas, e indicar la más adecuada, que pueden utilizarse para analizar el comportamiento y la interrelación de los elementos que afectan la sostenibilidad financiera de los municipios en la GIRSU, a lo largo del tiempo. Como resultado, la Dinámica de Sistemas (DS) presentó ventajas sobre otras herramientas y métodos de investigación operativa estática, al considerar los sistemas GIRSU, debido a su naturaleza compleja, cambiante y reconocible de los elementos del mundo real. Este estudio aporta importantes aportes a futuras investigaciones y planificación de la GIRSU, ya que proporciona información sobre las herramientas más relevantes y actuales para el desarrollo de estudios dirigidos a la gestión de residuos y la sostenibilidad financiera del sistema.

PALABRAS CLAVE

Manejo de residuos sólidos; Sostenibilidad financiera; Métodos de evaluación.

1. INTRODUCTION

On the 28th of July, 2022, the UN (the United Nations) announced a new human right, a resolution on the right to "a clean, healthy and sustainable environment" (UN, 2022). The United Nations General Assembly declared that this issue should be a universal human right and requested that countries, companies and international organizations increase their efforts to obtain this goal. In order to make this become reality, governments should engage in one of the biggest challenges of current times: solid waste management.

Municipalities consider the management of waste to be a challenge due to various factors, the main factor being the high financial demand of the process. According to Chaves et al. (2020), municipalities are unprepared to efficiently manage urban solid waste (USW), which unfolds into multiple dimensions: management (administrative and technical), political and budgetary-financial. According to Byamba and Ishikawa (2017), the interconnectivity of various waste management aspects is important to the general system's function and performance. Therefore, the analysis must consider socioeconomic, environmental, financial and political (institutional) aspects since the integrated approaches are promising tools to face the current situation of waste management, especially in developing countries.

Various authors still highlight deficits in public management (LEAL FILHO et al., 2018), such as the lack of specialized labor force and local technical qualification (MARINO; CHAVES; SANTOS JUNIOR, 2018), the involvement of political interests (CHAVES; SANTOS; ROCHA, 2014), the lack of planning (MUÑOZ et al., 2021) and information (DUTRA; YAMANE; SIMAN, 2018), low efficacy in implementing policies (XIAO et al., 2020), lack of technology improvement (KHAN et al., 2022) and limitation of financial resources to perform the necessary changes (AGATON et al., 2020; CAMPOS-ALBA et al., 2021; CETRULO et al., 2018; FERRONATO et al., 2018; PLASTININA et; al., 2019; REBEHY et al., 2017; VIOTTI et al., 2020), which are restrictive factors for efficient USW management. Therefore, one of the main aspects of USW management is linked to financial sustainability.

Financial sustainability is defined as a set of financial strategies, administrative, accounting and operational procedures that aim to guarantee continuous operations, all of which the institution must be able to financially fulfill their present and future obligations (HURST; LUSARDI, 2004; KAKATI; ROY, 2021). From the point of view of financial sustainability in Integrated Management of Solid Urban Waste (IMUSW), the goal is to guarantee the provision of services such as waste collection, transportation, recycling, processing and disposal, in order to financially cover all costs, as well as the expansion of services that accompanies population growth and future uncertainties, maintaining financial balance.

The management cost of USW in the world should grow by almost 100% by 2025, going from costing R$ 1 trillion (US$ 205 billions) to almost R$ 2 trillions (US$ 376 billions) in 2025 (RAZZAQ et al., 2021). According to the World Bank (2018), costs with USW management in developing countries represent up to 20% of the municipal budget (KAZA et al., 2018). In Brazil, according to data from the National System of Information on Sanitation (SNIS), the expenses per capita for USW management in municipalities increased in 13.2% between 2017 and 2019 (SNIS, 2020), achieving R$ 25 billions in 2020 (SNIS, 2021), which compromises the balance of bills from USW management service holders.

Besides high costs, the management of solid residue is associated to the lack of understanding on various factors that affect the whole management system and to the connections necessary to allow the operation of the whole system (ABDEL-SHAFY; MANSOUR, 2018; GUERRERO; MAAS; HOGLAND, 2013). In light of this, this study seeks to clarify the following question: Which tools can be applied to analyze the behavior and interrelationship between the elements that affect the financial sustainability of municipalities in IMUSW over time? Therefore, the main contribution of this article is to identify the tools (and indicate the most adequate ones) that can be used to analyze the behavior and interrelationship of the elements that affect financial sustainability of municipalities in IMUSW over a time frame.

It is worth noting that no similar study to the one proposed in this research was found in the literature. This gap was even identified in the study conducted by Brumatti et al. (2024), where the authors aimed to highlight research gaps in the literature related to the financial sustainability of Integrated Solid Waste Management Systems (ISWMS) in municipalities across different countries.

2. METHODOLOGY

The methodology of this article was developed through bibliographic and systematic research. Bibliographic research analyzes published materials that provide an examination of recent and current literature and may cover a wide range of subjects at various levels of completeness and scope. It may include research findings and offer new perspectives on an issue or highlight an area in need of further research. Systematic research seeks, through selected elements of interest, to systematically evaluate the selected portfolio of articles and synthesize research evidence. (GRANT; BOOTH, 2009).

In accordance with this, Figure 1 displays the steps followed in order to obtain the articles portfolio to develop systematic analysis.

Figure 1: Steps to obtain the portfolio of articles.
Source: Authors.

After defining the research question (step i), the next step defined the search terms (step ii), which were identified in articles, books and documents related to the theme. The identified terms were then inserted into databases to assess their relevance, focusing on approximately three thematic areas: the research object: (financial* sustainab*, financial* stability, financial* viability, financial* viable, financial* self-sufficiency, financial* evaluation, balance financial*, financial* independence, financial* analysis, financial* commitment, financial* planning, financial* performance, financial* efficiency, economic* sustainab*, economic* stability, economic* viability, economic* viable, economic* self-sufficiency, economic* evaluation, balance economic*, economic* independence, economic* analysis, economic* commitment, economic* planning, economic* performance, economic* efficiency), typology of the studied waste (municipal solid waste, urban solid waste), and the action of the involved actors (management, governance) .

For the execution of step iii, the Scopus and Web of Science databases were chosen due to their greater relevance for searching scientific literature (KHUDZARI et al., 2018; SOLIS et al., 2019), and to their extensive coverage, which enables the reaching of a greater number of articles (SALVADOR et al., 2019). The research in databases was developed by combining the presented search terms and using boolean operators, which act as words that inform the search engine to combine search terms by using OR and AND. Furthermore, an asterisk (*) was used in the search terms to capture all variations of the selected terms. This research was conducted in 2022, therefore the temporal delimitation was between January 1st, 2017 and March 17th, 2022, aiming to consider the most recent studies.

Only research articles were contemplated, and the search terms were limited to titles, keywords and abstracts, resulting in a gross total of 356 articles. Following that, the Smart bibliometrics method was used to compile the articles found in the databases into one single Excel sheet and to standardize information such as year, title, authors, impact factor, number of citations, keywords and abstract, in order to analyze and filter the results. This method is employed in the research environment to provide an overview of the state of the art of the scientific knowledge about a specific theme; it is an important technique to guide the selection of bibliographical repertoire and to justify the theoretical discussion (PESSIN; YAMANE; SIMAN, 2022).

Subsequently, step iv was carried out, filtering the articles by elimination duplicates and articles whose titles, abstracts and keywords did not correspond to the researched theme, resulting in a total of 130 articles. Finaly, in step v, the 130 articles were read integrally to verify their compatibility with the previously mentioned research question. Of these, 48 studies were selected to compose the final article's portfolio, when the tools used in each conducted research were surveyed and analyzed. The survey and discussion on the tools, as well as the indication of the most suitable one, prioritized the following criteria: it should be capable of analyzing economic impacts (process costs); it should take into consider innumerable variables; it should have the ability to represent complex systems; it should consider the temporal effects resulting from changes in the system over time; it should be visual and comprehensible to allow the participation of various stakeholders involved in SWM; and its limitations.

3. RESULTS AND DISCUSSION

Figure 2 presents which tools were the most used to achieve the objective in the studies selected for this research.

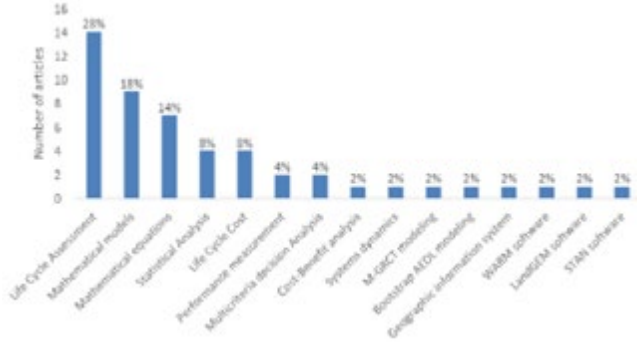

Figure 2: Methods used in the analysis studies of USW management.
Source: Authors.

The Life Cycle Assessment (LCA) was the most used within the selected articles, present in 14 articles, that is, in 28% of the sample gathered. Out of these 14 studies, 3 associated LCA to Life Cycle Cost (LCC), other 3 studies associated LCA to the mathematical model method and 1 other study associated LCA to Multi-criteria Analysis and Cost-Benefit Analysis methods. Thereby, the remaining 7 articles used LCA without association to any other method. Since LCA is considered to be a tool for quantifying environmental impacts and for decision-making intended to improve the environmental performance of products and systems, it cannot evaluate the economic impacts of the processes by itself (DONG; NG; LIU, 2021; ILYAS; KASSA; DARUN, 2021).

Still on the use of LCA, Rizwan et al. (2020), in their study of analysis on processing routes for USW management under economic and environmental criteria, pointed out a limitation in the solution proposed for the multi-objective optimization structure, as it does not lead to an optimal or unique solution. Instead, it provides a series of solutions. Additionally, these authors point out the demand for a large quantity of data for modeling each technological alternative. De Feo et al. (2017), aiming to evaluate the recovery of recyclable materials in municipal solid waste management, pointed out that the economic benefits were only calculated according to the revenue from recovered material, instead of also considering the costs of waste management, increasing the percentage of source separation to calculate revenues. Furthermore, modeling linearity was assumed for environmental evaluation, even in high recycling rates. As it is observed, the tool most used by authors also presents limitations in the variation of variables that compose the system, either due to the lack of information or due to rigidity of the method. In other words, this tool is not capable of absorbing changes in waste management over time.

Some authors, when using mathematical equations, also indicated failures related to the rigidity of the method when using this tool. Azis, Kristanto e Purnomo (2021), by displaying a technical-economical evaluation of a WtE commercial floor plan in Indonesia, warned that the cost was set on US$ 6.76 per ton of waste, not taking into consideration the change this number may suffer regionally, depending on the condition and composition of the waste. Chen et al. (2022), considering environmental impact, energy conservation and economical cost, presented technology combinations for IMUSW in China and pointed out the lack of more management objectives and alternative technology for broader consideration. Habib et al. (2021), who studied the generation and management of USW at Rajshahi City Corporation, Bangladesh, pinpointed the absence of important parameters, such as recyclable residue values, quantity of pollution in waste, among others, for a better comprehension of global waste management. This demonstrates that mathematical equations are not the best tool to work with many variables, such as in the analysis of elements that hinder sustainability in USW management.

Höke e Yalcinkaya (2021) used mathematical models as a tool in their study which intended to develop a model to investigate the optimal location and the economical impacts of USW Transference Stations in Türkiye. Regarding the limitations of the study, the authors revealed that a future projection of waste generation was not considered. An increase of waste generation, of the costs of work force and of the costs of fuels throughout time can make a Transference Station economically inviable in the area of study. This means that uncertainties cannot be considered, compromising the study.

Amal et al. (2020) utilized multi-criteria analysis and a Geographic Information Systems (GIS) to analyze USW at Sfax, the second most populated city in Tunisia. They indicated the existence of different criteria, such as economical, social, political, technical and environmental as a limitation of the method, which implies that the data is ill-defined. Ferreira e Barros (2021), on the other hand, used statistical evaluations to present a panorama of municipal public expenditure between 2009 and 2017 with urban cleaning services for the municipalities that make up the Metropolitan Region of Belo Horizonte - MG, Brazil; they indicated some limitations of the study. The authors suggested a deeper analysis and reported a lack of studies relating the themes "costs and waste", both nationally and

internationally, pointing this as a complicator to compare and understand public expenditure behaviors. Bui et al. (2020) also utilized statistical evaluations to analyze the validity and reliability of management attributes in Vietnam. Additionally, they encouraged future studies to extend the research structure by adding more related attributes or by applying the structure present in the study to different areas with waste management.

Leite et al. (2022) used the Waste Reduction Model (WARM) software in order to assess application potential, economical and environmental feasibility of different USW treatment technologies in Brazil. The limitation of this work was regarding higher levels of precision in potentiality, since the population projection of each municipality was not taken into consideration, and regarding gravimetry, as average gravimetry was assumed for Brazilian municipalities. In addition, the technology of pyrolysis was not analyzed in the same way as the others. Muhammad and Salihi (2018), in order to evaluate solid waste management in Kano, Nigeria, utilized the SubSTance flow Analysis (STAN) 2 software, in which they encountered difficulties to develop their work due to the limited availability of the necessary data to use this tool.

Pinha and Sagawa (2020) used the Systems Dynamics (SD) tool to develop a USW management model that provides an extensive view of the resources involved in waste destination and in the structure of costs for the services/systems involved. Brazil was chosen for the model simulation, but it can be done with any other country or region. As a limitation of the model, the authors pointed out the absence of consideration of the effect of the specific policies of the system.

Razzaq et al. (2021) used the Auto-Regressive Distributive Lag (ARDL) bootstrap modeling, an empiric model, to estimate the effect of USW recycling in environmental quality and economic growth in the United States. They investigated the co-integration relationship between USW recycling, economic growth, carbon emissions and energetic efficiency. This approach test tool was recently developed, it performs co-integration relationship analysis between variables and, as a result, can obtain recommendation of policies.

The Geographical Information Systems (GIS) is a computerized system used to store, manage and manipulate geographic data to manipulate geographically referenced maps and digital images (SANTOS; BRITO; SILVA-NETO, 2022). The WARM and LandGEM software programs serve the purpose of evaluating environmental impacts in studies that demand estimates of the main gas emissions associated to waste treatment technology (LEITE et al., 2022; SOUZA et al., 2019). The STAN2 software is used to perform material flow analysis of generated waste from its origin until various destinations (MUHAMMAD; SALIHI, 2018). The GIS methods, WARM software, LandGEM software and STAN2 software are tools that do not have the purpose of financial analysis; they only work as auxiliaries in this evaluation. Therefore, considering their limited contribution to this issue, these methods are not approached in depth in this discussion.

The difficulties of the methods lie in encompassing the full complexity of evaluating financial sustainability of IMUSW. The assessment of financial sustainability itself may involve strategic, tactical and operational (accounting) elements (BING et al., 2016), in addition to endogenous and exogenous variables that affect the system, which call for methods that allow handling a several variables. To this end, methods can be associated with the purpose of reproducing a real system as best as possible and obtaining more reliability in results.

Chart 2 contains the description of the main methods for analysis of USW management highlighted in this study, along with their characteristics.

Methods	Objectives	Advantages	Disadvantages
Life Cycle Assessment (LCA)	quantitatively evaluate the environmental impacts of products, services and processes from phases "cradle" to "grave"	- widely used by the scientific community as it can be applied to any area - ready to use software availability	- difficulties in data obtention, thus, it is not used all variables necessary for an in-depth analysis in the study - cannot evaluate the economic impacts of processes - questionable reliability of results - large number of assumptions and leads to diverging results
Life Cycle Cost (LCC)	to determine a product's total cost over the period of time from the point-of-use until the end of its shelf life	- widely used by the scientific community as it can be applied to any area - ready to use software availability - it is adopted to calculate costs and revenues related to all included problems and its results	- it does not necessarily consider technical feasibility and revenue and profit indicators, which are essential for business and decision-making in investment - are generally assumed as constant parameters and linear relationships
Systems Dynamic (SD)	to describe, model, simulate and analyze problems and/or dynamically complex systems in terms of processes, information, limits and organizational strategies	- allows the study of inherent questions in complex systems of qualitative and quantitative perspectives inside a long term dynamic process - enables simulation of scenarios, easing comprehensive analyses - simulates linear and non-linear relationships of complex systems over time - predicts uncertainties in systems - allows for analysis of structure, interactions and behaviors of the system, as well as exploring, evaluating and predict its impacts in an integrated and holistic way - ready to use software availability - easy to understand graphic representation of the system	- it is easy to introduce ambiguity and subjectivity by modelers - in simulation, the feedback mechanism of each system subject is expressed by differential equations, this way it is not possible to express the interaction mechanism as it cannot be expressed by functional equations
Multi-criteria Analysis and Cost-Benefit Analysis	to study high uncertainty questions, multiple interests and objectives, organizing alternatives in a hierarchy by using perspectives from interested shares and information on cost/benefit;	-they are efficient in classifying various potential places and selecting the best among them according to the identifies attributes - allows classification of alternatives and considers actors' point of view - useful in accounting multiple criteria by classifying or optimizing alternatives - used when various parameters influence a task's performance	-- they select ideal alternatives classifying them by using consideration criteria that was subjectively established and solely by one interested share - they possess limitations and are subjective, thus, it is difficult for them to create an objective with a unified pattern to determine the weight of evaluation indicators - this approach fails to find alternative classification derived from all possible combinations of potential places

Methods	Objectives	Advantages	Disadvantages
Mathematical models and mathematical equations	to represent the behavior of the real system under determined conditions through a set of appropriately quantified and structured assumptions and approaches, in order to predict and compare logical alternatives susceptible to simulation	- they are practical instruments for creators of policies as they can be used to solve important problems	- the method is stiff - uncertainties, such as future projection of waste generation, cannot be taken into consideration, which can compromise the study - are not the best tool for working with various variables
Statistical Analysis	to analyze and predict the current situation of USW generation	- efficient and easy to operate	- applicable to scenarios with limited dispersion and tendencies to change obvious sequence - the method is highly dependent and it is hard to guarantee its precision - it is specially used for short-term predictions - it is impossible to explore the influence mechanism of various factors
M-GRCT Modeling	to stimulate systems of solid recyclable waste management in order to analyze circular economy	- decision-making tool - allows studying the implementation of strategies for recyclable waste management by applying a circular economy	- used for low-income municipalities with populations under 20.000 inhabitants and USW generation per capita under 0.70 kg/person.day
Auto-Regressive Distributive Lag (ARDL) bootstrap modeling	to examine co-integration relations between variables, including discrepancies on dependent variables as well as on explanatory variables	- allows the analysis of long-term co-integration relationships between variables; - identifying multiple cointegrating vectors	- cannot be used with small data that is not approximate to the size of the population; the data presents many outliers
Performance measurement	to obtain information on measures related to a product, process, system or magnitude, retaining solely the essential meaning of the aspects analyzed; its main characteristic is synthesizing information	- provides important information for planning and managing processes, possibly contributing to the decision-making process; - measures the success rate of an implemented strategy considering if the established goal was achieved	- reactive and non-indicative tool; - only measures one snapshot; - must be applied to every single evaluation; - displays a specific, punctual contribution; - has complex or difficult to measure indicators that may preclude the operationalization due to the cost to obtain it.

Chart 2: Characteristics of the main methods used in studies on analysis of USW management.

Source: Authors, based on: Ali; Pumijumnong; Cui, 2017; Dong; Ng; Liu, 2021; Hadian; Madani, 2015; Hellweg; Canals, 2014; Ilyas; Kassa; Darun, 2021; Jung, 2017; Kollikkathara; Feng; Yu, 2010; Kunc, 2017; Mahmud et al., 2021; Mak et al., 2019; Massarutto, 2015; Menconi; Grohmann, 2014; Meng; Zhang; Wang, 2021; Mesa; Fúquene; Maury-Ramírez, 2021; Pruyt, 2013; Sabaghi; Mascle; Baptiste, 2016; Soltani; Sadiq; Hewage, 2016; Sterman, 2010, 2018; Vargas-Terranova Et Al., 2022; Wang, Jiang Jiang et al., 2009; Wang, Zhiguo et al., 2020; Xiao et al., 2020; Yadav et al., 2020; Zimmermann et al., 2020.

As demonstrated in the Chart 2, each method has different objectives and is indicated for different types of study. In studies on USW management, when comparing methods, the statistical model can be used when bigger applicability is desired, enabling inferences on population, being able to even generalize it for other municipalities. When the study aims at higher precision, mathematical models are more suitable; however, they may ignore qualitative and subjective considerations, such as the impact of illegal disposal of USW inadequate places, as well as other socioeconomic and environmental factors that are essential for IMUSW. The multi-criteria analysis tool is used when there are conflicting interests or objectives and when the results should present the alternatives in a hierarchical manner. Cost-benefit analysis is useful to monetize costs and benefits related to the investment options of public resources to reduce environmental risks, which requires technical data and information produced by climate science and economics. M-GRCT modeling is characterized as a numeric model which, despite encompassing the calculus of financial indicators that measure the economic feasibility of waste commercialization, is geared towards simulating systems of recyclable solid waste management for circular economy analysis. ARDL bootstrap modeling is a new approach that analyzes the co-integration between the variables of the model, leading to similar results to those of statistical models. Only one article applied this method, maybe because this method was first proposed more recently. This leaves an opening for possibilities and opportunities in this research area.

On the other hand, performance measurement, which is a method frequently used for financial evaluation in organizations (SILVA; BORNIA; PAMPLONA, 2006), including the proposition of comprehensive performance measurement systems, such as Balanced Scorecard (KAPLAN; NORTON, 1992; TSAI, 2020), was used in only two articles from the database. It is a significant tool for planning, obtaining information on a given reality, but it possesses specific contributions, meaning it must be applied to each evaluation.

If the purpose of the USW management analysis is more detailed and it aims at assessing a study around the diversity of variables, LCA and SD can be utilized. LCA was the most employed tool among the USW management studies, but it is angled towards the environmental process analysis, thus, LCC should be used for economic studies. The use of SD for USW management studies has been increasing in the scientific community since it enables the evaluation of non-linear relationships. This tool is highly suitable for studies on systems that are not static and in which time inference is desired. Various studies in the field of solid waste management have been utilizing this tool lately, as exposed by Galavote et al. (2023), Jovi˘ci´c et al. (2022), Phonphoton and Pharino (2019), Sancheta, Chaves and Siman (2021), Silva, Fugii e Santoyo, 2023 e Xiao et al. (2020). However, only one article from our search scope used this method, thus, revealing an opportunity for studies that aim to incorporate the influence of causal relations and the temporary aspect of financial sustainability in USW management. In this regard, it is worth mentioning that the method Agent Based Model (ABM) also enables the analysis of various components from one system, as well as time analysis (BORSHCHEV; FILIPPOV, 2004). Although this was not found in the articles collected for this research, the ABM can simulate simultaneous operations and interactions between the different agents of a determined environment. Individual agents are assumed as rational (limited), acting on maximizing their performance measurement (in order to obtain economic benefits, for example), by using heuristic concepts or simple rules for decision-making (NUZZOLO et al., 2018). Therefore, this method, which has also been applied to financial analyses (BOOKSTABER; PADDRIK; TIVNAN, 2018) and USW management (SOUZA; BLOEMHOF; BORSATO, 2021), may signal opportunities for future studies.

SD and ABM can model various systems, however, there are differences between the methods. One important characteristic of the SD model is the loop structure of interactive feedback which interconnects different variables (TAKO; ROBINSON, 2010) and leads to endogenously-generated behavior, a type of behavior that greatly interests dynamic systems. As for the ABM, its structure is based on the agent, in which the environment is modeled according to one or more agents, displaying different properties of the actors. Each agent receives a set of rules according to how it interacts with other agents; this interaction generates the system's general behavior (SCHIERITZ; MILLING, 2001). However, the agents used in modeling practice are diverse, and there is still much discussion about universally accepted definitions regarding the type of characteristics an object must possess to “deserve” to be denominated as an agent: pro- and reactivity, spacial conscience, learning ability, social ability, "intellect" or others (BORSHCHEV; FILIPPOV, 2004). Another difference between these two methods is that in ABM, the approach is known as the bottom-up type,

because it is done by analyzing the behavior of individual units and how these behaviors change due to interactions, which, then, makes it possible to obtain the behavior of the entire system (BUSCH et al., 2017). Meanwhile, SD is known as the top-down, that is, the system is modeled by dividing it by its main elements and modeling the interactions of the components (MACAL, 2010).

Among USW management studies, understanding the system's behavior in time is important because the system obligatorily undergoes changes, that is, it possesses dynamic nature. Population and city growth constantly modifies tons of generated waste and the configuration of collection routes, in which even the capacity of the garbage truck influences the design of the route. Landfill options can be exhausted, entailing on shut down and on the necessity of new waste disposal alternatives. Additionally, the number of transference stations needed for effective USW management may increase or the best places for transference stations may change. All these changes that IMUSW go through in a time frame may require an increase in financial resources for management, demanding policies directed at raising funds, environmental awareness, monitoring and encouraging recycling.

Considering all that has been discussed regarding tools applied to behavior analysis and interrelation between critical elements that affect the financial sustainability of IMUSW in a time frame, especially regarding the countless variables that compose the system and the possibility of time analysis, to answer the research question, the most suggested tool is SD. In a lesser indication, ABM is favored, as the feedbacks of system components are considered important for the dynamism of the analysis.

Kuo et al. (2019) point out that SD is the most appropriate tool to simulate system performance when multiple variables change at the same time and for dynamically optimize the effects of mixed policies. According to Sterman (2010, 2018), SD is a technique used to study complex systems, being able to depict different temporalities and display, through this, existent feedback mechanisms over time. In accordance with Mak et al. (2019), using SD also allows simulating scenarios, which facilitates wider analyses of quantitative and qualitative results. Popli, Sudibya e Kim (2017) point to distinctive advantages to analyze waste management, connecting it to environmental, social, political and economical approaches.

4. CONCLUSIONS

The elements that affect the financial sustainability of IMUSW are interconnected, so that when one is affected, there is an effect on the other. Policy changes affect other elements, such as management, economy and social aspects. A management element may entail a higher cost, but but bring higher social benefits, for example. This means that factors are correlated, and in order to perform the effective assessment of the financial sustainability of IMUSW, it is necessary that the chosen methods consider the interrelationship of these elements. Preferably, a more comprehensive study would involve an integration of all the analyzed elements. However, this was not found in the literary analysis, indicating a gap to be filled.

It is also necessary to analyze the behavior and interrelation between these elements throughout the time frame due to the changing nature of the USW management systems. To this end, we advise that future studies use tools able to consider these systems' complexity, simulate linear and non-linear relations, and predict uncertainties. In this sense, Systems Dynamics is the most adequate method to correlate the financial sustainability elements of USW management and to evaluate these elements' behaviors and interrelation over time. Its dynamic characteristic displayed advantages over other static tools and methods of operational research in IMUSW systems due to the complex, changing and recognizable nature of the real-world elements. In addition, the graphic representation of the system is easy to understand, which allows people that are not familiar with this type of model simulation approach to easily understand the model and participate in the construction process.

Life Cycle Assessment was the most used tool in the studies surveyed, however, by itself, the tool cannot be used for financial analysis of the process. Moreover, this analysis is based on linear relations and this tool does not allow time analysis. Since Auto-Regressive Distributive Lag bootstrap modeling is a new approach that allows long-term co-integration analysis between the variables of the model, it presents new possibilities and opportunities for this research area.

This study provides useful contributions to the managers for planning, altering or implementing IMUSW systems in cities, providing information on the tools used in the most relevant and current articles on developing studies for waste management. The analyses conducted provided suggestions for the development of future studies by researchers, indicating the need for integration

among the elements affecting financial sustainability in USW management, as well as the methods with potential for this approach.

IMUSW is a multifaceted system and is one of the most challenging, complex and multidisciplinary tasks for municipalities. It cannot be viewed in a unidimensional perspective since many of its decision issues of different levels are interrelated. It is difficult to balance social, economic and management perspectives in IMUSW, while also meeting environmental policies, due to the inevitable conflict between the objectives related to the sustainability pillars. Management should therefore be analyzed through tools that enable a holistic approach and a systemic and multidimensional perspective, indicating an integration of various disciplines in order to understand and propose improvements in financial sustainability performance.

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AUTHORS

ORCID: 0000-0001-5619-5423
DAYANE VALENTINA BRUMATTI, Mestra | Universidade Federal do Espírito Santo - UFES | Pós-graduação em Engenharia Ambiental | Vitória, ES - Brasil | Correspondência para: Av. Fernando Ferrari, 514 - Goiabeiras, Vitória - ES, 29075-910 | E-maill: dayane.brumatti@edu.ufes.br

ORCID: 0000-0001-6359-9063
GISELE DE LORENA DINIZ CHAVES, Doutora. | Universidade Federal de Santa Catarina - UFSC | Pós-graduação em Engenharia de Produção e Engenharia Ambiental | Florianópolis, SC - Brasil | Correspondência para: R. Eng. Agronômico Andrei Cristian Ferreira, s/n - Trindade, Florianópolis - SC, 88040-900 | E-maill: gisele.chaves@ufsc.br

ORCID: 0000-0003-2939-7403
RENATO RIBEIRO SIMAN, Doutor | Universidade Federal do Espírito Santo - UFES | Pós-graduação em Engenharia Ambiental | Vitória, ES - Brasil | Correspondência para: Av. Fernando Ferrari, 514 - Goiabeiras, Vitória - ES, 29075-910 | E-maill: renato.siman@ufes.br

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GREENWASHING AND BOYCOTT: CRITICAL APPRECIATION OF ACADEMIC PRODUCTION

GREENWASHING E BOICOTE: APRECIAÇÃO CRÍTICA DA PRODUÇÃO ACADÊMICA

GREENWASHING Y BOICOT: APRECIACIÓN CRÍTICA DE LA PRODUCCIÓN ACADÉMICA

TAÍS PASQUOTTO ANDREOLI, Dra. | UNIFESP – Universidade Federal de São Paulo, Brasil
PATRÍCIA CARDOSO SILVA | UNIFESP – Universidade Federal de São Paulo, Brasil

ABSTRACT
The lack of effective regulation has contributed to the proliferation of the practice of greenwashing, relegating the responsibility for identification, differentiation and protection to consumers. The article aimed to evaluate academic production regarding greenwashing and the consumer boycott movement. As a methodological procedure, a systematic review of the literature was carried out, through a bibliometric survey associated with a critical analysis of academic production with the themes of greenwashing and boycott (boycott/buycott), mapping the main scientific platforms (Capes, Proquest, Scielo , Scopus, Spell). With this, it was possible to evaluate the current state of the art on the subjects, consolidating what had been studied so far, in addition to making it possible to suggest future studies to advance the topic in academia and in practice. As a main result, it was found that there are few approaches that encompass both themes in question, jointly, emerging as an important research gap, with new studies encouraged.

KEYWORDS
Greenwashing; Boycott; Consumer; Academic Production.

RESUMO
A falta de regulamentação efetiva tem contribuído para a proliferação da prática de greenwashing, relegando a responsabilidade de identificação, diferenciação e proteção aos consumidores. O artigo teve como objetivo avaliar a produção acadêmica concernente ao greenwashing e ao movimento de boicote por parte dos consumidores. Como procedimento metodológico, foi realizada uma revisão sistemática da literatura, por meio de um levantamento bibliométrico associado à uma análise crítica da produção acadêmica com as temáticas de greenwashing e boicote (boycott/buycott), mapeando as principais plataformas científicas (Capes, Proquest, Scielo, Scopus, Spell). Com isso, foi possível avaliar o atual estado da arte sobre os assuntos, consolidando o que foi estudado até então, além de possibilitar a sugestão de estudos futuros para o avanço do tema na academia e na prática. Como principal resultado, constatou-se que são escassas as abordagens que englobam ambas as temáticas em questão, de forma conjunta, despontando-se como uma importante lacuna de pesquisa, com novos estudos incentivados.

PALAVRAS-CHAVE
Greenwashing; Boicote; Consumidor; Produção Acadêmica.

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RESUMEN

La falta de una regulación efectiva ha contribuido a la proliferación de la práctica del greenwashing, relegando la responsabilidad de identificación, diferenciación y protección a los consumidores. El artículo tuvo como objetivo evaluar la producción académica sobre el greenwashing y el movimiento de boicot de los consumidores. Como procedimiento metodológico, se realizó una revisión sistemática de la literatura, a través de un levantamiento bibliométrico asociado a un análisis crítico de la producción académica con las temáticas de greenwashing y boicot (boycott/buycott), mapeando las principales plataformas científicas (Capes, Proquest, Scielo, Scopus, Hechizo). Con esto, fue posible evaluar el estado actual del arte sobre los temas, consolidando lo estudiado hasta el momento, además de permitir sugerir estudios futuros para avanzar el tema en la academia y en la práctica. Como principal resultado, se encontró que existen pocos enfoques que abarquen ambos temas en cuestión, de manera conjunta, surgiendo como un importante vacío de investigación, siendo estimulados nuevos estudios.

PALABRAS CLAVE

Greenwashing; Boicot; Consumidor; Producción Académica

1. INTRODUCTION

Environmental movements that began in the 19th century already expressed, in a pioneering way, concerns about the impact that unrestrained consumption causes on the environment (Andreoli, Crespo & Minciotti, 2017). In this context, new purchasing and consumption habits guided by greater awareness and socio-environmental responsibility have stood out as an important market trend (Topal, Nart, Akar & Erkollar, 2020).

As a consequence, there is a movement within the organizational environment to meet these new and growing demands, requiring a review of its strategies towards the implementation of more sustainable practices, as is the case with environmental or green marketing (Riccolo, 2021). However, this new scenario also enabled many organizations to practice greenwashing, a term that denotes the misappropriation or even false appropriation of ecological appeals, without due practical support (Andreoli, Crespo & Minciotti, 2017; Andreoli, Costa & Prearo, 2022). In other words, according to the aforementioned authors, the practice of greenwashing is characterized when the published image is washed or made up - whether of a product, a brand or an organization - so that it appears environmentally responsible, without necessarily being.

As an aggravating factor, it is noteworthy that there are still practically no effective regulatory actions regarding this practice in the country and in the world (Andreoli & Batista, 2020), a scenario that corroborates the argument of wide and growing proliferation of greenwashing (Andreoli, Minciotti & Batista, 2024). In this context, the role of the consumer is highlighted, as both a target audience and an end point in the chain (Jong et al, 2020; Andreoli, Costa & Prearo, 2022). In this way, the responsibility of not only identification and differentiation ends up being imposed on the consumer, but, more importantly, of protecting the practice, emerging as a possible regulatory agent (Andreoli & Batista, 2020; Andreoli, Costa & Prearo, 2022).

One of the main forms of consumer demonstration is through boycott movements, a term used to characterize behavior of repudiation towards a product, brand or organization. (Cruz, 2012). In this sense, Klein, Smith and John (2004) define a boycott as an individual or collective action by the consumer market to stop purchasing and consuming a product or brand. It is precisely this anti-consumption movement that differentiates the boycott from other protest practices in the consumer market, such as social movements, demonstrations or activist marches (Friedman, 1999; Soule, 2009; Cruz & Pirez Jr, 2013).

In light of the above, the article aimed to evaluate academic production regarding greenwashing and the consumer boycott movement. The theoretical framework discussed the practice of greenwashing, contextualizing it in particular within the consumer market, in order to discuss the manifestation of boycotts. As a methodological procedure, a systematic review of the literature was carried out, through a bibliometric survey associated with a critical analysis of academic production with the themes of greenwashing and boycott/buycott.

2. GREENWASHING AND THE CONSUMER BOYCOTT MOVEMENT

Greenwashing is understood as the practice of washing or making up a product, a brand or an organization, so that it appears environmentally correct, without necessarily being so (Andreoli, Crespo & Minciotti, 2017; Andreoli, Costa & Prearo, 2022). Thus, greenwashing can be defined as the intersection of two behaviors on the part of organizations, being, on the one hand, low environmental performance, but, on the other, positive communication about this environmental performance (Delmas & Burbano, 2011).

For this reason, it is noteworthy that the term is directly associated with marketing communication actions carried out by the most diverse organizations with the aim of emphasizing their activities as good environmental practices, minimizing the negative environmental impacts arising from their actions and/or unduly valuing their offer (Souza, 2017). Therefore, the practice of greenwashing creates and promotes a false model, which intentionally misrepresents reality, misleading the consumer (Souza, 2017; Andreoli, Costa & Prearo, 2022).

The topic of greenwashing has been gaining significant academic interest. A seminal survey of production carried out in 2017 identified only 42 articles classified in the Qualis criteria of the period, with an even smaller number when considering a greater level of depth of discussions (Andreoli, Crespo & Minciotti, 2017). More recently, a systematic literature review carried out in 2020 updated and expanded the sum of academic production, identifying 67 articles of interest (Freitas Netto, Sobral, Ribeiro & Soares, 2020).

In general, the literature is consensual when contextualizing the current alarming situation of the practice of greenwashing, defending the growing and even proliferation of organizational cases (Andreoli, Crespo

& Minciotti, 2017; Freitas Netto, Sobral, Ribeiro & Soares, 2020; Andreoli, Costa & Prearo, 2022). The aggravating factor is the lack of effective regulation of the practice in the country and in the world (Andreoli & Batista, 2020), justified, in large part, by the voluntary nature linked to the organizational incorporation of socio-environmental values (Márquez, González & Ramírez, 2022).

In this context, we end up praising the role of the consumer, target audience and main interested party (Jong et al, 2020; Andreoli, Costa & Prearo, 2022). More than that, it is argued that, as the final end of the production chain, the consumer has an important role in questioning and demanding from the organizational environment (Jong et al, 2020; Andreoli, Costa & Prearo, 2022). In this way, the outcome ended up being to impose on the consumer the responsibility for regulating the practice of greenwashing, in the sense of identification and differentiation, in addition to self-protection and dissemination to others (Andreoli & Batista, 2020; Andreoli, Costa & Prearo, 2022).

There are several studies that address consumer reactions to the practice of greenwashing, in particular pointing out various harmful effects on the organization reported and/or caught as acting in this regard. Nyilasy, Gangadharbatla and Paladino (2014) argued the possibility of consumer fluctuations in relation to the brand, or even their detachment from it. Parguel, Benoît-Moreau and Larceneux (2011) defended the decrease in purchase intention, just as Hamann and Kapelus (2004) mentioned the loss of consumer loyalty. Furthermore, there is mention of loss of reliability, both in a targeted way, for the specific organization, and in a generalized way, for the green market as a whole (Parguel, Benoît-Moreau & Larceneux, 2011; Chen & Chang, 2013; Guyader, Ottosson & Witell, 2017).

If the mere reaction of the consumer, in an individual and unstructured way, is already argued to be important and impactful, it is to be expected that a more active movement will be even stronger. This includes boycott, understood as one of the main forms of consumer expression, characterized by behavior of repudiation in relation to a product, a brand or an organization (Cruz, 2012). Boycott is defined as an anti-consumption action, in which the consumer intentionally reduces or even interrupts purchasing and consumption with a certain brand or organization (Klein, Smith & John, 2004; Soule, 2009; Cruz & Pirez Jr, 2013).

3. METHODOLOGICAL PROCEDURE

A systematic literature review was conducted, carried out through a bibliometric survey and a critical analysis of academic publications that address the themes of greenwashing and boycott/buycott. This allowed a general mapping of what has already been produced on the topic, both qualitatively and quantitatively, not only to consolidate what has been studied so far, but also to enable a critical analysis to advance the topic in academia and practice.

More specifically, the systematic review was guided by three research questions, namely: 1. How is the current academic production on the topics of boycott and greenwashing characterized? 2. How does the relevant literature study consumer boycott related to the practice of greenwashing?

A methodological procedure similar to that adopted in related literature was applicated here, with the same objective of evaluating the state of the art, one focused on the theme of greenwashing, in general (Andreoli, Crespo & Minciotti, 2017), and the other related to bluewashing theme (Andreoli, 2023). Therefore, the structure proposed by Kitchenham (2004) was adopted as a model, which summarized PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyzes) into three main phases: (1) Review Planning, with a description of the need review and development of the protocol; (2). Conducting the Review, stage in which the search, selection, evaluation, extraction and synthesis of the collected data is carried out; and 3. Review Report, with the presentation and analysis of the results.

3.1 Review Planning

Six different forms or variations of the terms of interest were considered for the search, always combined (AND command), namely: greenwashing and boicote, greenwash and boicote, greenwashing and boycott, greenwash and boycott, greenwashing and buycott e greenwash and buycott. The databases used for the search were Portal Capes, Proquest, Scielo, Scopus and the Spell platform, as they represent the most complete academic databases. Access to them was done through an institutional login, so that unrestricted return of results was possible. In all cases, the advanced search engine was used in order to work with the aforementioned combinations. Furthermore, on some platforms, the academic journals filter was used.

Therefore, the inclusion criteria were publications in academic journals, available as full text on the internet

and written in English, Portuguese or Spanish. The search process was carried out at the beginning of January 2023, being repeated by a third-party researcher the following week, in order to check and validate the results found. Thus, all results up to the beginning of 2023 were included, returning an analysis period from 1998 to 2022. The exclusion criteria, in turn, were all other forms of publication, such as reports, conference articles, book chapters, dissertations and theses.

The extracted data was consolidated into an Excel spreadsheet for subsequent analysis. All duplicate articles were discarded, and an initial analysis was carried out to define the set of publications that would be used for the investigation. Various points of interest were used to conduct and consolidate the results, such as title, year of publication, periodical, authorship, quote, keywords, objective, conceptual bases, methodological procedure, mentions of the term, among others.

3.2 Conducting Review

Applying the search procedure in the selected databases, the total number of publications was 413 articles, practically all found on the ProQuest platform, in addition to two returned on the Capes Portal. There was no occurrence in the Scielo, Scopus and Spell databases. Table 1 shows the detailed distribution according to the expressions studied and the platforms used.

Despite the 413 articles found, several cases of duplicity were identified within the platforms themselves and between variations of expressions. In this way, repeated articles were eliminated, resulting in 331 different studies.

	Search plataforms					
	Capes	Pro-quest	Scielo	Scopus	Spell	
Greenwashing Boicote	0	0	0	0	0	
Greenwashing Boycott	0	260	0	0	0	
Greenwashing Buycott	0	10	0	0	0	
Greenwash Boicote	0	1	0	0	0	Total
Greenwash Boycott	2	136	0	0		
Greenwash Buycott	0	4	0	0	0	
Sum of Categories	2	411	0	0	0	413

Table 01: Relationship between searched terms and search platforms

Source: Authors

Also at this stage, 7 articles were removed because they did not present a version in standard languages, stipulated as inclusion criteria, such as Portuguese, English and/or Spanish, as well as 13 works that did not qualify as scientific articles, defined as exclusion criteria. such as interviews, news articles, book chapters, among others, which resulted in an initial selection of 311 articles.

After that, a second check was carried out, in which the search terms were searched again, but this time directly in the body of the study text, analyzing article by article. The verification process was repeated here by a third-party researcher, ensuring the reliability of the procedure. With this, it was possible to identify several (108) articles whose mentions of one or both terms appear only in the list of bibliographic references or in explanatory notes, works that were also discarded. In this way, a final selection of 203 articles was delimited for analysis, as shown in Table 2.

Initial Search	No Duplicity	Standard Language	Scientific Article	Mention in the body of work
413	331	324	311	203

Table 02: Cleaning steps until final selection.

Source: Authors

3.3 Review Report

Regarding the date of publication, it was noted that academic interest in the themes of greenwashing and boycott is relatively recent, with the first publication occurring in 1998, maintaining a timid level in the first decade. From 2011 onwards, there was an increase in production, which became more significant after 2019, intensifying even further in 2021 and 2022. This illustrates the growing timeline of production (Figure 1), including both the recency and relevance of the subjects.

A wide diversity in the origin of production was observed, involving 115 different journals. The journals that stood out with the highest recurrence of publication

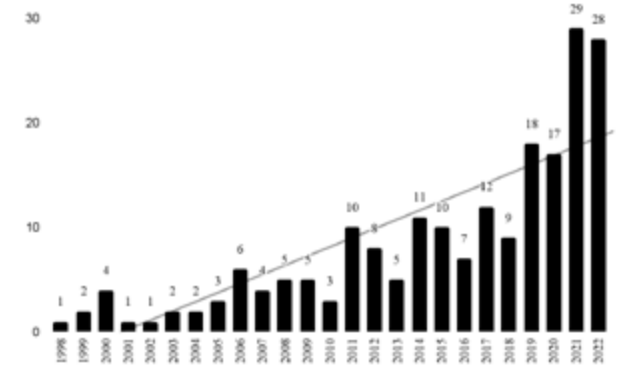

Figure 01: Production timeline.

Source: Authors

were the Journal of Business Ethics and Sustainability, with 27 articles each. It is interesting to mention that the first journal also presented greater representation in academic production related to greenwashing, in general (Andreoli, Crespo & Minciotti, 2017; Freitas Netto, Sobral, Ribeiro & Soares, 2020) and also to bluewashing (Andreoli, 2023). Also with repeated publication, but less frequently, appeared the Accounting, Auditing & Accountability Journal and the Organization & Environment, with five articles each, in addition to the Social Responsibility Journal and the Sustainability Accounting, Management and Policy Journal, both with four articles, and Business Strategy and the Environment, International Journal of Operations & Production Management and Environmental and Resource Economics, with three articles each.

