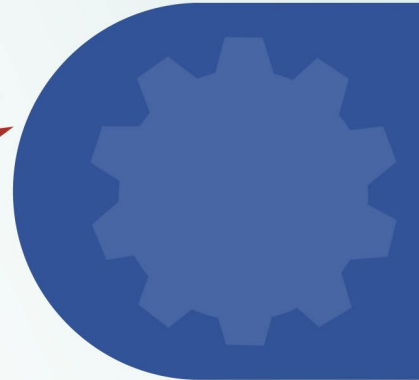
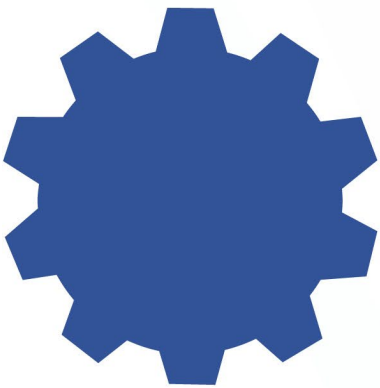


BOOK OF ABSTRACTS





PPREFACE

Welcome to the conference proceedings of the Women's Research Engineering Network (WREN) Symposium 2026 – "Share Your Impact. Lead the Future."

The journey towards sustainable development is one that requires collective effort, innovative solutions, and interdisciplinary collaboration. It is a journey that transcends borders, disciplines, and sectors, requiring us to come together to address the complex challenges facing our planet and its inhabitants.

In these proceedings, you will find a diverse collection of research papers, each offering valuable insights and innovative solutions aimed at advancing the Sustainable Development Goals (SDGs). From ending poverty and promoting health and wellbeing to ensuring inclusive education and fostering economic growth, the research presented here exemplifies the dedication and commitment of researchers towards building a more sustainable and equitable world.

As we navigate the challenges and opportunities on the path towards achieving the SDGs, it is essential to recognize the critical role that research plays in informing policy, inspiring action, and driving positive change. The contributions in these proceedings reflect the tireless efforts of researchers from around the world who are dedicated to making a difference in their communities and beyond.

The research presented at this symposium exemplifies the power of collaboration and innovation in driving positive change. We are proud to highlight the best-voted presentations from our 4 sessions:

- The vulnerable population is paying the bill: influence of wall properties on the electricity consumption in Brazilian social housing – Dr. Vítor Freitas Mendes (Federal Institute of Minas Gerais, Brazil)
- "Safe-and Sustainable-by-Design" engineering of nano-enabled UV filters: A Mini Review – Dr. Nuwangi P Cooray (University of Wollongong, Australia)
- Microalgae and Bacillus Aryabhattai as Complementary Bioinputs for Sustainable Crop Production – Bianca Dionísio (Univ Estadual Paulista, Brazil)
- SIREN: A Conceptual Framework for Multimodal Neurophysiological Early Warning of Heat Strain – Dr. Angé Weinrabe (The University of Sydney, Australia)

We extend our sincere gratitude to all the authors, reviewers, and contributors who have made this publication possible. Their dedication, expertise, and passion for sustainability have enriched our collective understanding of the complex issues facing our world today.

As we embark on this journey together, let us continue to collaborate, innovate, and advocate for positive change. Together, we can make meaningful strides towards a more sustainable, inclusive, and prosperous future for all.

Thank you for joining us on this journey.

WREN Organizing Committee 2026



ABOUT THE WOMEN'S RESEARCH ENGINEERING NETWORK (WREN)

At WREN, we are committed to achieving gender equity in engineering fields, striving to increase participation and retention among all genders, with a special focus on women.

Our vision is a world where engineering is equally accessible and rewarding for everyone, and our purpose is rooted in creating a sustainable and equitable environment that values diversity and inclusivity. This commitment is reflected in our mission to serve as a dynamic platform for international collaboration among women research engineers, enhancing their visibility and encouraging supportive policies. We connect women across various stages of their careers — early, mid, and senior — through international collaborations, including grant proposals, joint publications, and co-teaching partnerships.

Additionally, we maintain and deepen relationships with international partners, equip our members with career-advancing tools, amplify research led by women and underrepresented groups, and tackle systemic barriers through grassroots advocacy. Through these efforts, WREN not only supports individual career growth but also contributes to reshaping the engineering landscape into a more inclusive and equitable field. To learn more about our work or to join our network, please visit our website (<https://thewren.global/>) and get in touch.



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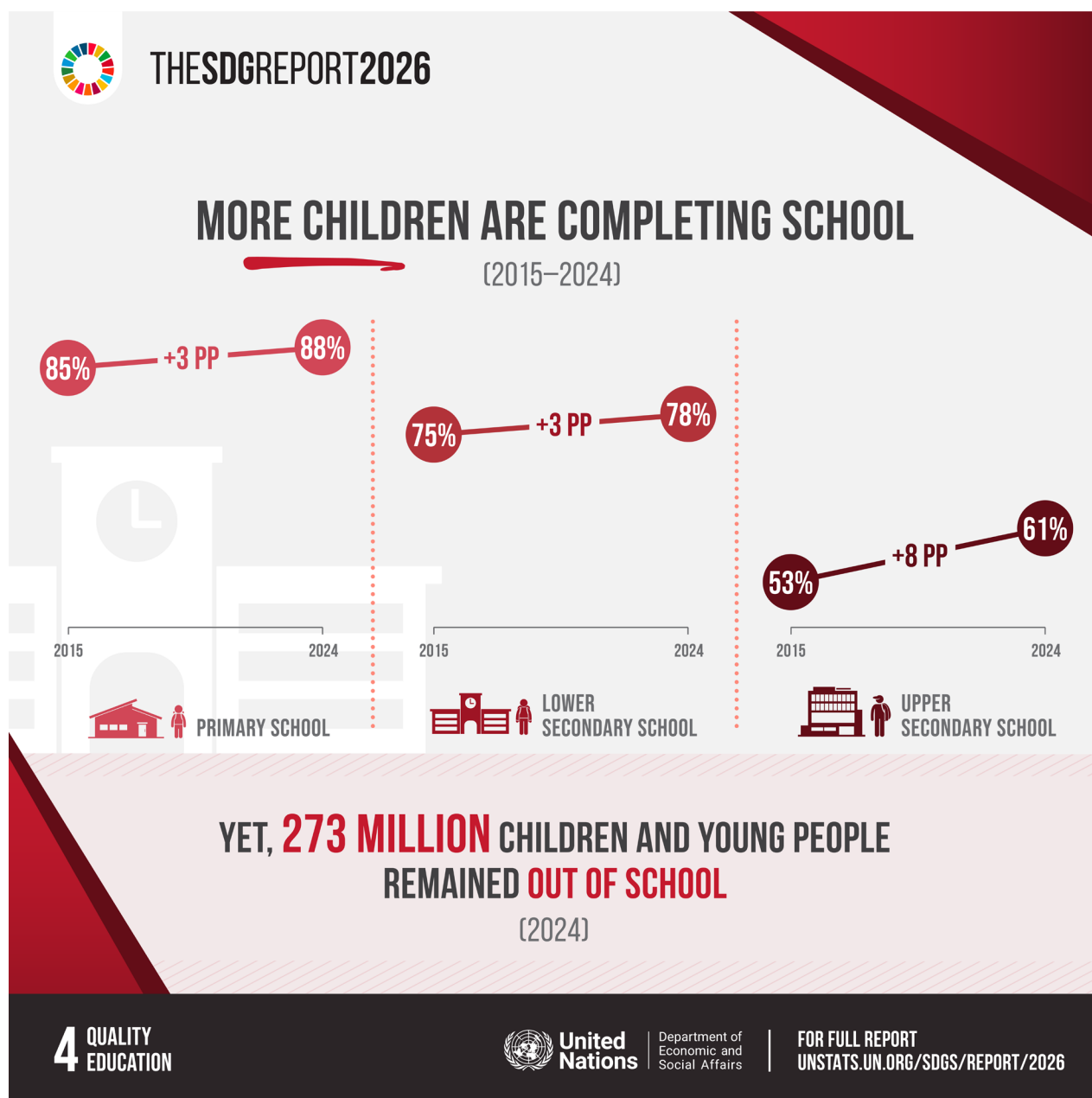
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GOAL 4: ENSURE INCLUSIVE AND EQUITABLE QUALITY EDUCATION AND PROMOTE LIFELONG LEARNING OPPORTUNITIES FOR ALL



Source: UN's The Sustainable Development Goals Report 2026



SECURING RETRIEVAL-AUGMENTED GENERATION: A RAG-TO-EVIDENCE (R2E) GOVERNANCE ARCHITECTURE FOR PROMPT INJECTION, DATA EXFILTRATION, AND KNOWLEDGE-BASE ATTACKS

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ABSTRACT

Retrieval-Augmented Generation (RAG) is increasingly used to ground Large Language Models (LLM) outputs in organisational knowledge bases, improving utility but expanding the attack surface. Prompt injection, insecure output handling, sensitive data exposure, and knowledge-base manipulation can undermine confidentiality and integrity in enterprise and public-sector deployments. This extended abstract proposes a RAG-to-Evidence (R2E) governance architecture that combines defence-in-depth controls with audit-ready evidence generation. R2E is structured using the Open Worldwide Application Security Project (OWASP) Top 10 for LLM Applications and aligned with the National Institute of Standards and Technology (NIST) Artificial Intelligence Risk Management Framework (AI RMF) and Generative AI Profile to define lifecycle governance artefacts for design, deployment, monitoring, and incident response. The contribution is a practical blueprint for AI engineering and security teams to deploy RAG systems with least-privilege retrieval, classification-aware indexing, privacy-preserving logging, and evidence packs suitable for assurance, supporting SDG 4 and SDG 9.