Anticipating the analysis of the relevance of production, using the Qualis criteria for the 2017-2020 quadrennium, it is worth highlighting that all the journals with the highest recurrence of publication were classified in the highest strata, with the majority being A1, followed by A2. Furthermore, it is worth reflecting on the scope of the most prominent journals in the production of the topic, which aim to discuss organizational theories and practices in a more systemic way, considering possible impacts on society and the environment. This result is also aligned with the states of the arts mapped by the aforementioned authors. Furthermore, the entire production was published in the English language, demonstrating the lack of national repertoire.

In addition, 113 different journals were counted for the 203 publications, in which the relevance of production was analyzed, using the Qualis criteria for the four-year period 2017-2020. Of these, 38 journals were classified in the area of interest of this study, which is Public and Business Administration, Accounting Sciences and Tourism, in addition to another 18 classified in related areas. Thus, it is noted that 57 journals did not return classification in the last quadrennium, despite three of these being well classified (A1) in the previous quadrennium. More importantly, the high relevance of the classified journals stands out, practically all of them arranged in stratum A, with the majority being A1. These results are shown in Table 3.

There was a greater recurrence of publications with single (69) and double (65) authors, followed by triple (49) and other (20), with few repetitions of authors, the most prominent being Sarah Light, with 3 articles, followed by eleven authors with two articles each, namely: Jennifer Sumner, Darryl Reed, Cindy Isenhour, Jason F Shogren, Rajiv Maher, Brayden King, Michael Barnett, Injazz Chen

	A1	A2	A3	A4
Administration	24	13	1	0
Other areas	10	4	3	1
Without Classification	54			

Table 3: Classification of journals.

Source: Authors

and Aleksandr Kitsis (including co-authors) and Matthias Damert and Edeltraud Guenther (also co-authors). Applying Lotka's Law (Figure 2), presented in the following analysis, the low productivity of authorship in the area is evident, showing that the study is not very concentrated, with a wide variety and diversity of authorship.

Analyzing the titles of the articles, a variety of terms were recorded, with emphasis on corporate (65), social (57), response (44), sustainable (40) and environmental (36), in addition to green and CSR (23 each), and

Produção	Observado	Obs%	Esperado	Esp%
1	459	97,5%	459	73,5%
2	11	2,3%	115	18,4%
3	1	0,2%	51	8,2%
	471		**625**	

Figure 02: Lotka's Law Analysis.

Source: Authors

consumer (20), as illustrated in Figure 3. In this way, there is a clear link between the studies and the broader discussion about the social, environmental or sustainable responsibility of organizations. Furthermore, the scarce participation of terms of interest in the titles stands out, both greenwashing (6) and boycott (1), indicating a certain generality of studies, positioned in a more comprehensive way.

942 keywords were identified in the 203 selected

articles, which were subsequently analyzed according to the frequency of each component word, that is, when a keyword contained more than one element, each of them

Figure 03: Word Cloud - Title Analysis.
Source: Authors

was counted alone. For example, the term corporate social responsibility was computed as three independent words: corporate, social and responsibility. Therefore, the 942 keywords identified totaled 1,890 isolated words (Figure 4), of which the following stood out: social (99), corporate (87), response (77), sustainable (62) and environmental (53). The scarce participation of terms of interest is repeated here, both greenwashing (6) and boycott (1), again suggesting a certain generality of studies. Finally, a similarity between this analysis and the previous one can also be observed, illustrating the congruence between the titles and keywords of the articles investigated.

Furthermore, the number of citations of the articles analyzed was investigated, using the Google Scholar platform. As a result, there was a significant propagation capacity, with practically all articles having

Figure 04: Word Cloud - Keyword Analysis.
Source: Authors

some citation, which together totaled more than 22 thousand citations, returning an average of 110 citations per article. The highlight was the study 'The Impact of Corporate Sustainability on Organizational Processes and Performance', with almost three thousand citations. The Table 4 provides a summary of the most significant results, showing the articles that exceeded 500 citations.

With regard to the method used by the articles (Table 5), there was a predominance of the theoretical approach (97), which includes theoretical essays, literature reviews, bibliometric surveys, among others. In theoretical and

Article	Citation
The Impact of Corporate Sustainability on Organizational Processes and Performance	2968
Economic Perspectives on Corporate Social Responsibility	1339
Choosing the Right Green-Marketing Strategy	1312
The Maturing Of Socially Responsible Investment: A Review Of The Developing Link With Corporate Social Responsibility	1008
Green marketing strategies: an examination of stakeholders and the opportunities they present	960
Defining CSR: Problems and Solutions	777
Building Trust Between Consumers and Corporations: The Role of Consumer Perceptions of Transparency and Social Responsibility	560

Table 04: Citation – Scholar Google.
Source: Authors

empirical work, the quantitative approach (64) was highlighted, followed by the qualitative (35), and, finally, the mixed approach (7). The quantitative approach was divided between collecting primary data (40), carrying out quantitative surveys - surveys (26) and experiments (14), and secondary data, carrying out statistical analyzes (24), such as regression and modeling. A similar division was observed in the qualitative approach, with primary data collection (13), conducting interviews, and secondary data (23), conducting case studies (11) or even discourse or content analyzes (11). In this way, it was possible to verify the superiority of theoretical studies focused on the analysis

of secondary data, with studies that worked empirically using unpublished data being relatively scarce, which may suggest a certain lack of maturity in the themes.

Regarding the investigation of the mentions of terms, initially, we tried to carry out cluster analysis, in order to identify possible groupings; such an analysis was not possible, as the articles did not show good adherence to

Theoretical 97	Quantitative 64 Primary data-40 and secondary data-24	Qualitative 35 Primary data-13 and secondary data-23	Mixed 7

Table 05: Research Method.
Source: Authors

different groups. As a substitute, a crossover analysis was carried out between the mentions of both terms, as shown in Table 6. With this, it was possible to identify four general groups: (1) the largest of them, composed of articles that only mention (once or twice) both terms, without, however, delving deeper into their discussions, making interpretation possible. that they do not actually work with any of the themes; (2) on the one hand, a minority made up of articles that work with the theme of greenwashing, and only mention (once or twice) the term boycott; (3) on the other hand, another minority of works that work with the boycott theme, and only mention (once or twice) the term greenwashing; (4) and the last group, also a minority, composed of seven articles that have significant mentions (at least three) in both terms, jointly.

In line with the objective of this work, the last group was selected, as per the analysis above, identified as the one with the greatest depth in the topics of interest. Below is a detailed analysis of this section (seven articles).

*greenwashing * boycott/buycott Cross Tabulation*

Count

		Boycott / buycott													Total
		1	2	3	4	5	6	7	8	9	11	20	29	51	
Greenwashing	1	65	20	8	6	6	3	1	0	1	1	0	0	1	112
	2	24	5	1	0	2	1	1	0	0	0	1	1	0	36
	3	9	3	1	0	0	0	0	1	0	0	0	0	0	14
	4	9	3	1	1	0	0	1	0	0	0	0	0	0	15
	5	2	0	0	1	0	0	0	0	0	0	0	0	0	3
	6	2	1	0	0	0	0	0	0	0	1	0	0	0	4
	8	2	0	0	0	0	0	0	1	0	0	0	0	0	3
	9	0	1	0	1	0	0	0	0	0	0	0	0	0	2
	12	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	22	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	23	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	30	1	1	0	0	0	0	0	0	0	0	0	0	0	2
	34	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	36	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	45	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	69	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	71	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	84	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	86	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	91	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	106	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	107	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Total		120	40	11	9	8	4	3	2	1	2	1	1	1	203

Table 06: Mentions - Analysis of expressions.
Source: Authors

4. DETAILED ANALYSIS

In this topic, an in-depth analysis was carried out of the seven selected articles, which most mentioned both terms, together. It is worth highlighting the high relevance of the journals in which they were published, practically all of them being between A1 and A2, with just one exception. It is a period that also appears to be recent, between 2012 and 2022. Furthermore, a wide variety was observed in relation to the method used, with two theoretical essays, one qualitative article, three quantitative and one mixed.

The term greenwashing has been defined as selective, cosmetic, unfounded, misleading or erroneous disclosure that does not add environmental or economic value (Lyon; Maxwel, 2011). The mention of an intentional act of deceiving consumers was recurrent, whether in relation to the environmental practices of an organization, at an

institutional level, or in relation to the environmental benefits of a product, more specifically (Delmas; Burbano, 2011).

Regarding the boycott, definitions were scarcer, relating it to the movement of consumer activism or social commitment, as a form of disapproval and punishment of an organization whose behavior was unethical (Kneip, 2012; Brennan; Merkl-Davies, 2014; Gilbert; James; Shogren, 2018). In two cases, in fact, the boycott was investigated as a metric of interest. More importantly, there seems to be no consensus regarding its effectiveness: one article mentions its importance in terms of price devaluation practiced by the organization targeted by the boycott (Kitzmueller; Shimshack, 2012), but there is also mention that there are still no conclusive results in empirical studies (Poret, 2019).

Although all articles explicitly mention environmental issues, the discussions were developed around different stakeholders, from consumers and society, non-governmental organizations (NGOs), to the financial market. Different areas were also investigated, both more general, such as corporate social responsibility, and more specific, such as advertising, marketing, product labeling and the supply chain program. In the keywords, the emphasis is repeated on the terms of corporate social responsibility, in addition to marketing and advertising, as can be seen in Figure 5.

It is interesting to mention that five articles aimed to investigate the logic of reward and punishment by the market, based on stakeholders, as a result of the implementation of a more sustainable organizational

Figure 05: Word Cloud - Keyword Analysis.
Source: Authors

strategy (corporate social responsibility). The other two articles aimed to understand the effects resulting from the reactive positioning of organizations in relation to some environmental issue, as in the case of apologies. In other words, it was possible to group the articles analyzed around two main objectives: the first group focused on discussing sustainable practice, in a more general way, and the second aimed at analyzing the consequences of mitigating responses given by organizations in reaction to some repercussion. negative. Considering these similarities, the articles were grouped according to this logic, as discussed below.

4.1 Corporal Social Responsibility

Included here are five articles that discussed the effects of pressure from interested parties (stakeholders) in relation to organizations' Corporate Social Responsibility claims.: Economic Perspectives on Corporate Social Responsibility (Kitzmueller & Shimshack, 2012), Change of Mind: Marketing Social Justice to the Fashion Consumer (Heim, 2022), Corporate–NGO Partnerships through Sustainability Labeling Schemes: Motives and Risks (Poret, 2019), The impact of environmental supply chain sustainability programs on shareholder wealth (Dam & Petkova, 2014) and Authentic or cosmetic: stakeholders attribution of firms corporate social responsibility claims (Mombeuil & Zhang, 2020).

Kirzmueller and Shimshack (2012) seek to synthesize the literature on Corporate Social Responsibility, through a theoretical essay, defining it from an economic perspective, in addition to developing a taxonomy that connects different approaches. The article pointed out a consistency of empirical evidence in favor of corporate social responsibility mechanisms related to consumer markets and private and public policies. Greenwashing is only mentioned in the discussion of one article, mentioning the possibility of negative consumer perception regarding corporate social responsibility. The boycott is presented as a sufficient threat, with a more significant impact in more competitive markets. However, there is no related discussion between both themes.

Heim (2022) highlighted the objective of examining how fashion brands are experimenting with socially fair marketing strategies to transform consumer purchasing behavior (including boycott). Using a qualitative approach (with case studies of advertising campaigns), an opposite effect was observed as a result, in the sense of improving brand perception, with a consequent increase in consumption, instead of an effective change in purchasing behavior. Thus, the study brings the discussion of sustainability only in a comparative way to socially fair marketing, arguing the difference; Likewise, greenwashing appears as a counterpoint, as an unfounded appeal that can lead to market retaliation.

Also with a theoretical essay, Poret (2019) set out to examine the development of partnerships between

multinational companies and large non-governmental organizations (NGOs) for voluntary product labeling programs. As a result, it was shown that these partnerships enable the sharing of objectives, viability and visibility, in addition to the exchange of essential resources, information and legitimacy. The article highlights that empirical studies related to boycotts are inconclusive in relation to effectiveness, citing Baron (2012), adding that this happens even in cases of well-publicized protests, in which there was no significant financial impact, according to Vogel (2005). The argument is that this movement is costly in terms of consumer utility, encouraging what he calls free ride (similar to carpooling), in which the consumer does not engage in the boycott, but expects it to work. As a consequence, buycott emerged, seen as a new form of ethical or political consumption by the consumer.

Dam and Petkova (2014) aimed to investigate the influence of stakeholders, examining the possible financial implications of multinational companies' commitment to environmental supply chain sustainability programs. The authors conducted an event study followed by equation modeling, using a sample of 66 multinationals that have committed to such Carbon Disclosure Project (CDP) programs. The study found that there is generally a negative (marginally significant) share price reaction to the announcement of this participation, leaving companies even less likely to communicate this, given consumer pressure. Greenwashing is brought up as a possibility of visualization in relation to the development of additional supply chain programs, without adding environmental or economic value, on the contrary, using more resources and harming the organization's performance. The boycott is exemplified from some real cases, although not conceptualized, illustrating what happened and arguing how the companies in question became more cautious in relation to sustainable communications afterwards. There is no related discussion between both themes.

Finally, Mombeuil and Zhang (2020) also sought to investigate the role of stakeholders, both internal (employees) and external (university students and agents from non-governmental organizations), in relation to corporate social responsibility appeals from companies in the beverage industry. Adopting a mixed methodological procedure (qualitative, with analysis of organizational campaigns and carrying out two focus groups, followed by quantitative, with the application of questionnaires), a widespread perception of these actions as cosmetic was observed. This result was in line with the argument made in the theoretical framework, which discusses greenwashing based on its cosmetic appeal, which seeks to divert the attention of stakeholders from the irresponsible and unethical behavior of organizations, which intentionally makes it difficult to identify and differentiate. towards authentic practices. Despite this, there is mention of the possibility of boycott in the identified cases, seen as a potentially harmful risk of loss of reputation.

4.2 Reaction to Negative Repercussions

Two articles aimed to study the organizational reaction to the repercussions of some environmental issue, both with a quantitative approach, namely: The influence of green advertising during a corporate disaster (Bodkin, Amato & Amato, 2014) and Corporate apology for environmental damage (Gilbert, James & Shogren, 2018).

Bodkin, Amato and Amato (2014) sought to explore the influence of green propaganda and social activism during one of the worst episodes of adverse public relations in history: the British Petroleum (BP) Deep Water Horizon oil spill. The study was conducted longitudinally, over four years, with questionnaires administered to university students. As a result, consumer activism showed a difference in all four attitude scales during the time of the oil spill, in relation to advertising, the brand, the company and its environmental commitment. Furthermore, green advertising led to the best attitude towards the brand's environmental commitment, compared to advertising without environmental content, but only at a later period. Therefore, the study concludes that the lack of adequacy between communications and actual corporate social responsibility performance increases the potential for a significant consumer reaction against the organization in question. The case is analyzed as a practice of greenwashing, considering that the company in question promoted itself as sustainable, the outbreak of which resulted in a boycott by the consumer market. Thus, even though it was not conceptualized, the boycott is investigated as a response to consumer social activism, which proved to be influential in all attitudes regarding.

Gilbert and James (2018) aimed to investigate the results of public apologies for large-scale environmental disasters caused by companies, carrying out an experiment with a 3 x 3 factorial design in an oil spill scenario: total, partial or absent apologies, and the company's good, bad, or absent environmental reputation. The study highlighted the importance of both apologies and reputation, the latter being more significant. Furthermore, in the control group, the company's good reputation reduces the propensity for individual engagement in a boycott. Furthermore,

generally speaking, the authors argue that consumers want those at fault to be held accountable, but do not necessarily engage in vengeful actions unless they feel that accountability is not actually happening. Therefore, similar to the previous article, the scenario is analyzed as a practice of greenwashing, which can, in some cases, even improve organizational reputation. There is explicit mention of the term among the keywords. The boycott is investigated as a metric of interest, being one of the punitive results of the practice of greenwashing, on a personal level.

5. DISCUSSION OF RESULTS

The systematic review was guided by two research questions, which are explored below. Firstly, in relation to the current academic production on the topics of boycott and greenwashing, a relative recentness could be observed, with a significant increase in academic interest over time, especially more recently (after 2019). The study appears to be quite diverse, both in terms of publication origin (such as journals and areas of interest) and in relation to authorship. The production also proved to be scientifically relevant, especially considering the journals with the highest recurrence of publication. A consonance was verified regarding the scope of the journals in which they were published, with a more comprehensive view of organizational practices. Furthermore, the links between the texts and the themes of organizational responsibility, whether social, environmental or sustainable, are clear.

Despite this, such production does not actually seem consolidated, an argument that can be verified by considering the pattern in the methodological bias and the more generalist character. Regarding the method, there was a predominance of theoretical studies, followed by empirical articles focused on the collection and analysis of secondary data. As for the depth of discussion, there were almost all isolated and specific mentions of terms of interest in the texts, with few studies actually focused on in-depth discussion. Still, even with a more detailed analysis of these few articles that stood out in terms of mentions of both terms, the more closely linked relationship between boycott and greenwashing was practically non-existent, as was the joint deepening of both concepts. Therefore, it is argued that knowledge about the boycott movement related to the practice of greenwashing is not mature, a point that will be explored later.

Secondly, regarding the study of consumer boycott related to the practice of greenwashing, the previous discussion is reinforced, in which few contributions were identified in this regard. This is evident in both the general and detailed analysis. In the first case, for example, the mention of the terms together was not found in any of the analyzed criteria: title, keywords and objective. There appears to be a slightly greater expression of greenwashing (10 times in keywords and six times in both titles and objectives), compared to almost no mention of boycott (just once). Even in these, two articles only cited the same reference, that 77% of consumers claimed to boycott a company if they had been deceived, according to a survey by Cone Communications in 2012. It is worth noting that an article cited a more recent version of the survey, from 2015, in which this number rose to 90%. Finally, one of the studies even permeates the topic, addressing negative environmental word of mouth, but only mentioning the boycott as a possible consequence of it (Guerreira & Pacheco, 2021).

In the detailed analysis, the process of grouping the articles itself reinforces the above argument. In the first set, there was a more comprehensive discussion of the social, environmental or sustainable responsibility of organizations, with superficial mention of boycott behavior. Furthermore, there was a contradiction regarding the effectiveness of the boycott, with two studies referring to the possible reputational risks arising from it (Dam & Petkova, 2014; Mombeuil & Zhang, 2020), but another citing the ineffectiveness of some real cases (Poret, 2019). In the second set (Bodkin, Amato & Amato, 2014; Gilbert, James & Shogren, 2018), an investigation of the possible organizational reaction to the negative repercussions of some environmental issue was identified, in which the boycott theme appeared as a contextualization or even a backdrop, as a potential punitive response to misleading practices. In this way, the focus was more on the possibility of retraction by the organization, rather than on the boycott movement that could have given rise to this need.

It follows precisely from these points, with the identification of an important research gap, the suggestion for future studies. Given the lack of understanding, such suggestions are diverse. In general, a more comprehensive understanding of movements to boycott the organizational practice of greenwashing is necessary, both in terms of operating mechanism and in relation to effectiveness. In the first point, points are listed such as knowledge of the consumer's motivations for joining and remaining, the capacity for dissemination and engagement of these actions,

the critical factors that differentiate actions with different levels of adherence, among others. In relation to effectiveness, the aim is to map the potential and real damages caused to organizations, as well as monitoring the reactions derived from the initial movement, both on the part of the target organization and the consumer market. It is worth highlighting that such investigations are relevant whether related to real cases, with the elaboration of case studies, conducting interviews or the application of questionnaires, or simulated ones, with the development of experiments.

6. FINAL CONSIDERATIONS

The article aimed to evaluate academic production regarding greenwashing and the consumer boycott movement. With this, it was possible to evaluate the current state of the art on the subjects, consolidating what has been studied so far, in addition to making it possible to suggest future studies to advance the topic in academia and in practice. More specifically, the systematic review was guided by two research questions: how is the current academic production on the topics of boycott and greenwashing characterized, and how does the relevant literature study consumer boycott relate to the practice of greenwashing?

After applying the search procedure, considering the inclusion and exclusion criteria, 203 articles were selected. The results showed that academic production is relatively recent, but with growing academic interest, given the significant increase after 2011, with a greater peak between 2021 and 2022. Furthermore, it is scientifically relevant, with half of the articles published in high-impact journals, mainly in the areas of Public and Business Administration, Accounting and Tourism. The recurrence of periodicals that have as their scope a more comprehensive discussion of organizational performance, considering possible impacts on society and the environment, also emerged. A similar result was found in the analysis of keywords and article titles, revealing a strong association with terms such as corporate social responsibility, sustainability and environment.

Despite this, it can be argued that production is not consolidated, with the majority of studies being merely theoretical, followed by the collection and analysis of secondary data. More importantly, when the mentions of the two terms were investigated, it was possible to identify four general groups: (1) the largest of them, composed of articles that only mention (once or twice) both terms, without, however, delving deeper into their discussions, making it possible to interpret that they do not actually work with any of the themes; (2) on the one hand, a minority made up of articles that work with the theme of greenwashing, and only mention (once or twice) the term boycott; (3) on the other hand, another minority of works that work with the boycott theme, and only mention (once or twice) the term greenwashing; (4) and the last group, also a minority, composed of seven articles that have significant mentions (at least three) in both terms, jointly.

Focusing on this last group, which is of special interest to this work, the production appears even more recent and relevant, organized around two main objectives. The first objective focused on discussing sustainable practice, more generally, studying how organizations approach corporate social responsibility under pressure from stakeholders and how these practices can be perceived as greenwashing. The relationship between boycott and sustainability was addressed, with some research questioning its effectiveness. The second objective was aimed at analyzing the consequences of mitigating responses given by organizations in reaction to some negative repercussion, examining how societies react to negative impacts, such as environmental disasters. Analysis revealed that public apologies and company reputation play an important role in public reactions and impacts on consumer behavior, including boycotts.

In summary, this systematic literature review contributes by identifying an important research gap, with several suggestions for future studies. In general, a more comprehensive understanding of movements to boycott the organizational practice of greenwashing is necessary, both in terms of operating mechanism and in relation to effectiveness.

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AUTHORS

ORCID: 0000-0002-9173-9294
TAÍS PASQUOTTO ANDREOLI, Doutora | Administração (USCS) | Pós-doutorado em Comunicação (USP) Universidade Federal de São Paulo (UNIFESP) | Curso de Administração | Osasco, SP, Brasil | Correspondência para R. Oleska

Winogradow, 100 - Jardim das Flores, Osasco - SP, 06120-042 | tais.andreoli@unifesp.br

ORCID: 0000-0003-2282-0678
PATRÍCIA CARDOSO SILVA, Graduanda em Administração (UNIFESP) Universidade Federal de São Paulo (UNIFESP) | Curso de Administração | Osasco, SP, Brasil | Correspondência para R. Oleska Winogradow, 100 - Jardim das Flores, Osasco - SP, 06120-042 | patricia.cardoso@unifesp.br

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CHARACTERIZATION AND PROCESSING, BY MECHANICAL PROCESSING, OF PRINTED CIRCUIT BOARDS OF POST-CONSUMER SMARTPHONES

CARACTERIZAÇÃO E PROCESSAMENTO, POR PROCESSAMENTO MECÂNICO, DE PLACAS DE CIRCUITO IMPRESSO DE SMARTPHONES PÓS-CONSUMO

CARACTERIZACIÓN Y PROCESAMIENTO, MEDIANTE PROCESAMIENTO MECÁNICO, DE PLACAS DE CIRCUITO IMPRESO PARA SMARTPHONES POST-CONSUMO

TAMIRES AUGUSTIN DA SILVEIRA, Msc. | UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil
EMANUELE CAROLINE ARAUJO ESCHTILER, Msc.| UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil
KATIA ELIZANGELA OCANHA DORNELES | UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil
ANGÉLI VIVIANI COLLING, Dra.| UFRGS – Universidade Federal do Rio Grande do Sul, Brasil
CARLOS ALBERTO MENDES MORAES, Dr.| UNISINOS – Universidade do Vale do Rio dos Sinos, Brasil

ABSTRACT
Smartphones are electronic devices increasingly used by Brazilian society in recent years. With the advancement of technology, the consequence is an increase in the disposal of this equipment in a shorter period of time. On the other hand, there are elements such as copper, gold and others can be recycled. Thus, the aim of the study was to employ mechanical processing techniques on smartphone printed circuit boards (PCB) in order to concentrate metals, especially copper, and identify the main elements concentrated in each process. For this purpose, 87 smartphones were collected and disassembled, after a mass balance, the PCB were comminuted and separated into 4 particle size ranges. Through chemical characterization, it is possible to verify a variation in the composition, according to the granulometry. With magnetic separation, iron contents of 9% to 34% were obtained, increasing the concentration proportionally to the increase in granulometry. The non-magnetic fraction went through the electrostatic separation process, in which conductive fractions of up to 52% copper were generated. It can be concluded that mechanical processing techniques are efficient for concentration of metals and alloys, especially copper, and, therefore, can bring economic and environmental benefits.

KEYWORDS
Smartphones; Characterization; Electronic waste; Urban mining.

RESUMO
Os aparelhos smartphones são os eletroeletrônicos cada vez mais utilizados pelos brasileiros nos últimos anos. Com o avanço da tecnologia têm-se como consequência o crescimento no descarte destes equipamentos em um menor intervalo de tempo. Por outro lado, há elementos como cobre, ouro, entre outros possíveis de serem recuperados. Assim, o objetivo do trabalho foi empregar técnicas de processamento mecânico, em placas de circuito impresso (PCI) de smartphones, a fim de concentrar metais de interesse, especialmente o cobre, e identificar os principais elementos concentrados em cada processo. Para isso, 87 smartphones foram coletados e desmontados, após um balanço de massa, as PCI foram fragmentadas e separadas em 4 faixas de tamanho de partícula. Através da caracterização

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química, foi possível verificar uma variação na composição, de acordo com a granulometria. Com a separação magnética, obteve-se teores de ferro de 9% a 34%, aumentando a concentração proporcionalmente ao aumento da granulometria. A fração não magnética passou pelo processo de separação eletrostática, no qual foram geradas frações condutoras de até 52% de cobre. Pode-se concluir que as técnicas de processamento mecânico são eficientes para a concentração de metais e ligas, especialmente o cobre, e, portanto, podem trazer benefícios econômicos e ambientais.

PALAVRAS-CHAVE

Smartphones; Caracterização; Resíduos eletroeletrônicos; Mineração urbana.

RESUMEN

Los smartphones son los dispositivos electrónicos cada vez más utilizados por los brasileños en los últimos años. Con el avance de la tecnología, la consecuencia es un aumento en la eliminación de estos equipos en un menor período de tiempo. Sin embargo, existen elementos como el cobre, oro, entre otros que se pueden recuperar. Así pues, el objetivo del trabajo fue emplear técnicas de procesamiento mecánico en placas de circuito impreso (PCI) de smartphones con el fin de concentrar metales de interés, especialmente cobre, e identificar los principales elementos concentrados en cada proceso. Para ello se recolectaron y desmontaron 87 smartphones, luego de un balance de masa, los PCB fueron fragmentados y separados en 4 rangos de tamaño de partículas. A través de la caracterización química se pudo verificar una variación en la composición, según granulometría. Con la separación magnética se obtuvieron contenidos de hierro del 9% al 34%, aumentando la concentración proporcionalmente al aumento de la granulometría. La fracción no magnética pasó por el proceso de separación electrostática, en el que se generaron fracciones conductoras de hasta un 52% de cobre. Se puede concluir que las técnicas de procesamiento mecánico son eficientes para la concentración de metales y aleaciones, especialmente cobre, y, por tanto, pueden traer beneficios económicos y ambientales.

PALABRAS CLAVE

1. INTRODUCTION

The smartphone industry has been growing constantly, including the consumer market, development of new models, and suppliers. (Laricchia, 2024a). In 2022, smartphone sales reached 1.39 billion units all the word and must reach 1.34 billion units sold in 2023 (Laricchia, 2023b).

Consequently, this portion of post-consumer equipment significantly adds to the amount of electronic waste (WEEE) being produced and has the potential to cause negative impacts on the availability of natural resources, on human health, and on the environment, because, just like other WEEE, smartphones contain toxic, rare, and precious materials (Mejame et al., 2016; Bookhagen et al., 2020; Kastanaki; Giannis, 2022).

In order to meet requirements for size, lightness, and functionality, a smartphone can use up to 50 different types of metals, which can range from basic ones such as copper and tin, up to precious metals such as silver, gold, and palladium (United Nations Environment Programme (UNEP), 2009). Many of these metals are considered critical, present industrial and technological importance, as well as supply risk (Işildar et al., 2019; European Commission, 2020; Kastanaki; Giannis, 2022).

Mobile phones and smartphones are packed with high-tech minerals, which are strategically important for emerging Chinese industries, such as cobalt, palladium, antimony, beryllium, neodymium, praseodymium, and platinum (He, 2020).

In general, a cell phone device can be divided into larger parts: printed circuit board (PCB), a display unit (screen), a battery, and a box/cover; in addition, antenna and accessories such as headphones, for example, are also included (Internacional Precious Metals Institute (IPMI), 2003; Gu; Summers; Hall, 2019).

Box 01 presents a review of the materials used in the main parts of a smartphone. According to the table, the diversity of critical metals that are used in a single smartphone can be seen, as well as how each metal is important due to its properties, and, consequently, assigns important functions to the equipment.

Part/ component	Elements
Electronics	Gallium, nickel, and tantalum, which are used in connections and various devices; silicon dioxide doped with phosphorus, antimony, arsenic, boron, indium, or gallium are used to produce the chips. Copper, gold, and silver make up the microelectronics and wiring. For welds that previously used tin and lead, these were replaced by mixtures of tin, silver, and gold after the 2003 RoHs.
Screen	They can be divided into three parts: - **A glass cover:** basically composed of aluminosilicate and may contain potassium ions to strengthen it. **- A capacitive layer (touchscreen)**: in which a thin, transparent, and conductive layer of mixed indium and tin oxides is used to produce the touch sensitivity property. In addition, silver, gold, and palladium can also be found. - **A screen:** in order to produce the colors of the screen, a varied composition of rare-earth elements is used, such as yttrium, lanthanum, terbium, praseodymium, europium, dysprosium, and gadolinium.
Microphones and speakers	Nickel is used in the diaphragms of the microphones; in addition, in these components there are usually magnets produced from neodymium-iron-boron alloys (NdFeB), and, in some cases, dysprosium, praseodymium, or gadolinium can be used in these alloys. These metals, in addition to terbium, can also be used in vibration units.
Cover	Covers can be produced from metal or polymers or a mixture of the two. The most commonly used polymers are ABS or PC/ABS; when made of metal, however, magnesium alloys are usually used, but aluminum, copper, and iron/steel alloys can also be used. In addition, brominated flame retardants can be found, although they have been minimized.
Battery	Nowadays, batteries have been made mostly of lithium ions. They consist of an aluminum housing, inside of which are a positive electrode, usually made of lithium-cobalt oxide, a negative electrode, which is usually graphite, and an organic solvent that acts as an electrolytic fluid.

Box 01: Composition of the main parts of a smartphone

Source: Brunning (2014); Cordella, Alfieri and Sanfelix Forner (2020); Venditti (2021); Konyalioğlu and Bereketli (2021); Santos (2016)

The technological advancement of this equipment is directly related to the increased use of metals, some of which are precious, increasing the economic potential of recycling this equipment (Gu; Summers; Hall, 2019).

According to Holgersson et al. (2018), the mass composition of smartphones is 20% printed circuit board (PCB), 33% polymer and metal casing, 26% screen, 13% battery, among others.

The main technologies used for recycling printed circuit boards involve physical, chemical, thermal and mechanical processes, often combining more than one process (Oliveira, 2012).

Disassembly is the first and most important process among all recycling processes, which is carried out mainly manually, valuing existing materials and concentrating metals (Knoth et al., 2002; Gouveia; Ferron; Kuno, 2014; Moraes; Espinosa; Lucena; 2014; Silveira; Santos; Moraes, 2019; Santos et al., 2022). The process of disassembling printed circuit boards can be classified into two different categories: selective and simultaneous disassembly. In selective disassembly, the board components are removed individually and simultaneously, all components are removed at the same time, being subsequently sorted (Layiding et al., 2005; Oliveira, 2012).

Subsequently, there is mechanical processing or physical processing, which is considered a pre-treatment with the objective of previously separating metals, polymers and ceramics, through the steps of comminution, classification (granulometric) and separation by different methods (Gerbase; Oleiveira, 2012). For the mechanical treatment of printed circuit boards, the steps involved can be grinding, particle size classification, magnetic separation, electrostatic separation, separation in a dense medium, among others (Moraes, 2011).

After this stage, there is the metal recovery process, which can be the hydrometallurgical and pyrometallurgical stages (Oliveira, 2012).

Although there are studies that grind entire devices for subsequent recycling of materials, the tendency towards the complete recycling of mobile phones and smartphones is the disassembly and separation by parts, each being treated by appropriate techniques (Bachér; Mrotzek; Wahlström, 2015; Gu; Summers; Hall, 2019; Flerus et al., 2019). Disassembly is one of the most important stages throughout the life cycle of electronic waste (Liu et al., 2022).

Having a disassembly step is very important for this type of waste, since each part presents value-added materials, which are easier to recover with disassembly (Santos et al., 2022). With this step, it is possible to better concentrate the metals of interest, considering that recovery techniques or parameters can vary according to the material, thus, it is possible to recycle the maximum of materials, including polymers (Santos et al., 2022). Manual disassembly is still widely used, as there are still challenges regarding automated disassembly of these devices (Gu; Summers; Hall, 2019).

Gold, silver, and copper are the most interesting metals of these devices, however, there are some studies that have been focusing on other metals, such as gallium, indium, germanium, nickel, palladium, strontium, among others (Gu; Summers; Hall, 2019; Flerus et al., 2019; Panda et al., 2020; Flerus; Friedrich, 2020; Silveira et al., 2020; Pourhossein et al., 2021).

Thus, the aim of this work was to employ mechanical processing techniques in order to concentrate metals of interest, especially copper, and identify the main elements concentrated in each process.

2. EXPERIMENTAL

This work can be divided into 2 stages. The first consisted of the collection, cataloging, disassembly, and mass balance of the equipment, while the second focused on the mechanical processing of printed circuit boards and chemical characterization.

2.1 Collection, Cataloging, Disassembly, and Mass Balance of the Equipment

Through campaigns carried out at UNISINOS by the Environmental Management System (EMS), as well as through personal donations in the years 2017 and 2018, 87 smartphone units were collected, with a total mass of 10kg. The cell phones were disassembled, weighed, and cataloged according to the disassembly order, registering the brand/manufacturer, color, model, and total mass of the device. Tools were also used to disassemble the cell phones (Philips screwdrivers and hex keys of different sizes). For mass balance, the intact cell phones and their parts were weighed in a BEL Engineering semi-analytical balance.

The devices were separated into printed circuit board, display, battery, housing, and others (parts that did not fall into any of the previous categories).

2.2 Physical processing of printed circuit boards

The next stages of the work were carried out only with the PCBs, while the other parts were stored for future

studies. After weighing and separation, the printed circuit boards were comminuted whole in a cutter mill, model MGHS 2700, totaling approximately 1.5 kg of material.

The comminuted material went through two sieving phases. In a first moment, we used the classification methodology of the particle size according to the norm of Study Committee of Raw Materials (CEMP) 081 of the Brazilian Foundry Association (ABIFA) (2015), shaking for 30 minutes, using sieves with standardized openings - set of sieves with stainless steel frame 8" x 2" and Bertel shaker: sieves with the following openings: 3.35 mm; 2mm; 1.70mm; 1.0mm; 0.85mm; 0.60mm; 0.50mm; 0.425mm; 0.30mm; 0.21mm; 0.15mm; 0.106mm; 0.075mm; 0.053mm.

Then, the ground PCBs went through a second sieving, shaking for 15 minutes, after which the fractions presented in Box 2 were obtained.

The four fractions obtained were sent to a high intensity magnetic roller separator installed in the Laboratory of Corrosion, Protection, and Recycling of Materials (LACOR), from the Department of Materials

Fraction	Particle size
F1	Smaller than 0.5 mm (F1<0.5 mm)
F2	Between 0.5 and 1 mm (0.5 mm<F2<1mm)
F3	Between 1 and 2 mm (1mm <F3< 2mm)
F4	Greater than 2 mm (F4>2mm)

Box 02: Fractions obtained in the second sieving.
Source: Authors.

Engineering in the Federal University of Rio Grande do Sul (UFRGS). The equipment was operated using a magnetic field of 1300 Gauss, with a roller rotation of 80 rpm45. The rotation was determined visually, so that there was no overlap of particles. The feeding was performed manually and subsequently calculated at 67 g/min. In this step, it is possible to separate the materials into magnetic (MAG) and non-magnetic (NMAG).

The non-magnetic material fractions were subsequently subjected to electrostatic separation. In this work, an INBRAS electrostatic separator, model ESP-14/01S, was used in the Corrosion, Protection, and Recycling Laboratory (LACOR) of the Department of Materials Engineering of UFRGS. The equipment was regulated at 30 kV voltage and roller rotation of 50 rpm. In order to reduce the humidity of the air, which was of 44% at the time of operation, a dehumidifier was attached to the separator. From this process, three different outputs of materials were obtained: a conductive (CON), an intermediate or mixed (material conducts momentarily) (INT) and a non-conductive (NCON).

2.3 Chemical characterization

Chemical analyzes were carried out at different moments of the process. The first was carried out after grinding and separating the circuit boards into different particle sizes, with the aim of identifying the metals present in the raw PCBs, that is, before the magnetic and electrostatic separations.

The second sequence of chemical analyzes was carried out after the magnetic separation process and the third occurred after the electrostatic separation process. In both, metals from the magnetic and non-magnetic, and conductive and non-conductive fractions were identified and quantified.

For the characterization of the materials, PANanalytical X-ray Fluorescence Spectrometer (XRF) by Dispersive Energy were used.

3. RESULTS AND DISCUSSION

The results found in the study will be presented and explained next.

3.1 Collection, Cataloging, Disassembly, and Mass Balance of the Equipment

87 smartphone devices were disassembled and identified, whose release years ranged from 2009 to 2015, belonging to 11 different manufacturers: Apple, Asus, Booster, LG, Motorola, Nokia, Positivo, Samsung, Sony, Wei, and ZTC. The total mass of the devices was 10 kg. From the initial characterization, it was possible to identify that the housing is the part with the highest mass (31%), followed by the display (30%), battery (20%), PCB (16%), and others (3%).

The higher mass of the housing occurs due to the fact that, in many mobile phones, it is made of polycarbonate (PC), or acrylonitrile butadiene styrene (ABS), or a blend of both, as well as a heavier internal housing, made of metallic or composite material. The value found by Holgersson et al. (2018) when quantifying the whole housing (plastic exterior plus interior) of smartphones was 33%, very close to the one found in this work.

Singh et al. (2018) separated the plastic housing from the metal one. The plastic one presented an average of 35.6% of the total mass of smartphones, while the metal one presented 27.72%, totaling 63.32% of the

mass of smartphones in housings. However, the authors considered screws and other metal parts in the sum of the metal housing. Figure 1 shows the parts of the disassembled smartphones, in this work, and highlights the polymer and metal housings.

The displays of the devices also showed a high mass (30%). This result was already expected, as smartphones have touch displays with large dimensions. In addition, with the advancement of technology, there have been wider screen sizes than the ones from the previous generation cell phones. The same behavior was observed by Dorneles et al. (2016) when characterizing the devices

Figure 2: Outer housing parts (in red) with an inner housing part (yellow).
Source: Authors.

of two generations (feature phones and smartphones), in which smartphone displays are equivalent to 18% of the mass of the cell phone, against 8% in conventional devices. Singh et al. (2018), when doing this same analysis, found screens of 9.13% and 14.79% of the mass of conventional cell phones and smartphones, respectively.

The printed circuit boards make up 16% of a smartphone and had an average mass of 18 g. The PCBs vary in size according to manufacturer and model. There is no standard size even between devices of the same manufacturer. In total, the studied PCBs corresponded to 1.50 kg of the 10 kg of cell phones. This means that for every 10 kg of smartphone waste, approximately 1.50 kg is of electronic circuits with metals that are available for recovery and insertion back into the production chain.

3.2 Physical processing of printed circuit boards

The printed circuit boards subjected to grinding suffered a 9% loss in the process. According to Tuncuk et al. (2012), losses between 10% and 30% may occur due to an insufficient release of metals during the comminution process. Silvas (2014) reports that, during grinding, the segregation of fine and light particles such as fiberglass can occur; these particles are expelled.

According to Andrade et al. (2022), grinding is one of the most widely used pretreatment processes in WEEE recycling. It can improve both their recycling as well as precious material recovery rates.

Many researches involving metal recovery in PCBs of mobile phones and smartphones perform a grinding step as a pretreatment, employing various techniques and obtaining various particle sizes (Jeon et al., 2018; Hossain et al., 2018; Díaz-Martínez et al., 2019; Liu et al., 2020; Wang et al., 2021a).

After comminution in the cutter mill, the particle size of the printed circuit boards was identified through the particle size distribution, in which there was a large variation. However, the largest amounts of material were concentrated in the particle sizes between 3.35 and 1.7 mm (44%) and between 1.7 mm and 0.85 mm (39%), as shown in Figure 2.

This variation occurred because PCBs are composed of materials that have different hardnesses. The particle sizes of 1.7 mm and 0.85 mm – 83% of the grinded PCBs – presented, predominantly, parts with copper tracks and other metals adhered to the glass fiber. In smaller particle sizes – from 0.6 mm – it was possible to visually some free metals, such as iron.

Subsequently, the separation of the material into the three particle sizes studied confirmed that the highest amounts of PCBs are concentrated in fractions of higher

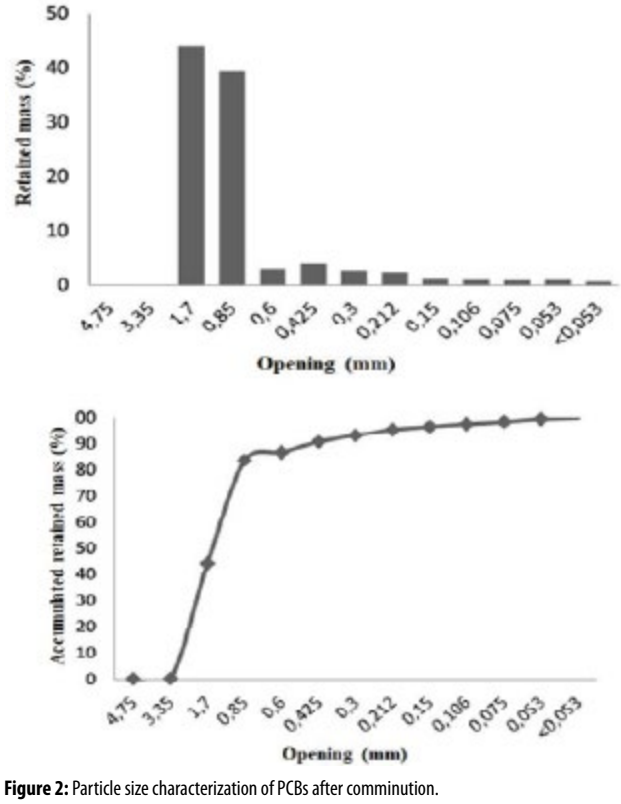

Figure 2: Particle size characterization of PCBs after comminution.
Source: Authors.

particle size, in a directly proportional relationship. That is, the higher the particle size, the greater the amount of PCBs retained. Most of the comminuted material (43%) was concentrated in the particle size above 2 mm (F4). The rest was retained in other sizes, being: F3 (33%), F2 (14%) and F1 (10%).

Moraes (2011) also verified that, after grinding, the PCBs from mobile phones have the tendency to accumulate in larger particle sizes. Copper and iron, for example, because they are ductile metals, are more difficult to grind than polymers. Therefore, they require a longer grinding time to achieve the same particle size of plastics, which are released more easily and in less time. Jesus and Casqueira (2015) state that "PCBs are materials that are difficult to grind, due to their high metallic content, which makes it difficult to obtain greater quantities of metals in the smallest fractions", this conclusion of the authors corroborates with the behavior obtained in particle size classification in the present work.

3.3 Chemical characterization

The samples before the separation processes (magnetic and electrostatic), called raw samples, which only underwent comminution and particle size separation, were chemically characterized by detecting the presence of many elements. In Figure 3 it is possible to verify the presence of 35% copper, 11% silicon, 5% aluminum, 3% iron, 3% nickel and 3% tin.

As expected, copper was the element found in the greatest quantity. This is the main metal used in the manufacture of PCBs. Its presence is mainly associated with the conductive tracks of the boards, connection pins, and also its presence in some electronic devices (Oliveira, 2012; Magalini; Kuehr; Baldé, 2015).

The presence of silicon and aluminum is related to the PCB armor. In addition to the glass fiber that is used to reinforce the board, silica and aluminum hydroxide are the main materials used to provide thermal expansion of the material. Aluminum is also used in some electronic devices as capacitors. The ceramic materials of PCBs are

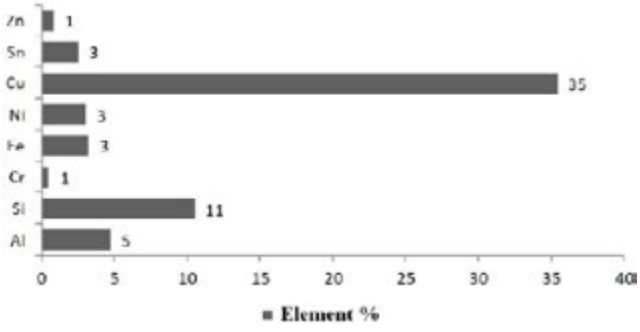

Figure 3: Elemental (average) analysis of gross printed circuit boards.
Source: Authors.

mainly represented by alumina and silica (Sanapala et al., 2009; Oliveira, 2012).

Iron is employed in some magnetic components and in PCBs links to the outside. Zinc is mainly found in resistors and also in Sn-Zn welds. Chromium and nickel are applied in metal alloys of electronic components, such as wires and conductive films of resistors. Nickel also has antioxidant function in circuits. Gold, despite having only an indication of its presence in the PCBs studied (< 1%), for its good electrical conductivity and solubility in tin welds, as well as its malleable and ductile nature, is used in the coatings of microchip connection pins and integrated circuits (Oliveira, 2012; Magalini; Kuehr; Baldé, 2015; Ribeiro, 2017).

As for rare-earth elements, the technique indicated the presence of Europium (Eu) as a trace element, in concentrations also below 1%. Rare-earth are used in the manufacture of PCBs electronic devices because they have the characteristic of, when added to a semiconductor, changing its electrical properties (Oliveira, 2012; Magalini; Kuehr; Baldé, 2015; Ayres; Peiró, 2013; Loureiro, 2013).

Tin and lead (currently prohibited in Europe by the RoHS directive) are used in the weld to fix the devices onto the plate substrate. However, a small amount of lead (1%) was identified in one of the fractions characterized (F3).

Comparing the characterization of the PCBs of the electronics from this study with others, the amount of copper is similar to that found by Yamane et al. (2011) and Holgersson et al. (2018) when chemically characterizing the PCBs of cell phones, presenting a low percentage variation among themselves when analyzing only the results of these authors. In all studies the major element was copper, as expected.

Wang et al. (2021b) analyzed, via ICP-OES, six points of PCBs of mobile phones (not specifying whether they were smartphones or not) that had a gold plating and, even so, for all points copper was the main metal.

Table 01 presents the concentration of the main metals in printed circuit boards obtained and comparison with other authors.

As can be seen, there is a difference in the concentration of other elements (iron, mainly) found by different studies. The PCBs of the cell phones studied by Holgersson et al. (2018) contained 34.27% copper, while those characterized by Bachér, Mrotzek, Wahlström (2015) had 21%. This difference was more significant for this element and for aluminum. For the other elements, the difference did not vary more than 1.5%. The variation of the concentration of the quantified metals may occur due to the different techniques used in the quantification (ICP-OES, ICP-MS, XRF, etc.), as well as the different types of devices (conventional cell phone, smartphone), manufacturing year, and PCB models (conventional cell phone, smartphone) (Hamerski, 2018).

Figure 4 shows the concentration of the main elements in raw PCBs with different particle size ranges.

The analysis by particle size fraction indicated that most of the elements are present in all particle size fractions, varying only their content. Aluminum varied between 6% and 4%, decreasing its concentration as the particle size increased. The same behavior was seen in silicon (18-8%), iron (6-1%), and tin (5-0.5%). Copper was the only element that remained predominant in all particle size ranges, having its lowest concentration in F1 (24%) and reaching the range of 40% in the other particle sizes studied (F2, F3 and F4.). Because it is ductile, copper is harder to grind than silicon and aluminum, for example. Due to this property, the amount in finer particle size ranges is smaller.

The copper concentration presented a directly proportional relation to the particle size, as 24% of Cu was identified in F1, with it remaining in the range of 39% in the largest particle sizes (F2, F3 and F4). It can be seen that, as the particle size of the PCB fraction increases, the amount of the element also increases. This is because copper is mainly used on the surface of the PCB as conductive tracks, making it difficult for it to be released. In larger particle sizes, copper is not free, but adheres to the tangles of fiberglass and resin, making it more difficult to separate due to its ductility (Oliveira, 2012; Silvas, 2014).

Economically important elements such as nickel and gold were more concentrated in the intermediate fractions – Ni with a content of 5% in F2 and <1% Au in F3, the only particle size in which the presence of gold was indicated. Aluminum had its highest concentration in the fraction with the smallest particle size, as well as in the PCBs of computers studied by Ribeiro (2013), who reports that this is probably "due to the fact that aluminum is in the form of oxide (alumina), a hard and fragile compound". According to the author, ceramic materials are pulverized, being concentrated on the smallest particle sizes. It should be noted that aluminum is also present in electronic devices as capacitors (Oliveira, 2012; Magalini; Kuehr; Baldé, 2015).

The contents of most metallic elements are generally lower in the finer fractions, according to Oliveira (2012), because scrap metals are hardly pulverized in grinding, as they have higher mechanical strength than the polymeric material. However, observing the PCBs before the magnetic and electrostatic separation processes, several quantified elements showed their highest concentration in the smallest particle size studied (Al – 6%, Si – 18%, Fe – 6%, and Sn – 5%), indicating that the cutter mill grinding was able to release these metals and/or their alloys or compounds.

3.4 Magnetic and electrostatic separation

It was observed that 68% of the PCB of the devices are constituted by a fraction of non-magnetic material, while 29% of it are magnetic. This result was already expected, since the most abundant metal found in PCB is copper, considered a non-magnetic conductor. Checking the mass balance at the outlet of the electrostatic separation, it was proved that the conductive material (72%) predominates over the non-conductive (23%) and intermediate (5%). The same trend was observed by Yamane et al. (2011) when processing computers and cell phones; the authors

Author	PCB Origin	Analytical technique	Metal (%)						
			Fe	Al	Cu	Sn	Pb	Zn	Ni
Moraes (2011)	Cell phone	ICP-OES	12.49	0.26	35.5	3.39	1.87	5.92	3.41
Yamane *et al.* (2011)	Cell phone	ICP-OES	10.57	0.26	34.49	3.39	1.87	5.92	2.63
Bizzo *et al.* (2014)	Cell phone	-	3.08	ND	14.2	4.79	2.5	0.18	0.41
Bachér, Mrotzek, Wahlström (2015)	Cell phone	XRF	1.5	4.8	21	2.4	0.42	0.49	1.6
Holgersson *et al.* (2018)	Cell phone	ICP-MS	0.68	1.9	34.27	1.93	0.37	0.55	1.16
	Smartphone	ICP-MS	0.88	1.78	39.5	3.22	0.03	0.67	1.54
Park and Kim (2019)	Mobile phone	ICP-OES	0.50	ND	47.90	2.00	ND	ND	0.8
Wang *et al.* (2021)	Mobile phone	ICP-OES	1.4	1.9	29.7	0.2	0.6	0.8	1.3
This study	Smartphone	XRF	3	5	35	3	0	1	3

Table 1: Concentration of the main metals obtained in printed circuit boards and comparison with other authors.
Source: Authors.

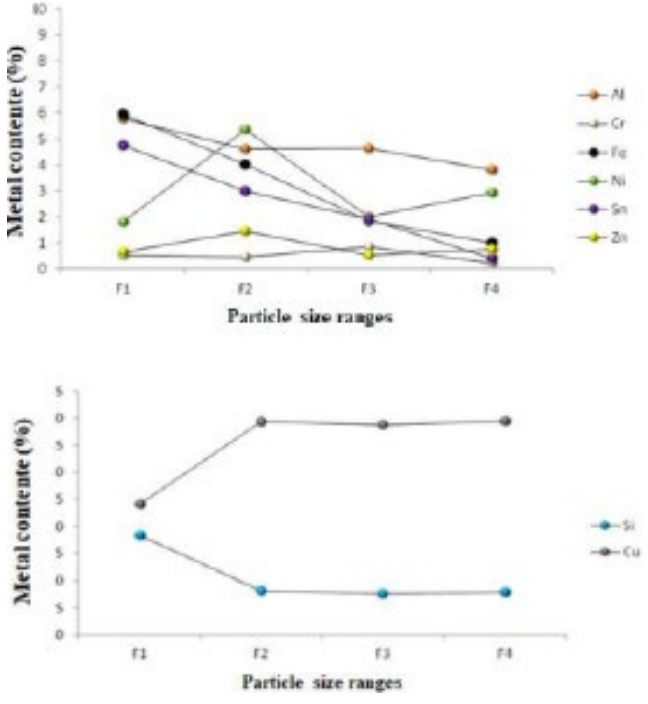

Figure 4: Concentration of the main elements in the gross PCBs with different particle size ranges
Source: Authors.

obtained non-magnetic material in greater quantity and, after an electrostatic separation, predominantly conductive material. For conventional cell phones, the author obtained 82% of non-magnetic material. The amount of conductive material, on the other hand, was lower (50%) than the one found in this study.

Figure 5 shows the amount of magnetic and non-magnetic material according to the granulometric range.

Thus, it is noted that, except in F1, non-magnetic material predominates over the magnetic one in all other fractions. That is, it is already inferred, from only the mass balance, that copper (non-magnetic element) is in greater quantity than iron and nickel, being concentrated mainly in the fractions F2, F3, and F4 than in the studied fraction of finer particle size. This is confirmed by the chemical analysis presented previously, in which copper, in the gross PCB analysis, had its lowest concentration in F1, with 24%.

Thus, it was already possible to identify, in the magnetic portion, the predominance of iron in all fractions analyzed. Although, in the F4 (>2 mm), only 29% of magnetic material

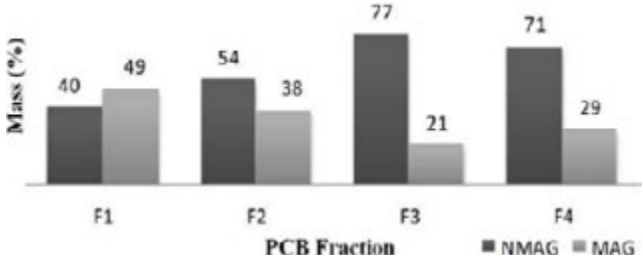

Figure 5: Portion of magnetic and non-magnetic material by PCB fraction
Source: Authors.

was obtained, this was the particle size in which the release of this element was most easily noticed. In the non-magnetic portion, free copper was observed in fractions from lower to higher particle size, as well as polymers.

3.5 Chemical characterization

The results obtained from the quantitative chemical analysis by X-ray Fluorescence after the magnetic and electrostatic separations are presented in Table 02 in

Appendix A and below is a discussion of these results.

In all samples, the concentration of copper is the most noticeable, except in the magnetic fraction of larger particle size (F4), in which the iron content is higher than that of copper. In F1 (<0.50 mm), the copper content reached 52% in the conductive portion, decreasing to 49%, 44%, and 40% as the particle size increases.

Analyzing the concentration of iron and nickel after magnetic separation, which aims precisely to separate these two metals from the rest, it is observed that the process allowed the concentration, in the magnetic fraction, of 9-34% of iron, 0-1.5% in the conductive fraction, and 0-0.5% in the non-conductive fraction. As for nickel, its highest contents were also concentrated in the magnetic portion when comparing the conductive and non-conductive ones. However, the amount of this element is much lower than that of iron, with contents between 3 and 11%.

Regarding the electrostatic separation, whose main objective is to concentrate copper, a content of 40-52% of the element was found in the conductive fractions. The portions of non-conductive material, however, also presented a considerable content of this element (22-37%). This means that the electrostatic separation process was not as effective, with high amounts of copper remaining in the portion of non-conductive material.

The presence of metals such as chromium (used in the manufacture of electronic components) and lead (used in welding, the most toxic of the elements and accumulative) was found. Lead-based welds are used for fixing electronic components in PCBs, and the tin-lead alloy is the most used one; this is due to its characteristics that give a good finish to the product, such as the degree of wetting (Almeida et al., 2013), low melting point, low cost, among other properties (Wehbie; Semetey, 2022).

According to Silvas (2014), the composition is still influenced by technology, since in more recently manufactured devices there is a tendency to replace the Sn/Pb alloy, used in older devices, with alloys containing Sn/Ag. and Sn/Bi, as well as other materials that have been replaced, such as Hg, Cd, Cr VI and flame retardants (polybrominated biphenyl-PBB and polybrominated diphenyl ether-PBDE).

This replacement is a consequence of Directive 2011/65/EU called Restriction of the use of certain hazardous substances (RoHS), which determines the restriction on the use of dangerous substances, such as lead, in electrical and electronic equipment (European Union, 2011; European Union, 2012; Silvas, 2014; Cheng; Huang; Pecht, 2017).

The results obtained from the PCB fractions after magnetic separation can be seen in Figure 6.

A high amount of iron is observed, which increases as the particle size of the material increases, as follows: 9%, 10%, 15% and 34%. According to Santana et al. (2013), in cell phones, iron is used in supports, shields, and screws, which is why the element is generally free, concentrating, then, in the thicker fractions.

Copper is the predominant element in PCBs and, despite not being magnetic, its presence in this portion of material is due to the drag it suffers with the iron and nickel particles attracted by the magnet (Veit, 2005).

The main objective of this stage of the process is precisely to separate iron, in addition to nickel, considered magnetic materials, to enable a greater concentration of copper in electrostatic separation. Therefore, it is more

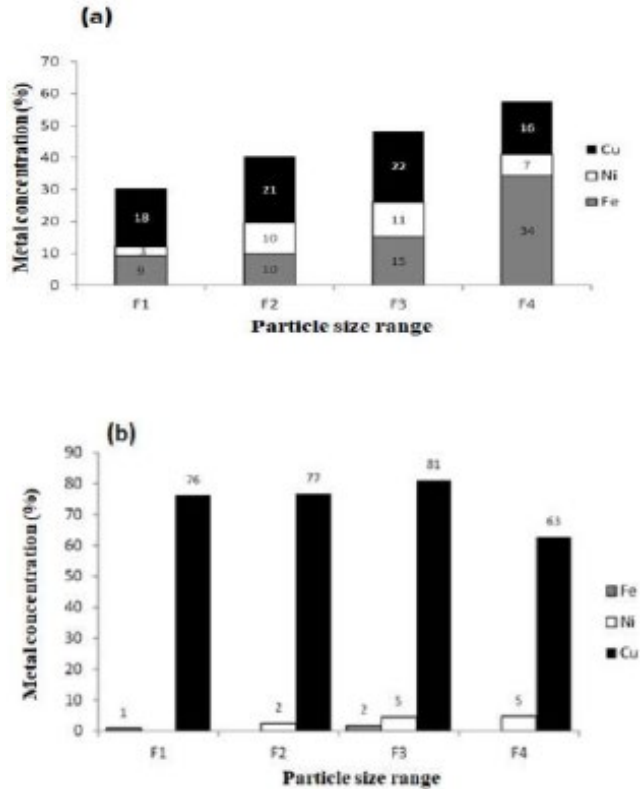

Figure 6: Amount of Fe, Ni, and Cu in magnetic particle size fractions (a) and Amount of Fe, Ni, and Cu in non-magnetic particle size fractions (b).

Source: Authors.

interesting that the highest concentrations of copper are found in the non-magnetic material portion, as can be seen in Figure 6 (b). These reasons determined the selection of these three elements for quantification in this topic: iron and nickel because they are the main magnetic elements, and copper because it is the element in greatest quantity and the one of greatest interest in PCBs.

In the portion of non-magnetic material (Figure 6

(b)), very high concentrations of copper were obtained for all particle size ranges studied: 76% in F1, 77% in F2, 81% in F3 and 63% in F4. Comparing with the amounts found in the magnetic portion (18%; 21%; 22% and 16%) the concentration of copper is evident, as well as the high amount of this element in all particle sizes. This result corroborates the study by Veit (2005), which found that metals tend to concentrate in intermediate particle sizes.

Iron was detected only in two particle size ranges (F1 and F3), and nickel in three (F2, F3 and F4), in low concentrations (1-5%), indicating that the objective of the magnetic separation process was achieved – to separate iron, mainly, and nickel, from the non-magnetic portion, keeping mostly copper (63-81%) for the next stage of the process (electrostatic separation).

After comminution of the PCBs, separation into different particle size ranges and magnetic separation, the portion of non-magnetic material was subjected to electrostatic separation, generating three different outputs of process materials: conductive, mixed and non-conductive.

From the mass balance (Figure 7), it is observed that, in all fractions, the predominance of conductive material over non-conductive material, leaving a smaller portion of mixed material, which corresponds to materials that momentarily conduct. In F4 (> 2mm) the largest amount of conductive material was observed, with 79% of mass.

With the percentages shown in Figure 7, there is a predominance of copper, as it is a conductive metal, over other materials that make up the PCBs of smartphones.

In each particle size fraction, the elements for both the conductive and non-conductive fractions were quantified, disregarding the intermediate portion due to its low mass representation (4-10%) when compared to the two other portions. The results of the main elements found for each sample are presented in Figure 8.

Copper was the element found in the greatest quantity, both in conductive samples (F1 had the highest value at 52%) and in non-conductive samples. However, the variation in the content of this element between the particle size ranges studied was between 40-52%, decreasing as the particle size increased. In non-conductive samples, the variation identified was between 22% and 37%.

Some metals, such as copper, are found in both the magnetic and non-magnetic fractions, as it is a metal with a high quantity in WEEE PCBs, this element ends up being dragged along with the attracted iron and nickel particles (Veit, 2005). This is also a result of the agglomeration of particles which results in the attraction of some non-ferrous being carried by the ferrous fraction.

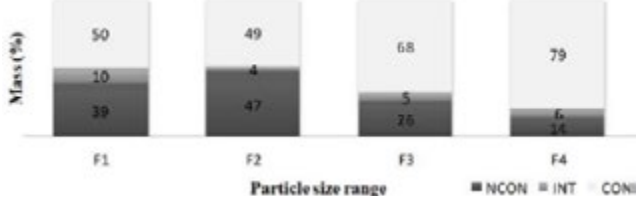

Figure 7: Amount of conductive, non-conductive, and intermediate PCB after electrostatic separation.

Source: Authors.

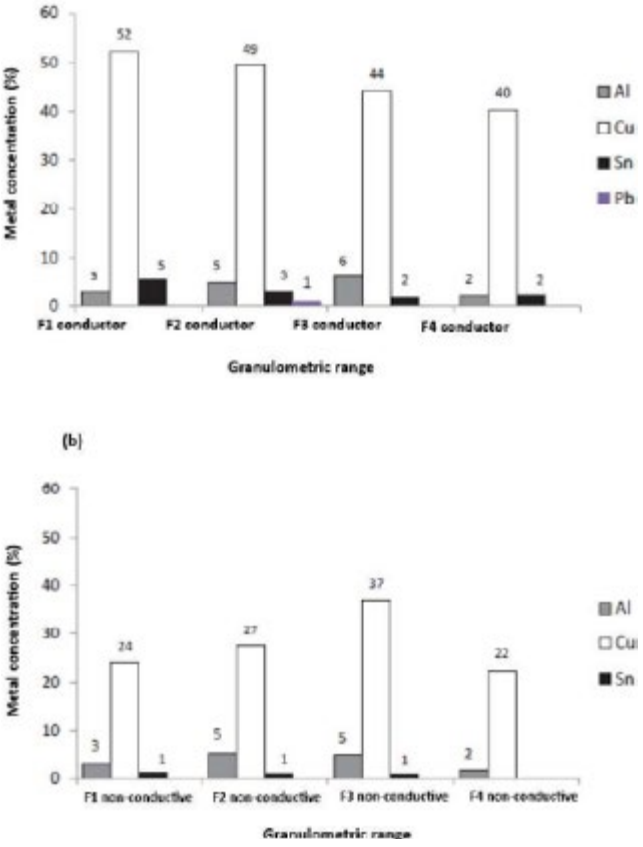

Figure 8: Amount of Cu, Al, Sn and Pb in conductive (a) and non-conductive (b) samples of different particle sizes.

Source: Authors.

In addition to copper, metals with conductive characteristics such as aluminum (2-6%), tin (1-5%) and lead (1% in conductive F2) were identified in low concentration.

Iron and nickel, magnetic elements, were also quantified and their concentration can be observed in Figure 9 (a) and (b).

Iron (0-2%) and nickel (0-5%), despite being magnetic, are also present in the conductive portion, but as trace elements (<5%). In non-conducting samples, this quantity is insignificant, with these elements in concentrations of 0.02 and 0.49%. This indicates that the magnetic process was efficient to concentrate both elements, mostly, in the

magnetic fraction.

4. CONCLUSION

From the results obtained in this work, it is possible to conclude that:

- Smartphones are composed of housing (31%), display (30%), battery (20%), PCB (16%), and others (3%);

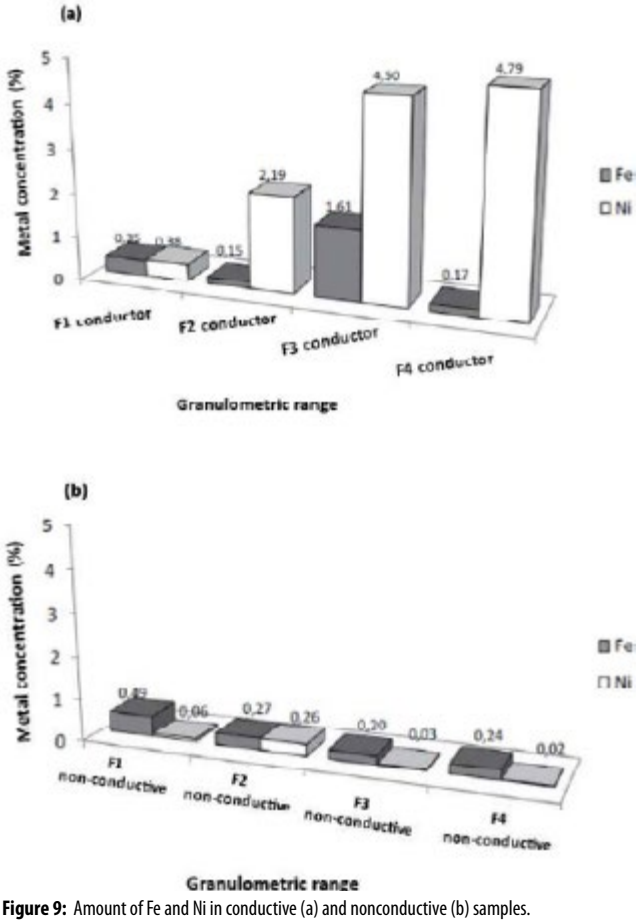

Figure 9: Amount of Fe and Ni in conductive (a) and nonconductive (b) samples.
Source: Authors.

- The grinding of PCB in a cutter mill causes a 9% loss of the material, generating PCB fragments with particle sizes ranging from over 2 mm (44%) to 1-2 mm (33%), 0.5-1 mm (14%), and <0.5 mm (10%);

- Smartphone printed circuit boards are mainly composed of, on average, copper (35%), silicon (11%), aluminum (5%), iron (3%), nickel (3%), tin (3%), zinc (1%), and chromium (1%), as well as polymers and ceramics;

- From the chemical analysis by particle size fraction, it was verified that these elements are present in all particle size fractions, especially copper, which reached a 39% content in fractions F2, F3, and F4 of the PCBs;

- Copper is the element in greater quantity in smartphone PCBs, with contents of 81% in F3 and 77% in F2 in the portion of non-magnetic material. The variation in the portion of conductive material was between 52-40%, from the lowest to the highest particle size fraction studied. This indicates the efficiency of electrostatic separation, for concentrating mostly this element, as well as the grinding of PCB, for providing the release of this metal;

- In order to obtain pure copper it would be necessary to adopt complementary refining techniques, which could be applied in the conductive fractions, especially in F4. Hydrometallurgy or biotechnology techniques could be used, for example;

- Regarding the influence of particle size on the concentration of metals in the gross/before the separation processes PCBs, copper is concentrated in the intermediate particle sizes. The lowest concentration (24%) was in the smallest particle size (F1). Aluminum and Iron increase the amount as the particle size decreases. On the other hand, the relationship between particle size and metal concentration after the separation processes was as follows: in the conductive portion, the higher the particle size of the PCB, the lower the amount of copper. In the magnetic fraction, the larger the particle size fraction of the PCB, the greater the amount of iron;

- The use of magnetic separation proved to be efficient, as it allowed the accumulation of iron in the magnetic fractions (9-34%), retaining little of this element in the non-magnetic fractions (<5%);

- The presence of metals in high concentrations, especially copper, according to the characterization carried out, makes smartphones an interesting source

of materials.

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AUTHORS

ORCID: 0009-0001-5361-8870
TAMIRES AUGUSTIN DA SILVEIRA, Engenheira Ambiental, Mestre em Engenharia Civil | Universidade do Vale do Rio dos Sinos | São Leopoldo, RS – Brasil | Correspondência para: Felicíssimo de Azevedo, 622, Auxiliadora, Porto Alegre/RS. 90540-110 | E-mail: tamires_augustin@hotmail.com

ORCID: 0009-0001-5361-8870
EMANUELE CAROLINE ARAUJO ESCHTILER, Engenheira Ambiental, Mestre em Engenharia Civil | Universidade do Vale do Rio

dos Sinos | Programa de Pós-graduação em Engenharia Civil - PPGEC | São Leopoldo, RS – Brasil | Correspondência para: Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750| E-mail: emanuelecarolinearaujo@gmail.com
ORCID: 0000-0002-1004-749X

KATIA ELIZANGELA OCANHA DORNELES, Gestora Ambiental, Mestranda em Engenharia Civil | Universidade do Vale do Rio dos Sinos | Programa de Pós-graduação em Engenharia Civil - PPGEC | São Leopoldo, RS – Brasil | Correspondência para: Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750| E-mail: katia.ocanha@hotmail.com

ORCID: 0009-0008-8299-2440
ANGÉLI VIVIANI COLLING, Engenheira de Bioprocessos e Biotecnologia | Mestrado e Doutorado em Engenharia, Área de concentração: Tecnologia Mineral e Ambiental | Universidade Federal do Rio Grande do Sul, Porto Alegre, RS – Brasil | Correspondência para: Av. Bento Gonçalves, 9500 - Setor IV, Prédio 43426, Sala 211 - Porto Alegre - RS - Brasil| E-mail: collingangeli@yahoo.com.br

ORCID: 0000-0001-7295-2826
CARLOS ALBERTO MENDES MORAES, PhD. | Universidade do Vale do Rio dos Sinos| PPG's em Engenharia Civil e Engenharia Mecânica| São Leopoldo, RS - Brasil | Correspondência para: Av. Unisinos, 950, Bairro Cristo Rei - RS, 93022-750| E-mail: cmoraes@unisinos.br

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INVESTIGATION OF GROUND TEMPERATURES FOR THE IMPLEMENTATION OF GEOTHERMAL SYSTEMS IN HISTORICAL AND FUTURE PERIODS

INVESTIGAÇÃO DAS TEMPERATURAS DO SOLO PARA A IMPLEMENTAÇÃO DE SISTEMAS GEOTÉRMICOS EM PERÍODOS HISTÓRICOS E FUTUROS

INVESTIGACIÓN DE LAS TEMPERATURAS DEL SUELO PARA LA IMPLEMENTACIÓN DE SISTEMAS GEOTÉRMICOS EN PERÍODOS HISTÓRICOS Y FUTUROS

IVAN JULIO APOLONIO CALLEJAS, Dr. | UFMT – Universidade Federal do Mato Grosso, Brasil
EMELI LALESCA APARECIDA DE GUARDA, Dra. | UFMT – Universidade Federal do Mato Grosso, Brasil
LUCIANE CLEONICE DURANTE, Dra. | UFMT – Universidade Federal do Mato Grosso, Brasil
FERNANDA MARQUES BOTELHO ARÊDES | UFMT – Universidade Federal do Mato Grosso, Brasil
KARYNA DE ANDRADE CARVALHO ROSSETI, Dra. | UFMT – Universidade Federal do Mato Grosso, Brasil

ABSTRACT

This study investigated variations in ground temperatures in four cities in Mato Grosso, considering the emission scenario SSP5-8.5 from the Sixth IPCC Assessment Report. Using computational simulations and historical and future climatic data, the research revealed significant changes in average ground temperatures. In Alta Floresta, simulations indicated a notable increase, especially in the months of April, May, and June, contrasting with estimates based on the EPW climatic file. Alto Taquari showed a distinct response, while Campo Verde and Sinop exhibited significant temperature increases until 2080. The research highlights the importance of considering specific soil characteristics for accurate projections, providing crucial insights for climate change adaptation strategies. There is an emphasis on the need to implement passive cooling strategies in buildings, especially in hot regions, to adapt to future conditions.

KEYWORDS

Climate change, Ground temperature, Computational simulations, SSP5-8.5 scenario, Environmental adaptation

RESUMO

Este estudo investigou variações nas temperaturas do solo em quatro cidades de Mato Grosso, considerando o cenário de emissão SSP5-8.5 do Sexto Relatório de Avaliação do IPCC. Utilizando simulações computacionais e dados climáticos históricos e futuros, a pesquisa revelou mudanças significativas nas temperaturas médias do solo. Em Alta Floresta, as simulações indicaram um aumento notável, especialmente nos meses de abril, maio e junho, contrastando com as estimativas baseadas no arquivo climático EPW. Alto Taquari mostrou uma resposta distinta, enquanto Campo Verde e Sinop exibiram aumentos significativos de temperatura até 2080. A pesquisa destaca a importância de considerar características específicas do solo para projeções precisas, fornecendo insights cruciais para estratégias de adaptação às mudanças climáticas. Há ênfase na necessidade de implementar estratégias de resfriamento passivo em edifícios, especialmente em regiões quentes, para se adaptar às condições futuras.

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PALAVRAS-CHAVE

Mudanças Climáticas, Temperatura do Solo, Simulação Computacional,
Cenário de Emissões SSP5-8.5, Adaptação Ambiental

RESUMEN

Este estudio investigó variaciones en las temperaturas del suelo en cuatro ciudades de Mato Grosso, considerando el escenario de emisión SSP5-8.5 del Sexto Informe de Evaluación del IPCC. Utilizando simulaciones computacionales y datos climáticos históricos y futuros, la investigación reveló cambios significativos en las temperaturas medias del suelo. En Alta Floresta, las simulaciones indicaron un aumento notable, especialmente en los meses de abril, mayo y junio, en contraste con las estimaciones basadas en el archivo climático EPW. Alto Taquari mostró una respuesta distinta, mientras que Campo Verde y Sinop exhibieron aumentos significativos de temperatura hasta 2080. La investigación destaca la importancia de considerar características específicas del suelo para proyecciones precisas, proporcionando información crucial para estrategias de adaptación al cambio climático. Se hace hincapié en la necesidad de implementar estrategias de enfriamiento pasivo en edificios, especialmente en regiones cálidas, para adaptarse a las condiciones futuras.

PALABRAS CLAVE

Cambio Climático, Temperatura del Suelo, Simulación Computacional,
Escenario de Emisiones SSP5-8.5, Adaptación Ambiental

1. INTRODUCTION

Climate change is considered a potential risk of vulnerability for building occupants in the 21st century. Air temperatures are rising, and extreme events are becoming more frequent. Consequently, the demand for artificial cooling in residential buildings could increase by up to 750%, and in commercial buildings by 275% by 2050 (SANTAMOURIS, 2016).

In 2022, the Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report (AR6), presenting emission scenarios known as Shared Socioeconomic Pathways (SSPs), categorized into five illustrative scenarios: sustainability (SSP1-1.9), intermediate scenario (SSP1-2.6), regional rivalry (SSP2-4.5), inequality (SSP3-7.0), and high use of fossil fuels (SSP5-8.5). The projected warming by 2100 ranges from 1.0°C to 1.8°C for SSP1-1.9 and from 3.3°C to 5.7°C for SSP5-8.5 (IPCC, 2022).

In this context, building performance simulations emerge as a crucial analytical tool, especially when considering predictions of future climate changes to adapt buildings to new conditions. The dynamic interaction between building systems and the external climate in the face of climate change is notably complex, involving a wide range of variables and parameters, making the use of computational simulation techniques an efficient approach (KUTTY, et al. 2024).

During simulations, the incorporation of various independent variables is essential. These include the thermophysical parameters of the building and the conditions of the deployment region. Emphasis is placed on considering soil temperature, particularly for ground-level structures with direct contact between the floor and the soil. This complex variable represents dynamic heat exchanges through conduction between indoor spaces and the adjacent soil (NUNES, et. al, 2019)

In recent years, the direct use of geothermal energy has globally expanded its installed capacity (POIEL, WOJTKOWIAK, BUERNACKA, 2001). The primary application of ground geothermal energy is in building conditioning. This has generated interest and the need to develop or enhance predictive models capable of estimating variations in soil temperature at shallower depths.

Therefore, the aim of this research is to investigate variations in soil temperature for geothermal systems, considering the SSP5-8.5 emission scenario from the IPCC's Sixth Assessment Report, both in the historical period and projections for 2050 and 2080. These variations will be obtained through computational simulation and compared with temperatures provided by historical and future climatic files.

2. METHODOLOGY

2.1 Characterization of the study regions

For the investigation, five cities located in the state of Mato Grosso, in the Central-West region of Brazil, were selected. The cities chosen for the study were Alto Taquari, Campo Verde, Paranatinga, Sinop, and Alta Floresta. Table 1 provides the description of these cities.

City	Long.	Lat.	Alt.	Biome*
Alta Floresta	17°49.0'	53°16.9'	289m	AM
Alto Taquari	9°51.9'	56°6.3'	877m	CE
Campo Verde	15°31.9'	55°7.9'	751m	CE
Paranatinga	14°25.0'	54°1.9'	476m	CE
Sinop	11°58.9'	55°34.0'	373m	CE

*Legend: Amazon Rainforest (AM), Cerrado (CE), and Pantanal (PA) Biomes

Table 1: Description of the study regions.

Most of the state is represented by the Aw climate type (tropical with summer rainfall), covering approximately 90% of its territory, while approximately 10% is classified as the Am climate type (tropical with monsoon climate). This climatic classification is commonly found in various regions worldwide, located between the Tropics of Cancer and Capricorn, and it is the second most prevalent climate type, covering about 11.5% of the Earth's land area (PEEL, FINLAYSON, McMAHON. 2007). Additionally, the representative biomes of the state are the Amazon Rainforest, Cerrado, and Pantanal.

2.2 Development of Future Climate Scenarios

The Morphing method has been employed to mathematically transform the current climate into future climates, considering scenarios of climate change (BELCHER, HACKER, POWELL, 2015). The Future Weather Generator tool utilizes the Morphing methodology to make climate projections, illustrating monthly changes in climatic variables. This tool is based on the GCM model EC-Earth3, which is part of the CMIP6 project and serves as the foundation for the Intergovernmental Panel on Climate Change's Sixth Assessment Report (AR6) (IPCC, 2022).

The tool utilizes a base climatic period for the projections from 1985 to 2014 and generates future climatic files for 2050 (period 2036-2065) and 2080 (period 2066-2095) for emission scenarios SSP2-4.5, SSP3-7.0, and

SSP5-8.5. It presents the results as future climatic files in the EPW format, widely used in thermal and energy performance simulations of buildings and cities.

Additionally, the tool was developed in the Java programming language, and its source code is freely available under the Creative Commons Attribution 4.0 Share-Alike license (RODRIGUES, FERNANDES, CARVALHO. 2023). To make its use more accessible for simulators and designers, the authors created a graphical interface that allows the insertion of historical climatic files and, consequently, the generation of future climatic scenarios.

In this research, the SSP5-8.5 scenario, labeled as "pessimistic" by the AR6 (IPCC, 2022), was chosen for the projections of 2050 and 2080. The base climatic files for the cities consist of the Solar and Wind Energy Resource Assessment (SWERA) due to its better alignment with the historical period used as the basis for the projections, as indicated in the tool's documentation.

2.3 Obtaining Soil Temperature for Geothermal Systems: A Perspective on Climatic Files and Computational Simulation in Historical and Future Periods

The acquisition of soil temperature involved two processes, namely: i) through historical and future climatic files, and ii) through computational simulation. In the header of EPW-type climatic files, it is possible to obtain soil temperatures at depths of 0.50 meters, 2.0 meters, and 4.0 meters. Therefore, this research utilized soil temperatures at a depth of 2.0 meters provided by these files for the historical period and future projections for 2050 and 2080.

Subsequently, the auxiliary program "CalcSoilSurfTemp" in the EnergyPlus software version 9.1 was employed. This program is dedicated to calculating three essential parameters for integrating tubes in geothermal systems based on buildings. These parameters encompass the annual average temperature of the soil surface, the amplitude of the soil surface temperature, and the constant phase of the soil surface temperature.

The CalcSoilSurfTemp program estimates these parameters considering a multitude of factors. These factors include convective heat transfer between air and soil, absorption of solar radiation by the soil, emission of long-wave radiation from the soil, and the loss of latent heat resulting from the evaporation of moisture present on the soil surface (KUSUDA, ACHENBACH, 1965). The soil type adopted in this analysis was classified as "Heavy and saturated," while the soil surface type was categorized as "Bare and wet."

Based on the results obtained, it became feasible to calculate the monthly soil temperature. This calculation was performed using the method developed by Kusuda and Achenbach (KUSUDA, ACHENBACH, 1965), with Equation [1] serving as a guiding reference.

$$T_{z,t} = T_m - A_s \exp\left[-z\left(\pi / 365\alpha_s\right)^{1/2}\right] \cos\left\{\left[2\pi/365\left[t - t_o - z/2\left(365/\pi\alpha_s\right)^{1/2}\right]\right\}\right. \quad (1)$$

Where:

$T_{z,t}$ – Soil Condition;
T_m - Average Surface Soil Temperature (°C);
A_s - Amplitude of Surface Soil Temperature (°C);
t_o - Phase Constant of Soil Temperature
α_s - Thermal Diffusivity of Soil

For the execution of this procedure, specific values were adopted for soil properties. The thermal diffusivity of the soil was set at 0.80 W/m·K, while the soil density was established at 2,240 kg/m^3. Additionally, the specific heat of the soil was determined to be 15,165 J/(kg·K). These properties play a crucial role in calculating thermal variations. Furthermore, the tubes were positioned at a depth of 2 meters in the soil.

This choice of depth is relevant for determining the influence of deeper thermal conditions on geothermal system simulations. This procedure was carried out for both the historical period and future scenarios.

3. RESULTS AND DISCUSSION

3.1 Alta Floresta

The annual average soil temperature obtained through simulation for the historical period is 34.8°C, whereas in the EPW climatic file, it is 24.2°C, resulting in a difference of 10.6°C. However, with the impact of climate change, the annual average soil temperatures increase by +2.2°C and +4.8°C in simulations and by +3.1°C and +6.3°C in the EPW file for the years 2050 and 2080, respectively.

It can be observed that the temperatures obtained through simulation exceed 28.0°C in all months, reaching values higher than 34.0°C in April, May, and June during the historical period (Figure 1-A). In contrast, temperatures obtained from the EPW climatic file do not exceed 25.0°C in any month during the same period (Figure 1-B). With the impacts of climate change, monthly average temperatures increase, surpassing 31.0°C in 2050 and 33.0°C in 2080 in computational simulations (Figure

1-A), and above 23.0°C in 2050 and 25.0°C in 2080 in the climatic file (Figure 1-B).

The discrepancies in soil temperatures obtained through simulation and from the EPW file arise from the consideration, in the simulation, of specific soil characteristics such as thermal diffusivity, density, and specific heat. In the climatic file, it is often an estimate based on air temperature.

3.2 Alto Taquari

In Alto Taquari, during the historical period, the annual average soil temperature obtained through simulation is 30.1°C, while in the EPW file, it is 24.5°C. In 2050 and 2080, simulated temperatures increase to 33.1°C and 35.6°C, respectively, while those obtained from the EPW rise to 27.8°C and 30.5°C, showing an increase of approximately +3.0°C in 2050 and +5.5°C in 2080 in both datasets.

It is observed that simulated temperatures during the historical period exceed 30.0°C only in the months of April, May, and June, while in other months, they remain around 29.0°C (Figure 2-A). Temperatures recorded by the EPW exceed 24.0°C only in the months of December, January, and February; in other months, temperatures do not exceed 23.5°C during the historical period (Figure 2-B). It is worth noting that in the months of July and August, the soil temperature obtained by the EPW during the historical period is around 20.5°C.

In the period of 2050 and 2080, monthly average temperatures increase, reaching values above 30.6°C and 32.8°C in all months in the simulated files (Figure 2-A), while in the EPW, temperatures are above 23.1°C and 24.5°C, respectively (Figure 2-B).

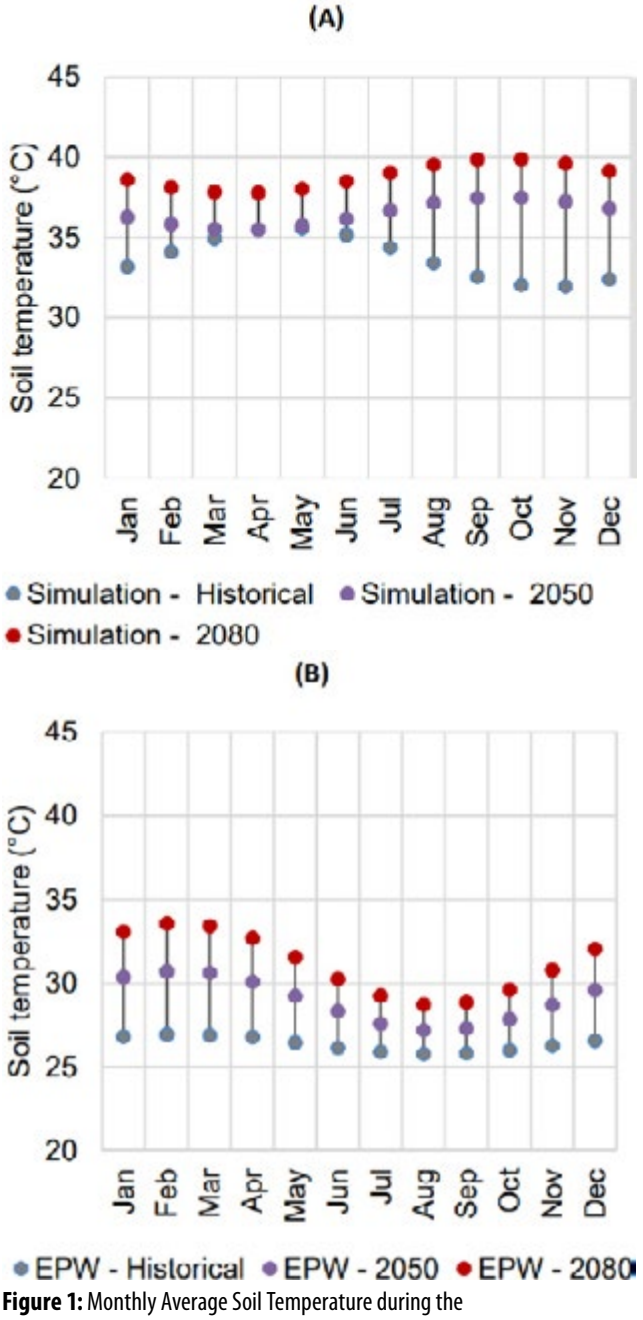
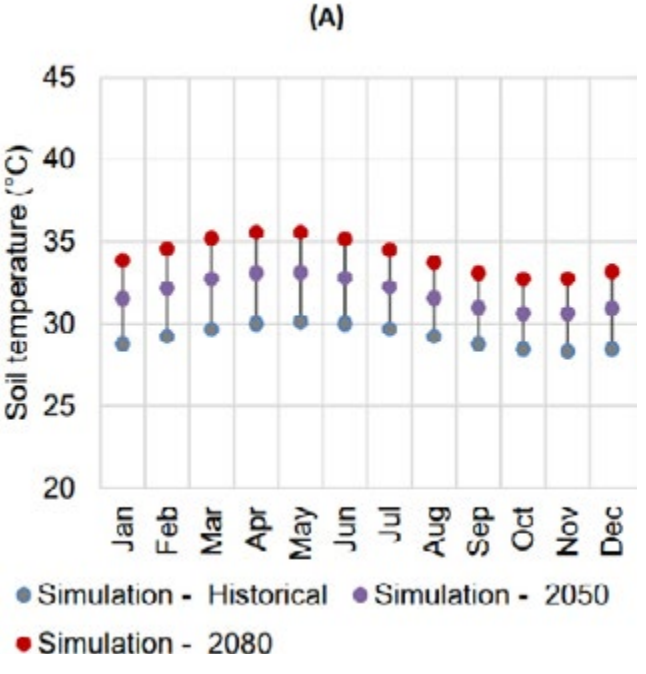


Figure 1: Monthly Average Soil Temperature during the Historical Period and Future Scenarios in Alta Floresta

3.3 Campo Verde

In Campo Verde, the monthly average soil temperature during the historical period is 30.1°C, while computational



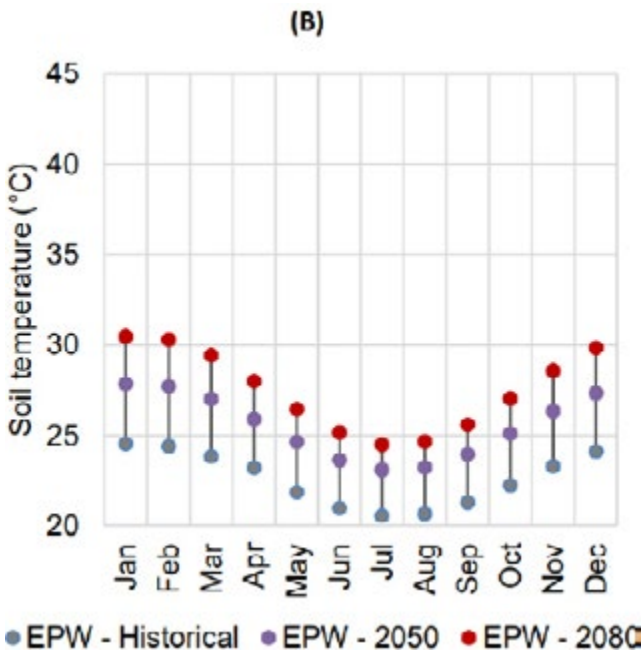


Figure 2: Monthly Average Soil Temperature during the Historical Period and Future Scenarios in Alto Taquari

simulations and EPW data record values of 25.3°C. In 2050, simulations indicate a significant increase, raising the soil temperature by +4.5°C, reaching 34.6°C. For the year 2080, an even greater increase is predicted, reaching +6.9°C and resulting in an average temperature of 37.1°C. In the same temporal context, temperatures estimated by the EPW also show increases of +3.1°C and 6.1°C in 2050 and 2080, respectively, rising to 28.3°C and 31.4°C.