Keywords: Large Language Models (LLM); retrieval-augmented generation; prompt injection; AI governance; security assurance.

INTRODUCTION

RAG systems retrieve documents from a knowledge base and generate answers conditioned on retrieved content. While this can improve factuality, it changes the security boundary: the system now mediates access to internal documents and may be induced to reveal or misuse sensitive information. The Open Worldwide Application Security Project (OWASP) identifies prompt injection and insecure output handling among the most significant LLM application risks, reflecting the ease with which attackers can steer model behaviour or cause unsafe downstream effects [1].

Research has also demonstrated that language models can expose memorised training sequences in some settings, motivating strong confidentiality controls and



careful data governance in model-integrated systems [2]. For RAG specifically, recent work shows that attackers can corrupt knowledge sources to influence outputs (knowledge corruption attacks) and can jam retrieval effectiveness through blocker documents [3]. These risks motivate architectures that treat retrieval as a governed action with enforceable access controls and auditable evidence.

MATERIALS AND METHODS

R2E is defined as a reference architecture with three coupled layers: policy enforcement, retrieval constraint, and evidence generation. OWASP's LLM Top 10 is used as a risk taxonomy to prioritise controls for prompt injection and insecure output handling, as well as data exposure risks. Governance alignment is informed by the National Institute of Standards and Technology (NIST) AI RMF 1.0 and the NIST Generative AI Profile (AI 600-1), which emphasise lifecycle risk identification, measurement, documentation, and organisational accountability for generative AI systems [4], [5].

The architecture specifies: (i) a policy gate that constrains unsafe instruction patterns and enforces input/output handling rules; (ii) least-privilege retrieval policies and classification-aware indexing to limit document eligibility per user/task context; and (iii) privacy-preserving logging that captures retrieval decisions and policy outcomes while minimising exposure of sensitive content in telemetry. Evidence packs are defined to include policy versions, index changes, retrieval eligibility decisions, exception approvals, evaluation regressions, and incident/remediation timelines. Figure 1 depicts the R2E architecture.

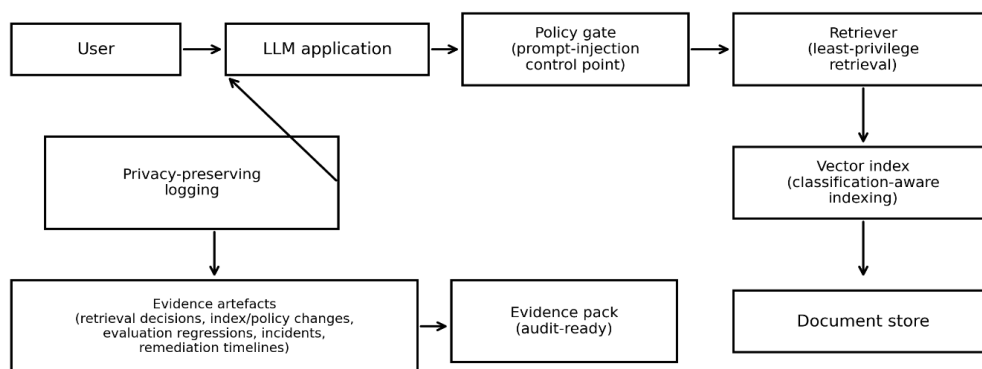


Figure 1 – RAG-to-Evidence architecture



RESULTS

Framework proposal

R2E links key control points to evidence artefacts so that security and governance claims remain verifiable after deployment. Retrieval is treated as a governed action: for each response, the system can record what content was eligible for retrieval, which policy version authorised it, and what safeguards were applied to outputs. Evidence packs provide a structured record that supports assurance activities and post-incident investigation.

DISCUSSION

The model addresses prompt injection and output handling risks by placing enforceable policy controls at the system boundary and recording the policy decisions needed for auditability [6]. By incorporating classification-aware indexing and least-privilege retrieval, R2E reduces exposure pathways relevant to knowledge-base manipulation and retrieval jamming attacks demonstrated in recent RAG security research. The evidence-pack construct also operationalises NIST's guidance on measurement and documentation by embedding accountable artefacts into routine operations for generative AI systems [6]. This positions RAG deployments as governable infrastructure rather than ad hoc applications, supporting safer adoption in education and enterprise contexts.