The monthly average soil temperatures in Campo Verde, during the historical period, obtained through computational simulation, exceed 28.3°C, reaching values of 30.0°C in the months of April, May, and June (Figure 3-A). In contrast, soil temperatures obtained by the EPW remain around 24.0°C throughout all months of the year (Figure 3-B).

With the impact of climate change, there is an increase in temperatures, especially in the simulations. In 2050, simulated temperatures become higher than 31.0°C, particularly in the months of April, May, and June, with soil temperatures above 34.0°C. For 2080, the monthly average temperatures reach an average of 35.0°C (Figure 3-A). Meanwhile, soil temperatures estimated by the EPW remain below 30.0°C in both future climate scenarios. Only in 2080 do they exceed the 30.0°C mark in the months of February, March, and April (Figure 3-B).

3.4 Sinop

Finally, in Sinop, the average annual soil temperatures are 34.8°C and 24.2°C in the historical period for

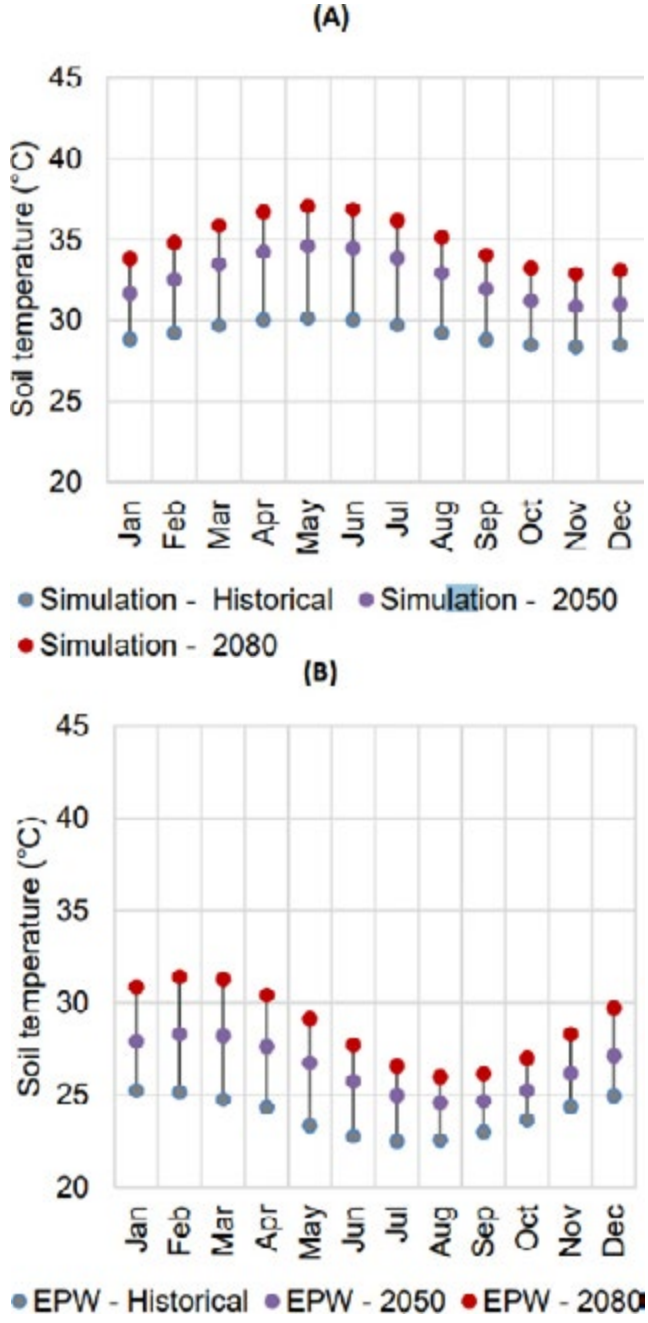


Figure 3: Monthly Average Soil Temperature during the Historical Period and Future Scenarios in Campo Verde

simulation files and EPW, respectively. However, due to the impacts of climate change, these temperatures rise to 37.0°C and 27.2°C in 2050 and to 39.6°C and 30.4°C in 2080, representing an increase of +4.8°C and +6.3°C, respectively, compared to the historical period.

The average monthly temperatures in Sinop, during the historical period, stand out for their elevation compared to other cities. The temperatures obtained through computer simulation exceed 31.0°C from February to August, while in other months, they remain around 28.5°C (Figure 4-A). In contrast, temperatures

obtained through EPW do not exceed 24.0°C (Figure 4-B).

In future climate scenarios, these temperatures experience a significant increase, surpassing 32.0°C in all months of the year in simulations and exceeding 25.0°C in EPW in 2050. In 2080, soil temperatures reach high levels, recording values of 39.6°C in April for simulations, while EPW estimates indicate temperatures around 30.3°C for the same month.

4. CONCLUSION

The study of climate projections in different regions (Alta Floresta, Alto Taquari, Campo Verde, and Sinop) reveals significant changes in average soil temperatures over time, considering historical and future scenarios. Computational simulations, which take into account specific soil characteristics such as thermal diffusivity, density, and specific heat, provide results that contrast with estimates based on EPW climate files, often grounded in air temperature.

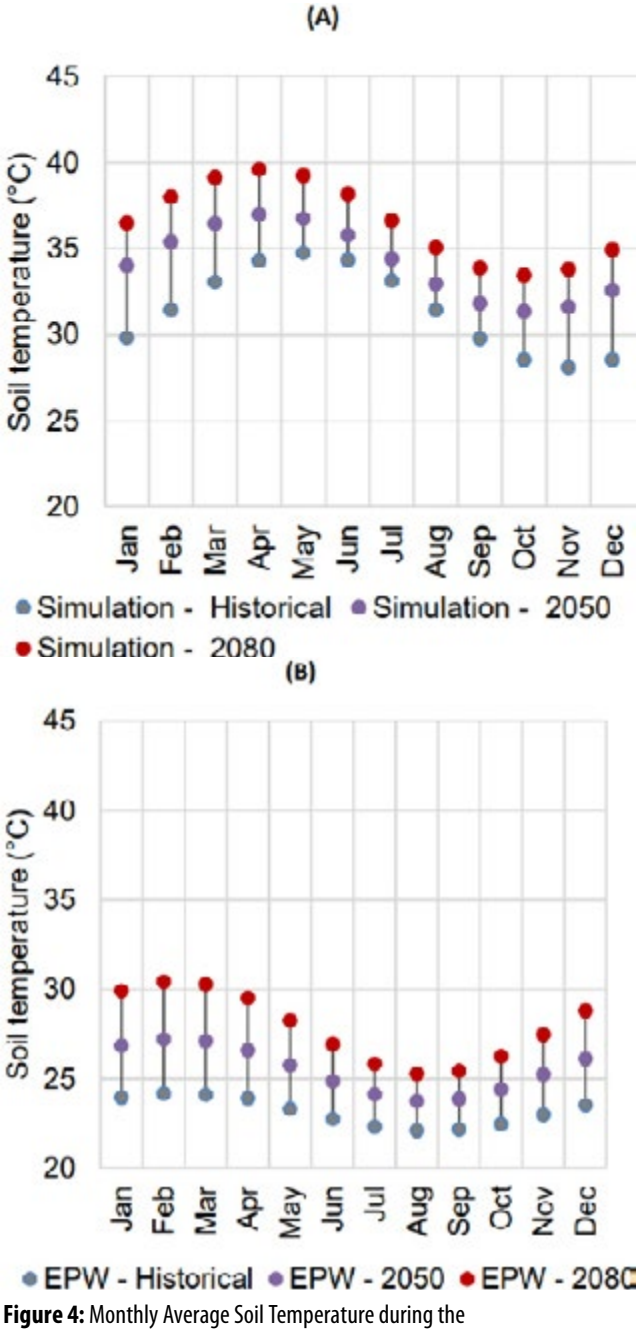


Figure 4: Monthly Average Soil Temperature during the Historical Period and Future Scenarios in Sinop

In Alta Floresta, a notable disparity was observed between simulated temperatures and those from EPW, highlighting the influence of soil characteristics on projections. The projected increase in average annual temperatures, especially in the months of April, May, and June, underscores the sensitivity of this region to climate change, presenting a challenging scenario for environmental management and agricultural activities.

Alto Taquari, on the other hand, shows a distinct but equally relevant response to climate change. Simulations indicate an increase in average annual temperatures, while EPW shows a more moderate behavior. Seasonal variations in soil temperatures emphasize the importance of considering specific soil data for more accurate predictions.

Campo Verde presents a similar scenario, with projections of a significant increase in soil temperatures until 2080. Computational simulations predict values exceeding 34.0°C, especially in the months of April, May, and June, highlighting the need for adaptive strategies to address environmental changes. Finally, in Sinop, projections indicate a substantial increase in average annual temperatures, especially in simulations. The contrast between simulated temperatures and EPW estimates suggests the importance of more detailed approaches in regional climate modeling.

In summary, the results of this study highlight the importance of considering specific soil characteristics when assessing climate projections. This more detailed approach is crucial for a precise understanding of the impacts of climate change in different regions, providing valuable insights for planning and implementing adaptation strategies. Despite these projected increases, it is crucial to emphasize the importance of implementing passive cooling strategies in buildings. This is particularly relevant in hot regions, serving as a means to adapt structures to the evolving future conditions.

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AUTHORS

ORCID: 0000-0001-7877-7029
IVAN JULIO APOLONIO CALLEJAS | Universidade Federal de Mato Grosso | Professor do Departamento de Arquitetura e Urbanismo da Faculdade de Arquitetura, Engenharia e Tecnologia - UFMT | Departamento de Arquitetura e Urbanismo | Cuiabá, MT - Brasil | ivancallejas1973@gmail.com | Lattes: http://lattes.cnpq.br/7395380953207614

ORCID: 0000-0001-7536-4448
EMELI LALESCA APARECIDA DA GUARDA | Professora da Universidade Federal do Mato Grosso do Sul | Departamento de Arquitetura e Urbanismo | Naviraí, MS - Brasil | emeliguarda@gmail.com | Lattes: http://lattes.cnpq.br/3670370461390342

ORCID: 0000-0002-4998-4587
LUCIANE CLEONICE DURANTE | Universidade Federal de Mato Grosso | Professor Associado IV do Departamento de Arquitetura e Urbanismo da Faculdade de Arquitetura, Engenharia e Tecnologia - UFMT | Cuiabá, MT - Brasil | luciane.durante@hotmail.com | Lattes: http://lattes.cnpq.br/3288386869580332

ORCID: 0009-0004-0245-5356
FERNANDA MARQUES BOTELHO ARÊDES | Universidade Federal de Mato Grosso | Bolsista de iniciação científica no Laboratório de Tecnologia e Conforto Ambiental (LATECA) da Universidade Federal de Mato Grosso (UFMT) | Cuiabá, MT - Brasil | fernandambaredes@gmail.com | Lattes: https://lattes.cnpq.br/0549957221168412

KARYNA DE ANDRADE CARVALHO ROSSETI | Universidade Federal de Mato Grosso | Professora Associada da Universidade Federal de Mato Grosso | Departamento de Arquitetura

e Urbanismo | Cuiabá, MT - Brasil | karyna.rosseti@gmail.com | Lattes: http://lattes.cnpq.br/7485943917892114

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THE ROLE OF RENEWABLE HYDROGEN IN ACHIEVING SUSTAINABLE URBAN TRANSPORTATION

O PAPEL DO HIDROGÊNIO RENOVÁVEL NO ALCANCE DO TRANSPORTE URBANO SUSTENTÁVEL

EL PAPEL DEL HIDRÓGENO RENOVABLE EN EL ALCANCE DEL TRANSPORTE URBANO SOSTENIBLE

VICTOR HUGO SOUZA DE ABREU, Dr. | UFRJ – Universidade Federal do Rio de Janeiro, Brasil
RAFAEL FERRAZ DOS SANTOS | UFRJ – Universidade Federal do Rio de Janeiro, Brasil
ANDREA SOUZA SANTOS, Dra.| UFRJ – Universidade Federal do Rio de Janeiro, Brasil
SANDRA ODA, Dra. | UFRJ – Universidade Federal do Rio de Janeiro, Brasil

ABSTRACT
The increasing global demand for a more sustainable economy is propelling the exploration of alternatives to conventional practices. The adoption of a hydrogen production and distribution system is gaining global consensus, driven by its lower environmental impact compared to fossil fuels. This study delves into the feasibility of renewable hydrogen, sourced from avenues like solar and wind power, particularly in the realm of sustainable urban transportation. The urgency for innovative technologies, underscored by emissions targets and sustainable development goals, positions hydrogen as a promising solution with superior calorific value and reduced emissions to mitigate the impacts of the transport sector on the environment. Nonetheless, challenges, including limited infrastructure and the requirement for substantial investment, pose significant hurdles to its widespread adoption. The pertinence of this study is further emphasized by the necessity to continually update the literature, ensuring alignment with the dynamic developments in this field.

KEYWORDS
Sustainable economy; Renewable hydrogen; Innovative technologies; Sustainable urban transportation.

RESUMO
A crescente demanda global por uma economia mais sustentável está impulsionando a exploração de alternativas às práticas convencionais. A adoção de um sistema de produção e distribuição de hidrogênio está ganhando consenso global, impulsionada por seu menor impacto ambiental em comparação com os combustíveis fósseis. Este estudo investiga a viabilidade do hidrogênio renovável, proveniente de vias como a energia solar e eólica, especialmente no âmbito do transporte urbano sustentável. A urgência de tecnologias inovadoras, ressaltada por metas de emissões e objetivos de desenvolvimento sustentável, posiciona o hidrogênio como uma solução promissora com valor calorífico superior e emissões reduzidas para mitigar os impactos do setor de transportes no meio ambiente. No entanto, desafios, incluindo infraestrutura limitada e a necessidade de investimentos substanciais, representam obstáculos significativos para sua adoção generalizada. A pertinência deste estudo é ainda mais enfatizada pela necessidade de atualizar continuamente a literatura, garantindo o alinhamento com os desenvolvimentos dinâmicos nesse campo.

PALAVRAS-CHAVE
Economia sustentável; hidrogênio renovável; tecnologias inovadoras; transporte urbano sustentável.

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RESUMEN

La creciente demanda global de una economía más sostenible está impulsando la exploración de alternativas a las prácticas convencionales. La adopción de un sistema de producción y distribución de hidrógeno está ganando consenso a nivel mundial, impulsada por su menor impacto ambiental en comparación con los combustibles fósiles. Este estudio investiga la viabilidad del hidrógeno renovable, proveniente de fuentes como la energía solar y eólica, especialmente en el ámbito del transporte urbano sostenible. La urgencia de tecnologías innovadoras, resaltada por metas de emisiones y objetivos de desarrollo sostenible, posiciona al hidrógeno como una solución prometedora con un mayor valor calorífico y emisiones reducidas para mitigar los impactos del sector del transporte sobre el medio ambiente. Sin embargo, desafíos, como la infraestructura limitada y la necesidad de inversiones sustanciales, representan obstáculos significativos para su adopción generalizada. La relevancia de este estudio se enfatiza aún más por la necesidad de actualizar continuamente la literatura, garantizando el alineamiento con los desarrollos dinámicos en este campo.

PALABRAS CLAVE

Economía sostenible; hidrógeno renovable; tecnologías innovadoras; transporte urbano sostenible.

1. INTRODUCTION

Today, there is an increasing global demand for a more sustainable economy, driven by nations' commitment to achieving emissions targets and sustainable development (SAEEDMANESH, MAC KINNON & BROUWER, 2018). In this context, the urgency for new technologies and solutions to replace traditional practices is more evident than ever (CEVALLOS-ESCANDÓN et al., 2023). The need for change is imperative to meet the expectations of a more sustainable future (EHRENSTEIN et al., 2020; SANTOS et al., 2021; DE ASSIS et al., 2022a; 2022b).

Thus, the implementation of a hydrogen production and distribution system, which has greater calorific value and reduced carbon emissions compared to fossil fuels (WIDERA, 2020; LAL & YOU, 2023), has gradually become a global consensus (SANTOS et al., 2021; CAPURSO et al., 2022). Hydrogen can be used as a feedstock, fuel or energy carrier and store to balance electricity supply and demand (EUROPEAN COMMISSION, 2019), resulting in an estimated global demand of more than US$12 trillion - equivalent to R$62.56 trillion - by 2050 (ONI et al., 2022).

Currently, hydrogen production is predominantly divided into three main categories: (i) renewable origin; (ii) fossil-origin with carbon capture and storage (CCS) or carbon capture, utilization and storage (CCUS); and (iii) fossil origin. Presently, hydrogen production processes are predominantly driven by non-renewable sources. However, To boost the development of the clean hydrogen market, global discussions have been held on standards for renewable hydrogen (LIU et al., 2022). Renewable hydrogen is produced using renewable energies such as solar and wind power and represents a more promising long-term solution for the transition to a carbon-free economy in various sectors including transportation (GULOTTA et al., 2022).

The use of renewable hydrogen as an energy source in urban transportation offers substantial advantages for promoting environmental sustainability (ACAR & DINCER, 2020). By eliminating harmful emissions and contributing to climate change mitigation, hydrogen stands out for its versatility and storage efficiency, providing vehicles with extended autonomy (DE ASSIS et al., 2022a; 2022b). In addition to the environmental benefits, the transition to renewable hydrogen drives technological innovation, the creation of specialized jobs and promotes an improvement in air quality, positively impacting public health and solidifying the position of cities at the forefront of the energy revolution.

Despite the obvious advantages, the widespread adoption of renewable hydrogen in the urban transportation sector faces significant challenges such as limited hydrogen production, distribution and supply infrastructure, requiring substantial investments to become widely accessible, among others. Thus, this paper aims to conduct a literature review to identify the advantages of hydrogen for sustainable urban transport, as well as assess its main challenges and best practices that can be implemented to minimize them.

2. METHODOLOGY

The methodology of this study consists of the following steps:

- Formulation of the Research Question: The research is guided by the question: "What is the role of renewable hydrogen in achieving a sustainable urban transportation matrix?"

- Search strategy: To identify relevant studies, relevant keywords were selected, such as "renewable hydrogen", "green hydrogen", "fuel cells" and "sustainable urban transportation". The search was conducted in specialized databases, including Web of Science, Scopus, and others related to energy and sustainability.

- Source selection: Articles were meticulously chosen based on predetermined inclusion and exclusion criteria. Only studies directly addressing the role of hydrogen in sustainable urban transportation were deemed relevant, prioritizing methodological rigor and contemporary relevance.

- Organization of the Review: The selected studies were grouped into thematic categories, including hydrogen technologies, public policies, challenges and opportunities. This approach aims to provide a comprehensive and structured overview of the current state of research on the topic.

- Reading and Synthesis: A critical reading of the scientific papers highlighted essential information on the role of hydrogen in sustainable urban transport. Synthesis involves condensing the main conclusions, methodologies and findings, providing an in-depth understanding of the topic.

• Critical Analysis: The reviewed studies underwent rigorous scrutiny, identifying potential biases, methodological constraints, and strengths. This comprehensive approach is intended to foster a nuanced interpretation of the evidence presented in the literature, ensuring a balanced.

• Contextualization and Integration: The results were contextualized within the broader panorama of sustainable urban transport and energy policies. The integration of findings from different sources seeks to build a cohesive narrative about the role of hydrogen in this context.

• Writing and structuring the text: The literature review will be structured according to a logical organization, including an introduction that contextualizes the topic, a development that addresses the thematic categories and a conclusion that highlights the specific contributions of the studies reviewed.

• Review and Update: To uphold the relevance of the review, regular assessments of the literature will be conducted. Ongoing surveillance of emerging developments in the hydrogen and sustainable transportation sectors will guarantee the integration of the latest information.

3. MAIN ADVANTAGES OF USING RENEWABLE HYDROGEN IN THE URBAN TRANSPORTATION SECTOR

Over the years, the transportation sector has stood out as the most promising for the adoption of hydrogen as an energy source (FRANZITTA et al., 2017). It is important to note that transportation is responsible for approximately a quarter of all energy-related greenhouse gas (GHG) emissions, and of these emissions, around 72% come from road transport (IEA, 2020). These figures reinforce the urgent need to explore innovative solutions, such as the use of hydrogen, especially renewable hydrogen, to mitigate the negative environmental impacts caused by the transportation sector (MANIATOPOULOS, ANDREWS & SHABANI, 2015; SANTOS et al., 2021).

Renewable hydrogen can be used as a vehicle fuel in various ways, depending on the chemical composition of the fuel and the energy converter used to transform chemical energy into mechanical energy. In terms of fuel composition, hydrogen can be used in its pure form or as a raw material for the synthesis of more complex molecules, such as ammonia, hydrocarbons, or alcohols (PROENÇA et al., 2023). As for energy conversion equipment, the most common devices applied in vehicles are internal combustion engines and gas turbines, both conventional technologies and fuel cells, which are based on the direct electrochemical conversion of a fuel into electrical energy, which can be used in an electric powertrain (DE ABREU, PROENÇA and SANTOS, 2023).

Fuel cell systems typically have higher efficiency (around 50%), lower pollutant emissions and lower maintenance requirements than existing technologies but are still characterized by a higher cost. Typically, vehicles are powered by polymer electrolyte membrane fuel cells (PEMFCs) fed by pure hydrogen, but other solutions are being developed using other types of cells or different fuels, such as alcohols and hydrocarbons (PROENÇA et al., 2023). The use of hydrogen as an energy source in the transport sector offers several significant advantages for promoting sustainable urban transport, as shown in Table 1.

Advantage	Description
Improved energy security	In terms of energy security, renewable hydrogen offers the advantage of being able to be produced through different routes, mainly from clean and domestic sources, such as renewable energies, nuclear, biomass and biofuels (DE ABREU et al., 2023a). This diversity of production routes is extremely important for ensuring energy security in countries that have a high dependence on fossil fuel imports to supply their transportation sector (BALL & WIETSCHEL, 2009; LI & TAGHIZADEH-HESARY, 2022).
Reducing GHG emissions	Renewable hydrogen used as a fuel in vehicles produces only water as a by-product of its combustion, resulting in zero GHG emissions at the point of use (MNEIMNEH et al., 2023). This contributes to reducing the carbon footprint and mitigating the impacts of climate change (SALVI & SUBRAMANIAN, 2015; DE ABREU, PROENÇA and SANTOS, 2023).
Reducing air pollution	Hydrogen-powered vehicles do not emit harmful air pollutants such as nitrogen oxides (NOx) and fine particles, helping to improve air quality in urban areas, reducing risks to human health and reducing respiratory and cardiovascular problems (WEGER, LEITÃO & LAWRENCE, 2021).
Renewable energy source	Hydrogen can be produced from renewable energy sources such as solar, wind and hydroelectric power. By using these clean sources, hydrogen contributes to the decarbonization of the transport sector and reduces dependence on non-renewable fossil fuels (SINGH et al., 2015; DE ABREU et al., 2023a, 2023b).
Energy storage	Hydrogen is used to store intermittent renewable energy. intermittent renewable energy. Excess renewable energy can be converted into hydrogen through electrolysis. This hydrogen is stored and can later be used to generate electricity or fuel vehicles, balancing the supply and demand of renewable energy (BALL & WIETSCHEL, 2009; LI & TAGHIZADEH-HESARY, 2022; CAPURSO et al., 2022).
Longer range and faster refueling times	Hydrogen-powered vehicles offer a generally longer range compared to battery electric vehicles, for example. In addition, hydrogen refueling can be carried out in similar times to refueling conventional liquid fuels, allowing for a smoother and more convenient transition for users (WEGER, LEITÃO & LAWRENCE, 2021).
Diversifying energy options	The use of hydrogen in urban transportation helps to diversify the energy options available, reducing exclusive dependence on fossil fuels. This helps to promote energy resilience, making the transportation system less susceptible to fluctuations in oil prices and supply interruptions (BALL & WIETSCHEL, 2009; LI & TAGHIZADEH-HESARY, 2022).
Flexibility of application	Hydrogen can be used in different types of vehicles, including small, medium and large passenger and cargo vehicles. Its application covers a wide range of transportation modes, enabling the transition to a more sustainable fleet in various sectors (SINGH et al., 2015; LI & TAGHIZADEH-HESARY, 2022; PROENÇA et al., 2023).
Noise reduction	Hydrogen-powered vehicles have quieter operation compared to conventional internal combustion vehicles. This contributes to reducing noise pollution in urban areas, providing a quieter and healthier environment (BALL & WIETSCHEL, 2009).
Reuse of existing infrastructure	In many cases, existing infrastructure for the supply of liquid fuels, such as gas stations, can be adapted to supply hydrogen. This allows for an easier transition to the use of hydrogen as a fuel, using already established infrastructure and reducing implementation costs (WEGER, LEITÃO & LAWRENCE, 2021).
Potential long-term cost savings	Although hydrogen-powered infrastructure and vehicles may have higher initial costs, economic benefits can be achieved in the long term. Mass production, technological advances and reduced manufacturing costs could make hydrogen competitive with traditional fossil fuels, as well as reducing the volatility of oil prices (PROENÇA et al., 2023).
Stimulating innovation and job creation	The transition to the use of hydrogen as a fuel in urban transportation drives innovation and technological development. This transition also creates opportunities for industry, stimulating job creation in sectors related to the production, storage, distribution and maintenance of hydrogen and hydrogen-powered vehicles (PROENÇA et al., 2023; MNEIMNEH et al., 2023).

Advantage	Description
Extended autonomy in micromobility	Hydrogen-powered micromobility vehicles can offer extended autonomy compared to the conventional batteries used in these vehicles. This allows users to travel longer distances without the frequent need to recharge or change batteries, increasing convenience and accessibility.
Last Mile Operational Efficiency	The use of hydrogen in "last mile" vehicles provides efficient and reliable performance in the delivery of goods in congested urban areas. Hydrogen-powered vehicles offer extended autonomy and rapid refueling, ensuring continuous availability and reducing operational delays. This advantage is crucial for meeting the demands of e-commerce and fast delivery services, where speed and efficiency are essential.
Increased flight time and autonomy in drones	In contrast to conventional drones, hydrogen-powered drones offer a more efficient energy source, allowing for a greater amount of energy concerning their weight, resulting in a significantly extended flight time of up to several hours (RAGUPATHI, 2023).

Table 1: Advantages of using hydrogen-powered vehicles in relation to road transport.

Table 1 highlights the advantages of incorporating hydrogen, especially renewable hydrogen, into the energy matrix of the road transport sector. However, it is highly recommended to carry out a comprehensive technical and economic feasibility analysis of the hydrogen energy system, considering available resources, production technologies, storage, fuel transportation, distribution and use. In addition, special attention should be paid to the technical issues and their control strategy to address the problems of the transportation system using hydrogen (SALVI & SUBRAMANIAN, 2015; SINGH et al., 2015).

The advantages offered by using renewable hydrogen as an energy source in the transportation sector have a significant impact on decision-makers at all levels of jurisdiction. This information highlights the importance of considering hydrogen as a viable and promising alternative to boost sustainability and efficiency in transportation. For policymakers and business leaders, understanding the benefits of hydrogen can guide the implementation of strategies and incentives to promote its wide-scale adoption (KIM & MOON, 2008). In addition, this study can stimulate technological advances in Research and Development projects and investments in infrastructure for the use of hydrogen in transportation (DE ABREU, PROENÇA and SANTOS, 2023).

4. CHALLENGES OF USING RENEWABLE HYDROGEN IN THE URBAN TRANSPORT SECTOR

Although renewable hydrogen will play a crucial role in the energy transition, not only catalyzing decarbonization, but also driving a new era of sustainable economic development and global innovation, it is imperative to recognize that even the most promising solution is not without its challenges, be they technological or political.

As highlighted by the Green Hydrogen Portal, renewable hydrogen has the potential to replace non-renewable energy sources in different timeframes - short, medium, and long - but challenges remain in terms of price, transportation, distribution, and storage. These barriers still need to be overcome to effectively implement the technology on a large scale (BEZERRA, 2021), as shown in Table 2.

Hydrogen, when produced from renewable sources, becomes a conventional alternative. To ensure the success of the 'hydrogen economy' shortly, it is crucial to quickly address the technical and economic challenges associated with this substance. Although finding practical solutions to these challenges may take some time, technological progress through continuous efforts ensures that hydrogen will emerge as the ultimate solution to meet future energy demands in the transportation sector (SINGH et al., 2015).

Challenge	Description	How to minimize it?
Improving the Regulatory Framework	The existence of a well-established institutional, legal and regulatory framework is an essential condition for providing legal certainty for arge-scale investments in the hydrogen sector. In the context of the decarbonization of energy production and consumption systems, the market value of hydrogen can vary significantly based on its production origin, although this has no technical impact on its use (OLIVA JÚNIOR, 2021).	The market is expected to evolve to encourage the production of renewable hydrogen, due to its environmental attributes that contribute to achieving sustainability goals. This could result in a "premium" being paid depending on where the hydrogen is produced. Consequently, it is likely that, soon, governments will adopt public policies that offer subsidies and incentives for the production and consumption of renewable hydrogen by companies, further boosting the sustainable development of this sector (OLIVA JÚNIOR, 2021).
Supply and distribution infrastructure	The infrastructure for refueling renewable hydrogen in hydrogen-powered vehicles is currently limited compared to traditional fuel stations (SINGH et al., 2015). Establishing a widespread and accessible network would require substantial investments and a significant period for implementation (DE ABREU et al., 2023a).	There are options for the safe transportation of hydrogen that include those already used for the transportation of fossil fuels, such as in gaseous or liquid form in trucks or ships, and the pumping of gaseous hydrogen in its own pipelines or by sharing with the existing infrastructure for the transportation of natural gas (MIRANDA, 2017).
Storage problems	A major challenge to achieving a solid hydrogen economy is the maturation of storage technologies that are safe, compact and cost-effective (ABE et al., 2019).	Typically, hydrogen can be retained as a pressurized gas, cryogenic liquid or physically or chemically bound to specific solid materials. Among these options, solid-state storage systems based on metal hydrides stand out as promising due to their potential to offer a high gravimetric capacity for hydrogen storage. These systems provide a safe, efficient, compact and repeatedly reversible approach, gradually gaining prominence in hydrogen-related applications (ABE et al., 2019).
Availability of renewable sources	The production of renewable hydrogen depends on the availability of renewable energy sources, such as solar or wind power (YAKUBSON, 2022).	To promote a sustainable expansion in hydrogen production, it is essential to direct substantial investments into research aimed at making these technologies economically viable (SINGH et al., 2015). In addition, the implementation of strategic public incentive policies, aimed at both companies and consumers, is essential to make the option of hydrogen more attractive (YAKUBSON, 2022).
Market acceptance	The acceptance of hydrogen as a vehicle fuel represents a significant cultural challenge, as it involves changing established paradigms and promoting a transformation in attitudes and perceptions towards traditional means of propulsion (DE ABREU, PROENÇA e SANTOS, 2023).	Promoting the widespread adoption of hydrogen as a vehicle fuel requires a substantial effort in raising public awareness and overcoming entrenched prejudices. Making people aware of the environmental and economic benefits of hydrogen, while proactively addressing common concerns and misconceptions, is imperative to achieving wider and more effective acceptance of this innovative technology in the transportation landscape (DE ABREU, PROENÇA e SANTOS, 2023).

Table 2: Challenges for implementing renewable hydrogen as a promising form of sustainable urban transport.

5. FINAL CONSIDERATIONS

In terms of sustainability, hydrogen reduces GHG emissions and air pollutants, helping to mitigate climate change and improve air quality. In addition, its energy efficiency and storage capacity allow for longer flight times for drones, extended autonomy in "last mile" vehicles and a balance between supply and demand for renewable energy. Hydrogen also promotes the diversification of the energy matrix, reducing dependence on fossil fuels and boosting technological innovation in the transportation sector. These combined advantages make hydrogen a promising solution for tackling environmental and energy challenges, driving the transition to a more sustainable and efficient transportation system.

The importance of this study for decision-makers lies in the promising contribution that renewable hydrogen offers to environmental and energy challenges, driving the transition to a more sustainable and efficient transportation system. The identification of business opportunities, integration with renewable sources, and the positive impacts on the economy and the environment are points of equal importance in the current scenario. Specifically, the emphasis on integration with renewable energy sources and on economic benefits provides concrete pathways for future decision-making, always in line with sustainability indicators, among other socio-environmental and economic commitments.

However, the rapid transition to a global low-carbon hydrogen economy faces significant technical and economic challenges, including the escalating prices of fossil fuels such as gasoline and gas. Yet, these very price increases can accelerate the competitiveness of renewable fuels. With increased demand and ongoing technological advances, there's promising potential to reduce these costs, ultimately making renewable hydrogen fully competitive in the energy market.

The supply of hydrogen to industrial users presents a substantial business opportunity, particularly in coastal industrial hubs where there is an existing demand for pure hydrogen. Moreover, integrating industry and transportation applications with nearby offshore wind and solar photovoltaic sources in regions such as the North Sea in Europe, Southeast China, Western Australia, and Northwest India enhances the attractiveness of these locations for such endeavors.

The outcomes of this initiative might encompass the formulation of supportive policies and regulations, the forging of public-private partnerships to spur innovation, and the creation of a resilient infrastructure for hydrogen production, storage, and distribution. Such initiatives can potentially expedite the shift towards a more sustainable transportation ecosystem, thereby mitigating carbon emissions, enhancing air quality, and fortifying energy resilience.

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AUTHORS

ORCID: 0000-0002-2557-2721
VICTOR HUGO SOUZA DE ABREU, Doutor | Pesquisador de Pós-Doutorado | Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia da Universidade Federal do Rio de Janeiro | Engenharia de Transportes | Correspondência para: Av. Horácio Macedo, 2030, 101 – Cidade Universitária – Rio de Janeiro, RJ, Brasil | E-mail: victor@pet.coppe.ufrj.br

ORCID: 0009-0003-5182-9513
RAFAEL FERRAZ DOS SANTOS | Mestrando | Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia da Universidade Federal do Rio de Janeiro | Engenharia de Transportes | Correspondência para: Av. Horácio Macedo, 2030, 101 – Cidade Universitária – Rio de Janeiro, RJ, Brasil | E-mail: rafael.ferraz@pet.coppe.ufrj.br

ORCID: 0000-0002-5984-6313
ANDREA SOUZA SANTOS, Doutora e Professora | Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia da Universidade Federal do Rio de Janeiro | Engenharia de Transportes | Correspondência para: Av. Horácio Macedo, 2030, 101 – Cidade Universitária – Rio de Janeiro, RJ, Brasil | E-maill: andrea.santos@pet.coppe.ufrj.br

ORCID: 0000-0002-1317-4232 |
SANDRA ODA, Doutora e Professora | Departamento de Engenharia de Transportes da Escola Politécnica da UFRJ | Correspondência para: Av. Athos da Silveira Ramos, 149 - Centro de Tecnologia - Bloco D, Sala 209. Cidade Universitária - Ilha do Fundão - CEP 21941-909 - Rio de Janeiro, RJ, Brasil | E-maill: sandraoda@poli.ufrj.br

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ANALYSIS OF CONSUMERS' WILLINGNESS TO ADOPT SUSTAINABLE PRACTICES WHEN CHANGING AUTOMOTIVE LUBRICATING OILS

ANÁLISE DA DISPOSIÇÃO DOS CONSUMIDORES SOBRE PRÁTICAS SUSTENTÁVEIS NA TROCA DE ÓLEOS LUBRIFICANTES AUTOMOTIVOS

ANÁLISIS DE LA DISPONIBILIDAD DEL CONSUMIDOR SOBRE PRÁCTICAS SOSTENIBLES EN EL INTERCAMBIO DE ACEITES LUBRICANTES AUTOMOTRICES

KATIA CRISTINA BERGAMINI TITAO | UNIOESTE – Universidade Estadual do Oeste do Paraná, Brasil
ELAINE CRISTINA DANTAS PEIXOTO MECÊS | UNIOESTE – Universidade Estadual do Oeste do Paraná, Brasil
CARINA LANGARO | UNIOESTE – Universidade Estadual do Oeste do Paraná, Brasil
JERRY ADRIANI JOHANN, Dr. | UNIOESTE – Universidade Estadual do Oeste do Paraná, Brasil
GEYSLER ROGIS FLOR BERTOLINI, Dr. | UNIOESTE – Universidade Estadual do Oeste do Paraná, Brasil

ABSTRACT

This research aimed to verify consumers' willingness to pay more for a sustainable lube oil change service and the practical considerations involved in choosing the place to carry out the change. The methodology used was descriptive research with a quantitative approach and the data was collected using questionnaires applied to 162 participants in Catanduvas/PR which contained questions about motivation, consumption habits, evaluation of competition and acceptance of sustainable practices. The data was analyzed using statistical tests to validate the hypotheses formulated. The results presented an analysis of the factors influencing the adoption of a sustainable oil change service, using data from four blocks to understand consumer attitudes and preferences. The results highlighted awareness of the need for regular oil changes and the complexity involved in consumer choice. Competitor analysis highlighted the influence of reliability, service and recommendations. The concept test confirmed consumers' willingness to pay more for a sustainable service, highlighting their reluctance to change oil in inappropriate places. The confirmed hypotheses have crucial implications for strategies, emphasizing awareness, education and supply in line with expectations. The findings demonstrate the feasibility of implementing sustainable actions, positively impacting the economy, technology, safety and the environment, in line with awareness and sustainability trends. It can be inferred that entrepreneurs can adapt their establishments to offer ecologically correct services and invest in advertising. Just as commercial associations can create programs to promote sustainable companies and publicize them to the population, public authorities can create subsidies and programs for companies in the sector that adopt sustainable practices and adhere to environmental programs. Through a comprehensive analysis of sustainable oil change services, this research contributes to confirming the willingness to pay extra for ecological practices and highlights the importance of environmental awareness in decision-making.

KEYWORDS

Sustainability; Oil change; Consumer behavior; Automotive services; Environmental awareness.

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RESUMO

O objetivo dessa pesquisa foi verificar a disposição dos consumidores em pagar mais por um serviço sustentável de troca de óleo lubrificante e as considerações práticas envolvidas na escolha do local para realização desta troca. A metodologia utilizada foi uma pesquisa descritiva com abordagem quantitativa e os dados foram coletados por meio de questionários aplicados a 162 participantes em Catanduvas/PR que continham perguntas sobre motivação, hábitos de consumo, avaliação da concorrência e aceitação de práticas sustentáveis. Os dados foram analisados usando testes estatísticos para validar as hipóteses formuladas. Os resultados apresentaram a análise dos fatores influenciadores da adoção de um serviço sustentável de troca de óleo, utilizando dados de quatro blocos para entender atitudes e preferências dos consumidores. Os resultados realçaram a consciência da necessidade da troca regular de óleo e complexidade envolvendo a escolha dos consumidores. A análise da concorrência destacou a influência da confiabilidade, atendimento e recomendações. O teste do conceito confirmou a disposição do consumidor em pagar mais por um serviço sustentável, destacando a relutância em trocar óleo em locais inadequados. As hipóteses confirmadas têm implicações cruciais para estratégias, enfatizando conscientização, educação e oferta alinhada às expectativas. Os achados demostram a viabilidade para implementar ações sustentáveis, impactando positivamente na economia, tecnologia, segurança e meio ambiente, em consonância com as tendências de conscientização e sustentabilidade. Pode-se inferir que os empresários podem adequar seus estabelecimentos na oferta de serviços ecologicamente corretos e investir em publicidade. Assim como as associações comerciais podem criar programas para promoção das empresas sustentáveis e divulgação das mesmas para a população, bem como os poderes públicos podem criar subsídios e programas para as empresas do setor que adotem práticas sustentáveis e aderem a programas ambientais. Através de uma análise abrangente em relação serviços com práticas sustentáveis de troca de óleo, essa pesquisa traz como contribuição a confirmação da disposição para pagamento adicional por práticas ecológicas e destacou a importância da conscientização ambiental na tomada de decisões.

PALAVRAS-CHAVE

Sustentabilidade; Troca de óleo; Comportamento do consumidor; Serviços automotivos; Consciência ambiental.

RESUMEN

El objetivo de esta investigación fue verificar la disposición de los consumidores a pagar más por un servicio de cambio de aceite lubricante sustentable y las consideraciones prácticas involucradas en la elección del lugar para realizar este cambio. La metodología utilizada fue una investigación descriptiva con enfoque cuantitativo y los datos fueron recolectados a través de cuestionarios aplicados a 162 participantes en Catanduvas/PR que contenían preguntas sobre motivación, hábitos de consumo, evaluación de la competencia y aceptación de prácticas sustentables. Los datos fueron analizados mediante pruebas estadísticas para validar las hipótesis formuladas. Los resultados presentaron un análisis de los factores que influyen en la adopción de un servicio de cambio de aceite sostenible, utilizando datos de cuatro bloques para comprender las actitudes y preferencias de los consumidores. Los resultados resaltaron la conciencia de la necesidad de cambios regulares de aceite y la complejidad que implica la elección del consumidor. El análisis de la competencia destacó la influencia de la confiabilidad, el servicio y las recomendaciones. La prueba de concepto confirmó la voluntad del consumidor de pagar más por un servicio sostenible, destacando la reticencia a cambiar el aceite en lugares inadecuados. Las hipótesis confirmadas tienen implicaciones cruciales para las estrategias, enfatizando la concientización, la educación y la provisión en línea con las expectativas. Los hallazgos demuestran la viabilidad de implementar acciones sustentables, impactando positivamente la economía, la tecnología, la seguridad y el medio ambiente, en línea con las tendencias de concientización y sustentabilidad. Se puede inferir que los empresarios pueden adaptar sus establecimientos para ofrecer servicios ecológicamente correctos e invertir en publicidad. Así como las asociaciones comerciales pueden crear programas para promover empresas sustentables y darlas a conocer a la población, las autoridades públicas pueden crear subsidios y programas para empresas del sector que adopten prácticas sustentables y se adhieran a programas ambientales. A través de un análisis integral de los servicios relacionados con prácticas sustentables de cambio de aceite, esta investigación contribuye a confirmar la disposición a pagar adicionalmente por prácticas ecológicas y destacó la importancia de la conciencia ambiental en la toma de decisiones.

PALABRAS CLAVE

Sostenibilidad; Cambio de aceite; Comportamiento del consumidor; Servicios automotrices; Conciencia ambiental.

1. INTRODUCTION

The National Solid Waste Policy (PNRS) defines reverse logistics as an economic and social development instrument characterized by a set of actions involving processes such as collection, inspection, repair, disassembly, disposal, recycling and remanufacturing of collected products (Paredes-Rodriguez et al., 2022). The PNRS made it compulsory to properly manage lubricating oils and the waste resulting from their exchange and the shared responsibility between all the links involved in the logistics chain for this product, while Resolution 362/2005 of the National Environment Council (CONAMA) requires oils to be recycled through the re-refining process (Batista et al., 2019).

Automotive lubricating oil is a non-biodegradable chemical compound that poses risks of environmental contamination, according to the Brazilian standard NBR 10.004/2004 (Nascimento et al., 2016). CONAMA Resolution 9/1993 classifies lubricating oil as derived from petroleum or chemical synthesis and contaminated lubricating oil, known as OLUC, as that which is unsuitable for its original purpose, contaminated as a result of use or contamination (Nascimento et al., 2016). OLUC contains dust, fuel, water and heavy metals that have a high potential environmental impact if not managed properly (Sencovici & Demajorovic, 2015).

Due to the difficulty in supervising the disposal of used lubricating oil, the waste is used in numerous illegal and unsustainable applications (Shuelter, Fernandes & Taglialenha, 2016). In order to win the trust of customers, companies are obliged to demonstrate an environmentally friendly stance by repositioning their products after sales and by using an image of preserving the environment in which they operate (Pires, 2015).

It can be seen that studies involving the topics of sustainability and lubricating oils have a variety of focuses, from government barriers (Gardas, Raut & Narkhede 2018; Gupta, 2022) to legislation (Schuelter, Fernandes & Taglialenha, 2016; Rebelatto, et al., 2016). In addition, several studies focus on reverse logistics on reverse logistics (Paredes-Rodríguez, Grisales-Aguirre & Sánchez-Zambrano, 2022; Batista, Oliveira, Oliveira, Moura & Santos, 2020; Nascimento, Teixeira, Menezes & Alves, 2016; Sencovici & Demajorovic, 2015); and waste disposal and collection (Ribeiro, Chaves & Muniz, 2018; Oliveira & Magrini, 2017; Gonçalves, 2013); as well as research assessing the costs involved in the reverse logistics process (Paydar, Babaveisi & Safaei, 2017; Seramim, Zanella, Araujo & Bertolini, 2016; Dacroce, Fujihara & Bertolini, 2016) and waste management (Marques, Marques & Silva, 2015; Santos & Conceição, 2017; Müller, Presrlak & Bertolini, 2016). There are also studies discussing the recycling of used lubricating oil (Martins, 2005; Gonzaga, Silva & Andrade, 2021; Tristão, Tristão & Frederico, 2017).

It can be seen that although the studies by Dacroce, Fujihara and Bertolini (2016) and Seramim, Zanella, Araújo and Bertolini (2016) address the issue of costs involved in the reverse logistics process, there are still research gaps to be filled regarding the economic viability of implementing sustainable practices in the process of changing automotive lubricant oils by establishments providing this service, especially regarding the importance that consumers attach to this type of sustainable practice. Thus, improving the organizational image to differentiate itself from competitors, as well as the intense change in consumer purchasing attitudes, are some of the reasons that lead the market to adopt measures and actions aimed at the environment (Bertolini et al., 2012), which leads to the following research question: considering consumers' willingness to pay more for a service, is it feasible to implement sustainable actions in the process of changing automotive lubricating oil? Given this context, the aim of the study is to verify consumers' willingness to pay more for a sustainable lube oil change service and the practical considerations involved in choosing the place to carry out this change.

This research is justified because, according to Tan, Johnstone and Yang (2016), exploring consumer perceptions of ecologically sustainable products, practices and consumption enables a new perception of the barriers and profile of this public, which has contributed to improving the positioning of the business in this market context, which is increasingly competitive and technological, resulting in environmental, social and, consequently, economic gains for the company.

2. LITERATURE REVIEW

Brazilian environmental legislation is made up of a set of legal norms that establish rules related to the environment in order to defend it, promote sustainability and preserve natural resources. Used or contaminated lubricating oil is classified, according to the Brazilian Association of Technical Standards NBR 10004, as hazardous waste, so its management is challenging and it must be recycled through re-refining so that so that there is no contamination of water, soil and air (Gonzaga, Silva & Andrade, 2021).

The main Brazilian laws relating to the recycling of lubricating oils are Law No. 12.305/2010, known as the National Solid Waste Policy, and CONAMA resolutions. Article 33, item IV of the National Solid Waste Policy establishes the obligation to manage solid waste, including OLUC and its packaging, indicating that after consumption it must be returned, via the consumer, to manufacturers, importers, distributors and traders (Rebelatto, et al., 2016).

It also establishes guidelines for structuring and implementing reverse logistics, independent of the public urban cleaning and solid waste management service. The PNRS aims to reduce the extraction of virgin raw materials from the environment and reduce costs in the manufacture of new products, using reverse logistics as a means of reinserting materials into new production processes (Rebelatto, et al., 2016).

Conama is a body that aims to advise, study and propose guidelines and government policies for the environment to other environmental bodies and to decide, within the scope of its powers, on norms and standards for the environment (Conama, 2023). Resolutions 362/2005 and 450/2012 stipulate that OLUC must be collected and re-refined in a way that causes less damage to the environment and prohibits the use of landfills to dispose of the oils; if the oils are contaminated, they must be incinerated with authorization from the environmental agency. CONAMA also determines the minimum percentage that must be collected of used or contaminated lubricating oil in Brazil and in each of the regions, this percentage was 45.5% in 2022, while IBAMA evaluates the results of implementing the resolution (Schuelter, Fernandes & Taglialenha, 2016; Conama, 2023).

There are many governmental barriers which are inadequate government policies or strict and ineffective regulations and this can influence all the other barriers. Understanding this type of barrier and its intensity is very important for making decisions about its elimination and is the first step towards the effective implementation of reverse logistics for lubricating oils (Gardas, Raut & Narkhede, 2018).

Brazil, despite having extensive environmental legislation, faces obstacles arising from the legislation itself. The following are examples of Brazilian governmental barriers to recycling automotive lubricating oils: the useful life of the product ends only after disposal, the manufacturer has responsibility for disposal, but coordinating the entire production chain is challenging (Sencovici & Demajorovic, 2015); recycling cooperatives can act as suppliers in some links of the recycling chain, but the turnover of waste pickers, lack of equipment and safety, precarious infrastructure and lack of legislation hinder the relationship between cooperatives and companies (Sencovici & Demajorovic, 2015); the implementation of reverse logistics must take place through a sectoral agreement, but conflicts between participants mean that agreements are slow in coming (Sencovici & Demajorovic, 2015).

Reverse logistics is an area of logistics that integrates the logistical aspects of returning goods that have reached the end of their useful life to the production cycle, involving processes such as collection, inspection, repair, disposal, disassembly, recycling and remanufacturing of the products collected, adding economic and environmental value to them, reducing damage to ecosystems and preventing waste from being disposed of in the environment (Paredes-Rodríguez, Grisales-Aguirre and Sánchez-Zambrano, 2022). This process becomes important in the sustainability scenario as it reflects the population's awareness, drives sustainable development and considers the end of the product only after it has been correctly disposed of after use (Gupta, 2022; Sencovici & Demajorovic, 2015).

The reverse logistics process for OLUC takes into account adequate infrastructure specifications for its management, both in mechanical workshops and in storage packaging and transportation, to ensure that all links in the chain fulfill their role and that OLUC has its final destination in accordance with the legislation (Batista, Oliveira, Oliveira, Moura and Santos 2020). OLUC is a non-biodegradable petroleum derivative that decomposes in approximately 300 years and whose incorrect disposal of 1 liter is equivalent to the domestic sewage of 40,000 inhabitants (Gonzaga, Silva & Andrade, 2021). The cycle that automotive lubricating oil goes through in order to be recycled includes the production and sale of the oil, its use in cars, collection and finally re-refining, which is the industrial process that makes used or contaminated oil have the basic characteristics of lubricating oils, by removing contaminants (Nascimento, Teixeira, Menezes and Alves (2016).

Companies must adapt to the demands and requirements of consumers if they want to remain competitive and gain a foothold in the market. This is no different for mechanical workshops, which face one of the major global challenges: reducing the amount of chemicals that are hazardous to the environment. This waste requires special attention because it affects people's quality of life and the environment, and this situation is exacerbated when it is discovered that most

workshops do not have a Solid Waste Management Plan (PGRS) due to a lack of resources or knowledge.

Most companies do not invest in environmental issues and, as improper disposal of waste is prohibited, different types of waste end up being mixed, turning non-hazardous waste into hazardous waste, which makes it difficult to collect these materials properly and they end up being disposed of in landfills in an inappropriate manner (Gonçalves, 2013). As seen in many emerging countries, Brazil has experienced exponential growth in the number of cars and with it an increase in the amount of hazardous waste generated, especially lubricating oils, the incorrect disposal of which causes extremely serious damage to the environment (Oliveira & Magrini, 2017). With this progress, the need to strengthen public policies to manage the waste generated has grown. Re-refining, a legal recycling activity for Contaminated and Used Lubricating Oil - OLUC, supported by National Environmental Council - CONAMA resolution no. 362/2005, was the alternative created to add value to this waste (Brasil, 2005).

The problems with refining are that there is little inspection by the responsible bodies and a great deal of prejudice among manufacturers towards the refined product. Another challenge is Brazil's vast territory, which makes it difficult to collect this material, especially in the North and Northeast. The population's lack of awareness about the proper disposal of this contaminated waste is another barrier, which makes it less efficient to send the material for recycling. According to recent studies, only 53% of the lubricating oil generated is sent for recycling (Ribeiro, Chaves & Muniz, 2018).

Companies that provide services and have an impact on the environment tend to allocate a greater proportion of their revenue to preserving, improving and repairing the environment, since they are under greater pressure from the environment in which they operate, and consequently invest more to compensate for damage, guaranteeing social legitimacy. And, depending on the industry, investing in sustainability is a strategic environmental positioning. If we consider that the car fleet in Brazil is growing at an average rate of 5% a year and that this increases the generation of solid waste, the investments needed to adapt the company go far beyond the legal requirements and the prospect of a return, and include the importance of sustainable actions focused on the environmental dimension that guarantees in the market. However, investing in environmental actions is often not a problem for managers, but a challenge that requires time, dedication and professional development (Seramim, Zanella, Araujo & Bertolini, 2016).

With regard to the challenges, the biggest ones are the high costs involved in reverse waste logistics. As these are highly polluting products, the more difficult it is to collect, recycle, reuse or dispose of them correctly, the higher the cost of the entire logistics process. This often ends up encouraging irregular disposal of the product (Paydar, Babaveisi & Safaei, 2017). An alternative to this is for companies to implement an RMSP, since when it is carried out properly, it enables economic, technological, occupational safety and environmental improvements, based on simple, low-cost actions that combine sustainable development and environmental preservation. For this, not only the company's turnover should be evaluated, but also the costs of all the adjustments needed to provide environmentally friendly services (Dacroce, Fujihara & Bertolini, 2016).

The waste generated in mechanical workshops has become a cause for concern and its improper disposal and storage results in environmental and public health problems. For this reason, machine shops must be concerned about all the waste generated in the process: packaging, flannels, towels and and even liquid effluents such as oils, greases and fuels used to clean the surfaces to be worked on or to clean parts. Plastic packaging is a major concern not only because of its disposal, but also because of the oil residue. That's why, after use, they need to be completely emptied, draining the product contained in the walls and bottom of the packaging, in order to reduce the remaining amount inside as much as possible (Santos & Conceição, 2017).

All this waste is classified according to the potential risks to the environment and public health. In order for them to be handled and disposed of properly, companies need to comply with NBR 10004, which deals with this subject, based on a sustainable policy. NBR 10004 divides this waste into 2 categories: class I: hazardous waste is waste whose physical, chemical or infectious properties pose a risk to public health and the environment if it is improperly managed; class II: non-hazardous waste, but which may have properties such as biodegradability, combustibility or solubility in water. As for storage, the standard emphasizes that the company must have a plan for "temporary containment, in an area authorized by the environmental control body, awaiting recycling, recovery or adequate final disposal, provided that it meets basic safety conditions". This demonstrates the importance of efficient workshop waste management and how this

contributes to preserving the environment (Marques, Marques & Silva, 2015).

One of the main contaminants of the soil is lubricating oils and petroleum products, when handled or disposed of improperly. Improving the quality of life mistakenly thought to be linked only to consumption, when it is important to note that the natural resources that are essential for the production of consumer goods are finite. This requires companies to adopt a sustainable stance, not just to reduce waste emissions, but by incorporating sustainable practices into their activities, saving direct and indirect costs, having a low negative impact on the environment and being socially responsible (Müller, Presrlak & Bertolini, 2016).

After the sale of automotive lubricants, the - successful - production chain ends and the environmental problem begins. When discarded, lubricant bottles still retain a significant amount of oil. Because of this, considering the characterization of the waste generated, the Plastic Bottle + Oily Waste combination can be considered "Hazardous" waste - Class I. The processes used to recycle it start with separation, grinding, washing, drying and agglutination, and finally extrusion and granulation (Martins, 2005).

Used oil, on the other hand, is a resource that, if properly recycled, can return to the production chain unlimited times, suffering only the losses of each process. Re-refining technology has come a long way since the days when oil was regenerated simply by removing water, dust, sludge and some volatile compounds. Today, re-refined oil goes through a process very similar to that which crude oil goes through in a refinery, with stages including vacuum distillation and hydrotreatment (Tristão, Tristão & Frederico, 2017).

The physical-chemical process of re-refining aims to recover the characteristics that are lost with the use of the oil, transforming it into a new raw material for the production of new lubricating oil. In addition to the environmental aspect, it is also economically viable, since producing base oil from used oil in a re-refinery consumes only 33% of the energy it would take to produce the same amount of base oil from crude oil in a refinery (Gonzaga, Silva and Andrade, 2021).

Based on the literature review carried out, several relevant variables were identified and analyzed in the context of the study on the reverse logistics of automotive lubricating oil. The following table summarizes these variables, together with the respective authors and the main findings of each article. This table seeks to provide a panoramic view of each author's contributions to the topic in question, highlighting the different perspectives and insights offered. By analyzing and comparing these variables and findings, we seek a more comprehensive and grounded understanding of the relationships investigated, providing a solid starting point for choosing the variables that will be used in the data collection:

Variables	Authors	Main results found
Legislation	Schuelter, Fernandes e Taglialenha (2016)	The effective establishment of reverse logistics depends on two factors: an increase in research and technological innovation activities and the creation of a market for recycled products.
	Rebelatto, et al.(2016)	Presentation of more robust critical considerations of the Agreements, seeking to broaden the understanding of the variables involved in the problem of Reverse Logistics, and to provide subsidies for the improvement of these Systems.
Reverse Logistics	Paredes--Rodríguez, Grisales-A-guirre e Sánchez--Zambrano (2022)	The most significant risks in the reverse logistics of used vehicle oil are inadequate storage, the lack of a suitable vehicle for transportation and the low quality of the waste.
	Batista, Oliveira, Oliveira, Moura e Santos (2020)	Reverse logistics of OLUC is not effective, and greater supervision of oil change establishments and environmental education are needed.
	Nascimento, Teixeira, Menezes e Alves (2016)	More than half of the respondents are aware of the important role of the controller's office, but the majority do not have sufficient knowledge, although they do take actions that are appropriate for the correct disposal of waste.
	Sencovici e Demajorovic (2015)	Technological advances now make it possible to generate re-refined oil with superior properties to virgin oil (economic and socio-environmental gains), but there are several difficulties in doing so.

Variables	Authors	Main results found
Disposal and collection	Ribeiro, Chaves e Muniz (2018)	Some companies still dispose of OLUC improperly. The main causes are: lack of supervision, complex taxation and the lack of credibility of the reused oil.
	Oliveira e Magrini (2017)	Reducing the proportion of LOPCs going to landfill has a positive impact on reducing the burdens caused by the life cycle of LOPCs. Incineration has proved to be a promising option, but it is not used in Brazil.
	Gonçalves (2013)	The results obtained led to the conclusion that not only is it technically feasible, but also environmentally and economically it has very favorable results.
Costs	Paydar, Babaveisi e Safaei (2017)	Two objective functions are considered: profit maximization and revenue risk minimization. The augmented ε constraint approach is used to solve the bi-objective model.
	Seramim, Zanella, Araujo e Bertolini (2016)	It was possible to conclude on the viability, based on consumers' willingness to pay more for services in a mechanic's shop that adds value to the service by using environmentally sustainable practices.
	Dacroce, Fujihara e Bertolini (2016)	Procedures were proposed that were easy to implement and affordable, but effective in reducing environmental impacts. The investment analysis of the ecological services project proved to be viable, generating a profit for the company.
Waste management	Marques, Marques e Silva (2015)	Waste management in the workshop, as in other companies in different segments, needs to be environmentally conscious and seek to promote environmental conservation, starting with the activity itself.
	Santos e Conceição (2017)	The results of the analysis of the effluent from the oil and water separator and the organization of the workshop showed the importance of the management system, which proved to be viable and necessary, especially given that the workshop under study is located near a body of water.
Waste management	Müller, Presrlak e Bertolini (2016)	With the data collected, suggestions for improvement were made based on current legislation, such as adapting the waste storage barrels and building a containment barrier for the used lubricant oil barrel.
Recycling	Martins (2005)	Discusses the problem of used commercial lubricant bottles (considering the disposal methods usually used and the technical and marketing aspects of the waste)
	Gonzaga, Silva e Andrade (2021)	The proper management of used lubricating oils is in line with ideas discussed worldwide. It is necessary to restructure waste management practices and actions to increase the performance of reverse logistics.
	Tristão, Tristão e Frederico (2017)	There are systemic deficiencies and a need to improve the LR system in the lubricant oil recycling process. Benefits: streamlining the process, adding value and minimizing environmental impacts.

Table 1: Variables and main findings of each author

Source: authors of the survey (2023)

Taking Table 1 into account, these variables make it possible to construct four distinct blocks. In the first block, information on the participants' socio-economic profile was collected. In the following blocks, the questions were organized and tabulated based on the variables listed in Table 1. The second block, related to consumption habits, used variables such as costs, waste disposal and collection. In the third block, which dealt with knowledge and evaluation of the competition, the variables used were costs and reverse logistics. Finally, in the fourth block, referring to testing the business concept, the analysis used variables such as waste management, legislation, destination and collection, as well as the cost variable.

Assessing the feasibility of implementing the service at the garage is supported by analyzing consumers' willingness to make additional payments and what percentage they would be willing to pay. This approach is based on specific investments, as identified by researchers such as Seramim, Zanella, Araujo & Bertolini (2016), which include restructuring the infrastructure and effectively managing the solid waste generated by the garage. Among the necessary measures are waterproofing the

floor, installing containment channels, refurbishing the water and oil separator box, purchasing suitable containers for segregating waste and training employees, all of which require resources and commitment. In the business context, investments are directly linked to the prospect of a return, whether in terms of savings or the projection of the entity as an agent committed to environmental values. Although environmental actions should not depend exclusively on consumers' willingness to pay more, this variable needs to be considered and analyzed in greater depth. Therefore, in order to make the environmental project viable, it is essential to consider the following hypothesis:

Hypothesis 1: Price is the main factor in consumers' choice of where to get their vehicle's oil changed.

Hypothesis 2: There is a significant difference between consumers willing to pay more for an ecologically sustainable oil change service, with correct waste disposal and less environmental impact.

This hypothesis is broken down by the following sub-hypothesis:

Hypothesis 2.1: There is a significant willingness among consumers to accept an increase of up to 10% in the cost of ecologically sustainable oil change services.

These hypotheses are fundamental to directing the research and providing insights into consumer acceptance of sustainable services, as well as their financial expectations associated with such practices.

3. METHODOLOGICAL PROCEDURES

This study is characterized as exploratory research of a quantitative nature. This research requires a wide range of interconnected information, as highlighted by Triviños (1987), seeking to describe the characteristics of a given population and investigating the relationship between the variables found in the literature review. The final objective is to verify consumers' willingness to pay more for a sustainable lube oil change service and the practical considerations involved in choosing the place to carry out this change.

In order to establish the objective of this work, the initial procedure consisted of conducting a systematic literature review, with the aim of deepening the concepts related to the subject. To do this, the Web of Science, Scopus, Capes and Google Scholar databases were used, using the keywords "reverve" + oil. As exclusion criteria, only articles whose titles and abstracts were aligned with the scope of the research were considered, resulting in a final database made up of 4 articles from Web of Science, 4 articles from Scopus, 7 articles from Capes and 7 articles from Google Scholar.

The next step was to determine the size of the population needed for data collection. As the research is aimed at mechanics in the city of Catanduvas, the target audience was determined to be all residents of the city of Catanduvas who owned a car, and for this, the fleet of vehicles registered in the municipality, Detran in the year 2022, was considered. The total fleet was 5,571 vehicles, but of this number, only the types of vehicles that have their lubricating oil changed in mechanics' workshops were taken into account, i.e. cars, vans, pickup trucks and utility vehicles. All other vehicles were discarded, such as trucks, truck-tractors, mopeds, minibuses, motorcycles, scooters, motor homes, buses, quadricycles, trailers, semi-trailers, sidecars, crawler tractors, wheeled tractors, mixed tractors and tricycles. For the population, the sum of 3,114 cars, 730 pickup trucks, 182 vans and 38 utility vehicles was considered, for a total of 4,064 vehicles (DETRAN, 2022).

Thus, considering a population of 4064 vehicle users and a sampling error of 8%, the minimum sample size to be collected is 150 respondents. The sample was defined based on the following equations:

$$n_0 = \left(\frac{1}{\varepsilon_0}\right)^2 \quad \text{e} \quad n = \frac{(N * n_0)}{(N + n_0)}$$

Where n0 = first approximation of the sample size, e0 = sampling error, n = sample size and N = population size (Pinheiro, da Cunha and Carvajal, 2009).

Sample error	n0	Sample size (n)
1%	10000	2890
2,5%	1600	1148
5%	400	364
6%	277,77	260
7%	204,081	194
8%	156,25	150
10%	100	98
15%	44	44
20%	25	25

Table 1: Sample Error Table
Source: authors of the survey (2023)

For data collection, a questionnaire was drawn up via Google Forms containing 15 (fifteen) questions sent to residents of the city of Catanduvas/PR via messaging apps, emails and social networks, between July 14 and 28, 2023. The structure of the questionnaire included obtaining information on the socio-economic profile, consumption habits, knowledge and evaluation of the competition, as well as testing the business concept.

The four blocks of questions created from Table I were treated individually, allowing for a detailed exploration of the relationships within each domain. Subsequently, the information collected was cross-referenced in order to identify broader patterns and reveal interconnections between different aspects of consumer behavior, so as to enable companies to analyze the consumer's willingness to make an additional payment due to the company's adoption of a sustainable stance, incorporating environmentally conscious practices and having a positive impact on the environment and society (Müller, Presrlak & Bertolini, 2016). In this context, the comprehensive and systematic analysis of this data will provide valuable insights that will guide the implementation and development strategies of the service provided, based on the preferences and trends identified in the sample of the population surveyed and based on the data related to the socioeconomic profile of the 162 respondents, the diverse representativeness of the sample becomes evident.

After collecting the data, a total of 162 responses were added to the database, providing a solid basis for the subsequent analysis of the results. Data analysis was conducted using Action Stat software version 3.6. After the individual analysis of each block of questions, we proceeded to test the hypotheses that had previously been tabulated. This approach allowed for a thorough evaluation of the results and a well-founded conclusion on the issues raised in each block of the questionnaire about consumer willingness to implement sustainable actions in the process of changing automotive lubricant oil.

4. RESULTS AND ANALYSIS

Data analysis represents a crucial step in understanding the factors that influence the acceptance of an ecologically sustainable oil change service. The questionnaire that was applied covered a variety of areas, including socio-economic profile, consumer habits, knowledge of regulations and assessment of competition, as well as testing the concept behind the proposed business.

The first block to be analyzed is the socio-economic profile of the respondents (Table 2). There is a balanced distribution of age groups, with the highest proportion of respondents aged between 29 and 38 (37.65%), followed by 39 to 50 (29.63%) and 18 to 28 (16.67%). This distribution reflects a sample that covers a wide range of ages, which allows us to explore how different age groups can influence acceptance of the proposed service.

What's your gender?	Female	Male	
	48,77%	**51,23%**	
What is your marital status?	Married	Divorced	Living with partner
	52,47%	**6,17%**	**17,28%**
	Single	Widowed	
	23,46%	**0,62%**	
What is your age?	18 to 28 years	29 to 38 years	39 to 50 years
	16,67%	**37,65%**	**29,63%**
	51 to 60 years	Over 61 years	
	11,11%	**4,94%**	
What is your salary range?	R$ 1.320,00 to R$ 2.640,00	R$ 2.641,00 to R$ 5.280,00	R$ 5.281,00 to R$ 7.920,00
	15,43%	**25,31%**	**15,43%**
	R$ 7.921,00 to R$ 10.560,00	R$ 10.561,00 or R$ 13.200,00	R$ 13.201,00 or more
	13,58%	**8,64%**	**21,60%**
What is your level of education?	Incomplete primary education	Incomplete primary education	High school incomplete
	3,09%	**1,23%**	**1,23%**
	Completed high school	Complete university degree	Postgraduate studies
	12,35%	**25,31%**	**56,79%**

Table 2: Socio-economic profile of questionnaire respondents
Source: authors of the survey (2023)

As for education, the results indicate a significant presence of respondents with completed higher education (25.31%), followed by those with postgraduate degrees (25.31%) and completed high school (12.35%). This educational panorama reinforces the importance of understanding how the level of education can influence attitudes towards sustainability and the adoption of ecologically responsible services. When analyzing the salary distribution, we noticed that the majority of respondents fall into the intermediate income brackets, especially those with salaries between R$ 2,641.00 and R$ 5,280.00 (25.31%), R$ 5,281.00 and R$ 7,920.00 (15.43%), and R$ 7,921.00 and R$ 10,560.00 (13.58%). With regard to marital status, most respondents were single (23.46%), followed by married (17.28%) and living with a partner (17.28%).

In the next stages of the analysis, these data will be compared and correlated, providing a more comprehensive view of the interactions between socio-economic variables and the willingness to adopt an ecologically sustainable oil change service. The meticulous approach of individual analysis and subsequent cross-checking of this data will contribute to a deeper understanding of consumers' motivations and behaviors towards sustainability.

Based on consumption habits, the evaluation contributes to a deeper understanding of consumer preferences and the possible influences that shape their decisions. Of the 162 respondents, 95.71% indicated that they already own or have owned a vehicle, demonstrating a potential for adherence to the oil change service. When asked if they had ever taken their vehicles in for an oil change, 144 of the participants (88.34%) answered positively and only 11 people (6.75%) mentioned that someone else in the family is responsible for this task. This statistic suggests that the majority of respondents recognize the importance of having their oil changed regularly.

One notable aspect of consumer habits is the attention paid to the manufacturers' oil change recommendation. Among those interviewed, 123 people (75.46%) said that they usually comply with this recommendation, changing oil according to the specified period, and 29 participants (17.79%) admitted to following the recommendations most of the time, while 5 (3.07%) said they didn't pay any attention to it. This contrast indicates a variety of approaches to vehicle maintenance, which demonstrates the need for research to fill the gaps related to the economic viability of the process of implementing reverse logistics for lubricating oils and all the costs involved in this process (Paydar, Babaveisi & Safaei, 2017). In this sense, the analysis of consumption habits therefore suggests that the vast majority of participants recognize the importance of oil changes and try to follow the manufacturers' recommendations. This disposition can directly influence the acceptance of an ecologically sustainable oil change service, as consumers already have a history of engagement in vehicle maintenance.

With regard to the Knowledge and Evaluation of Competition block, the analysis of these answers provides

a significant insight into the underlying influences and motivations that guide the choice of places to change automotive oil. By considering the factors that impact this decision, it is possible to better understand how consumers perceive and evaluate the available options.

When analyzing the interviewees' responses to this block, it is worth noting that the majority of interviewees (81.60%) expressed a preference for having their oil changed at trusted places where they are already used to having the service carried out. This finding suggests the importance of building a relationship of trust between the customer and the service provider, indicating that loyalty is influenced by past experience. In addition, analysis of the data reveals that service plays a significant role in the motivation to choose a place for an oil change. Around 70 participants (42.94%) cited service as a decisive factor, highlighting the relevance of the customer experience in the choice process.

Concern about price also emerged as a key consideration for many respondents. Approximately 28 respondents (17.18%) highlighted price as one of the main motivators for choosing an oil change location. This finding underscores the importance of price competitiveness in the automotive service market. Recommendations, both from gas station attendants and acquaintances, proved to be influential for a significant proportion of those interviewed. Around 23.31% of respondents indicated that recommendations play an important role in their decision-making, indicating the importance of third-party opinions in shaping choices. It is noteworthy that the option of concern for the environment was not a decisive factor for the interviewees, as only 7 (4.32%) of the interviewees said that this would be a factor in their choice of location for the service.

If you choose a place to have your car's oil changed, what motivates your choice?	
Service	43,21%
Recommendation	23,46%
Price	17,28%
Proximity to your home	5,56%
Concern for the environment	4,32%
Vehicle warranty	1,85%
Cost-effectiveness	1,23%
Service	0,62%
Quality	0,62%
Confidence	0,62%
I've never owned a car	0,62%
I don't have a car	0,62%
Grand Total	**100,00%**

Table 3: Answers to the questionnaire on motivation for choosing an oil change
Source: authors of the survey (2023)

Thus, the analysis of the data related to Knowledge and Evaluation of Competition revealed the interaction of factors that guide the choice of oil change locations, which should be analyzed together with the other blocks to provide a more complete understanding of the dynamics of consumer decisions, allowing a clearer picture to be drawn of the influences that shape consumer preferences and motivations in relation to sustainability and environmentally responsible practices.

The last block analyzed was the Business Concept Test, where the answers provided valuable insights into consumers' receptiveness to the ecologically sustainable oil change service and their willingness to pay more for this service, especially considering the variables of legislation, disposal and collection.

By assessing the attitudes and considerations of the participants, it is possible to understand the feasibility and potential success of introducing a service focused on sustainability. Initially, when asked whether they had considered disposing of the lubricating oil and waste generated, we found that 108 participants (66.26%) said they had not considered this aspect, while 54 (33.14%) said they had already considered disposing of the oil. This

split in responses suggests that a significant proportion of consumers may be less aware of the proper disposal of this waste, creating an opportunity for education and awareness-raising.

With regard to the existence of specific legislation for the disposal and collection of lubricating oil, 95 participants (58.28%) said they were aware, while 67 (41.02%) said they were unaware. As the PNRS made it compulsory to properly manage lubricating oils and waste (Batista et al., 2019), it is clear that there is a gap in consumer awareness regarding the obligation of establishments to comply with disposal rules. This distribution reveals that a considerable proportion of those interviewed are already informed about the regulations, which may indicate a growing awareness of environmental issues, but may be a warning sign for the service offered, and it is necessary to assess the willingness of these consumers to pay.

When asked about their willingness to change their vehicle's oil at a place that does not follow the appropriate waste disposal standards, 113 participants (69.33%) said they would not stop changing the oil, while 49 (30.06%) said they would stop if the place did not follow the existing legislation and standards. This result is a warning sign, as Brazil has experienced exponential growth in its automobile fleet and consequently in the amount of hazardous waste generated, especially lubricating oils, the incorrect disposal of which causes extremely serious damage to the environment (Oliveira & Magrini, 2017). This result suggests that, although a significant portion of those interviewed value compliance with disposal regulations, the majority still consider oil changes to be a priority and that proper disposal would not be a decisive factor when choosing where to change the oil.

On the other hand, a sustainability approach seems to find greater acceptance when we consider the willingness of participants to adopt an ecologically sustainable oil change service. Approximately 132 respondents (81.00%) stated that they would be interested in a service that disposed of waste correctly and had less impact on the environment, even if this meant a slightly higher price. This shows that if the workshop manages to implement an efficient waste management system, it will help to attract new customers and also help to preserve the environment (Marques, Marques & Silva, 2015). This suggests that environmental awareness can be a significant motivating factor for adhering to a sustainable service, which is directly reflected in the answer to the next question.

When asked about the maximum amount they would be willing to pay extra for this sustainable service, the majority of participants (61.35%) indicated that they would be willing to pay up to 10% more. In addition, a considerable portion would be willing to extend this amount, with 23 respondents (14.11%) indicating a willingness to pay up to 15%, while 7 participants (4.29%) would consider paying up to 20% more. On the other hand, a minority would choose not to pay an additional amount, with 25 respondents (15.34%) saying they would not be willing to pay more for an ecologically sustainable service. A small group (7 participants, corresponding to 4.29%) were willing to pay more than 25% for a sustainable service.

These findings constitute a crucial element in shaping the pricing and communication strategy of the service, with a view to meeting the different mentalities and motivations of consumers in relation to sustainability, since a properly carried out RMSP makes it possible to improve not only economically, but also technologically, It is based on simple, low-cost actions that combine sustainable development and preservation of the environment. Not only should the company's turnover be assessed, but also the costs of all the adjustments needed to provide environmentally friendly services (Dacroce, Fujihara & Bertolini, 2016).

What is the maximum amount you would be willing to pay extra for an ecologically sustainable lube oil change service?	
I wouldn't be willing	15,43%
Up to 10%	61,73%
Up to 15%	14,20%
Up to 20%	4,32%
More than 25%	4,32%
Grand Total	**100,00%**

Table 4: Answers to the questionnaire on willingness to pay extra for sustainable services
Source: authors of the survey (2023)

5. HYPOTHESIS TESTING

After analyzing the data from each block, the data was submitted to test the previously formulated hypotheses. The comprehensive and detailed information obtained by investigating the four blocks, as well as the attitudes towards the concept of an ecologically sustainable oil change service, provide a solid basis for evaluating these hypotheses. Our focus is on verifying the consistency

between the hypotheses and the patterns observed in the data collected. In order to rigorously test the hypotheses, we chose to use ACTION STAT statistical software, version 3.6. It was chosen because of its ability to carry out statistical analysis, allowing a precise and detailed approach to the relationships between variables. The use of this tool gives robustness to the evaluation of the hypotheses, ensuring reliable and substantial results that support the conclusions of this study.

To test Hypothesis H1, we used the proportion test, a statistical technique suitable for assessing the association between categorical variables, where the hypothesis is rejected when the p-value is less than 0.05 ($\alpha = 0.05$). In this case, the variable analyzed refers to the motivation for choosing a place to get an oil change. It was found that only 25 of the respondents indicated price as the main factor in their choice. This result showed a significantly low p-value (p-value = 1.37E-18), which suggests strong statistical evidence to reject the hypothesis. Therefore, based on this analysis, the initial assumption that consumers have price as the main factor in choosing where to change their vehicle's oil is not confirmed.

To estimate the validity of Hypothesis 2 (H2), which asks whether there is a significant difference between consumers willing to pay more for an ecologically sustainable oil change service, with correct waste disposal and less environmental impact, the proportion test was used. The variable considered was the participants' willingness to pay extra for this type of service. The analysis showed that 82.10% (133) of the respondents were willing to pay extra, while 17.90% (29) were not. The test resulted in a p-value of 3.06E-16, which suggests a statistically significant difference between the proportions.. Therefore, these results support H2, demonstrating that there is a significant difference between consumers willing to pay more for an ecologically sustainable oil change service. This contributes to an informed perception of consumers' willingness to adhere to more sustainable practices.

The last test carried out to validate hypothesis H2.1 explored consumers' willingness to accept an increase of at least 10% in the cost of services related to ecologically sustainable oil changes. To examine this, we analyzed the variable that asked participants about the maximum amount they would be willing to pay extra for the ecologically sustainable lube oil change service. The proportion test was used to determine whether a significant proportion of consumers were willing to pay this extra. The results were revealing, with a p-value of 2.17E-18, rejecting the null hypothesis and showing that there is a marked willingness among consumers to accept a minimum 10% increase in the cost of ecologically sustainable services. The success ratio in the sample, calculated at 0.8447, confirms this trend, and the lower (0.7888) and upper (0.9007) limits of the success ratio offer a reliable range of results. Based on these findings, it can be concluded that respondents are inclined to consume a more sustainable service, even with a modest increase in costs.

6. DISCUSSION

In short, this study sought to analyze the factors that influence the acceptance of an ecologically sustainable oil change service in the city of Catanduvas/PR. Through the data collected in four blocks, it was possible to obtain valuable information about consumer attitudes, motivations and preferences in relation to motivation, consumption habits and environmental sustainability.

The findings in relation to the socio-economic profile of the participants revealed a diverse sample in terms of age group, level of education and salary distribution. This diversity demonstrates the representativeness of the sample and enriches the understanding of the nuances that permeate the acceptance of sustainable services in different demographic groups.

With regard to consumption habits, the results showed a significant awareness of the importance of regular oil changes, with the majority of participants following the manufacturers' recommendations. Awareness of the importance of regular oil changes was also evidenced in the studies by Marques, Marques and Silva (2015). These studies pointed to the need for greater environmental awareness of the waste management practices adopted by garages, seeking to promote environmental preservation through their own activities. This is in line with the results found in this study. The attention given to the recommendation, as well as the concern about price, reinforced the complexity of the considerations that shape consumer choices. However, the lack of emphasis on concern for the environment as a decisive factor indicated an opportunity for additional awareness-raising and education. This result reinforces the conclusions made in the study by Nascimento, Teixeira, Menezes and Alves (2016), which indicate that more than half of the respondents are aware of the crucial role of environmental management, but many lack substantial knowledge, although they still carry out appropriate actions for the proper disposal of waste.

With regard to knowledge and evaluation of the competition, it was possible to gain a detailed insight into the underlying influences on the choice of oil change locations. The preference for trusted locations, the role of customer service and the influence of recommendations highlighted the importance of past experiences and reliability in the consumer's decision. Awareness of the existence of specific regulations revealed a gap in the awareness of some participants, highlighting the need for more comprehensive educational approaches. The willingness to pay a slightly higher price for an environmentally conscious service reflected a growing awareness of the importance of sustainability. However, the willingness to change oil at non-compliant disposal sites highlighted the complexity between valuing sustainability and the practical and cost-benefit considerations that consumers take into account.

Examining the responses related to the business concept test provided decisive information on consumers' receptiveness to a sustainable service.

This is in line with the results pointed out by Dacroce, Fujihara & Bertolini (2016), who stated that adaptations in organizations do not occur only to comply with legal requirements, but also due to the awareness of entrepreneurs and changes in the profile of consumers.

After carrying out the statistical tests to validate the three hypotheses formulated, the consumer's willingness to pay extra and accept an ecologically sustainable oil change service were verified. In the first test, when checking the influence of price on the choice of oil change location, it was found that only a minority of respondents pointed to price as the main factor. This result, reinforced by the low p-value (1.37E-18), contradicts the initial hypothesis, indicating that price is not the main motivator in decision-making.

Turning to the second test, which concerns consumers' willingness to pay more for an ecologically sustainable service, the extremely low p-value (3.06E-16) shows a significant difference between consumers willing to pay more for an ecologically sustainable oil change service. This result, which is supported by the proportions observed (82.10% in favor and 17.90% opposed), supports Hypothesis 2 and indicates that there is a solid basis for consumer adherence to more sustainable practices.

Finally, the third hypothesis, which aimed to assess consumers' willingness to accept a minimum 10% increase in the cost of ecologically sustainable services, was also supported by the results. The proportion test had an extremely low p-value (2.17E-18), indicating a statistically significant difference between consumers. These results, together with the proportions observed (84.47% in favor and 15.53% opposed), confirm that consumers are willing to accept a modest increase in costs in order to subscribe to a more sustainable service.

In relation to these findings, it is essential to note that the survey carried out by Seramim, Zanella, Araujo and Bertolini (2016) revealed that 35.29% of consumers rejected paying extra and that in the survey carried out by Dacroce, Fujihara & Bertolini, 2016, the vast majority of consumers would only accept paying a 5% price increase. These results reinforce the understanding that willingness to pay more should not be the only factor considered to attract consumers who prioritize environmental issues.

Thus, the results indicate that factors such as price, willingness to pay more for sustainable practices and acceptance of increased costs are interconnected and influential in consumer choice. These findings have significant effects for the implementation strategy of this service, supporting the need for a sustainable and conscious approach to meet consumer preferences and promote environmentally responsible practices.

Based on the data collected from the questionnaires and the hypotheses tested, it is clear that implementing sustainable actions in the process of changing automotive lubricating oil is feasible and can be widely accepted by consumers. Analysis of the information from the questionnaires revealed a significant willingness on the part of consumers to adhere to an ecologically sustainable service, with correct waste disposal and less environmental impact. At the same time, the results of the statistical tests confirmed that consumers are willing to pay more for a sustainable service, even if this involves an increase in costs.

These findings indicate the importance given by consumers to choosing reliable locations, quality service and consideration of environmental factors. The socio-economic profile of consumers also suggests a diversity of age groups, levels of education and income, which provides a solid basis for implementing strategies that cater to different consumer profiles.

Therefore, all the results found in this study corroborate previous studies, such as the results pointed out by Seramim, Zanella, Araujo and Bertolini (2016), which highlight the viability based on consumers' willingness to pay more for services in a mechanic's shop that adopts environmentally sustainable practices and the studies by Dacroce, Fujihara and Bertolini (2016) which point out that implementing accessible and effective practices to reduce environmental impacts attracts consumers and has proven viable, generating profit for the company.

7. FINAL CONSIDERATIONS

This study makes a significant contribution by demonstrating, through robust statistical tests, the willingness of consumers to adhere to ecologically sustainable services when changing their car's oil, even with an increase in costs. In addition to providing information for companies in the sector, these results enrich the academic field by broadening the understanding of consumer motivations and behaviors, and can serve as a basis for future research exploring sustainable practices in various industries and contexts.

One gap highlighted in this research was the scarcity of studies addressing the relevance that consumers attach to these sustainable practices. In this context, this research seeks to fill this theoretical void, contributing to the understanding and deepening of the subject, as well as to the knowledge base around consumers' willingness to pay more for environmentally conscious oil change services.

Therefore, considering the willingness of consumers to adhere to these practices, even at a higher cost, and the results obtained, it is feasible to implement sustainable actions in the automotive lubricant oil change process. The willingness shown by consumers to pay more for an ecologically responsible service, combined with growing environmental awareness and the search for more sustainable practices, provides a favorable environment for adopting practices that not only benefit the environment, but also contribute to the company's positive image and customer loyalty, consequently bringing economic gains to the company. Thus, entrepreneurs can obtain satisfactory results by adapting their establishments to offer ecologically correct services and investing in advertising, so that consumers are aware of the offer.

Thus, this study helps to understand the motivations, attitudes and behaviors of consumers in relation to the scope researched. The findings highlight the importance of environmental awareness and education strategies, as well as the need to align the offer of sustainable services with consumer expectations. Implementing an efficient waste management system can not only attract customers, but also contribute to economic, technological, occupational safety and environmental improvements. In the constantly evolving scenario of environmental awareness and the search for more sustainable practices, the results of this study have significant implications for companies seeking to incorporate ecologically conscious principles into their business models.

As a contribution to the field of studies related to consumer behavior and corporate sustainability, the article offers a detailed analysis of the factors that influence the acceptance of an ecologically sustainable oil change service, filling a gap in the understanding of these motivations in relation to environmentally responsible practices in the automotive sector.

In addition, the conclusions drawn about consumers' willingness to pay more for a sustainable service and the practical considerations involved in choosing oil change locations offer valuable insights for companies looking to develop business strategies in line with growing environmental awareness. Commercial associations, through their sectoral chambers, can create programs to promote sustainable companies and publicize them to the population.

These contributions not only inform business practices, but can also influence public policy by highlighting the importance of environmental education and awareness for sustainable behavior change on the part of consumers. In this way, public authorities have the possibility of creating subsidies and programs for companies in the sector that adopt sustainable practices and adhere to environmental programs.

This study offers several promising directions for future research at the intersection of consumer behavior and corporate sustainability. Further exploration is suggested in the search for effective environmental education and awareness strategies that can be implemented by companies to better inform consumers about the proper disposal of waste and the positive impacts of sustainable practices.

In addition, longitudinal studies that follow the evolution of consumer attitudes and behaviors over time would allow for a more in-depth understanding of trends in the adoption of ecologically sustainable services. Also, considering the growing importance of environmental issues in consumer decision-making, a future study could investigate the relationship between a company's perceived sustainability and its reputation and loyalty on the part of consumers.

Such future research has the potential to further enrich our understanding of the influences between consumer behavior and corporate sustainability practices.

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AUTHORS

ORCID: 0009-0005-3295-3003
KATIA CRISTINA BERGAMINI TITAO, Mestranda em Administração - Universidade Estadual do Oeste do Paraná, Cascavel – PR – Brasil. Correspondência para: R. Universitária, 1619 - Jardim Universitário. CEP: 85819-110 - Cascavel – PR. E-mail: kbtitao@gmail.com

ORCID: 0009-0008-0413-4344
ELAINE CRISTINA DANTAS PEIXOTO MECÊS, Mestranda em Administração - Universidade Estadual do Oeste do Paraná, Cascavel – PR – Brasil. Correspondência para: R. Universitária, 1619 - Jardim Universitário. CEP: 85819-110 - Cascavel – PR. E-mail: elaine_peixoto@hotmail.com

ORCID: 0000-0002-7769-1423
CARINA LANGARO, Mestranda em Administração - Universidade Estadual do Oeste do Paraná, Cascavel – PR – Brasil. Correspondência para: R. Universitária, 1619 - Jardim Universitário. CEP: 85819-110 - Cascavel – PR. E-mail: carinalangaro@hotmail.com

ORCID: 0000-0001-6184-8011
JERRY ADRIANI JOHANN, docente do Doutorado em Engenharia Agrícola, do Doutorado Profissional em Administração e do Mestrado em Contabilidade. Doutor em Engenharia Agrícola - Universidade Estadual do Oeste do Paraná, Cascavel – Pr – Brasil. correspondência para: R. universitária, 1619 - jardim universitário. cep: 85819-110 - cascavel – pr. e-mail: jerry.johann@hotmail.com

ORCID: 0000-0001-9424-4089
GEYSLER ROGIS FLOR BERTOLINI, docente do Doutorado em Desenvolvimento Rural Sustentável, do Doutorado Profissional em Administração e do Mestrado em Contabilidade. Doutor em Engenharia de Produção - Universidade Estadual do Oeste do Paraná, Cascavel – Pr – Brasil. correspondência para: R. universitária, 1619 - jardim universitário. cep: 85819-110 - cascavel – pr. e-mail: geysler_rogis@yahoo.com.br

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ECDPM: conceptualization, investigation and writing - original draft.