CONCLUSIONS

R2E provides a practical architecture for deploying RAG systems with security and governance built in, relevant to AI engineering, cybersecurity, and GRC assurance roles increasingly governing LLM integrations. The approach supports SDG 4 by improving safety of knowledge and education services and SDG 9 by strengthening secure digital infrastructure. Future work can apply R2E in organisational pilots to evaluate impacts on data exposure risk, incident handling effectiveness, and audit readiness.

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REFERENCES

- [1] Z. Li, B. Peng, P. He, and X. Yan, "Evaluating the instruction-following robustness of large language models to prompt injection," in Proceedings of EMNLP, 2024.
- [2] W. Zou et al., "PoisonedRAG: Knowledge Corruption Attacks to Retrieval-Augmented Generation of Large Language Models," in Proceedings of the USENIX Security Symposium, 2025.
- [3] A. Shafran, R. Schuster, and V. Shmatikov, "Machine Against the RAG: Jamming Retrieval-Augmented Generation with Blocker Documents," in Proceedings of the USENIX Security Symposium, 2025.
- [4] NIST, Artificial Intelligence Risk Management Framework: Generative Artificial Intelligence Profile, NIST AI 600-1, Jul. 2024.
- [5] OWASP, Top 10 for Large Language Model Applications, 2025.
- [6] N. Carlini et al., "Extracting Training Data from Large Language Models," in Proceedings of the USENIX Security Symposium, 2021.



INVESTIGATING CHALLENGES AND OPPORTUNITIES THAT AFFECT THE FEASIBILITY OF COMPREHENSIVE SEX EDUCATION AMONG TERTIARY STUDENTS IN KLANG VALLEY

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ABSTRACT

The absence of a culturally responsive sexual and reproductive health framework in Malaysia has contributed to inconsistent implementation and limited acceptance of sexuality education programs. Although sex education is formally included in the national curriculum, its delivery remains constrained by inadequate teacher training, sociocultural sensitivities, and limited curricular adaptation to contemporary sexual health issues. Existing research has largely concentrated on barriers within primary and secondary school contexts, leaving a significant gap in understanding how these challenges manifest at the tertiary level. This study addresses that gap by examining the institutional, pedagogical, and sociocultural factors influencing the implementation of comprehensive sexuality education among university students in the Klang Valley.

Despite the establishment of the National Reproductive and Social Health Education Policy in 2009, evidence indicates that many Malaysian university students continue to demonstrate insufficient knowledge of sexual and reproductive health. This persistent knowledge deficit is particularly concerning in light of rising rates of sexually transmitted infections and unplanned pregnancies among emerging adults. Cultural stigma, religious norms, and restrictive institutional policies often frame sexuality as a taboo subject rather than a public health priority, thereby limiting open discourse and effective educational engagement. As a result, young people frequently rely on informal and unreliable information sources, increasing their vulnerability to high-risk behaviors.

Keywords: Comprehensive Sex Education, Multicultural Malaysia, Sex Education Implementation, Sexual Health Education, Public Health.

INTRODUCTION

Sex education in Malaysia has faced criticism from various groups who argue that it promotes premarital sex, that the existing curriculum is sufficient, and that it may lead youths becoming overly sexualized. These were some of the reasons cited by the



Ministry of Education in opposing the implementation of a formal sex education program on 1st May 2010, stating that topics related to sex were already covered under Science, Biology, and Islamic Studies (Talib et al., 2012).

In a recent report, 17,000 unmarried teenagers aged 19 and below were recorded as pregnant at government health facilities between 2020-2024. The department of Women, Family and Community Development mentioned that 50% involved Malay youths, 11% were Iban, 9% involved Orang Asli in Peninsular Malaysia, 5% were Chinese youths, 3% were Indian youths and the remaining were from other ethnic groups (Mahari and Azmi, 2025). This is a staggering number which shows the lack of a comprehensive sex education and the importance of this research.

Premarital sex has been shown to cause a myriad of social issues such as health-related issues, emotional and psychological issues, social and cultural issues and legal repercussions. These issues will not only affect the individuals, but also affect the Malaysian government, hence, early intervention is required.

Despite the establishment of the National Reproductive and Social Health Education Policy in 2009, evidence indicates that many Malaysian university students continue to demonstrate insufficient knowledge of sexual and reproductive health. This knowledge deficit is particularly concerning considering rising rates of sexually transmitted infections and unplanned pregnancies among emerging adults. Cultural stigma, religious norms, and restrictive institutional policies often frame sexuality as a taboo subject rather than a public health priority, thereby limiting open discourse and effective educational engagement. As a result, young people frequently rely on informal and unreliable information sources, increasing their vulnerability to high-risk behaviors.

This study aims to develop a comprehensive sex education framework that would be effective to public secondary schools in Malaysia.