CL: conceptualization, investigation and writing - original draft.

JAJ: conceptualization, supervision, formal analysis and methodology.

GRFB: conceptualization, supervision and writing - review & editing.
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ASSESSMENT OF THE MECHANICAL AND ENVIRONMENTAL PROPERTIES OF CONCRETES WITH HIGH LEVELS OF LIME FILLER AND FLY ASH

AVALIAÇÃO DAS PROPRIEDADES MECÂNICAS E AMBIENTAIS DE CONCRETOS COM ALTOS TEORES DE FILER CALCÁRIO E CINZA VOLANTE

EVALUACIÓN DE LAS PROPIEDADES MECÁNICAS Y AMBIENTALES DE HORMIGONES CON ALTO CONTENIDO DE POLVO DE CALIZO Y CENIZAS VOLANTES

SILVANE SANTOS DA SILVA | UFSM – Universidade Federal de Santa Maria, Brasil
ANDRÉ LÜBECK | UFSM – Universidade Federal de Santa Maria, Brasil
GERALDO CECHELLA ISAIA | UFSM – Universidade Federal de Santa Maria, Brasil
GUSTAVO DE AGUIAR ISAIA | UFSM – Universidade Federal de Santa Maria, Brasil
ALMIR BARROS DA SILVA SANTOS NETO | UFSM – Universidade Federal de Santa Maria, Brasil

ABSTRACT
This study evaluated the possibility of producing high strength concrete (HSC) by replacing Portland cement (PC) with high levels of limestone filler (LF) in binary mixtures and ternary mixtures of PC, LF and fly ash (FA) in contents varying from 50 % to 80 %, with the objective of reducing CO2 emissions during manufacture. Parameters evaluated were axial compression strength, CO2 emissions of the constituent materials and cost per m^3 of concrete with focus on reductions in environmental impact. Results indicated the possibility of producing HSC with high LF and FA contents, reduced water/binder content (w/b = 0.25) and workability of 100 mm 20 mm through particle packaging and the use of a superplasticizer additive. The resulting concrete had axial compression strength of 51.8 MPa at 91 days with 77 kgco2/m3 of concrete for a mixture with 80 % of PC replaced with 70 % LF and 10 % FA. These amounts corresponded to the use of only 97 kg/m3 of PC (87 kg/m3 of clinker) and 104 L/m3 of water. Thus, it was demonstrated to be possible to obtain a HSC with fck of up to 80 MPa and low CO2 emissions through the use of high levels of mineral admixtures.

KEYWORDS
Sustainability; High strength concrete; Limestone filler; Fly ash; high strength concrete.

RESUMO
O presente artigo avalia a possibilidade de produção de Concreto de Alta Resistência (CAR) com a substituição de cimento Portland (CP) por teores elevados de fíler calcário (FC), em misturas binárias e ternária com cinza volante (CV), em proporções de 50% a 80%, com o propósito de diminuir as emanações de CO2 durante sua fabricação. Foram estudadas a resistência à compressão axial, a emissão de CO2 dos materiais constituintes e o custo por m3 de concreto, com vistas à redução do impacto ambiental. Foi possível a elaboração de CAR com elevados teores de FC e CV e reduzidos teores água/ligante (a/l = 0,25), através do empacotamento de partículas e da utilização de aditivo superplastificante, com uma trabalhabilidade de 10020 mm. Obteve-se concretos com resistência à compressão axial de 51,8 MPa, a 91 dias, com 77 kgCO2/m3 de concreto, onde 80% do CP foi substituído por 70% de FC e 10% de CV,

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com o uso de apenas 97 kg/m3 de CP (87 kg.m-3 de clínquer) e 104 L/m3 de água. Este trabalho mostra que é possível obter-se CAR com fck de até 80 MPa e baixas emissões de CO2, com o emprego de elevados teores de adições minerais.

PALAVRAS-CHAVE

Sustentabilidade; Fíler calcário; Cinza volante; Concreto de alta resistência.

RESUMEN

Este trabajo evalúa la posibilidad de producir concreto de alta resistencia (CAR) reemplazando el cemento portland (CP) por altos niveles de polvo calizo (PC), en mezclas binarias y ternarias con cenizas volantes (CV), en proporciones del 50% al 80%, con el objetivo de reducir las emanaciones de CO2 durante la fabricación. Se estudió la resistencia a la compresión axial, la emisión de CO2 de los materiales que lo componen y el coste por m3 de hormigón, con el fin de reducir el impacto ambiental. se logró producir car con altos contenidos de PC y CV y contenidos reducidos de agua/conglomerante (a/l = 0,25), mediante empaquetamiento de partículas y el uso de un aditivo superplastificante, con una trabajabilidad de 100 20 mm. con resistencia a compresión axial de 51.8 MPa, a 91 días, con 77 kgco2/m3 de concreto, donde se reemplazó el 80% de CP por 70% de PC y 10% de CV, con el uso de solo 97 kg/m3 de CP (87 kg/m3 de clinker) y 104 L/m3 de agua. el trabajo demuestra que es posible obtener CAR con fck de hasta 80 MPa y bajas emisiones de CO2, utilizando altos niveles de adiciones minerales.

PALABRAS CLAVE

Sostenibilidad; polvo de piedra caliza; ceniza volante; Concreto de alta resistencia.

1. INTRODUCTION

Brazilian standard NBR 6118 (ABNT, 2023) classifies concrete strength in 2 categories: class I contains concretes with strengths between 20 MPa and 50 MPa and class II had strengths between 50 MPa and 90 MPa, the latter being considered high strength concretes (HSC). High strength concretes are achieved with reduced porosity through: (a) lower water/binder ratios (w/b); (b) decreased amounts of water used by cubic meter of concrete with plasticizer and superplasticizer additives and (c) optimized particle packing with the selection of coarse aggregates with lower characteristic dimensions and adequate fine aggregate granulometries though mineral admixture (MA). From a sustainability point of view, HSC has advantages related to longer durability, decreased use of raw materials and lower Portland cement (PC) consumption per MPa of compressive strength (De Matos et al., 2019; Yousuf et al., 2019).

An alternative to obtain sustainable HSCs consists of the replacement of PC with MA such as limestone filler (LF) and fly ash (FA). Portland cement clinker, while the most important component of concrete, contributes the most to the emission of greenhouse gasses (GHG), in particular CO2. This is a consequence of approximately 2/3 of clinker being composed of calcium carbonates which are decarbonized in ovens during manufacture and, added to fossil fuel combustion of industrial processes, are the primary sources of emissions. Clinker contributes to 85 % to 90 % of concrete CO2 emissions and 5 % of total global emissions (GCCA, 2017). Since PC is the most manufactured material worldwide by mass, it presents a contradictory challenge of supplying social economic development while maintaining desired environmental sustainability.

Amongst inert MAs, limestone filler (LF) is the most used due to its worldwide availability, ability to induce good rheological characteristics to fresh cement, low cost and low GHG emissions. International standards limit LF content in concrete to between 5 % and 35 % depending on region and technological know-how. A common procedure is its addition to clinker during grinding in the production of cement. However, recent studies made use of higher PC to LF substitution ratios and even ternary concrete mixtures with pozzolans such as FA. These increased substitutions sought to obtain a sustainable HSC with lower cost per m3 of concrete while maintaining its durability (PALM et al., 2016). Furthermore, the use of inert LF with an active mineral admixture could produce additional benefits through synergic effects, not only with respect to general concrete properties and sustainability but also with respect to normalized factors such as the amount (kg) of agglomerates needed for each MPa of concrete strength (ISAIA et al., 2003).

Increases in concrete axial compressive strength are commonly obtained from lower water/binder ratios (w/b), superplasticizer admixtures and PC replacement with MA such as pozzolans or FA. Overall, these procedures are employed to lower environmental impacts associated with the use of PC. This application of HSC with further particle packing techniques can produce structures with equivalent strength and performance to one constructed with conventional concrete albeit with a lower volume of concrete consumption (De Matos et al. 2019; Scrivener et al., 2018; Gartner and Hirao, 2015). Mehta and Monteiro (2014) noted the additional sustainability effect of HSC in the decreased consumption of raw materials.

Durability, while not addressed in this study, is known to be associated with the performance HSC with strengths above 50 MPa and w/b ratios of less or equal to 0.30. As porosity decreases, permeability and fluid diffusion decrease drastically due to pore sizes becoming smaller than the critical diameter. Malhotra et al. (2000) reported that mixtures with 150 kg/m3 of PC, 200 kg/m3 of FA, 102 L/m3 of water and w/b ratio of 0.29 presented good durability, especially with respect to factors related to reinforcement corrosion in in situ observations up to 10 years.

Thus, the objective of this study was to test HSC mixtures with high PC substitution content that would lower environmental impact and achieve economic viability and acceptable performance with respect to standard values of axial compressive strength. The concrete mixtures of this study were binary of PC and LF and ternary with PC, LF and FA. Mixtures were prepared with particle packing techniques to minimize void spaces. Portland cement substitution ratios varied between 50 % and 80 %. Parameters evaluated were compressive strength, CO2 emissions and cost per m3 of concrete. Results showed that LF content can be comfortably increased beyond current limits set in standards. While not comprehensive, this study is part of a larger prospective study with the objective of decreasing clinker consumption to below 100 kg/m3.

2. LIMESTONE FILLER

Filler is any finely ground material of approximately the same or greater fineness than PC. Fillers imbue beneficial effects in some properties of concrete such

as workability, permeability, capillarity, extrusion and fissuring potential. They also have very low reactivity and are considered chemically inert which, depending on hydraulic characteristics or absence of undesirable reactions with cement paste products, is not a disadvantageous property (NEVILLE, 2016).

Limestone fillers are found in nature as: (a) calcite (calcium carbonate) with crystalline trigonal rhombohedral geometry; (b) dolomite (calcium and magnesium carbonate) with predominantly rhombohedral crystal structures and (c) aragonite (calcium carbonate) with metastable orthorhombic crystals. Of these minerals, the first two are most commonly used (SAMPAIO; ALMEIDA, 2008).

The addition of limestone filler is an important technique in reducing CO2 emissions in the manufacturing process of cement. The main effect is a decrease in decarbonation and related decreases in fossil fuel combustion emission and electrical energy consumption during grinding (BATAGGIN, A. F.; SILVA, 2019)

2.1 Physio-chemical reactions of limestone filler on concrete

2.1.1 Physical effect

Physical effects occur when the mere presence of the supplemental cementitious material or inert MA interferes with clinker hydration. This is due to surface electrical potential, also known as zeta potential (BERODIER and SCRIVENER, 2015; SCRIVENER et al. 2015),

2.1.2 Dilution effect

Dilution effects occur when particles of a reactive material are replaced with less reactive or inert ones. This can bring negative effects on durability and mechanical performance (IRASSAR, 2009) due to lower PC content and corresponding increase in effective w/b ratio (IRASSAR et al. 2015). As a consequence, less hydrated products are generated and a decrease in compressive strength occurs across all ages.

2.1.3 Heterogenous nucleation effects

The presence of LF alters the speed of reaction of PC, contributing to hydration at initial ages (KADRI and DUVAL, 2002). Heterogeneous nucleation occurs from LF due to the smaller particle size filling void spaces. Consequently, density and nucleation points for hydration products increase in the mixture. Thus, crystal growth occurs not only on the surface of PC grains but also on the surface of LF, with corresponding increases in reactions and types of hydration products being formed. The reduction in void spaces induces the formation of large number of small crystals in lieu of a few large ones (HEMALATHA and SANTHANAM, 2018; MEHDIPOUR et al. 2017).

2.1.4 Effect in hydration reactions

Different from pozzolans and pozzolanic activity, the chemical effect of LF (CaCO3) occurs from its interaction with alumina present in PC, especially C3A. From this interaction, a new hydrated monocarboaluminate phase is formed. This phenomenon was stressed by Battagin (2017) and Bonavetti et al. (2003) as an additional moderate chemical reactivity of LF with PC concurrent to their physical interaction.

2.1.5 Granulometry effects

Grain size and structure are defined from granulometric analysis and BET specific surface area. Their values drive LF reactivity in cementitious pastes or concretes of binary, ternary or quaternary composition. Espining (2008) noted the effects of granulometry as: (a) better physical nature of the packed material, whose higher density and better grain dispersal affected concrete flowability and compressive strength; (b) fineness and specific surface area increased nucleation, with effects on compressive strength depending on the affinity of LF with hydrated PC products; (c) higher BET area LF decreased concrete flowability and increased autogenous shrinking, with cascading effects of decreased evaporation, decreased plastic fissuring and increased compressive strength; (d) an BET area increase in the order of 1,000 m^2/kg required a 0.8 % increase by mass in the amount of water to maintain concrete workability and decreased plastic shrinkage by 20 % and (e) the increase in water content due to BET area increase tended to increase fissuring and decrease mechanical strength.

2.2 Effect of high replacement content of limestone filler

Studies over the last 3 decades examined the performance of LF in PC concrete and denoted a rising substitution content trend. However, there were still diverging results with respect to rheological and mechanical behaviors and durability (Lollini et al., 2014). As LF content increased in the paste with disregard to granulometry and water

content, the w/b ratio increased, and performance declined. This behavior could be controlled by lowering the w/b ratio, improving workability with superplasticizer admixtures and, critically, controlling particle dispersal to decrease void spaces. This would increase packing between PC and LF grains with the aggregates of the mixture. According to Fennis and Walraven (2012), it was possible to elaborate concretes with low CO2 emissions by replacing 50 % of PC with MA and optimizing mixtures with particle packing techniques.

John et al. (2018) proposed a new perspective on lowering clinker content with an innovative technique. Their methodology combined low clinker and high LF content with dispersants so that water content would be reduced to counter dilution. This technique has been successfully applied in related fields such as pre-manufactured and pre-cast concrete industries.

Similarly, Proske et al. (2013) reported that concrete with 20 % to 35 % LF replacement content with respect to PC by mass and common w/b ratios had a critical level of performance. Consequently, desired concrete durability could only be achieved with reductions in w/b ratio. Proske et al. (2013) further listed the main principles for the development of a low clinker (high LF) content concrete: the use of a high-performance superplasticizer admixture and optimized packing density. These two principles allowed a reduction in water content and simultaneously minimized PC clinker levels.

Palm et al. (2016) applied elevated LF replacement content (above 50 %) with respect to PC and evaluated mechanical properties, durability and sustainability characteristics of the concretes. It was concluded that: (a) concretes with 50 % PC and 50 % LF content by mass and a w/b ratio of 0.35 could have sufficient mechanical properties for practical construction applications if properly monitored; (b) the w/b ratio was the main parameter for high LF content concretes; (c) LF did not appear completely inert as its effect on compressive strength was substantial as clinker was further replaced with LF; (d) all concretes with 50 % PC and 50 % LF content by mass and a w/b ratio of 0.35 had compressive strength equal or higher than the reference mixture with a w/b ratio of 0.50. Thus, in concert with results from other studies over the past 2 decades, Palm et al. (2016) demonstrated that high LF content concretes had viable HSC mechanical properties with respect to compressive strength as well as sustainability.

2.3 Ternary mixtures with LF and FA

Ternary mixtures with LF and FA have to account for synergic effects since physical and chemical effects of both MA cannot be separated. This synergic effect was studied by Isaia (1995) with several MA mixtures. It was concluded that the reactivity of a MA was not limited to its amorphousness or crystallinity but also linked to physical and chemical effects of other active or inert additions.

Deschener et al. (2012) and De Weerdt et al. (2011) noted that synergy occurred between the carbonaceous materials of LF with FA. By itself, LF reacted with aluminates of hydrated PC to form carboaluminates. But this effect was enhanced with additional carboaluminates introduced in the mixture from the pozzolanic reaction of FA. De Weerdt et al. (2011) further noted that LF reaction with aluminates and FA contributed to decreasing concrete porosity.

3. METHODOLOGY AND MATERIALS

The objective of this study was to evaluate the potential of high strength concretes (HSC) with PC replaced with high contents of limestone filler (LF) and fly ash (FA). Two replacement ratios were tested: binary mixtures with 50 % and 60 % FC content and a ternary mixture with 70 % LF and 10 % FA for a total 80 % replacement of PC. All materials were characterized, and packing techniques evaluated to achieve the best concrete compaction. Results from previous studies were used to elaborate 4 concrete mixtures: (a) reference (REF) mixture with 100 % CP V-ARI cement; (b) 50 % LF and 50 % CP V-ARI cement (50LF); (c) 60 % LF and 40 % CP V-ARI cement (60LF) and (d) 70 % LF, 10 % FA and 20 % CP V-ARI cement (70LF10FA). All concretes were mixed with a w/b ratio of 0.25. After molding and manufacture of test bodies, axial compression strength, CO2 emissions and cost per m3 of concrete were evaluated.

3.1 Materials

The PC used in this study was CP V-ARI with high initial strength due to its low original LF content (up to 10 %) as produced nationally. A chemical analysis conducted by Brazilian Association of Portland Cement (ABCP) determined that this type of cement contained 7.2 % calcite, 2.5 % plaster and 0.56 % loss on ignition, which corresponded to an approximate clinker content of 90 %. The LF selected for this study was extracted from veins in Caçapava do Sul (RS) and was of dolomite-calcite rocks abundant in this region. The LF was ground in a ball mill for 180 min to reach adequate granulometry and

fineness. Resulting BET surface area was 8.22 m^2/g and PC performance index was 92.4 %, which allowed adequate behavior with respect to consistency in the fresh state and compressive strength in the hardened state. The FA was obtained from the thermoelectric power plant in Candiota (RS) and was also ground in a ball mill for 120 min to become an F class pozzolan. Table 1 presents the characteristics of PC, LF and FA. It should be noted that LF had a higher performance index than FA even though the former was theoretically considered inert while the latter was a chemically active pozzolan. This was likely due to the finer BET surface area of LF which allowed more intense and quicker chemical reactions and greater attraction from the zeta potential. The result was the quicker production of carboaluminates filling void spaces in the paste.

Two types of natural sand were used from quarries in Santa Maria (RS) with fine sand having a maximum diameter of1.2 mm and medium sand having a maximum diameter of 2.4 mm. The sand types were selected in order to allow a gradual granulometric transition from the fine PC grains to the MA and coarse aggregate. The coarse aggregate was gravel from crushed diabase rock from the city of Itaara (RS), classified as type 0 gravel with maximum diameter of 12.5 mm.

Superplasticizer admixture was used in amounts appropriate to the achieve desired rheological parameters of the concretes. The superplasticizer was polycarboxylate-based BASF Master Glenium 54 with average solid content of 40 % and density of 1.1 g/cm3. The compatibility of the superplasticizer with the PC was checked with the Marsh cone test and determined to be an excellent 1 %.

3.2 Particle packing

Particle packing between aggregates, PC and MA was evaluated with EMMA (Elkem Materials Mix Analyzer) software. This was conducted in order to determine a granulometric mix ratio based on the real grain size of the materials. For each mix ratio, material quantities, densities and granulometric curves were entered and, by varying the ratios, a mix ratio closest to the ideal mix ratio curve was obtained. The ideal curve followed the recommendations of Funk and Dinger (1992) which made use of the Andreassen mathematical model. This model was selected since it was the most suitable for mixtures with

Physical characteristics		CPV-ARI	LF	FA
Specific mass (g/cm^3)		3.03	2.69	2.36
BET specific surface (m^2/g)		1.71	8.22	1.04
Performance index with PC at 28days (PI) (%)		-	92.4	92.0
Retention with 75 µm screen (%)		0.54	12.74	-
Average grain size (µm)		9.11	2.09	11.75
10 % diameter (µm)		1.09	0.73	1.25
90% diameter (µm)		23.12	19.42	26.93
Initial setting time (h)		3h:25min	-	-
Final setting time (h)		4h:15min	-	-
Normal consistency (%)		30.4	-	-
Compressive strength (MPa)	3 days	36.7	-	-
	7 days	46.8	-	-
	28 days	53.3	-	-

Table 1: Agglomerate characteristics
Source: the authors

small-sized particles. Furthermore, a value of 0.35 was used for the "q" distribution coefficient as recommended by Funk and Dinger (1992) in order to improve packing as in mixtures with high workability. The particle size distribution of the concrete mixtures is shown in Table 02.

3.3 Concrete preparation

Preliminary studies indicated optimum values for the concrete: 53 % for mortar content by mass and 8.33 % for the water/dry agglomerate ratio. These values were constant for all mixtures used in this study. The mixtures were prepared in a high-power mixer (900 W) equipped with high efficiency paddles and metallic drum under high rotations (between 645 rpm and 1,400 rpm). This set up was used comply with high energy requirements in mixing due to the low 0.25 w/b ratio. Table 3 presents the mix ratios of all concretes as kg/m3 of concrete.

Materials were added to the mixture in the following order: (a) 100 % quantities of PC, MA, water and admixtures; (b) fine and medium sand and (c) gravel. Consistency was measured with a slump test and kept in the range of 100 mm ± 20 mm.

Sustainability was evaluated with relative scores for each parameter examined with the best performance receiving a score of 100. The highest axial compression strength was obtained by REF mixtures across all ages, so it received a score of 100 for this parameter. The lowest CO2 emissions and cost occurred for the 70LF10FA mixture, which then received a score of 100 for those parameters. It should be noted that CO2 emissions and cost were

Grain size (GZ)	MIXTURE				Sieve Opening	% of Actual Passing Material	% of Theoretical Passing Material *
	REF	50% of cement, 50% of limestone filler (50LF)	40% of cement, 60% of limestone filler (60LF)	20% of cement, 70% of limestone filler, 10% fly ash (70LF10FA)			
	% Material	% Material	% Material	% Material	(mm)	(mm)	(mm)
GZ < 1 µm	0,99	1,83	1,99	1,44	0,001	1,56	1,58
1 µm < GZ < 10 µm	6,72	8,00	8,45	7,58	0,010	7,69	7,70
10 µm < GZ < 100 µm	7,59	6,07	7,50	8,94	0,100	7,53	7,52
100 µm < GZ < 1000 µm	33,02	33,95	30,95	32,24	1,000	32,54	32,56
1000 µm < GZ < 10000 µm	45,83	44,00	44,88	43,82	10,000	44,63	44,60
10000 µm < GZ	5,85	6,15	6,23	5,98	10 (>10)	6,05	6,04
Sum	100,00	100,00	100,00	100,00	-	100,00	100,00

* Equation used to calculate the percentagem of passing material based on grain size. CPFT = cumulative percentagem of paticles smaller than diameter D. CPFT (%) = $100 \frac{D^q - D_s^q}{D_L^q - D_s^q}$ (Funk and Dinger, 1994) , D = diameter of particles; Ds = diameter of the smallest particle in the distribution (0.00911 mm); DL = diameter of the largest particle in the distribution (in this case, 19.00 mm); and q = the distribution coefficient or modulus. Fo this case study, q = 0.35 wase used.

Table 2: Particle size distribution of the concrete mixtures.

Source: the authors

Mixture	Cement	Clinker	LF	FA	Fine sand	Medium sand	Gravel 0	Admixture	H_2O
REF	424	382	-	-	403	400	971	16.34	106
50LF	238	214	180	-	445	442	1.073	13.68	105
60LF	192	173	226	-	451	448	1.088	13.87	104
70LF10FA	97	87	283	36	467	463	1.125	13.46	104

Table 3: Amounts of materials per kg/m3 of concrete.

Source: the authors

inversely proportional to axial compressive strength. The most sustainable mixture was then selected through a mathematical average of the three relevant parameters of this study between the ages of 28 days and 91 days.

3.4 Axial compressive strength

Axial compressive strength tests were conducted in accordance with the procedures of standard NBR 5739 (2018) on cylindrical test bodies 10 cm in diameter and 20 cm in height molded in accordance to standard NBR 5738 (2015). The cylindrical test bodies were cured in water with limestone until the age for the tests, at which moment they were polished and crushed in an Instron model HDX 1500 hydraulic press. Tests were conducted at ages of 28 days and 91 days with 4 test bodies for each mixture. Non-conformant results were discarded, and the remaining values averaged out for each set of test bodies. Once axial compressive strength was determined, the normalized strength with respect to m3 of concrete, clinker intensity and binder intensity were determined for each mixture.

3.5 CO2 emissions

Coefficients used to determine CO2 emissions from the materials were based on certified values of Isaia and Gastaldini (2004). The following CO2 emission coefficients (in kg.CO2/ton) used were: a) PC = 617 (GCCA, 2017); b) LF = 26 (Habert et al., 2013); c) FA = 10; d) sand = 3; e) gravel = 4; f) water = 5; g) chemical admixture = 94 (Isaia and Gastaldini, 2004). These coefficients refer to average values for each of the constituent materials.

Multiplying the CO2 emission coefficients by the material consumption per cubic meter of concrete shown in Table 2 allows for calculating the total CO2 emitted by each of the concrete mixtures.

3.6 Cost per m3 of concrete

The cost per m3 of concrete of each mixture was calculated based on the amount of materials shown in Table 03. The amounts were linked to the TCPO (Tabela de Composições de Preços para Orçamentos, in portuguese) provided by PINI and prices per kg of material were sourced from the July, 2023 SINAPI (Sistema Nacional de Pesquisa de Custos e Índices da Construção Civil, in portuguese) reference table.

4. RESULTS

4.1 Axial compressive strength

Table 04 presents results for axial compressive strength, standard deviation and cost per m3 of concrete.

Figure 01 presents the relation of axial compressive strength at 28 days and 91 days with respect to LF substitution ratio. Overall, all concrete mixtures with MA had decreasing axial compressive strength as LF content increased. No mixture with MA substitution matched or exceeded the reference REF mixture strength. Sharp drops in strength were observed for LF contents above 50 % and ternary 70LF10FA mixture at 28 days. However, mixture 70LF10FA presented a considerable recovery in strength at 91 days with respect to its performance at 28 days. This was attributed to physical and chemical effects that occurred in between these 2 ages. The results of this study differed from Daminelli (2013) which observed an increase in compressive strength as LF content increased for a fixed w/b ratio.

Results of this study matched Madani et al. (2016), Zhao et al. (2015) and Dhir et al. (2007) with decreasing compressive strength across all ages as LF content increased for a fixed w/b ratio. Dhir et al. (2007) regarded the decrease in strength due to the low PC content as LF substitution increased. The relative increase in strength at 91 days when compared to 28 days was explained by Courard et al. (2018). Cementitious mixtures with LF form ettringite at first from monosulfate consumption. After monosulfate has been exhausted, monocarboaluminate was formed from hemicarboaluminate consumption. Once this latter phase was exhausted, the reactions cease leaving added calcium carbonate as a stable phase. Ettringite and monocarboaluminate filled pores as they formed, decreasing porosity and increasing compressive strength. On the other hand, leftover added carbonates tended to increase the number of pores which limited the increase in strength.

In the mixtures of this study, the minimum LF replacement content was 50 %. This content resulted in substantial carbonate formation which could explain the increase in porosity and decrease in axial compressive strength. Additionally, high BET specific surface could have resulted in particle coalescence and prevented water access to all grains. This limited LF activity, lowered carboaluminate generation, increased porosity and decreased strength. As noted by Perlot et al. (2013), these mechanisms could be further intensified by low w/b ratios (such as the 0.25 of this study). Another factor contributing to the decrease in strength as LF content increased would be the dilution effect as reactive particles were substituted with less reactive or inert ones. This dilution decreased hydration products and impacted strength development. In the case of the ternary LF7010FA mixture, pozzolanic effects increased strength due to the chemical effect of smaller pore size from secondary

C-S-H formation and physical effects of particle packing (Ramezanianpour and Hooton, 2014; Tsivilis, 2010; Espining, 2008; Lothenbach et al., 2008).

Mixture 70LF10FA yielded 51.8 MPa of compressive strength at 91 days, which represented an 85 % increase with respect to the 28.0 MPa measured at 28 days. This was attributed to the synergic effect between LF and FA as noted by Deschner et al. (2012) and De Weerdt et al. (2011). This synergy was the result of the interaction between LF and aluminates from pozzolanic reactions of FA. This led to carboaluminate formation which decreased porosity and increased strength. This phenomenon was not observed at 28 days since, as noted by Detwiler and Mehta (1989), physical effects dominated in the first 7 days and synergy of physical and chemical effects became noticeable only after 28 days. Isaia et al. (2003) postulated that the increase in compressive strength in ternary mixture containing pozzolans was a hybrid effect: a combined synergy between PC hydration, FA pozzolanic reaction and LF physical effects. Thus, mixture LF70FA10, despite its low PC content (20 %), benefited from this exact synergy and achieved an optimum bond between PC and MA particles as important as the amount of hydration products formed.

4.1.1 Clinker intensity (Ick)

Clinker intensity (Ick) is a ratio that indicates the mass of clinker necessary to obtain one unit of axial compressive strength in MPa. Thus, lower Ick corresponds to better performance of the mixture.

Table 5 presents Ick for all mixtures of this study. Results show that all mixtures with MA presented lower Ick than the reference REF mixture. This could be attributed to decreased clinker consumption from the low w/b ratio of 0.25. For low w/b ratios (below 0.4), part of the cement remained un-hydrated since there was no physical space for hydrated products, especially Portlandite. Consequently, this un-hydrated portion could be replaced with more cost-effective materials such as LF (BENTZ, 2006; BONAVETTI et al., 2003). Thus, as w/b ratio decreased, axial compressive strength increased and Ick decreased.

At 28 days, mixture 50LF presented the lowest Ick, below 3 kgck/m3/MPa. This value was considered highly relevant in this area of study at this age. Further analyses

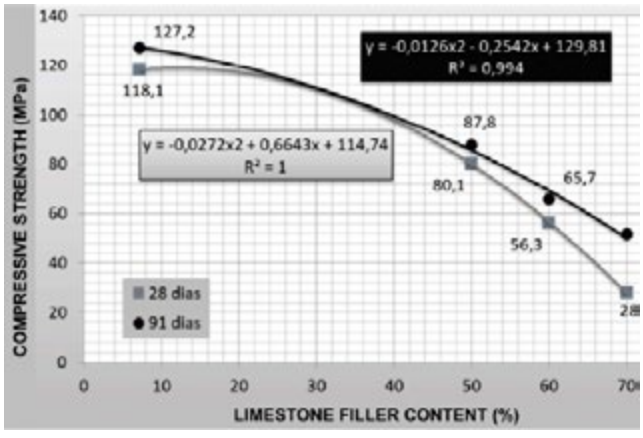

Table 3: Amounts of materials per kg/m3 of concrete.

Source: the authors

Mixture	Strength at 28 days (MPa)	Standard deviation at 28 days (MPa)	Strength at 91 days (MPa)	Standard deviation at 91 days (MPa)	Cost (R$.m^{-3})
REF	118.1	3.6	127.2	1.2	733.65
50FC	80.1	1.7	87.8	2.1	663.19
60FC	56.3	0.6	65.7	1.6	632.77
70FC10CV	28.0	0.4	51.8	0.5	561.55

Table 4: Average compressive strength, standard deviation and cost per m3 of concrete of the mixtures of this study

Source: the authors

showed that Ick at 91 days, compared to 28 days, were lower for all mixtures. This behavior was the result of clinker amount (kgck/m3) being fixed with respect to age while compressive strength increased over time.

At 91 days, Ick presented the same trend of decreasing Ick as LF content increased. In this case, this behavior was related to the decrease in agglomerates as LF content increased. As compressive strength increased from 28 days to 91 days, Ick decreased forming the trend.

4.1.2 Binder intensity (Ib)

Damineli (2013) proposed a binder intensity index (Ib) to relate the consumption of agglomerates with respect to the compressive strength of concrete. This was represented by Ib (kg/m3/MPa) and consisted of the total amount of binders consumed in kg/m3 divided by the axial compressive strength in MPa at 28 days. From this definition, Damineli (2013) proceeded to compile the Ib of 156 national and international studies.

When calculating Ib, LF amounts were not included since it was considered inert. For the purposes of the index, PC was considered to have a reactivity factor (k) of 1 while remaining reactive MA materials, such as FA, were attributed factors in this scale based on their relative reactivity (HABERT, 2012). In this study, the definition of clinker intensity (Ick – kgck/m3/MPa) was based on the Ib concept of Damineli (2013).

Table 06 presents Ib from converted Ick values for all mixtures of this study. Damineli (2013) noted that the minimum value for Ib was 5 kg/m3/MPa for concretes with compressive strength above 50 MPa. For concretes with strength below 50 MPa, Ib tended to be larger than this minimum value. Scrivener et al. (2018) expanded the concept of Ib and proposed a minimum Ib of 5 kg/m3/MPa for strengths above 50 MPa, 8 kg/m3/MPa for 30 MPa and a global average of 12 kg/m3/MPa for all variations in strength.

The concrete evaluated by Damineli (2013) was an ultra-high performance type (UHPC). It was produced from high pressure packing, thermal curing and consumption of special aggregates of 1,194.5 kg/m3. Resulting compressive strength was 800 MPa for an Ib of 1.49 kg/m3/MPa – high performance parameters but for an unconventional concrete.

In the case of this study, the binary 50LF mixture yielded an Ib of 2.42 kg/m3, which was lower than Damineli (2013) and others such as the 3 kg/m3 of Wongkeo et al. (2014). Thus, the 50LF mixture presented one of the lowest Ib registered so far and demonstrated the good performance of a concrete with high LF replacement content with respect to binding agents.

4.1.3 Normalized axial compressive strength (fcnorm)

Table 07 presents results of normalized compressive strength (fcnorm) for all mixtures of this study. This value was obtained by dividing the compressive strength by

Mixtures	Axial compressive strength (MPa)		(kg_{ck}/m^3)	I_{ck} (k_{ck}/m^3 / MPa)	
	28 days	91 days		28 dias	91 dias
REF	118.1	127.2	382	3.24	3.00
50LF	80.1	87.8	214	2.70	2.40
60LF	56.3	65.7	173	3.06	2.70
70LF10FA	28.0	51.8	87	3.09	1.70

Table 5: Clinker intensity (Ick) at 28 days and 91 days for the mixtures of this study.

Source: the authors

Mixtures	Axial compressive strength (MPa)		I_{ck} (kg/m³)	Ib (kg/m³/MPa)	
	28 days	91 days		28 days	91 days
REF	118.1	127.2	382.00	3.24	2.99
50FC	80.1	87.8	214.00	2.70	2.42
60FC	56.3	65.7	173.00	3.06	2.67
70FC10CV	28.0	51.8	87.00 + 22.00*	3.09	1.67

*Remaining binders (kg/m³), in this case FA.

Table 6: Clinker intensity (Ick) at 28 days and 91 days for the mixtures of this study

Source: the authors

the amount of PC consumed (C) in kgck/m3.

As seen in Table 07, the fcnorm of all MA replacement mixtures at 28 days were greater than the reference REF mixture. This was the result of the definition of fcnorm accounting for the combined physical, chemical and synergic effects so that, with respect to the amount of clinker present, strength was greater for high LF replacement content.

The increase in fcnorm could be the result of a "filler effect" in which LF interfered with PC hydration reactions through surface electrical potential (zeta potential) as noted by Scrivener et al. (2015). Of interest was the fcnorm of 0.32 MPa/kgcq/m3 for mixture 70LF10FA, which was only 3 % lower than the 0.33 MPa/kgcq/m3 of mixture 60LF despite having 50 % less clinker. This notable performance was attributed to synergic effects of LF and FA.

It was expected that aluminum oxides in FA would contribute to the added aluminate content in pozzolanic reactions. This would intensify LF interaction and increase carboaluminate production, leading to decreased porosity and increased normalized concrete strength (DESCHENER et al., 2012; DE WEERDT et al., 2011). However, it became apparent that FA did not fully realize its effect on compressive strength at 28 days (MEHTA; MONTEIRO, 2014). This was likely due to the low w/b ratio of 0.25 so that, at 28 days, FA contribution was mostly physical rather than pozzolanic (MINDESS et al., 2003).

Su and Miao (2003) suggested fcnorm between 0.11 MPa/kgck/m3 and 0.14 MPa/kgck/m3 for medium strength concretes with low PC content. On the other hand, Yu et al. (2015) cited values between 0.16 MPa/kgck/m3 and 0.19 MPa/kgck/m3 for high performance or eco-friendly concretes. In this study, the average fcnorm was of 0.33 MPa/kgck/m3 over all mixtures, which was 73.7 % higher than the upper limit proposed by Yu et al. (2015). Overall, it could be said that the mixtures of this study achieved a good performance with respect to fcnorm as they presented values higher than recommended in reference studies.

Binary mixtures 50LF and 60 LF presented small 9.76 % average increases in fcnorm over the tested ages. This was a reflection of the small increase of 9.96 % in compressive strength for both mixtures over the same time period. This indicated that fcnorm variation was proportional to the average variation in compressive strength. This was especially apparent at 28 days due to the small average increase in strength at this age.

Mixture 70LF10FA, as noted previously, had a considerable evolution in strength over time. Consequently, fcnorm performance was equally notable: at 91 days compressive strength was 51.8 MPa for a clinker consumption of 87 kgck/m3. This produced an fcnorm of 0.59 MPa/kgck/m3, the highest value of this study,

The good performance of mixture 70LF10FA, in addition to previously discussed factors related to LF, also benefitted from FA. As noted by Isaia et al. (2003), fcnorm increased considerably with the addition of FA due to the combined synergic effects of PC hydration, pozzolanic reactions of FA and physical effects of LF.

Over the ages tested, the average fcnorm over all mixtures was 0.42 MPa/kgck/m3, This value was higher than both Su and Miao (2003) and Yu et al. (2015). In particular, the fcnorm of 0.59 MPa/kgck/m3 of mixture 70LF10FA was over 3x greater than the upper limit proposed by Yu et al. (2015), making it a notable high performance eco-friendly concrete.

4.2 CO2 emissions per m3 of concrete

Table 08 presents CO2 emissions per m3 of concrete and its relation to the axial compressive strength. Values were determined with the following CO2 emission coefficients (in kgCO2/ton): (a) 617 for cement (GCCA, 2017); (b) 26 for LF (Habert et al., 2013); (c) 10 for FA; (d) 3 for sand; (e) 4 for gravel; (f) 5 for water and (g) 94 for the additive (Isaia e Gastaldini, 2004). These coefficients were average values

Mixtures	Compressive strength		C (kg_{ck}/m^3)	fc_{norm} ($MPa/kg_{ck}/m^3$)	
	28 days	91 days		28 days	91 days
REF	118.1	127.2	382.00	0.31	0.33
50LF	80.1	87.8	214.00	0.37	0.41
60LF	56.3	65.7	173.00	0.33	0.37
70LF10FA	28.0	51.8	87.00	0.32	0.59

Table 7: Normalized compressive strength (fcnorm) at 28 days and 91 days.

Source: the authors

for each material.

Table 08 shows that CO2 emissions were directly proportional to clinker content and axial compressive strength (Tables 03 and 04) and inversely proportional to LF content (Figure 02). The 50 % substitution of mixture 50LF presented a decrease in CO2 emissions of 40.7 % with respect to REF. Higher replacement of 60 % in mixture 60LF presented a 50.7 % decrease in CO2 emissions while the 70% replacement of 70LF10FA produced a corresponding reduction of 71.5 %. The direct relation between CO2 emissions and compressive strength were attributed to the need of increasing PC content to yield higher strengths as w/b ratio decreased. Kjellsen et al. (2005) noted that PC clinker was responsible for over 91 % of CO2 emissions of concrete. Consequently, any decrease in clinker content was a recommended option to decrease GHG emissions and increase global sustainability. Results of this study presented CO2 emissions from PC clinker of 87 % for the REF mixture, 82 % for 50LF, 80 % for 60LF and 70 % for 70LF10FA, which were proportional decreases in CO2 emissions as clinker content decreased.

Costa (2012) used CP V-ARI cement to obtain a concrete with compressive strength of 50 MPa. This required a PC consumption of 487 kg/m3 and resulted in 485 kgCO2/m3 of emissions. In comparison, mixture 70LF10FA of this study had a strength of 51.8 MPa at 91 days from a PC consumption of 97 kg/m3 (equivalent to 87 kg/m3 of clinker) and emissions of 77 kgCO2/m3. Compared to the results of Costa (2012), this represented a 390 kg/m3 savings in PC and 408 kg/m3 less CO2 emissions, corresponding to decreases of 80 % and 84 %, respectively per m^3 of concrete with essentially the same compressive strength.

As noted by Damineli (2013), the higher the compressive strength of concrete, the less CO2 emissions in kgCO2/m3/MPa. This can be seen in Table 08 as emissions at 28 days were in agreement with Damineli (2013) except for REF mixture. At 91 days, binary mixtures presented decreases in CO2 emission index as compressive strength increased. Notably, the ternary 70LF10FA mixture, which had the lowest measured strength at 51.8 MPa, had a sharp decrease in emission index due to synergy and pozzolanic reactions. This was reflected in the 85 % increase in compressive strength from 28 days to 91 days while CO2 emissions remained constant.

Mixtures	CO_2 Emissions ($kgCO_2/m^3$)	Strength at 28 days (MPa)	Coefficient of variance at 28 days (%)	28 days (kg_{CO2}/m^3/ MPa)	Strength at 91 days (MPa)	Coefficient of variance at 91 days (%)	91 days (kg_{CO2}/m^3 /MPa)
REF	270	118.1	3.1	2.29	127.2	1.0	2.12
50LF	160	80.1	1.7	1.98	87.8	2.4	1.82
60LF	133	56.3	1.0	2.36	65.7	2.4	2.02
70LF10FA	77	28	1.6	2.75	51.8	1.0	1.49

Table 8: Relationship between CO2 emissions and compressive strength.

Source: the authors

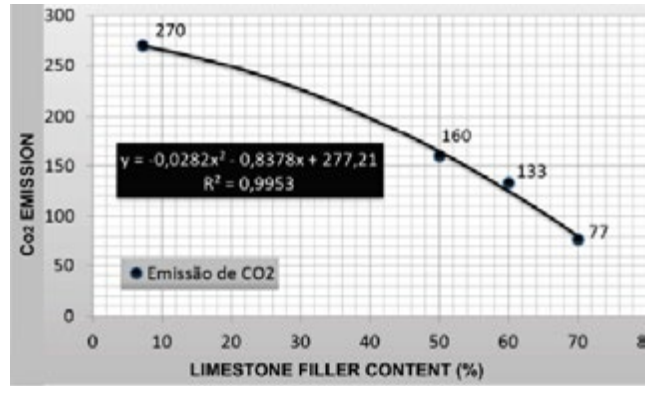

Figure 2: LF content (%) and CO2 emission (kgC02.m-3)

Source: the authors

Damineli (2013) obtained CO2 emission indices between 1.5 kgCO2/m3/MPa and 2 kgCO2/m3/MPa at 28 days, which were amongst the lowest reported in national and international studies. In this study, Table 08 presents an average emission index of 2.34 kgCO2/m3/MPa, which was 17 % higher than the cited upper limit. Damineli (2013) also noted that the smallest possible emission index for concrete production without clinker replacement was 4 kgCO2/m3/MPa at 28 days. In this study, mixture REF with no clinker replacement presented an emission index of 2.29 kgCO2/m3/MPa, or 42.8 % smaller than the proposed limit. These results demonstrated the good performance of the HSC of this study with respect to CO2 emissions per m3 of concrete and further signaled the positive impact in GHG emissions when PC was replaced with LF and FA.

4.3 Cost per m3 of concrete

Table 04 shows that cost was directly proportional to compressive strength and CO2 emissions while also inversely proportional to LF content. The first two factors were related to the PC content of each mixture, which was also the costlier material and higher GHG emitter per m3 of concrete. In contrast, excluding water, LF was one of the cheaper materials and its increasing replacement ratio contributed to the reduction of cost per m3 of concrete.

4.4 Susteinability comparisons

Results of Table 08 showed that binary and ternary mixtures containing LF had higher averages, with average global index of 63.2 % and coefficient of variance of 2.7 % at 28 days. Mixture 70LF10FA had the lowest CO2 emissions and cost but also low axial compressive strength at 28 days. It should be noted that all three replacement mixtures had similar cost at 28 days due to the elevated consumption of admixture. Nonetheless, at this age, mixture 50LF was considered the more sustainable option since it produced an fc28 of 80.1 MPa. In contrast, mixture 7LF10FA had the lowest performance at the same age with an fc28 of only 28.0 MPa despite its 80 % clinker substitution ratio. At 91 days, mixture 70LF10FA presented the highest average index of 74.1 %, followed by mixtures 50LF and 60LF with average indices of 64.9 %. The turnaround between 28 days and 91 days of mixture 70LF10FA was due to the 85 % increase in axial compressive strength to an fc91 of 51,8 MPa (the best performance at this age) while emissions and cost remained fixed. In comparison, mixtures 50LF and 60LF improved strength by only 9.6 % and 16.7 % from 28 days to 91 days, respectively. The relative increase in compressive strength as PC content decreased could be attributed to more available space in the mixtures for hydration reactions to occur. As noted by Isaia et al. (2003), special consideration must be given to aging since MA actions, in particular pozzolans, evolved over longer and longer times as synergic effects increased. Consequently, it should be stressed that sustainability did not depend solely on PC replacement with MA but also with ages in which concrete properties and cost were evaluated. Additives also contributed significantly to cost since polycarboxylate-based latest generation types tended to be expensive.