MATERIALS AND METHODS

This research utilizes a mixed method approach with an emphasis on explanatory sequential mixed method studies that “mixes the points of view, methods, data types, and analyses used in both quantitative and qualitative research to come up with detailed and complete results” (Plano Clark, 2019). An explanatory sequential mixed method is used to integrate quantitative data and qualitative text to draw a more nuanced conclusion. In the quantitative phase, a survey will be conducted to identify patterns and trends that would require further explanation. In the qualitative phase, an interview will be conducted, and the data will be collected and analyzed. Since this is a mixed method research, the qualitative method and the instrumentation used will be structured questions consisting of demographic details such as age, gender, ethnicity, name of high school and time since they left their high school and interview with these students on the syllabus for an efficient sex education framework.



In the quantitative phase, numeric data and the participant's demographics will be collected using a survey method, which will then be analyzed using SPSS Data Analysis for correlation and logistic regression which focuses on the relationships between the variables.

PARTICIPANTS

The participants of this study are 50 students at University of Wollongong Malaysia enrolled in the Foundation programme. These students have engaged with the comprehensive sex education curriculum as part of their classroom activities. Participant selection is based on high schools which are government or public school, ensuring that the intervention is situated within an authentic learning environment.

RESULTS

To summarize, Malaysia utilizes an abstinence approach while most developed countries utilize a more comprehensive sex education. The 50 participants listed "delivery problems" and "syllabus problems" listing that the teachers were "very shy" that they "breezed past" the syllabus. The syllabus was also "outdated" and very "theoretical". The framework aims to include consent, safe sex, healthy relationships, STIs and STDs. A sample of the teaching plan (consent) for Form 1 students is attached at Appendix 1. Appendix 1 is not just a pedagogical tool, but a cultural bridge as consent is an important tool or rather the first step in comprehensive sex education. Consent is important as it promotes mutual respect and personal safety, which are part of Malaysian values and culture. Consent is currently not covered in the Malaysian syllabus.

DISCUSSION

The tension between Malaysia's current abstinence-only framework and the global shift toward Comprehensive Sex Education (CSE) highlights a significant gap in both pedagogical effectiveness and student safety. Based on the feedback from the 50 participants, the status quo is failing due to a mix of cultural hesitation and outdated content. In Malaysia, sex education often faces implementation challenges because teachers, who usually lack specialized training, feel shy or uncomfortable teaching the subject. This discomfort leads to the topic being rushed or avoided, causing students to feel shame and seek information from unreliable online sources.

Relying solely on abstinence in sex education leaves students unprepared for real-life situations. A comprehensive approach focuses on risk reduction and supports those at risk, shifting Malaysia's education from a fear-based to an empowerment-based model.



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The author used AI to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] H. Mahari and A. Azmi, "Nearly 17,000 unmarried teenagers pregnant in Malaysia over four years," *New Straits Times*, Nov. 20, 2025. [Online]. Available: <https://www.nst.com.my/news/nation/2025/11/1318994/nearly-17000-unmarried-teenagers-pregnant-malaysia-over-four-years>
- [2] N. I. Mahd Nor, "Fenomena Anak Tak Sah Taraf Dalam Kalangan Orang Islam Di Malaysia," in *International Conference on Syariah & Law 2021 (ICONSYAL 2021)*, 2021. [Online]. Available: <https://conference.uis.edu.my/iconsyal/images/eprosiding/1015.pdf>
- [3] Malaysia Population Research Hub, "Youth: Sexual Education and Reproductive Health," 2024. [Online]. Available: <https://mprh.lppkn.gov.my/youth-sexual-education-and-reproductive-health/>
- [4] V. L. Plano Clark, "Meaningful integration within mixed methods studies: Identifying why, what, when, and how," *Contemporary Educational Psychology*, vol. 57, pp. 106–111, 2019, doi: 10.1016/j.cedpsych.2019.01.007.
- [5] J. Talib, M. Mamat, M. Ibrahim, and Z. Mohamad, "Analysis on Sex Education in Schools Across Malaysia," *Procedia - Social and Behavioral Sciences*, vol. 59, pp. 340–348, 2012, doi: 10.1016/j.sbspro.2012.09.284.



APPENDIX 1 (LESSON PLAN SAMPLE)

Topic: Consent	
Course: Sex Ed	Level: FORM 1
Unit: Sex Ed	Teacher: Date:

Learning Goal(s):	Success Criteria:
- Students will learn about the definition of consent. - Students will learn how to give, receive and recognize consent.	- I can define and understand what consent looks, feels, and sounds like. - I know how to give and receive consent.
Essential Questions for Lesson: - What is consent? - When can you give and receive consent? - Why is consent important?	