Results also demonstrated the possibility of producing structural concrete with PC and LF. At 28 days, mixture 50LF had PC content in the order of 238 kg/m^3 and fc28 of 80 MPa while mixture 60LF had 192 kg/m^3 and 56.6 MPa, respectively. Mixture 70LF10FA at 91 days had an fc91 of 51.8 MPa with only 97 kg/m^3 of PC content (87 kg/m^3 of clinker) and 104 L/m^3 of water. These values were equivalent to a clinker intensity of only 1.68 kgck/MPa (2.32 kg/MPa of binder intensity) and were one of the smallest values reported in this area. These results denoted an exceptional sustainability capacity of this mixture and confirmed other similar results such as Damineli (2013).

The statistical analysis of Isaia et al. (2012) gathered 7,308 results on microstructural and durability factors. It was shown that, in the case of dependent variables in general multiple linear regression models, MA content and w/b ratio had the most statistical significance. Regarding durability, Isaia et al. (2012) reported the best performance for a concrete with 70 % MA content and w/b ratio of 0.35, for a compressive strength of 50 MPa. This performance was attributed to physical, chemical and synergic effects that developed over time. Similar results were observed in this study with the high MA replacement content of mixture 70LF10FA and w/b ratio of 0.25, which corresponded to a water consumption of around 100 L/m3.

5. CONCLUSIONS

This study presented HSC of binary mixtures with 50 % and 60 % LF content and ternary mixtures with 70 % LF and 10 % FA content. The concretes were produced with reduced water content, in the order of 100 L/m^3, and particle packing techniques.

Resulting compressive strengths were in the order of 50 MPa to 80 MPa at 28 days for the binary mixtures and 50 MPa at 91 days for the ternary mixture.

In terms of sustainability parameters, a concrete was produced with a 51.8 MPa compressive strength at 91 days and 77 kgCO2/m3 of emissions in a mixture in which 80 % of PC was replaced by 70 % LF and 10 % FA. The resulting eco-friendly concrete had low clinker (87 kg/m3) and water (104 L/m3) content. This demonstrated that a sustainable HSC with low carbon emissions could be obtained with high LF content and low clinker content of only 1,68 kgck/MPa. The combination of high LF content and low w/b ratio was possible due to controlled granulometry through particle packing and the resultant concrete had lower GHG emissions, lower cost and more global sustainability potential.

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AUTHORS

ORCID: 0000-0002-5169-735X
SILVANE SANTOS DA SILVA | Universidade Federal de Santa Maria (UFSM), Programa de Pós-graduação em Engenharia Civil (PPGEC) | Correspondência: Av. Roraima, 1000, Centro de Tecnologia, Camobi, CEP 97105-900, Santa Maria – RS, Brasil | e-mail: silvaneengciv@hotmail.com

ORCID: 0000-0001-5772-9933
ANDRÉ LÜBECK | Universidade Federal de Santa Maria (UFSM), Programa de Pós-graduação em Engenharia Civil (PPGEC) | Correspondência: Rua Prefeito Evandro Behr, 4279, Casa 08, CEP 97110-800, Santa Maria – RS, Brasil | e-mail: andre.lubeck@ufsm.br

ORCID: 0000-0003-0653-1227
GERALDO CECHELLA ISAIA | Universidade Federal de Santa Maria (UFSM) | Correspondência: Av. Roraima, 1000, Centro de Tecnologia, Camobi, CEP 97105-900, Santa Maria – RS, Brasil | e-mail: geraldoisaia@gmail.com
ORCID: 0000-0001-8536-61051
GUSTAVO DE AGUIAR ISAIA | Universidade Federal de Santa Maria (UFSM) | Correspondência: Av. Roraima, 1000, Centro de Tecnologia, Camobi, CEP 97105-900, Santa Maria – RS, Brasil | e-mail: gustavoaisaia@gmail.com

ORCID: 0000-0001-7306-5313
ALMIR BARROS DA SILVA SANTOS NETO | Universidade Federal de Santa Maria (UFSM), Departamento de Estruturas e Construção Civil (DECC)| Correspondência: Rua Araujo Viana, 141, apto 701, CEP 97015-040, Santa Maria – RS, Brasil: almir.neto@ufsm.br

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ECONOMIC-FINANCIAL FEASIBILITY ANALYSIS OF PROJECTS IN HISTORIC SITES: CASE OF ENGENHO MONJOPE

ANÁLISE DE VIABILIDADE ECONÔMICO-FINANCEIRA DE EMPREENDIMENTOS EM SÍTIOS HISTÓRICOS: CASO DO ENGENHO MONJOPE

ANÁLISIS DE VIABILIDAD ECONÓMICO-FINANCIERA DE PROYECTOS EN SITIOS HISTÓRICOS: CASO DE ENGENHO MONJOPE

EMANOEL SILVA DE AMORIM, Msc. | UPE – Universidade de Pernambuco, Brasil
GIRLÂNDIA DE MORAIS SAMPAIO | UPE – Universidade de Pernambuco, Brasil
AMANDA AIRES VIEIRA, Dra. | UPE – Universidade de Pernambuco, Brasil
ALBERTO CASADO LORDSLEEM JÚNIOR, Dr. | UPE – Universidade de Pernambuco, Brasil

ABSTRACT

Restoring historical heritage is more than keeping the memory alive, it also consists of applying science to the evolution of public equipment to the modern needs of society. This objective article presents the economic-financial feasibility study of the historical and cultural heritage of Engenho Monjope, which was built in the mid-1600s, being listed in 1986 by the Government of Pernambuco, as a State Historic Heritage, recognized by the community as an asset. heritage to be preserved. The methodological processes were separated into two stages, the surveys being: costs (investment, operation and maintenance), revenues and result of the 1st year and the critical evaluation (Cost-benefit and Distributive Impact). The pathogenic results that the project is viable in the social, patrimonial and distributive impact (Cid) aspects, as well as in the economic and financial aspects. As a great contribution to success, the research shows that economic and financial feasibility studies are crucial to guarantee its undertakings, avoiding unforeseen events in the operation, preventing situations, suggesting postures and recommendations that foster success.

KEYWORDS

Historical Heritage; Sustainability; Economic-financial viability; Private Public Partnerships.

RESUMO

Restaurar um patrimônio histórico é mais do que manter a memória viva, consiste também na aplicação da ciência para a adequação do equipamento público às necessidades modernas da sociedade. O presente artigo objetiva apresentar o estudo de viabilidade econômico-financeira do patrimônio histórico-cultural do Engenho Monjope, o qual foi construído em meados de 1.600. sendo tombado em 1.986, pelo Governo do Pernambuco, como Patrimônio Histórico Estadual, reconhecido pela comunidade como bem patrimonial a ser preservado. Os processos metodológicos foram separados em duas etapas, sendo os levantamentos: dos custos (investimento, operação e manutenção), das receitas e resultado do 1º ano e a avaliação crítica (Custo-benefício e Impacto Distributivo). Os resultados obtidos demonstraram que o projeto é viável nos aspectos social, patrimoniais e coeficiente de impacto distributivo (Cid), assim como nos aspectos econômico e financeiro. Como grande contribuição a pesquisa apresenta que os estudos de

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viabilidade econômico-financeiro são cruciais para garantir o sucesso destes empreendimentos, evitando imprevistos na operação, prevendo situações, sugerindo posturas e recomendações que fomentem o êxito.

PALAVRAS-CHAVE

Patrimônio Histórico; Sustentabilidade; Viabilidade econômico-financeiro; Parcerias Públicos Privadas.

RESUMEN

Restaurar un patrimonio histórico es más que mantener viva la memoria, también consiste en aplicar la ciencia para adaptar los equipamientos públicos a las necesidades modernas de la sociedad. Este artículo tiene como objetivo presentar el estudio de viabilidad económico-financiera del patrimonio histórico-cultural de Engenho Monjope, construido a mediados del siglo XVII. siendo catalogado en 1986, por el Gobierno de Pernambuco, como Patrimonio Histórico del Estado, reconocido por la comunidad como bien patrimonial a preservar. Los procesos metodológicos se separaron en dos etapas, siendo las encuestas: costos (inversión, operación y mantenimiento), ingresos y resultados del 1er año y evaluación crítica (Costo-Beneficio e Impacto Distributivo). Los resultados obtenidos demostraron que el proyecto es viable en los aspectos sociales, patrimoniales y del coeficiente de impacto distributivo (Cid), así como en los aspectos económicos y financieros. Como aporte importante, la investigación presenta que los estudios de factibilidad económico-financiera son cruciales para garantizar el éxito de estos emprendimientos, evitando imprevistos en la operación, prediciendo situaciones, sugiriendo actitudes y recomendaciones que fomenten el éxito.

PALABRAS CLAVE

Patrimonio histórico; Sostenibilidad; Viabilidad económico-financiera; Asociaciones Público-Privadas.

1. INTRODUCTION

The preservation of historic sites is a widely discussed topic today; however, this process is extremely complex, as it requires financial and human resources that are not always available and sometimes conflicts with rapid urban growth. (RODRIGUES; AMORIM, 2018; AMORIM; SAMPAIO; SILVA, 2022; AMORIM; SAMPAIO; SILVA, 2023).

To preserve a historic asset, it is not enough to simply restore it; it must also be integrated into society, ensuring appropriate and synergistic use with the needs of the local population. In this way, social aspects should be integrated with economic aspects (OLIVEIRA, 2022), enabling sustainable regional development.

Therefore, to achieve sustainability of an enterprise located in historic sites, it is not enough to simply restore the built heritage (MOURA; LIRA; MELO, 2022); often it is necessary to requalify the asset, that is, to assign a new function to the asset together with actions to improve its aesthetic aspect (DEMARCHI; NITO, 2022), ensuring the sustainability of the enterprise. Therefore, requalification redefines the broader sense of conservation actions.

Therefore, "sustainability, based on its economic, environmental, and social spheres, has been increasingly discussed" (ÁVILA et al., 2016, p. 7), and it is an essential premise to evaluate the economic and financial feasibility of enterprises located in historic sites.

According to Ross et al. (2015), economic and financial feasibility study is characterized by the relationship between money, time, considerations regarding risk, and return. It involves data collection, estimation of net cash flow, determination, calculation, and analysis of economic viability indicators, issuing a conclusive opinion, and managerial decision-making (BORCA JR; BARBOSA-FILHO, 2023). For this, market uncertainties and variations regarding the potential profitability of the studied product are considered, thus evaluating whether the projections raised can be realized or not (OLIVEIRA, 2022).

The economic and financial feasibility study uses indicators in the investment analysis process, with the most common ones being: net present value (NPV), internal rate of return (IRR), minimum attractive rate (MAR), and payback period. After determining these indicators, they should be analyzed considering, among many variables, the objectives and structure of the organization intending to implement or produce this innovation. Feasibility must meet the organization's demands, which involves not only economic and financial values but also the willingness to take the risk of investing in the new product or project. (BIASI; ZILLI; CORREIA, 2022).

It is common for management and administration in projects located in historical sites to be a partnership between the government and the private sector (OLIVEIRA, 2022). This partnership is welcome as it increases the chances of ensuring financial sustainability for the maintenance of historical heritage, while reducing government costs and increasing social benefits.

With that said, the object of this research is the requalification project of the Monjope Sugar Mill, located in Igarassu, a municipality in the state of Pernambuco, Brazil. The mill was built in the mid-1600s and was designated as a State Historical Heritage Site by the Government of Pernambuco in 1986, recognized by the community as a heritage asset to be preserved. According to a historical survey conducted by the Foundation of Historical and Artistic Heritage of Pernambuco (FUNDARPE), in its document titled "Actions for the Safeguarding of the Monjope Sugar Mill," it is noted that the Monjope Sugar Mill is the only mill in the Metropolitan Region of Recife that contains the four characteristic buildings of a sugar mill: the main house, chapel, slave quarters, and sugarcane field, along with the overseer's house, enriching the composition of the historic site.

Given such historical significance, this research aims to present the economic and financial feasibility study conducted for the implementation of the Monjope Sugar Mill Cultural and Ecological Reserve project. This involves evaluating the economic impact and economic and financial feasibility of the investment, as well as the financial sustainability of preserving the historical heritage and the relationship between government costs and social benefits over a period of 20 years.

2. AREA CARACTERIZATION

The municipality of Igarassu is located between the North Metropolitan economic pole and Goiana, which consists of the municipalities of Paulista, Abreu e Lima, Araçoiaba, Igarassu, Itapissuma, Goiana, and Ilha de Itamaracá. Together, these seven municipalities occupy a continuous area of 1,262.285 km^2, where 650.820 inhabitants live, representing 1.28% of the state's area and 7.38% of the population of Pernambuco. Approximately 70% of the active population in this region is engaged in service sector activities. It is also worth noting that this region contributes 5.90% to the formation of the state's Gross Domestic Product (GDP). (CONDEPE/FIDEM, 2020).

The North Metropolitan and Goiana poles are known for being the cradle of settlement in Brazilian lands, possessing a rich natural and historical heritage, with numerous religious, civil, and military buildings representative of the colonial period, comprising a vast and valuable collection that reveals the splendor of its past (CONDEPE/FIDEM, 2020). The North Metropolitan and Goiana poles are rich in potentialities related to urban infrastructure (Figure 1), tourism and culture (Figure 2), and socioeconomic development (Figure 3).

Figure 1: Urban infrastructure in the North Metropolitan and Goiana Poles
Source: CONDEPE/FIDEM, 2020.

Figure 2: Tourism and culture in the North Metropolitan and Goiana Poles
Source: CONDEPE/FIDEM, 2020.

Figure 3: Socioeconomic development initiatives in the North Metropolitan and Goiana Poles
Source: CONDEPE/FIDEM, 2020.

2.1 Object of study

2.1.1 The Engenho Monjope

The Engenho Monjope is part of the 13 sugar mills classified in the Preservation Plan of the Historic Sites of the Metropolitan Region of Recife. It was listed as a state heritage site through process no. 0038/86 with an announcement dated 28/02/86, after which it was expropriated and compensated according to the relevant legal norms.

The Engenho is strategically located, situated one kilometer west of the BR-101 highway, 31 km from the capital Recife, between the Cruz de Rebouças district and the center of the municipality of Igarassu. It lies along a stretch that is part of the tourist circuit connecting the northern coast of the state of Pernambuco to João Pessoa/PB.

The Master (Figure 4) is a solid, two-story prismatic construction with a mansard roof, and a support structure located at a higher point of the terrain, from which a clear view of all the activities of the engenho is allowed. It is characterized by arcades on the facade of the main entrance, topped by doors with lowered arches on the upper floor, protected by balconies with cast iron railings.

Figure 4: Socioeconomic development initiatives in the North Metropolitan and Goiana Poles
Source: Authors, 2024

The chapel, located next to the Master, features a choir and pulpit, in addition to the bell tower, sacristy, and ossuary (Figure 5). The Moita, situated to the left of the Main House, showcases the entire structure of the sugar cane

mill mechanism, the water channels that made it turn for the production of cane syrup and brandy. Adjacent to the Moita in a strategic position (opposite side) is the Captain of the Woods' House.

Figure 5: The Chapel of Engenho Monjope
Source: Authors, 2024

In terms of production characteristics, the use of hydraulic power, through a vertical water wheel, to drive the mill represents a feature of the mill's production process. Contextually, sugar mills of that time used three types of motive power: hydraulic, human force, and animal traction. The choice of one or the other type of energy depended on economic and geographical factors. Additionally, the mill stands out for having a set of English metal mills. This fact highlights the Monjope process, as most sugar mills opted for wooden equipment to facilitate maintenance.

In this aspect, the Monjope ensemble is of significance because it still preserves, albeit with the main house in a compromised state, the entire set of buildings. This showcases the grandeur of the main house and the chapel, bearing witness to the economic cycle of sugarcane and the class relations of the time.

The architecture of the time sought to replicate European trends while reconciling contingent factors such as the site's geography, natural landscape, available materials, and the requirements resulting from the tropical climate of the Colony. Additionally, the architecture aimed to adapt to local ways of living, habits, and customs, such as Portuguese imperialism, social relationships, and the needs of rural patriarchal and slaveholding society. Despite the less defined internal spaces due to the state of preservation, it can be observed that the Monjope Master fulfilled the objectives of the time: providing space for an extended family while maintaining isolation and privacy.

2.1.2 The Cultural and Ecological Reserve of Engenho Monjope

The requalification project of Engenho Monjope was developed with the aim of structuring the foundations for the implementation of the Cultural and Ecological Reserve of Monjope Sugar Mill, which will host local knowledge developed by humans, agricultural, gastronomic, artisanal, semi-industrial practices, habits, and forms of human resistance, allied with the preservation of cultural and natural heritage. Participants in the project will include performers, artists, artisans, fishermen, farmers, breeders, cooks, administrators, among others, as well as guides and facilitators of social inclusion in the productive environment. (FUNDARPE, 2018).

For this purpose, the Reference Center will have a shared management, aiming at the protection and conservation of the property as cultural, historical, architectural, archaeological, environmental, and landscape heritage, recognized at the local, state, national, and international levels. Additionally, it will focus on reintegrating these aspects into the daily life of the population with the sugar mill, integrating them into tourist itineraries, and boosting the local economy.

Thus, the requalification guidelines for Engenho Monjope were based on local socio-cultural vocations and potentials. A demand analysis study was conducted, which diagnosed the best uses according to popular decision-making and potential investors. Therefore, the venture comprised service, cultural, and gastronomic sectors, with the listed facilities distributed as per Table 1.

3. METHODOLOGY

Sectorization	Function	Equipment
Services	Events	Chapel: Spaces for ecumenical worship and buffet services.
		Soccer field
		Multicultural space
		Convention Center and Professional Training Center
	Hotelkeeping	Slaves, where the inn will be located.
Cultural	Craft Shop	Máster and Moita
	Museum	
	Exhibition/Visits	
Gastronomic	Cafeteria	Capitain of yhe Wood's House
	Regional Restaurant	

Table 1: Sectorization of the venture

Source: Authors, 2024

Figure 6: Research stage.

Source: Authors, 2024

3.1 Research characterization

The research is of an applied nature aiming to generate knowledge for practical application, using the case study procedure with a quantitative approach, indicating that the relationships presented solely refer to the research object. The methodological processes were divided into two stages (as per the flowchart presented in Figure (6).

3.2 Survey

3.2.1 Costs

For the economic evaluation, the investment costs and operation and maintenance costs of the proposed equipment related to the historical heritage recovery project were presented.

The economic analysis works with prices referred to as efficiency prices, correcting prices based on market imperfections (taxes and subsidies) and reflecting the social cost of unskilled labor.

Thus, it was necessary to provide the investment costs and operation and maintenance costs, broken down into the following categories: skilled labor, unskilled labor, national materials, imported materials, national equipment, imported equipment.

For the transformation of financial prices into economic prices, the conversion factors defined in the Operational Regulation of the PRODETUR Nordeste II Program, Appendix M-2, were used. For economic benefits, the Standard Conversion Factor of 0.94 (zero point ninety-four) was applied. (PRODETUR, 2010).

3.2.2 Revenue

With the defined use for each building, an estimate of expected revenue was made. The revenue was demonstrated through demand studies and estimates of rental value or user fee charges. As the project will be managed by both the public and private sectors, the revenues were calculated in two ways:

- For the equipment managed by the private sector, revenue was estimated through rental calculations;
- For the equipment managed by the public sector, revenue was calculated through the implementation of social activities.

3.2.3 Result of the first year

Determined by the difference between the total sum of costs and the total sum of revenues obtained in the first year of operation of the enterprise.

3.3 Critical evaluation

3.3.1 Cost-benefit

The cost-benefit analysis presented globally, in efficiency prices, included the sum of the project's total benefits, comparing them to investment costs, operation, and maintenance costs, in a cash flow over 20 years, discounted at a rate of 12% (twelve percent) per annum. At the end, the results of the following indicators were provided: (i) Internal Rate of Return (IRR); (ii) Net Present Value (NPV) of the cash flow; and (iii) Benefit/Cost Ratio (B/C) of the project.

In this section, financial analysis was presented, which evaluates the liquidity ratios of an enterprise, i.e., its ability to meet its obligations, as well as the leverage ratios, which demonstrate the degree of indebtedness of the business. This type of analysis focuses on the company's cash flow, its expenses, revenues, and the composition of its budget, which can result in a positive or negative final diagnosis. Additionally, the analysis of the financial situation of the enterprise was also presented, with the proper determination of profits or losses incurred in a certain accounting period. In this analysis, profitability ratios are examined, showing the return on investments made by the company, as well as activity ratios, which demonstrate variations in the operational cycle of the business (KRUGER; ZANELLA; BARICHELLO, 2023).

Finally, the financial sustainability of the project was analyzed by presenting the investment costs, operation and maintenance costs, and revenues. For this stage of the project, three distinct sensitivity studies were conducted to observe the existence of variations in the feasibility diagnosis. The analyzed scenarios are enumerated as follows:

- Increase of 25% in the initial project investment value;
- Reduction of 20% in project revenues;
- Increase of 20% in operating costs.

3.3.2 Distributive Impact (DI)

It is important to understand the profile of the beneficiaries of a project. In the case of historical heritage recovery projects, the entire community benefits. Therefore, it was necessary to characterize this population from the perspective of family income, aiming to understand the participation of each economic group in the distribution of the project's economic benefits, particularly focusing on low-income beneficiaries.

The Distributive Impact Coefficient (DIC) was estimated according to item 5.1.4 of Appendix K of the Operational Regulation of the PRODETUR Program. According to the Operational Regulation of the PRODETUR Nordeste II Program, low-income population is defined as those whose family income is less than 5 (five) minimum wages. (PRODETUR, 2010).

3.4 Methodological Bases

The data sources feeding this research were produced by public agents, professional associations, non-governmental organizations, and surveys conducted with entrepreneurs. Regarding data used in bibliographic research, they were obtained from academic works by specialists, newspapers, specialized books, and conventional media.

The present research is a guideline for decision-making; however, it does not constitute a real guarantee, as an organization or enterprise is a social system subject to economic, social, political, demographic, and technological variables, which cannot be fully predicted and influence the dynamics of the enterprise. Thus, all planning, by its nature and contingent, is subject to periodic evaluations and eventual changes (FUNDARPE, 2009). Therefore, the research followed the following premises:

- the study was developed considering a temporal horizon of 20 years;
- the investment amount to be made was detailed in the budgets presented in the annex;
- the prices adopted in the construction budgets are market prices;
- the total investment values were calculated at market prices;
- the expected benefit is the appreciation of properties located within a radius of 100 meters from where the buildings of the enterprise are contained, according to the perimeter map attached. The current value adopted for these properties (R$ 3,023,417.09) is in accordance with the real estate register of the Municipality of Igarassu. The nominal list of properties is attached;
- a representative interest rate of 12% per year was adopted as the opportunity cost of invested

capital, which was used as the discount rate for the analyses conducted;

- The costs associated with ambiance investment (furniture, utensils, equipment) will be the responsibility of the lessees and are not considered in the present project;
- The management of the enterprise will be carried out by the Foundation for Historical and Artistic Heritage of Pernambuco (FUNDARPE), the owner of the cultural center. The administration of the equipment will be carried out by third parties through public tender, with the exception of the Cachaça Museum and the multipurpose space, which will be the responsibility of the public sector;
- Whenever necessary, financial updates and corrections were made using the National Construction Cost Index (INCC), following Equation 1 for determining the adjusted value.

Where:

R= Adjusted value (R$)

Io= Price index verified in the month of the opening of the bidding process or the proposal for the private work.

Ii= Price index for the month of January/2023

V= Construction cost (R$)

4. RESULTS OBTAINED

4.1 Costs

4.1.1 Investiments

$$R = \frac{Ii - Io}{Io \times V}$$

The estimated investment value was calculated using the cost estimation method, which is an approximate assessment of costs for the execution of an engineering project. The results of a cost estimate are based on previous projects. In other words, they are based on similar works previously carried out in the same region (KIEZA, 2023). That said, the estimated investment value was based on the investment value of the Engenho São João project. (FUNDARPE, 2007). The redevelopment project of the Engenho São João was chosen because it has similar characteristics to the Engenho Monjope in terms of construction period, construction system, architectural aesthetics, and location. The values were updated using the INCC. Thus, the market value of the Engenho Monjope investment is R$ 6,041,102.93, as per Table 2 - Investment Estimate.

4.1.2 Maintenance Costs

The cost of preventive maintenance for the set of buildings was calculated by averaging three quotes provided by building maintenance companies. The estimated total maintenance cost for the first year of the project amounted to R$ 33,116.00. at market values, as described inTable 3.

4.1.3 Operational Costs

For the calculation of operational costs, the assumptions described in the methodology were taken into consideration. The estimated values of annual operational costs were totaled at R$ 283,308.00 at market prices and are presented in Table 4. Operational costs for the use of all equipment were estimated using expenses from similar structures as a basis, along with consumption calculations. For salary calculations, the requirements of the CLT (Consolidation of Labor Laws) were considered, and the burden values were allocated monthly. Personnel involved in cleaning and maintenance comprise the maintenance cost, calculated by specialized

Engenho São João		Engenho Monjope	
Total Area	4,973,73 m²	Total Area	3.778,64 m²
Budget	R$ 7.951,742,52	Orçamento	R$ 6,041,102,93
Valor do m²	R$ 1,608,45	Valor do m²	R$ 1,598,75

Table 2: Investment Estimate

Source: Authors, 2024

Annual maintenance cost	
Discrimination	**Value**
Financial Planning for Preventive and Corrective Maintenance	
Architectural physical structures	R$ 500.00
Hydrosanitary installations	R$ 400.00
Fire detection, prevention, and fighting installations	R$ 2,000.00
Air conditioning installations	R$ 6,000.00
Lighting and extra illumination installations	R$ 1,600.00
Physical structure of landscaping and arrangements	R$ 1,400.00
Electrician	R$ 4,896,00
Mason/plumber	R$ 4,896,00
Gardener	R$ 4,896,00
Assistants	R$ 6,528,00
Total	**R$ 33,116.00**

professionals. Table 4 presents the detailed expenditure on annual payroll by function.

4.2 Reveneus

The revenues were calculated in two ways: for the equipment managed by the private sector, revenue is estimated through the calculation of rents, and for the equipment managed by the government, revenue will be calculated through the hosting of social activities.

The government, through the state government, will assume the management of the activities of the equipment whose uses are social and commits to making transfers of financial and economic resources necessary to cover operational costs in addition to providing for depreciation and amortization of investment at an annual rate of 12%.

Note that, although it is the direct responsibility of the

Annual Operational Cost			
Description	**Amount**	**Value**	**Total Value**
Manager	1	R$ 1,500.00	R$ 18,000.00
Security	6	R$ 800.00	R$ 57,600.00
Ticket seller	2	R$ 600.00	R$ 14,400.00
Engines	2	R$ 600.00	R$ 14,400.00
Support assistance	1	R$ 600.00	R$ 7,200.00
Energia Elétrica	-	-	R$ 42,000.00
Water	-	-	R$ 24,000.00
Miscellaneous expenses	-	-	R$ 16,308,00
Paper towel	-	-	R$ 4,320.00
Toilet paper	-	-	R$ 1,200.00
Cleaning supplies	-	-	R$ 9,600.00
Office supplies	-	-	R$ 3,000.00
Uniforms	-	-	R$ 600.00
Petty cash	-	-	R$ 6,000.00
Telephony	-	-	R$ 7,200.00
Accounting services	-	-	R$ 9,600.00
Fees	-	-	R$ 720.00
Transportation expenses	-	-	R$ 3,000.00
IPTU(Brazilian Tax)	-	-	R$ 10,200.00
Insurance	-	-	R$ 360.00
Reserves	-	-	R$ 33,600.00
Payroll	-	-	R$ 111,600.00
Total			**394,908.00**

Table 4: Annual operating cost

Source: Authors, 2024

state government, the administrations of the lodging-school, professional training center, and school restaurant spaces may be transferred to other federal, state, or municipal public entities whose work is associated with each use.

Table 5 presents the project revenue from leasing to the private sector and from ticket sales. The values were calculated at market prices. Table 6 shows the total revenue obtained through budget allocation transfers from the state government for the social use of the space. The state government should establish a budget allocation fund to meet the demands arising from the execution and maintenance of this project.

It is worth noting that although the cachaça museum is a publicly used facility, it has been included in the revenue from private sources due to the possibility of its use for exhibitions by private companies in the field, as well as other events of various kinds, such as exhibitions and book launches. Similarly, the revenue from the multipurpose space, whose administration is associated with FUNDARPE, was calculated based on the rental of the area ten times a month, at a unit value of R$ 1,500.00. In this space, events such as theater performances, film screenings, concerts, graduation ceremonies, among others, are expected to take place. The calculation basis considered the revenue from similar spaces. Finally, Table 7 summarizes the project's annual revenues.

4.3 Net Income

The Table 8 below presents the results of the first year of operation of the Project.

4.4 Cost-Benefit Analyses

4.4.1 Financial Analysis

Table 9 presents the forecast of the annual cash flow of revenues and operating, administrative, and maintenance expenses of the equipment in current values. For the corrected calculation of the cost estimate over the period, the value of the inflation target established by the Central Bank of Brazil over the last five years was considered. This counting format is in accordance with what is established

Equipment	Rent - monthly	Rent - annual
Cachaça museum	R$ 1,200.00	R$ 14,400.00
Cafeteria	R$ 700.00	R$ 8,400.00
Craft shop	R$ 500.00	R$ 6,000.00
Event area, chapel, and mini-center	R$ 6,000.00	R$ 72,000.00
Multipurpose Space	R$ 15,000.00	R$ 180.000.00
Revenue from ticket sales		
Full amount	R$ 2,178,00	R$ 26,136,00
Half-price ticket	R$ 1,089,00	R$ 13.068,00
Condominium revenue	R$ 2,950.00	R$ 35,400.00
Total	**R$ 29,617.00**	**R$ 355,404.00**

Table 5: Revenue from leasing to the private sector
Source: Authors, 2024

Usos	Monthly value	Annual value
Lodge-school	R$ 15,000.00	R$ 180,000.00
Professional training center	R$ 15,000.00	R$ 180,000.00
School restaurant	R$ 15,000.00	R$ 180,000.00
Total	**R$ 45,000.00**	**R$ 540,000.00**

Table 6: Transfers of budget allocation resources from the government for the social use of the space
Source: Authors, 2024

Total revenue in current prices	
Leasing to the private sector	R$ 355,404,00
Transfer of resources via budget allocation	R$ 540,000.00
Total revenue	**R$ 895,404.00**

Table 7: Total revenue in current prices
Source: Authors, 2024

in similar estimates. The IGP-M was the index used to adjust annual revenues, as this price index is used in rent adjustments. For the projection, the average value of the index over the last five years was considered.

Net income	
Total revenue	R$ 895,404,00
Total costs [1]	R$ 316,424,00
Net income	**R$ 578,980.00**

Table 8: Net income
Source: Authors, 2024

Table 10 presents the present values of revenues, investment costs, operating, administrative, and maintenance costs, and net results discounted at an annual rate of 12%. Note that the investment value was divided into two parts considering that 40% of the redevelopment work will be carried out in the first year and the remaining part will be carried out in the second year.

Through the analysis of Table 11, it can be seen that the project presents a negative Net Present Value (NPV) of R$ 461,007.69, which renders the project financially unviable by the NPV criterion. Therefore, it is not possible to calculate the Internal Rate of Return (IRR), making the project unfeasible.

It should be emphasized that this unfeasibility is associated with the characteristics of the intended uses for the

FINANCIAL ANALYSIS		
Revenues (Market prices)	**Operating, administrative, and maintenance costs (Marketprices)**	**Net Result (1-2)**
R$ 895,404.00	R$ 316,424.00	R$ 578,980.00
R$ 945,994.33	R$ 330,663.08	R$ 615,331.25
R$ 999,443.01	R$ 345,542.92	R$ 653,900.09
R$1,055,911.54	R$ 361,092.35	R$ 694,819,19
R$1,115,570.54	R$ 377,341.51	R$ 738,229.03
R$1,178,600.27	R$ 394,321.87	R$ 784,278.40
R$1,245,191.19	R$ 412,066.36	R$ 833,124.83
R$1,315,544.49	R$ 430,609.34	R$ 884,935,15
R$1,389,872.75	R$ 449,986.76	R$ 939,885,99
R$1,468,400.56	R$ 470,236.17	R$ 998,164.40
R$1,551,365,20	R$ 491,396,80	R$1,059,968,4
R$1,639,017.33	R$ 513,509.65	R$1,125,507,6
R$1,731,621.81	R$ 536,617.59	R$1,195,004.2
R$1,829,458.44	R$ 560,765,38	R$1,268,693,0
R$1,932,822.84	R$ 585,999.82	R$1,346.823,0
R$2,042,027.33	R$ 612,369.81	R$1,429,657,5
R$2,157,401.88	R$ 639,926.45	R$1,517,475,4
R$2,279,295,08	R$ 668,723.14	R$1,610.571,9
R$ 26,772,942.58	**R$ 8,497,593,00**	**R$ 18,275,349.58**

Table 9: Financial Analysis
Source: Authors, 2024

Engenho. Therefore, it is necessary to provide additional financial resources for the operation and maintenance of the project.

4.4.2 Economic Analysis

Considering the assumptions presented above, the indicator adopted for the viability of the project is the comparison of the investment cost with the Net Present Value (NPV) of the discounted cash flow added to the real estate appreciation in the vicinity of Engenho Monjope of 10% in the first year of operation, in addition to the calculation of the Internal Rate of Return (IRR) of the investment. The Table 11 presents the real estate appreciation in market values and present values, as well as in price-efficiency. It is worth noting that the present value uses a discount rate of 12%. It is also noted that to calculate the real estate appreciation in terms of price-efficiency, the product between the market value and the standard conversion factor (0.94) was used. Table 12 shows the cash flow in current values, and Table 13 presents the cash flow in terms of present value, with costs calculated in terms of price-efficiency. It is mentioned here that the real estate appreciation value calculated in column 1 of the table refers to the discounted price-efficiency value for year zero.

Through the analysis of Table 11, it can be seen that the project presents a negative Net Present Value (NPV) of R$ 2,354,270.85, which indicates that it does not meet the established criteria. It is also noted that, given the negative NPV result, the NPV criterion analysis method becomes

Year	Receita Valor Presente	Custos de Operação, administração e manutenção Valor Presente	Resultado Líquido (1-2)
Year 01	-	R$ 2,368,176,13	R$ 2,368,176,1
Year 02	-	R$ 3.171,664,46	R$ 3.171,664,4
Year 03	R$ 799,467,8	R$ 282,521,43	R$ 1,081,989,2
Year 04	R$ 754,140.8	R$ 263.602,58	R$ 1,017,743,4
Year 05	R$ 711,383,7	R$ 245,950.62	R$ 957,334,41
Ano 06	R$ 671,050.8	R$ 229,480.72	R$ 900.531,59
Year 07	R$ 633.004,6	R$ 214,113,70	R$ 847,118,39
Year 08	R$ 597,115,5	R$ 199,775,73	R$ 796,891,31
Year 09	R$ 563.261,2	R$ 186,397,89	R$ 749,659,15
Year 10	R$ 531,326,3	R$ 173.915,89	R$ 705,242,25
Year 11	R$ 501,202,0	R$ 162,269,74	R$ 663.471,79
Year 12	R$ 472.785,6	R$ 151.403,46	R$ 624.189,14
Year 13	R$ 445,980.4	R$ 141,264,84	R$ 587,245,26
Year 14	R$ 420.694,9	R$ 131,805,14	R$ 552,500.06
Year 15	R$ 396,843,0	R$ 122.978,90	R$ 519,821,93
Year 16	R$ 374,343,4	R$ 114,743,71	R$ 489,087,15
Year 17	R$ 353.119,5	R$ 107,059,98	R$ 460.179,48
Year 18	R$ 333.098,	R$ 99,890.78	R$ 432,989,67
Year 19	R$ 314,213,3	R$ 93.201,67	R$ 407,415,04
Year 20	R$ 296,398,6	R$ 86,960.48	R$ 383.359,08
Total	**R$ 9,169,431, 19**	**R$ 8,547,177,85**	**R$ 622,253,35**

Table 10: Financial analysis
Source: Authors, 2024

unviable. It is worth noting that the project will be carried out in the rural area of the Municipality of Igarassu, and therefore, real estate appreciation had a minimal effect on economic viability. We conclude by informing that most of the established uses were of a social nature, which generates significant social benefits for the population of the Mata Norte Pernambucana.

4.4.3 Sensitivity Financial Analysis

In this stage, three possible scenarios were simulated to verify if the project's viability would be affected by changes in some of these items. In the first scenario, the

Year	Real Estate apreciation		Real Estate apreciation
	Current Value	Presente value	Efficiency Prices
Year 01	-		-
Ano 02	-		-
Year 03	R$ 302,341,7	R$ 215,200.8	R$ 284.201,20
Total	**R$ 302,341,7**	**R$ 215,200.8**	**R$ 284,201,20**

Table 11: Economic Analysis
Source: Authors, 2024

Year	Revenues (Market Prices)	Operating, administrative, and maintenance costs (Market Prices)	3 - Net Result (1-2)
Year 01	-	-	-
Year 02	-	-	-
Year 03	R$ 302,341,7	R$ 316,424,00	R$ 14,082,30
Year 04	-	R$ 330.663,08	R$ 330.663,08
Year 05	-	R$ 345,542,92	R$ 345,542,92
Year 06	-	R$ 361.092,35	R$ 361,092,35
Year 07	-	R$ 377,341,51	R$ 377,341,51
Year 08	-	R$ 394,321,87	R$ 394,321,87
Year 09	-	R$ 412,066,36	R$ 412,066,36
Year 10	-	R$ 430.609,34	R$ 430.609,34
Year 11	-	R$ 449,986,76	R$ 449,986,76
Ano 12	-	R$ 470.236,17	R$ 470.236,17
Year 13	-	R$ 491.396,80	R$ 491,396,80
Year 14	-	R$ 513.509,65	R$ 513.509,65
Year 15	-	R$ 536,617,59	R$ 536,617,59
Year 16	-	R$ 560.765,38	R$ 560.765,38
Year 17	-	R$ 585,999,82	R$ 585,999,82
Year 18	-	R$ 612,369,81	R$ 612,369,81
Year 19	-	R$ 639,926,45	R$ 639,926,45

Year 20	-	R$ 668,723,14	R$ 668,723,14
Total	**302,341,70**	**R$ 8,497,593,00**	**R$ 8,195,251,30**

Table 12: Cash flow
Source: Authors, 2024

Year	Revenues Efficiency Prices	Operating, administrative and maintenance costs Efficiency Prices	Net Result (1-2)
Year 01	-	R$ 1,830.011,47	R$ 1,830.011, 47
Year 02	-	R$ 2,450.908,21	R$ 2,450.908, 21
Year 03	R$ 212,288,80	R$ 241,113,00	R$ 28,824,20
Year 04	-	R$ 224,967,04	R$ 224,967,04
Year 05	-	R$ 209,902,28	R$ 209,902,28
Year 06	-	R$ 195,846,32	R$ 195,846,32
Year 07	-	R$ 182,731,61	R$ 182,731,61
Year 09	-	R$ 159,078,04	R$ 159,078,04
Year 10	-	R$ 148,425,49	R$ 148,425,49
Year 11	-	R$ 138,486,28	R$ 138,486,28
Year 12	-	R$ 129,212,65	R$ 129,212,65
Year 13	-	R$ 120.560.02	R$ 120.560.02
Year 14	-	R$ 112,486,80	R$ 112,486,80
Year 15	-	R$ 104,954,20	R$ 104,954,20
Year 16	-	R$ 97,926,02	R$ 97,926,02
Year 17	-	R$ 91,368,47	R$ 91,368,47
Year 18	-	R$ 85,250.05	R$ 85,250.05
Year 19	-	R$ 79,541,34	R$ 79,541,34
Year 20	-	R$ 74,214,91	R$ 74,214,91
Total	**212,288,80**	**R$ 2,566,559,65**	**R$ 2,354,270. 85**

Table 13: Cash flow
Source: Authors, 2024

impact of a 25% increase in the investment value was analyzed. Next, the scenario was observed when there is a 20% reduction in revenue in present values. Finally, the economic scenario was observed in the presence of a 20% increase in administrative, operating, and maintenance costs of the project. The results of the possible scenarios are presented in Table 14.

Through the analysis of the above Tables, it can be observed that any changes in one of the analyzed scenarios could lead the project to economic and financial unfeasibility. Thus, the importance of project management and control is reaffirmed.

4.4.4 Distributive Impact - Distributive Impact Coefficient (DIC)

In order to analyze the impact caused by the investment on families with income of up to five minimum wages, the Distributive Impact Coefficient (DIC) was calculated. The DIC measures the benefit of the project for low-income individuals relative to the total number of beneficiaries in

the project (PRODETUR, 2010).

After the coefficient calculations, it is observed that the fraction of low-income beneficiaries (0.928) is quite considerable when compared to the total number of beneficiaries. Thus, the social importance of the proposed intervention is reaffirmed, ensuring that this city is in need of investments of this magnitude.

Present value in scenario I	
Investiments	**Net profit for the period**
R$ 7,551,378,66	- R$ 1,540.284,71
Present value in scenario II	
Investments	**Net profit for the period**
R$ 6,041,102,93	- R$ 1,592,232,63
Present value in scenario III	
Investments	**Net profit for the period**
R$ 6,041,102,93	- R$ 359,813,84

Table 14: Present values in scenarios I, II, and III

Source: Authors, 2024

5. FINAL CONSIDERATIONS

In the governmental scope, few studies have been able to demonstrate the economic impact of investment in tourism activity, crucial information for destinations that intend to use tourism as an important sector.

A scarcity of economic resources combined with the numerous problems caused by poverty in the Brazilian Northeast makes it essential to seek maximum efficiency in the allocation of public investments in the region. Thus, ongoing concerns and discussions of modern society have contributed to stimulating debate and emphasizing the need to achieve sustainable development.

Tourism is one of the activities that has stood out in recent times, not only for significantly contributing to the growth of the global economy but also for providing development for the various regions that harness existing potential.

The present work presented a study of economic and financial feasibility for the redevelopment of Engenho Monjope, taking into consideration multiple sources of revenue and various costs. It has also been demonstrated that the project is viable in social and financial aspects, both in terms of cost-benefit and the Distributive Impact Coefficient (DIC).

The presented result is entirely linked to the manager's performance in achieving the revenue, cost, investment, and maintenance goals proposed in the study. The qualification, attitude, decisions, and performance of the manager directly influence the results of the project. Therefore, periodic evaluations of the performance achieved and comparison with the expected result are suggested to correct any shortcomings.

The Engenho Monjope is one of the few sugar mills that has all the elements of a colonial mill — the main house, slave quarters, mill, chapel, bushes, the house of the "captain of the woods" and other smaller elements. Restoration is necessary to bring it up to modern societal demands. It is indeed a historical heritage of notable importance to the history of Brazil, and it has the potential to make history again. Therefore, through the study in question, it was possible to conclude that the redevelopment project is completely viable, both financially and economically. Thus, it is concluded that economic and financial feasibility studies are crucial to ensuring the success of projects located in historic sites.

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FUNDARPE - Fundação do Patrimônio Histórico e Artístico de Pernambuco. **Anexo I: Termo de Referência: contratação de consultoria especializada para elaboração do projeto de revitalização do engenho Monjope: plano de gestão, projetos básico, executivo e complementares de engenharia, estudo de viabilidade, socioeconômica**. Pernambuco: FUNDARPE, 2018. Disponível em: <https://www.cultura.pe.gov.br/wp-content/uploads/2019/02/EDITAL_MANUTEN%C3%87%C3%83O_PREDIAL_PREVENTIVA_ATUALIZADO.pdf>. Acesso em : 04/02/2023.