	Time	Activities / Planning
No Means No!/ Boundary setting	10 min	Handshake activity - consent in practice - Students will walk around asking permission to shake hands with their peers. - Explain to students that they need to ask and receive permission in order to give a handshake. - Study how students say "no" clearly.
Action	30 min – 40 mins	Co-creating a definition of consent as a class - Creating a poster (NO MEANS NO!) that will hang in the class for reference. - Include other examples of consent. Consent Online - Online communication with strangers. - Explain how receiving, sending and sharing naked pictures requires consent.
Remembering	10 min	Give examples and students need to identify consent. - The examples will be shown on the board. - Students will use Kahoot to give their answers.



FACTORS RELATED TO TURNOVER AND PERCEPTIONS OF RETENTION IN AN OCCUPATIONAL HEALTH AND SAFETY COMPANY

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ABSTRACT

Employee turnover is a strategic challenge in human resource management, affecting costs, productivity, and organizational climate. This study aimed to explore turnover-related factors and retention perceptions in an occupational health and safety company. This is an applied research study with exploratory and descriptive objectives that seeks not only to understand the phenomenon but also to generate insights for managerial action. Data collection was carried out using a semi-structured questionnaire, applied to the person responsible for the Human Resources sector. According to the HR respondent, the company's turnover rate was considered low and was attributed to humanized management, benefits, and working conditions, including competitive benefits, a collaborative environment, and policies focused on occupational health. However, the analysis identified areas for improvement, notably the optimization of recruitment and selection processes, the expansion of career planning, and the development of professional development opportunities. Continuous investment in human capital development, combined with strengthening internal communication channels, is essential to consolidating the bond between the organization and its employees, thereby mitigating turnover and promoting a more stable, productive work environment.

Keywords: human capital; appreciation; work environment.

INTRODUCTION

Employee turnover is an increasingly relevant issue in the contemporary business environment, intensified by technological advances and globalization. With faster access to information, the labor market has become more dynamic, characterized by high competitiveness and, consequently, significant staff turnover.

The relevance of this topic is widely recognized in the literature in this field. As Chiavenato [1] points out, staff turnover significantly influences organizational processes and results and is a critical aspect of business dynamics. Therefore, organizations must invest in qualified human resources, equipped with diverse



knowledge, technical and behavioral skills, as well as competencies aligned with corporate objectives. Mobley [2] warns that high turnover negatively impacts production, the organizational climate, and interpersonal relationships. Understanding the aspects related to turnover is essential, since it is a phenomenon that generates high costs and operational wear and tear, making it essential to seek a sustainable balance between employee turnover and retention.

This study aligns with SDG 4 (Quality Education) by addressing professional development, training opportunities, and career planning as factors associated with employee retention in an organizational context. The study emphasizes how people management practices related to learning and development can foster more sustainable and supportive work environments.

In view of the above, this study aimed to explore factors related to employee turnover and retention in an occupational health and safety company from the perspective of the human resources sector.

MATERIALS AND METHODS

COMPANY PROFILE

The company operates in the occupational health and safety segment, providing services aimed at promoting occupational health and preventing occupational risks. Playing an important role in the Human Resources (HR) field, it provides strategic support to other companies in personnel management and compliance with legal obligations. Through a specific system, the company manages eSocial, conducts occupational exams, and monitors training, ensuring organizational efficiency in processes.

DATA COLLECTION

Data collection was carried out using a semi-structured questionnaire administered via the Google Forms platform. The instrument was completed by the professional responsible for the company's Human Resources department, the only person to hold the position during the period. Therefore, the evidence produced in this research reflects a single institutional perspective and does not represent the direct perception of employees. The research was conducted in November 2025.

The questionnaire was developed based on the literature on People Management, addressing the following aspects:

- a) Demographic and functional profile of employees (gender, education, work shift).
- b) Indicators and specific situations of turnover.
- c) Effectiveness of recruitment and selection processes.
- d) Retention policies, benefits, and incentive programs.



- e) Financial and operational impacts of turnover.
- f) Relationship between turnover and management factors (leadership, organizational climate, growth opportunities).
- g) Methods for monitoring satisfaction and engagement.
- h) The organization's perception of the value of people.

The study did not include quantitative turnover indicators. Therefore, statements regarding turnover level are based solely on the Human Resources respondent. Since the study relied on a single institutional respondent, the analytical procedure was designed to systematize, interpret, and discuss the perceptions reported by the human resources sector. The responses obtained through the questionnaire were analyzed using descriptive qualitative analysis and organized around the main themes addressed in the data collection instrument.

ETHICS STATEMENT

This study involved a single institutional respondent in a low-risk organizational context, without collection of sensitive personal data from employees. The information was used exclusively for academic purposes and is interpreted as an institutional perception.

RESULTS

The information collected enabled an analysis of the factors influencing turnover. The workforce is predominantly female (65%), a common trend in the service sector, especially in administrative and customer service positions. The predominant level of education is secondary and technical, with some employees having higher education, indicating a profile of professionals well qualified for the functions they perform.

An important point reported by the HR respondent is the perception that staff turnover is relatively low. According to the HR manager's response, the main reasons for resignations are related to "personal changes, such as moving to another city and seeking new career opportunities," rather than direct dissatisfaction with the company. This characteristic is a strong indicator that the organization maintains a positive organizational climate. The existence of a "healthy work environment, with respect for rules and efficient communication" was cited as a pillar for this stability. This result aligns with the study by Demirtas and Akdogan [3], which found that a positive organizational climate acts as a buffer against turnover by strengthening employees' emotional bond with the organization.

Among the factors that contribute to retention, the offer of benefits aligned with the market stands out. However, the analysis also pointed to an opportunity for



improvement. When asked about growth opportunities, the response was: “The company offers some training but does not have a formalized career plan.” This finding is crucial because the lack of clear prospects for growth and development is one of the main drivers of turnover, especially among technical and higher-level professionals who want to advance.

The recruitment and selection process was assessed as adequate, but the manager herself acknowledged that it could be more strategic. She mentioned that the focus is on “finding professionals with the necessary technical experience,” but that alignment with the culture could be further developed. This practice corroborates Chiavenato's [1] view that competency-based selection, which assesses both technical (know-how) and behavioral skills, is essential to long-term employee retention.

From the HR respondent's perspective, the perceived low turnover scenario may be associated with lower costs related to dismissals, training and integration. This data is easily explained by the literature, as Mobley [2] reports that the direct and indirect costs of turnover can range from 50% to 150% of the annual salary for the position held, significantly burdening organizational finances. This perception may suggest that retention practices contribute positively to organizational stability; however, no quantitative turnover indicators or financial measures were presented to confirm this relationship.

From the HR respondents' perspective, the results suggest that the company adopts people management practices that are perceived as positive. These practices emphasize valuing human capital and promoting a healthy work environment. In this sense, the HR sector appears to be a relevant strategic agent. Further investment in career development could strengthen the organization's retention practices.

CONCLUSIONS

The research conducted showed that turnover in the company is controlled and occurs mainly due to factors external to the organization. The company demonstrates concern for the well-being of its employees, investing in a balanced work environment and professional development, aspects that reduce the intention to leave.

Despite the positive results, the organization is recommended to continue improving its recruitment, training, and professional recognition processes to strengthen the bond between employees and the company. In addition, encouraging internal communication and career planning can boost motivation and talent retention.

However, the conclusions of this study must be limited to the available evidence. Since the research was based on one respondent and did not include objective turnover indicators or employee perceptions, it is not possible to generalize the findings or provide causal explanations for turnover. To provide a more robust



understanding of turnover and retention in similar organizational contexts, future studies should incorporate multiple respondents, employees' perspectives, and quantitative indicators.

DECLARATION OF AI-ASSISTED TOOLS

The author used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] I. Chiavenato. Gestão de pessoas: o novo papel dos recursos humanos nas organizações. 4. ed. Barueri: Manole, 2014.
- [2] W. H. Mobley. Employee turnover: causes, consequences, and control. Reading, MA: Addison-Wesley, 1982.
- [3] O. Demirtas, A. A. Akdogan. The Effect of Ethical Leadership Behavior on Ethical Climate, Turnover Intention, and Affective Commitment. *Journal of Business Ethics*, vol. 130, p. 59–67, 2015.



GOAL 5: ACHIEVE GENDER EQUALITY AND EMPOWER ALL WOMEN AND GIRLS



Source: UN's The Sustainable Development Goals Report 2026



AUGMENTING FEMINISM: REIMAGINING GENDER, POWER, AND REPRESENTATION THROUGH AUGMENTED REALITY

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ABSTRACT

Augmented Reality (AR) technologies are rapidly reshaping digital communication by overlaying virtual content onto educational resources, creating immersive experiences to enhance learning outcomes. This paper will explore gender quality, with a focus on feminism, and examine how it is reproduced, challenged, or transformed within augmented environments.

Drawing on feminist sociological theories and concepts, Augmented Reality combines a learning experience that uses narrative-driven videos, interactive content, and embedded quizzes to engage students in critically exploring the concepts, histories, and contemporary issues surrounding feminism.

The paper argues that while Augmented Reality has the potential to enhance learning experiences, it simultaneously offers opportunities for experiential learning, alternative representations, and content creation. Through conceptual analysis supported by examples, this paper contributes to the body of knowledge at the intersection of media psychology, feminism, and immersive technologies by proposing a framework for implementing Augmented Reality as a teaching and assessment tool.