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AUTHORS

ORCID: 0000-0001-6431-447X

EMANOEL SILVA DE AMORIM, Mestre em Engenharia Civil | Universidade de Pernambuco | Mestrado em Engenharia Civil | Recife, PE – Brasil | Rua Ieda, 20 - São Benedito, Olinda – PE, 53.270-600 | E-mail: esa7@poli.b

ORCID: 0000-0001-7804-0959
GIRLÂNDIA DE MORAIS SAMPAIO, Mestranda em Engenharia Civil | Universidade de Pernambuco | Mestrado em Engenharia Civil | Recife, PE – Brasil | Rua José Correia, 10 – Centro, Itapetim – PE, 56.720-000 | E-mail: gms8@poli.br

ORCID: 0000-0002-4199-0528
AMANDA AIRES VIEIRA, Doutora em Economia | Universidade Federal de Pernambuco | Doutorado em Economia | Recife, PE – Brasil | Rua Benfica, 455 – Madalena, Recife – PE, 50.720-001 | E-mail: amandaires@gmail.com

ORCID: 0000-0003-3276-0621
ALBERTO CASADO LORDSLEEM JÚNIOR, Profº Doutor | Universidade de Pernambuco | Mestrado em Engenharia Civil | Recife, PE – Brasil | Rua Benfica, 455 – Madalena, Recife – PE, 50.720-001 | E-mail: acasado@poli.br

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REINVENT: A PROJECT COMPOSITE SUSTAINABLE

REINVENTE: COMPÓSITO SUSTENTÁVEL PARA EMBALAGEM

REINVENT: COMPOSITE SOSTENIBLE PARA EMBALAJE

ISABELLA CHRISTINA DE LIMA E SANTOS | UTFPR – Universidade Tecnológica Federal do Paraná, Brasil
UGO LEANDRO BELINI | UTFPR – Universidade Tecnológica Federal do Paraná, Brasil
ANDRÉ CHRISTIAN KEINERT | UTFPR – Universidade Tecnológica Federal do Paraná, Brasil

ABSTRACT
The consumption habits of people over the years have led to a significant environmental impact. In the pursuit of development that is less harmful to the environment, one possible alternative is the development of composites that include plant-based products in their composition. Thus, this project discusses the use of sugarcane bagasse with lignin-based resin in a composite, applied to a new packaging design solution. The obtained composites used a medium granulometric fraction of sugarcane bagasse, bound with 30% lignin-based resin/particles, and manufactured in a pressing cycle of: 3 t, 100ºC, 10 min, achieved with an average density of 750 kg/m^3. Workability tests were conducted in laboratories, such as processing, drilling, and sanding, which presented satisfactory results that allow the applicability of the composite. The material obtained proved to be light, resistant, with satisfactory texture and appearance. A brainstorming session was conducted on the application of the composite, and it was decided to apply it in packaging for higher value-added products .The prototype, called Reinvente, has a rustic look, practicality, versatility, and easy handling. A survey was conducted with a group of people to validate the prototype. Therefore, it was observed that the composite is an excellent alternative material to be used in the creation of bioengineering projects and interior design, combining aspects of innovation and the environment.

KEYWORDS
Sustainability; Sugar cane bagasse; Lignin Resin; New Products.

RESUMO
Os hábitos de consumo das pessoas ao longo dos anos levaram a um impacto ambiental significativo. Na busca por um desenvolvimento menos nocivo ao meio ambiente, uma possível alternativa é o desenvolvimento de compósitos que incluam produtos de base vegetal em sua composição. Assim, este projeto discute o uso de bagaço de cana-de-açúcar com resina à base de lignina em um compósito, aplicado a uma nova solução de design de embalagens. Os compósitos obtidos utilizaram uma fração granulométrica média do bagaço de cana-de-açúcar, vinculada com 30% de resina/partículas à base de lignina, e fabricados em um ciclo de prensagem de: 3 t, 100ºC, 10 min, alcançando uma densidade média de 750 kg/m³. Foram realizados testes de trabalhabilidade em laboratórios, como processamento, perfuração e lixamento, que apresentaram resultados satisfatórios, permitindo a aplicabilidade do compósito. O material obtido mostrou-se leve, resistente, com textura e aparência satisfatórias. Uma sessão de brainstorming foi realizada sobre a aplicação do compósito, e decidiu-se aplicá-lo em embalagens para produtos de maior valor agregado. O protótipo, chamado Reinvente, possui um aspecto rústico, praticidade, versatilidade e fácil manuseio. Foi realizada uma pesquisa com um grupo de pessoas para validar o protótipo. Portanto, observou-se que o compósito é um excelente material alternativo a ser utilizado na criação de projetos de bioengenharia e design de interiores, combinando aspectos de inovação e meio ambiente.

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PALAVRAS-CHAVE

Sustentabilidade; Bagaço de Cana-de-Açúcar; Resina de Lignina; Novos Produtos.

RESUMEN

La forma de consumo de las personas a lo largo de los años ha tenido un gran impacto ambiental. En la búsqueda de un desarrollo que dañe menos el medio ambiente, una posible alternativa es el desarrollo de composites que contengan productos de origen vegetal. Así, este proyecto analiza el uso de bagazo de caña de azúcar con resina a base de lignina en un composite, aplicado en una nueva solución al diseño de envases. Los composites obtenidos utilizaron una fracción granulométrica promedio de bagazo de caña de azúcar, ligada con un 30% de resina/partículas a base de lignina y fabricados en un ciclo de prensado de: 3 t, 100ºC, 10 min, obtenidos con una densidad promedio de 750 kg/m³. Se realizaron pruebas de trabajabilidad en laboratorios, como procesamiento, taladrado y lijado, las cuales presentaron resultados satisfactorios que permiten la aplicabilidad del composite. El material obtenido resultó ser ligero, resistente, de textura y apariencia satisfactoria. Se realizó una lluvia de ideas sobre la aplicación del composite y se decidió aplicarlo en envases para productos de mayor valor agregado (PMVA). El prototipo, denominado Reinvente, tiene aspecto rústico, practicidad, versatilidad y fácil manejo. Se realizó una encuesta a un grupo de personas para validar el prototipo. Por lo tanto, se observó que el composite es un gran material alternativo para ser utilizado en la producción de proyectos de bioingeniería y diseño de interiores, combinando aspectos de innovación y medio ambiente.

PALABRAS CLAVE

Sostenibilidad; Bagazo de caña de azúcar; Resina a base de lignina; Nuevos productos.

1. INTRODUCTION

The significant industrial growth observed over the years has changed people's consumption patterns and has led to a considerable environmental impact. Thus, sustainable innovation becomes unavoidable and should not be dismissed. It is necessary to adopt sustainable development alternatives in which the production of goods and services preserves diversity and respects the integrity of ecosystems (DIAS, 2015).

Therefore, a reorientation of social behaviors is necessary, encouraging the search for products and services that adopt and promote sustainable alternatives. The transition from this form of material consumption should be driven by choice, that is, by recognizing each as an opportunity to improve well-being (MANZINI; VEZZOLI, 2002). In this process, an evident alternative is the development of composites that include products of vegetable origin in their composition. A composite can be considered as the combination of properties of two or more distinct materials, resulting in a new material (CALLISTER; RETHWISCH, 2018).

One of the possibilities for developing composites, as a solution to Design, is the use of sugarcane bagasse with lignin-based resin, which was the focus of the project study. The research brought innovation based on the reuse of by-products that would otherwise be discarded. Thus, the focus was on studying a potential application for the developed composite, considering its utility and the optimization of its life cycle.

1.1 OBJECTIVES

The objective of this work was to develop a composite made from sugarcane bagasse combined with lignin--based resin and apply it to a sustainable packaging that could be reused for other purposes. To achieve this objective, the aim was to understand Design, Sustainability, and their relationship, as well as to define what composites are. This understanding enabled the progression to the production stages and the application in a prototype.

2. DESIGN FOR SUSTAINABILITY

In 1750, the Industrial Revolution began in England, introducing a new production model, changing traditional artisanal products, and establishing various aesthetic movements. This gave rise to Design, which, according to Manzini and Vezzoli (2002), encompasses all territorial project activities, as well as graphic design, architecture, and consumer goods. These activities involve a creative process focused on the needs of the population, aiming to enhance their well-being (HSUAN-AN, 2018).

Thus, the designer has the role of creating effective solutions to societal demands, transforming them into concrete results (HSUAN-AN, 2017). Among these challenges, the professional can also contribute to sustainability by choosing materials that favor environmental preservation, linking the technically possible with the ecologically necessary, and creating proposals that are socially and culturally meaningful (MANZINI; VEZZOLI, 2002).

The significant industrial growth observed over the years has changed people's consumption patterns and led to a considerable environmental impact (DIAS, 2015). As a result, sustainable innovation becomes unavoidable and should not be dismissed. Therefore, a reorientation of social behaviors is necessary, encouraging the search for products and services that adopt and promote sustainable alternatives (MANZINI; VEZZOLI, 2002).

In this context, aesthetics play a fundamental role in the design of these new products because sustainable innovation, if not perceived as an improvement, is insufficient. The entire set of characteristics that make the product attractive must be considered (VEZZOLI, 2010). Thus, it is the designer's task to create projects that provide innovation, ideas, and new concepts, understanding how to make them aesthetically captivating, and designing with all stages in mind to convey to consumers the conscious vision necessary to achieve sustainability (MANZINI, 2008).

One way to offer sustainable alternatives to consumers is through what the term upcycling proposes. Coined by Reine Pilz in 1994 and popularized by William McDonough and Michael Braungart, this process involves the reuse or repurposing of materials that would otherwise be discarded, maintaining the essence of the original product, even if the initial function is altered (SILVA et al., 2012). In this process, an evident alternative is the development of composites that include natural-origin products in their composition.

3. COMPOSITE MATERIALS

The emergence of composites as materials occurred in

the mid-20th century with the production of multiphase composites. The recognition of this new way of combining materials led to the identification of composites as a distinct new class separate from traditional metals, ceramics, and polymers (CALLISTER, RETHWISCH, 2018).

From this, we can understand that composites are the union of two or more materials used together to result in a new combination of properties. They can be selected to achieve combinations of stiffness, mechanical strength, density, performance at high temperatures, corrosion resistance, hardness, and conductivity (ASKELAND, WRIGHT, 2014).

Considering these different characteristics, these materials can have various applications depending on factors such as structural performance, cost, availability of raw materials, and the progress of their manufacturing process, among other parameters (NETO, PARDINI, 2018).

3.1 Fiber-Reinforced Composites

There are various methods for producing composites, depending on the application and materials. Short fiber--reinforced composites are formed by mixing fibers with a liquid or plastic matrix and then using relatively conventional techniques, such as injection molding for polymer--based composites or casting for metal matrix composites (ASKELAND; WRIGHT, 2014).

To produce composites with plant-based materials, it is necessary to achieve the proper mixing of fibers, select the appropriate matrix, apply suitable surface treatments, and, if necessary, use low-cost manufacturing techniques. This ensures greater adhesion, reduced moisture, and lower sensitivity in the composites (SATYANARAYANA, 2010).

The use of plant-based fibers in a composite primarily aims to create a sustainable and cost-effective material. One possibility for developing a plant-based composite is the use of sugarcane bagasse with resin, which is the focus of this project.

3.2 Sugarcane bagasse

Introduced by the Portuguese in the 1530s, sugarcane cultivation is one of the oldest forms of agriculture and a symbol of the Brazilian territory. According to data from the Food and Agriculture Organization of the United Nations (FAO), since 1980, Brazil has become the world's largest producer of sugarcane (IBGE, 2017).

Almost all by-products of sugarcane can be utilized. Among them, sugarcane bagasse stands out. It is a fibrous residue from the extraction of juice through the mills. The amount produced depends on the fiber content of the processed cane, with an average of 46% fiber and 50% moisture, resulting in approximately 280 kilograms of bagasse per ton of processed cane (ALCARDE, 2009).

3.3 Lignin-based resin

Lignin is a biopolymer derived from plants that provides structure and rigidity to wood and plants, acts as an internal transport system for nutrients and water, and protects against microbial attacks. However, lignin can also be found as a by-product in the paper industry, during the process of extracting cellulose from wood, known as pulping, which reduces wood to cellulose pulp (CALVO-FLORES et al., 2015).

4. METHODOLOGY

To ensure the project's success in its technical development aspects, the composite was produced following the methodology outlined by Mike Baxter (2011) in 'Product Design: Practical Guide for Designing New Products.' To create an effective market solution in design, it was necessary to gather information and opinions from potential consumers. For this purpose, part of the methodology from Gavin Ambrose (2011) in 'Design Thinking' was used, considering that the project's development timeline did not allow for the full implementation of the proposed methodology.

For better understanding, the process adopted in the work was divided into the following stages: (a) Definition; (b) Analysis; (c) Material Analysis; (d) Idea Generation; (e) Production; (f) Feedback and Communication.

4.1 Equipment

The equipment used in the production of the composite included: a Lucadema drying and sterilization oven at 70°C (Figure 01), a Marconi hydraulic press for crushing with heating (Figure 02), waterproof Teflon sheet for the thermal press, wooden board for mold support, MDF mold for depositing the mixture, plastic containers for holding the resin and fiber, rubber gloves, a 10kg digital scale Original Line model SL0363, and a plastic tray for mixing (Figure 03).

Figure 01: Drying and Sterilization Oven.
Source: Authors.

Figure 02: Hydraulic Press for Crushing with Heating.
Source: Authors.

Figure 03: Other materials used.
Source: Authors.

To divide the sugarcane bagasse, granulometric sieves with mesh openings of 2 and 7 millimeters were used (Figure 04), making it possible to separate the fibers into 3 different sizes.

Figure 04: Granulometric Sieves.
Source: Authors.

4.2 Materials

The phenol-lignin-formaldehyde resin used in this work was Eco Residur, supplied by GPC Química. It is a dark red liquid resin (Figure 05). According to the analysis report provided by the company, it is suitable for bonding wood products and porous materials in general, such as water-resistant plywood, cement fiber, and others.

Figure 05: Lignin-Based Resin.
Source: Authors.

It has a shelf life of 60 days when stored at an average temperature of 25°C. At low temperatures (below 10°C), it is stable, but its viscosity increases, while at high temperatures, its shelf life is reduced. It is advisable to use gloves, safety goggles, and an apron when handling it. Curing occurs with heat, starting from 6 minutes at 100°C.

The sugarcane bagasse used was donated by a sugar and alcohol plant in the interior of São Paulo. The material underwent drying and granulometric separation. The separation was done to divide the fibers into 3 sizes: fine, medium, and coarse (Figure 06).

First, the fine fibers were separated using a 2-millimeter mesh sieve. Subsequently, the division between medium and coarse fibers was done using a 7-millimeter mesh sieve.

Figure 06: Sugarcane Bagasse Fibers Separated into Fine, Medium, and Coarse.
Source: Authors.

4.3 Composite Production

Initially, to determine the amount of material to be used in the manufacturing process, a volume calculation was performed based on the dimensions of the available mold and the desired thickness of the plate. Next, the density of the desired plate was calculated, using the density of MDF as a reference, which corresponds to $1m^3 = 700$ kg. This allowed for the determination of the amount of fibers needed.

Thus, the amount of sugarcane bagasse used was approximately 90 grams. To determine the resin dosage, the non-volatile content of the resin was considered, which is 51% of the total. The values used in production were varied to understand how the material would behave, and were adjusted based on the results obtained.

With this, it was possible to proceed with the composite production. First, the fibers were separated according to the desired size into a container and weighed on a scale. Then, the resin was poured into another container and weighed. Next, the fibers were placed in a tray, and the resin was gradually poured over them, mixing the two materials (Figure 07).

Figure 07: Preparation of the Fibers.
Source: Authors.

Next, the mixture was placed into the MDF mold to accommodate the material. The mold was supported on a wooden board with the Teflon sheet underneath to prevent the material from sticking to the heated plate. Then, another Teflon sheet was placed on top, and the setup was placed into the hydraulic press (Figure 08).

Figure 08: Shaped Fibers Ready for the Press.
Source: Authors.

5. EXPERIMENTATION

To better understand the behavior of the materials, several samples were made, varying the amount of resin and fiber granulometry. All variations yielded different results, demonstrating the vast potential of composite materials.

The following samples were subjected to 100°C with a pressure of 3 tons and a total time of 10 minutes: (a) 90g of medium fiber and 18g of resin; (b) 90g of fine fiber and 38g of resin; (c) 90g of coarse fiber and 38g of resin; (d) 90g of coarse fiber and 18g of resin; (e) 90g of medium fiber and 27g of resin; (f) 90g of fine fiber, 27g of resin, and a piece of jute; (g) 90g of medium fiber and 38g of resin (Figure 09).

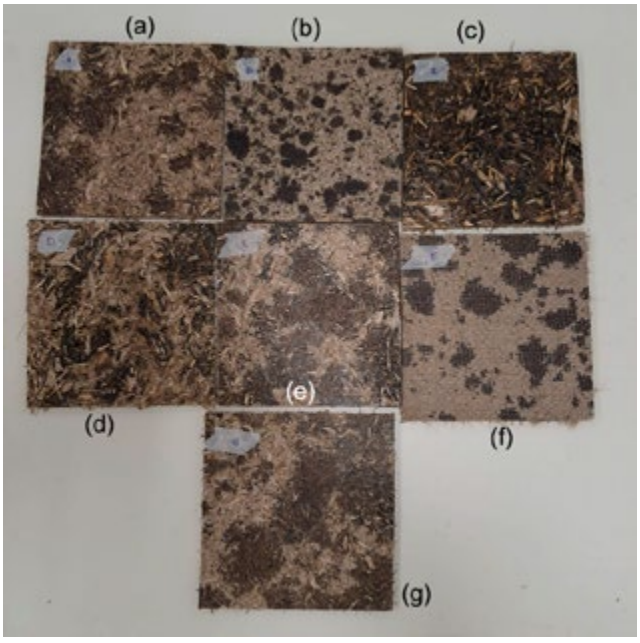

Figure 09: First Batch of Samples.
Source: Authors.

The following samples were subjected to 180°C, with a pressure of 2 tons and a time of 5 minutes: (a) 90g of coarse fiber and 18g of resin; (b) 90g of medium fiber and 27g of resin (Figure 10).

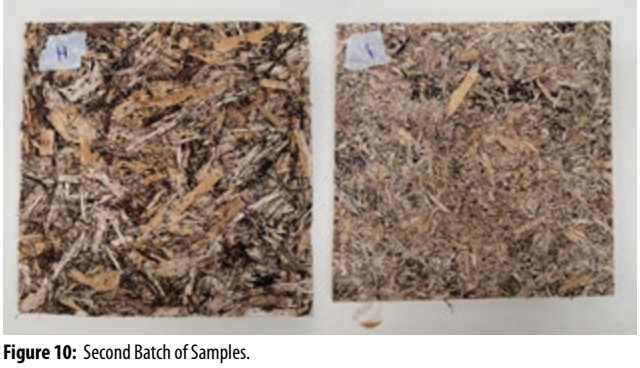

Figure 10: Second Batch of Samples.
Source: Authors.

The following samples were subjected to 120°C, with a pressure of 2 tons and a time of 8 minutes: (a) 90g of medium fiber and 27g of resin; (b) 90g of coarse fiber and 18g of resin (Figure 11).

Figure 11: Third Batch of Samples.
Source: Authors.

The samples that were exposed to higher temperatures and/or pressures and times exhibited a drier appearance, making the fibers more brittle. To understand the material's behavior during machining, the samples were subjected to a band saw (Figure 12), a drill with different sizes of bits (Figure 13), and also a cut with Computer Numerical Control (CNC) (Figure 14). It was also displayed in possible

Figure 12: Machining with Band Saw.
Source: Authors.

Figure 13: Machining with Drill.
Source: Authors.

Figure 13: Machining with CNC.
Source: Authors.

This allowed us to define some requirements for proceeding to the next stages. It was observed that the sample with fine fibers, despite having higher resin absorption and thus greater difficulty in distribution, exhibited greater resistance to machining. In contrast, the medium and coarse fiber samples, particularly those with lower amounts of resin, tended to come apart more easily, forming more burrs and resulting in a more fragile piece.

The sample chosen for the next phase was the one with medium fibers, as it allowed for better resin distribution and less material loss during machining compared to the coarse fibers. The amount of resin was increased to 50%, or 45 grams, to provide greater resistance.

6. CONCEPT

According to Baxter (2011), the conceptual design aims to produce principles for a new product, meeting consumer demands and differentiating it from existing products on the market. This allows for the development of basic lines of the desired form and function. By incorporating the concept of sustainability into the project, the goal was to apply the requirement of eco-efficiency to the system, known as system life optimization. This requirement aims to extend the product's life and enhance its use. Thus, a product with a longer life than another with the same function generally implies a lower environmental impact (VEZZOLI, 2010). Consequently, the product has a primary function, but once in the possession of the end user, it may serve additional functions.

Considering that the material studied did not achieve satisfactory results in organic forms, the product needed to have flat shapes, i.e., be geometric. Therefore, the specified concepts were: (a) Functionality; (b) Life optimization; (c) Practicality.

To ensure that the prototype could be easily identified and remembered, a name was created for the project. Taking into account the reuse of materials, a suggestion for a product different from the conventional, and the optimization of the product's lifespan, the project was named "Reinvente" (Reinvent). Thus, it encompasses its already defined concepts: Reinvent the way you consume, Reinvent the way you produce, and Reinvent new ways to use.

7. PROTOTYPE

Upon determining the product configuration, with the 3D model and technical drawings defined, and preparing the specifications for manufacturing, the cutting of the pieces was carried out using the CNC machining method (Figure 15).

Figure 15: Machining of the parts for the prototype.
Source: Authors.

A varnish was applied to the parts to provide greater resistance and durability to the product, as well as to give a more aesthetically pleasing finish. Glue was used to reinforce the joints, providing increased durability. For this work, Marine Varnish Poliulack from Sayerlack and White Glue Polyvinyl Acetate - PVA Extra from Mundial Prime were used, both of which are water-based materials.

7.1 Finalization

To better visualize the prototype, studio photos were taken with detailed framing (Figures 16 and 17).

Figure 16: Detailed photos of the prototype.
Source: Authors.

Figure 17: Detailed photos of the prototype.
Source: Authors.

It was also displayed in possible everyday scenarios. The first demonstrated its primary use as a perfume packaging (Figure 18). The second shows its use as a jewelry holder (Figure 19), and the third shows the separated packaging, with one part used as a key holder and the other part for storing received letters (Figure 20).

Figure 18: First use scenario: perfume packaging.
Source: Authors.

Figure 19: Second use scenario: jewelry holder.
Source: Authors.

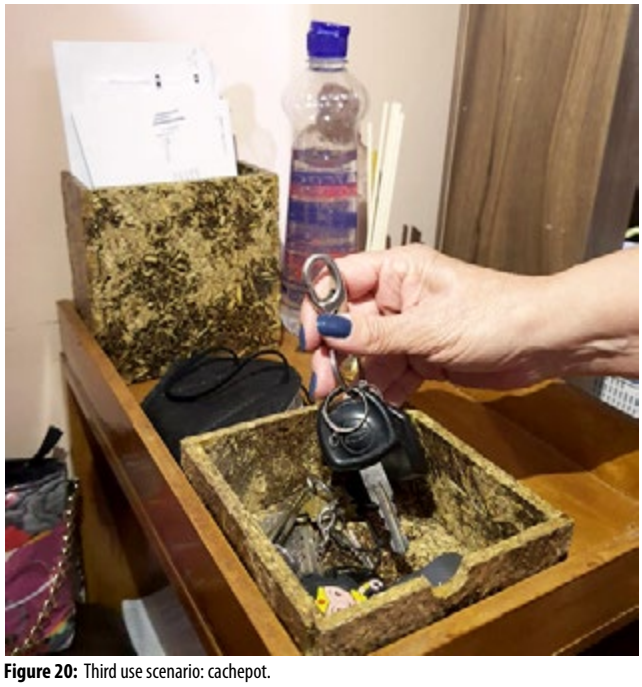

Figure 20: Third use scenario: cachepot.
Source: Authors.

8. FEEDBACK

To gather validation information on the usability of the developed prototype, analyzing possible changes and future improvements, a form was created on the Google platform to obtain feedback. The survey was divided into three parts: knowledge of the study area, product analysis, and finally, functionality, including photos and relevant information, and did not include the identification of the respondents.

Most respondents considered it important to have products in this production line and would purchase them if they were less expensive than conventional ones, as most could not determine if they would buy them if the cost were higher. They also found both designated functionalities for the packaging to be valid.

They liked the idea and concept of the project, considering the importance of sustainability as hope for a better future and the relevance of material reuse. Aesthetically, it was considered rustic, which pleased most people.

Due to the project's tight deadline, it was not possible to implement the subsequent stages of research and product improvement. However, the importance of obtaining more feedback for the continuous refinement of the product is recognized.

9. FINAL CONSIDERATIONS

The proposal to obtain a composite from sugarcane bagasse, bound with lignin-based resin, was feasible. This research successfully combined aspects of sustainability and innovation in the environment by utilizing residual biomass bound with a 30% dosage of resin particles that contain, in their composition, residual black liquor from the cellulose extraction process.

The effectiveness of the pressing cycle used (3 t, 100°C, 10 min) was demonstrated, and the obtained composites had an average density of 750 kg/m^3, allowing for excellent performance in workability and surface aspects. Combined with CNC machining for glue-free joints, this enabled the creation of a prototype packaging designed for high-value products, such as perfumes and jewelry.

According to the feedback received from the evaluation group, the prototype exhibited a rustic appearance and excellent functionalities for packaging, and the importance of projects with sustainability and material reuse aspects was emphasized.

Thus, the prototype, named "Reinvente," features a rustic look, practicality, versatility, and ease of handling. It is noted that the composite is a great alternative material for use in bioengineering projects and interior design, merging

aspects of sustainability, innovation, and the environment.

This was an exploratory project, utilizing plant-based residues to propose a new type of composite, aiming to provide relevant information and encourage the study of new materials. For future work, considering the potential already demonstrated, it is recommended to observe the resin's lifespan according to the project, use higher capacity equipment to evaluate new uses and applications in larger composites, base research on applying the resin to other types of fibers, its extraction and pressing cycle, deepen its mechanical and technical characterizations, and disseminate the obtained knowledge so that other researchers can conduct new studies.

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AUTHORS

ISABELLA CHRISTINA DE LIMA E SANTOS. Designer. DADIN/ Universidade Tecnológica Federal do PR. Av. Sete de Setembro, 3165 Rebouças, Curitiba-PR, 80230-901. E-mail: isachris111@gmail.com

UGO LEANDRO BELINI. Eng. Florestal. DADIN/PPGSAU/ Universidade Tecnológica Federal do PR. Av. Sete de Setembro, 3165 Rebouças, Curitiba-PR, 80230-901. E-mail: ubelini@utfpr.edu.br

ANDRÉ CHRISTIAN KEINERT. Eng. Ind. Madeireiro. Doutorando PPGSAU/Universidade Tecnológica Federal do PR. Av. Sete de Setembro, 3165 Rebouças, Curitiba-PR, 80230-901. E-mail: andrechristiankeinert@gmail.com

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ALTERNATIVE BINDER TO PORTLANDCEMENT PRODUCED WITH MAGNESIUMOXIDE AND METAKAOLIN

MARIA PAULA HÊNGLING CHRISTÓFANI MORAES, MSc. | UNESP – Universidade Estadual Paulista
CESAR FABIANI FIORITI, Dr.| UNESP – Universidade Estadual Paulista

1. INTRODUCTION

The construction sector is constantly growing, similar to the production and consumption of Portland cement. However, its entire production and use process requires a large consumption of natural resources and high energy consumption, in addition to being one of the main sources of emissions of so-called greenhouse gases (SCRIVENER, 2014; CAO et al. 2021; WALLING e PROVIS, 2016; ALI et al., 2011; RASHAD e ZEEDAN, 2011).

In this way, alternative formulations for the binder have been studied; among them, magnesium cement stands out, which, among different formulations, can be produced by combining magnesium oxide (MgO) and a siliceous material, that is, rich in silicon dioxide. (SiO2 – also called silica), resulting in a binder with characteristics similar to Portland cement and which presents several sustainable aspects.

In view of the above, this work aimed to study the behavior of an alternative binder composed of MgO and metakaolin as a source of SiO2 for the system and compare it to a more studied reference system composed of MgO and silica fume (the most commonly used source of SiO2). For this purpose, pastes were prepared and analyzed with two different proportions of constituents (40/60 and 60/40 by mass) and with two different water/binder (w/a) ratios (0.6 and 0.7). Figure 1 presents examples of test specimens used in the research.

Figure 1: Examples of specimens used.
Source: Authors.

2. METHODOLOGY

The experimental program included x-ray fluorescence (XRF) assays, x-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM); thermogravimetry (TG), compressive strength; temperature by time and water absorption by capillarity.

3. RESULTS

The results obtained allowed us to understand that the combination of MgO with metakaolin produces hydration products capable of providing compression resistance to the pastes, as occurs with the MgO and silica fume system, and also that, due to the presence of alumina in the chemical composition of metakaolin, the formation of another hydration product, called hydrotalcite, was confirmed. The compressive strength achieved with metakaolin pastes was lower than that of the reference system with silica fume, and therefore future studies should be conducted to improve the system.

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MATERIAIS SUSTENTÁVEIS PARA A INDÚSTRIA DA MODA ATRAVÉS DO PROCESSO DE DOWNCYCLING

JUNIOR COSTA, MSc. | UMINHO – Universidade do Minho
ANA CRISTINA BROEGA, Dra.| UMINHO – Universidade do Minho

1. INTRODUÇÃO

Em 2021 o Brasil entrou em dívida com o planeta no dia 21 de julho, data que marca o uso e esgotamento dos recursos naturais previstos para todo o ano, acima da capacidade natural de regeneração do planeta. Fato que se deve a exploração, produção e consumo descontrolado desde o início da Revolução Industrial. Partindo do pressuposto da necessidade de propor novas alternativas, métodos de fabricação e materiais, defendido por Fletcher e Grose (2011); e desenvolver novos materiais em substituição aos polímeros e resinas a base de petróleo utilizados atualmente, segundo Manzini (2008). Esta pesquisa propõe o desenvolvimento experimental de botões mais sustentáveis, abordando a problemática em torno dos resíduos sólidos, visando auxiliar na valoração, reuso e gestão como matérias-primas alternativas. Assim, a presente dissertação de mestrado em design e marketing de produto têxtil tem por objetivo investigar o setor de inovação em novos materiais sustentáveis através de matérias primas orgânicas provenientes de resíduos agroalimentares. A investigação académico-científica está inserida na área de Engenharia Têxtil, aborda a ciência dos materiais e economia circular, com foco em P&D&I.

2. METÓDO

A investigação com foco em desenvolvimento de produtos, teve início a partir de pesquisa bibliográfica de caráter qualitativo (Bogdan e Biklen, 1994), exploratório, com orientação analítico-descritiva do estudo de materiais e seus processos de produção (Bardin, 2004). A interpretação do material coletado segue métodos de análise de conteúdo e interpretação (Erickson, 1986). Pesquisa comparativa para análise e síntese de ideias. Após a etapa teórica, dá-se início a investigação de campo e experimental com a aplicação de métodos do Design Thinking para desenvolvimento de produtos (Tschimmel, 2017). No procedimento experimental, a matéria-prima (resíduos) foi pulverizada utilizando o moinho de anel e disco, o subproduto foi aplicado ao PLA, previamente levado a fusão em mufla a 214 °C, gerando um material compósito. O material foi moldado no formato final em formas de silicone.

3. RESULTADOS

O estudo utilizou de métodos experimentais realizados inicialmente em ambiente doméstico, replicados e validados em laboratório.The experimental program included x-ray fluorescence (XRF) assays, x-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM); thermogravimetry (TG), compressive strength; temperature by time and water absorption by capillarity.

Os botões da amostra (figura) foram produzidos a partir

Figure 1: Botão Sustentável a partir de Resíduos Agroalimentares.
Source: Autores..

das cascas de nozes, resíduo alimentar do consumo doméstico, objetivando a escalabilidade a partir de resíduos da indústria alimentícia. A validação técnica de resistência foi determinada inicialmente pelo método 5A de lavagem doméstica, seguindo a NP EN ISO 6330:2002.

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4. CONCLUSÕES

Os botões são itens imprescindíveis na construção do vestuário e ignorado quanto ao seu impacto negativo no meio ambiente. Em média existem 6 botões em cada peça de roupa, se somado toneladas de roupas pós-consumo descartadas anualmente, o seu descarte incorreto torna-se bastante significativo.

O papel da indústria é transformar os recursos naturais em matéria-prima, de onde são produzidos fibras e outros materiais. Ao considerar as indústrias por áreas de operação, fica visível que a têxtil, atrelada à cadeia da moda, não evoluiu harmonicamente a sua expansão e importância global, continuam a utilizar os mesmos materiais anteriores a revolução industrial. A reintrodução dos resíduos no ciclo de vida de produção (CVP) levando em conta os desenvolvimentos de produtos mais sustentáveis podem ser obter uma redução significativa impactos negativos e diminuir a constante preocupação ambiental e social que a indústria acarreta atualmente. A implementação do método ACV na indústria da moda pode promover grande utilidade quanto à busca de soluções adequadas mediante o objetivo de obter uma trajetória mais sustentável da cadeia produtiva.

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MATERIAIS EM HQ – ESTUDO DO BAMBU

PABLO HENRIQUE LAGUNA DIAS | UFSC – Universidade Federal de Santa Catarina
PAULO CESAR MACHADO FERROLI, Dr. | UFSC – Universidade Federal de Santa Catarina
LISIANE ILHA LIBRELOTTO, Dra. | UFSC – Universidade Federal de Santa Catarina

1. INTRODUÇÃO

O ensino de materiais e processos está em constante atualização no contexto educacional. A transmissão de conhecimento às novas gerações necessita de abordagens inovadoras, sustentadas pelas mudanças culturais dos últimos anos e diferenças inter e intrageracionais. Este resumo apresenta uma parte do projeto de IC/Extensão intitulado Materiais em HQ, com foco no bambu. Parte de uma série de publicações para ensino de materiais e processos objetivam atender as demandas de uma nova geração de estudantes da área projetual, sob a forma de histórias em quadrinhos, o capítulo do bambu aborda um material de uso milenar, que recentemente passou a ser estudado com mais intensidade, tanto pela academia quanto pelo mercado profissional. Os resultados apresentados neste resumo mostram o desenvolvimento dos princípios da HQ no capítulo referente ao bambu, com foco em suas propriedades, características, pontos fortes, limitações e exemplos de uso, mostrando o processo construtivo do capítulo, com as pesquisas direcionadas ao material em específico.

Figura 1: Oficina prática.
Fonte: própria

2. RESULTADOS

Conforme pode-se ver na figura 1, a ideia central é atrair os estudantes à leitura dos capítulos procurando inserir atividades universitárias cotidianas. No caso exemplificado a professora está conduzindo uma atividade prática, onde os participantes têm a oportunidade de estabelecer uma relação entre teoria e prática, através da vivência experimental construtiva com o bambu.

Já na figura 2 tem-se um exemplo de como o conteúdo propriamente dito é abordado, com o conceito do que é o material, e também suas principais características. Isso se repete ao longo do capítulo, até a parte final, onde a narrativa da HQ volta a ter um caráter diversificado, preparando o próximo capítulo.

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Figura 2: Parte conceitual do material.
Fonte: própria

As referências bibliográficas são passadas ao longo do texto, como indica a figura 3, que também demonstra o uso abundante de esquemas que conduzem o estudante ao estudo direcionado pretendido nas ementas das disciplinas.

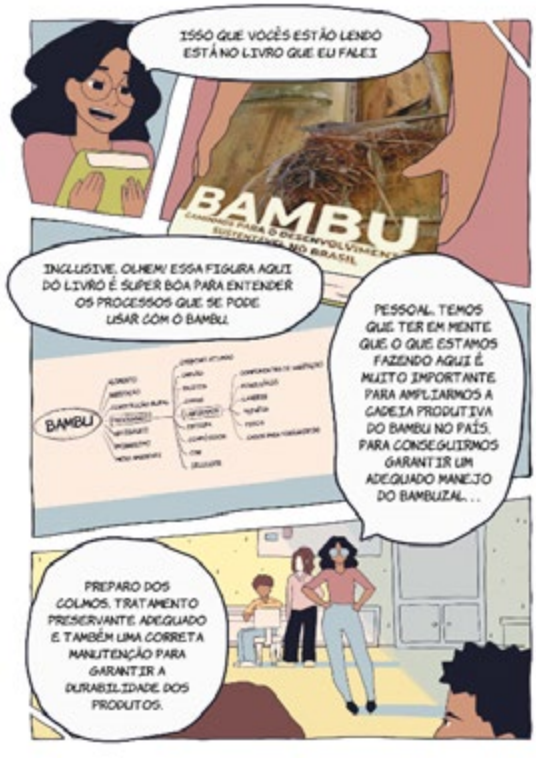

Figura 3: Exemplo de referências.
Fonte: própria

Na maioria dos capítulos, professores de outras instituições são convidados a participarem, conforme suas expertises. No caso do bambu, foi convidado o professor Fabiano Ostapiv, da UTFPR, que está representado na figura 4.

Na mesma figura é possível perceber a ênfase de processos construtivos, que acompanha a parte conceitual dos materiais estudados.

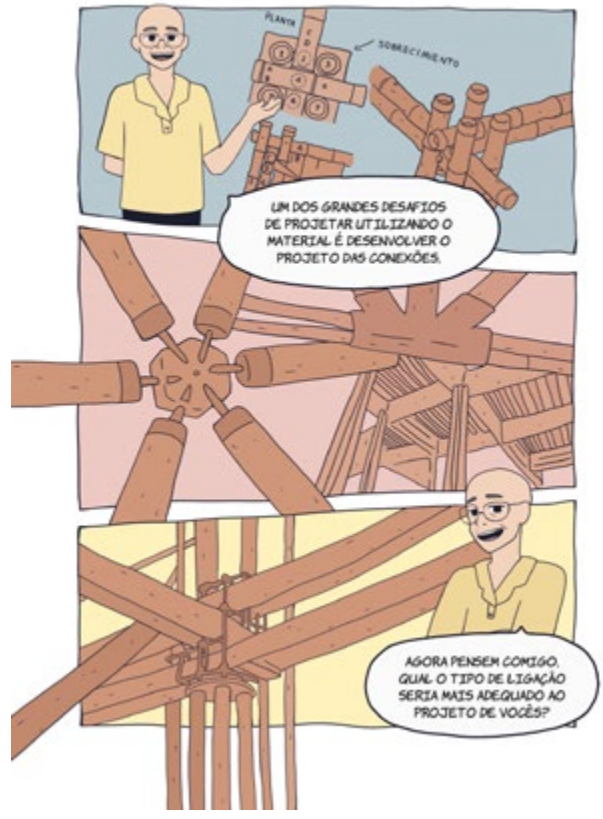

Figura 3: Conexões..
Fonte: própria

3. CONSIDERAÇÕES FINAIS

A atividade docente precisa se adequar constantemente, e é exatamente por isso que o ambiente universitário engloba ensino – pesquisa – extensão. Uma abordagem apenas focada no ensino torna-se obsoleta em curto espaço de tempo. No presente caso a pesquisa fornece os subsídios necessários para aprimoramento das questões técnicas (relacionadas a novos materiais e novos processos fabris, ou mesmo incrementos de materiais e processos já existentes) e questões visuais, de transmissão desse conhecimento (seja por meios gráficos, digitais ou mesmo por simulações computacionais ou elaboração de vídeos e tutoriais).

Ao colocar situações cotidianas dos alunos nas HQs (como filas do Restaurante Universitário, falta de dinheiro para participar de eventos científicos, dificuldades em conseguir estágios, ou mesmo a organização para uma

viagem técnica) mescladas no conteúdo formal previsto nas ementas das disciplinas almeja-se ter como resultado um melhor aproveitamento acadêmico.

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HUMAN FACTORS IN HEALTHCARE ARCHITECTURE: INDICATORS AND PERCEPTIONS

LUDMILA CARDOSO FAGUNDES MENDES, MSc. | UFMG – Universidade Federal de Minas Gerais
ROBERTA VIEIRA GONÇALVES DE SOUZA, Dra. | UFMG – Universidade Federal de Minas Gerais

1. INTRODUCTION

The activities carried out in Healthcare Facilities (EAS) tend to create tension among staff, patients, and visitors. Considering human factors in EAS encompasses the physical and psychological well-being of individuals (Medeiros, 2019). The Supportive Design Theory (SDT) and Evidence-Based Design (EBD) provide guidelines for reducing stress and promoting health in hospital environments. This research aimed to analyze how human factors are addressed in the professional practice of hospital architecture by investigating the application of recognized indicators in the components of SDT (sense of control, social support, and positive distractions) and EBD (natural lighting). The importance of promoting healing in EAS buildings underscores the significance of how these indicators are treated in publications by the Ministry of Health and in building evaluation systems, based on the synthesis of identified indicators.

2. METHODOLOGY

The method involved five stages: (1) administering a questionnaire to architects, engineers, designers working on hospital projects, as well as nurses, doctors, and hospital managers; (2) identifying the most relevant well-being indicators in the Collegiate Board Resolution Nº 50 (RDC 50/2002), which is the Technical Regulation for planning, programming, developing, and evaluating physical projects for healthcare facilities, in the Ambiance Guide of the National Humanization Policy, and in the Technical References of the AQUA-HQE (Alta Qualidade Ambiental - Haute Qualité Environnementale), LEED (Leadership in Energy and Environmental Design), and WELL Building Standard certifications (Fundação Vanzolini, 2011; GBC Brasil, 2022; IWBI, 2020); (3) applying these indicators in a case study, defined as the Hospital das Clínicas of UFMG; (4) analyzing the feasibility of their application; and (5) developing proposals to address the gaps identified in the evaluation of the indicators. The research was approved by the Ethics Committee of the Federal University of Minas Gerais and the Research Network of the Brazilian Hospital Services Company.

3. RESULTS

The questionnaire revealed that natural lighting is the most important component for human well-being. A total of 22 well-being indicators related to TDS components and natural lighting, as part of the EBD, were identified. Of these, 10 were selected for analysis: individual control of artificial lighting, areas for staff to rest and eat, privacy, accessible gardens, areas or gardens for social interaction, comfortable waiting areas, accommodations for overnight stays for companions, interview rooms, quality views, and availability of natural light. The case study involved applying these indicators in an intensive care unit and a clinical inpatient unit of a general hospital. Among the selected indicators, the case study fully met 56%, partially met 28%, and did not meet 17%. It is believed that the main challenges in implementing well-being indicators are related to decisions made during the architectural planning stages of EAS. The research emphasized the importance of a needs program for EAS buildings that goes beyond the requirements established by RDC 50/2002.

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INI-C'S SIMPLIFIED THERMAL COMFORT ASSESSMENT METHOD: AN EVALUATION

ROBERTA VIEIRA GONÇALVES DE SOUZA, Dra. | UFMG – Universidade Federal de Minas Gerais
HELDER GATTONI MEDEIROS, MSc. | UFMG – Universidade Federal de Minas Gerais

1. INTRODUCTION

A building is considered more energy efficient than another when it provides the same condition of thermal comfort for the occupant, with lower energy consumption (LAMBERTS, 2014). In this sense, buildings with natural conditioning must prove that they reach thermal comfort conditions when they are not using mechanical air conditioning systems.

The need to implement measures to mitigate the electricity consumption of buildings in the country led to the creation of the RTQ-C in 2009. Although Brazil has many naturally ventilated buildings, the RTQ-C is strongly oriented towards buildings artificially air conditioned. In 2021, the Brazilian Government published an improvement to the RTQ-C, renaming it to INI-C which, among other changes, presents a simplified method for evaluating the percentage of hours in thermal comfort (PHOCt) for naturally ventilated spaces.

This work, then, aims to analyze the applicability and possible limitations of this method using buildings from the UFMG Pampulha Campus as a case study.

2. METHODOLOGY

The Pampulha Campus of the Federal University of Minhas Gerais (UFMG), located in Belo Horizonte, was chosen as the object of study for this research. The choice was made due to the availability of the information necessary for the research, since the Metamodel for PHOCt evaluation is directed to school spaces, the existence of climate data for Belo Horizonte in the Metamodel and, also, the possibility that the results of the research could be used as a diagnosis for future improvements in the University.

The possibility of applying the method in buildings of different geometries was evaluated and the results of the simplified method were compared with results obtained through computer simulation with the EnergyPlus software. The 82 buildings considered of interest for the study were divided into three groups according to the applicability of the method in relation to geometric aspects, namely: 1) applicable, 2) applicable with adjustments and 3) not applicable.

3. RESULTS

To make the evaluations of the percentage of hours in comfort more expeditious, the Metamodel proposed by INI-C is effectively easy to use and makes the process faster in relation to simulation. In this study the simulation process when compared to the Metamodel use needed more than 10 times more hours for its execution.

Nevertheless tt was observed that 16% of the buildings belong to group 1, 61% to group 2 and 23% to group 3. If the limits of thermal transmittance and absorption of the roof and limit of variation between APPs are also taken into account, only 1 building would meet the limits of the metamodel (1.2%). Group 1 buildings resulted in PHOCt between 53% and 97%, with buildings with higher occupancy densities and small indoor environments tending to have the worst results and those with lower thermal transmittances of the roof tending to have the best results. In addition, the simplified method was applied with modifications in 3 buildings that belong to group 2 and the results were compared with computer simulations. The percentage differences in the PHOCt ranged from 2% to 6%, which was considered a satisfactory result for the simplified method even with the necessary adjustments. For now, it is considered that the new method is capable of promoting a general evaluation of natural ventilation solutions in buildings, but to enhance its use it is necessary to evaluate acceptable adjustments in its input parameters, eliminating, for instance, the rule that internal spaces should vary only 10% in area.

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