Keywords: Augmented Reality; Narrative storytelling, Feminism; Patriarchy; Education.

INTRODUCTION

Augmented Reality has emerged as a transformative medium that complements traditional forms of learning with digital offerings to enhance the learning experience, especially to grasp important theories. By overlaying digital content onto the physical world, Augmented Reality technologies possess the unique capacity to challenge dominant visual regimes (Gunderson, 2024).

Consequently, feminist interventions in Augmented Reality are increasingly utilizing this immersive potential to construct counter-narratives that amplify silenced voices and contest patriarchal spatial logics (Khatri, 2024; Silva *et al.*, 2022). Specifically, Augmented Reality projects have been deployed to address gender-based violence and promote social justice by situating critical narratives within physical environments,



thereby overcoming the limitations of traditional offline exhibitions and fostering deeper public engagement with these issues (Khatri, 2024; Lin, 2024).

For instance, initiatives like "Augmented Voices" utilize Augmented Reality to transition users from passive information receivers to active story participants, immersing them in the harsh realities of discrimination and violence while serving as an empathy catalyst that places users within the very context of injustice (Khatri, 2024). This immersive capability is further evidenced by site-specific Augmented Reality applications that empower activists to reveal hidden histories and challenge dominant narratives without requiring permission from traditional power structures (Silva *et al.*, 2024).

This capacity for unauthorized spatial intervention is particularly significant for movements like "Woman, Life, Freedom," where digital tools enable the creation of immersive installations that circumvent physical repression and provoke dialogue on gender equality (Mehan, 2023). This integration of AR into feminist placemaking not only broadens the reach of these artistic and activist endeavors but also intensifies the emotional impact on the audience, moving beyond simple observation to foster a profound, embodied understanding of gender-based social injustices (Dory, 2024). Such interventions allow for experiences that exist simultaneously in physical, lived, and media-represented spaces, thereby enabling historical narratives and fostering spatial justice (Jopling *et al.*, 2024).

This approach allows for the dynamic representation of feminist concerns within public spaces, offering a powerful tool for advocacy and awareness creation (Mehan, 2024). This paper will delve into the theoretical underpinnings and practical applications of AR as a feminist tool, critically examining its potential to explore traditional gendered power dynamics and foster inclusive digital and physical spaces. This exploration will specifically analyze how AR can enhance gender justice and awareness of sexual violence by overcoming the limitations of conventional outreach methods and encouraging participation in class (Lin, 2024).

MATERIALS AND METHODS

The aim of this research is to design and evaluate an Augmented Reality (AR) learning experience that integrates narrative-driven videos, interactive content, and embedded quizzes to engage students in critically exploring the concepts, histories, and contemporary issues surrounding feminism. The objective is to examine how immersive and interactive AR pedagogy influences students' critical thinking, conceptual understanding, and reflective engagement with gender-related issues within a higher education context.

PARTICIPANTS

The participants of this study will consist of students at University of Wollongong Malaysia enrolled in the Bachelor of Digital Media Production programme. These



students will engage with the Augmented Reality (AR) learning experience as part of their classroom activities. Participant selection is based on their academic context and relevance to the subject matter, ensuring that the intervention is situated within an authentic learning environment.

INSTRUMENT

A qualitative research design will be employed to examine students' learning experiences and critical engagement. Data will be collected through semi-structured interviews, classroom observations conducted during the AR intervention, and reflective journals completed after the experience. In addition, responses from the embedded quizzes within the AR experience will be analyzed as formative assessment data to evaluate students' conceptual understanding and engagement throughout the learning process. A sample of the quiz is attached in the appendix.

RESULTS

The study resulted in the development of a structured AR-enhanced lesson plan on feminism, integrating slides, vector-based visuals, and interactive elements. The experience includes guided sections—introduction, AR usage, feminist concepts, and an explanation on the four waves of feminism—each supported by embedded quizzes to assess understanding and reinforce learning outcomes.

DISCUSSION

The findings demonstrate how AR can be effectively translated into a pedagogical tool through accessible design platforms like Zapworks Designer, enabling educators to create interactive, narrative-driven learning without coding expertise. The integration of visual slides, vector graphics, and quizzes supports multimodal engagement and reinforces critical understanding of feminist discourse across its historical waves. This approach highlights AR's potential to transform abstract sociological concepts into immersive, student-centered experiences. However, this study is limited to the design and development phase of the Feminism AR experience. Future work will focus on user testing to evaluate its effectiveness in enhancing learning, engagement, and critical reflection.

ACKNOWLEDGEMENTS

The author used AI to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.



REFERENCES

- [1] H. Khatri, "Augmented Voices: An Augmented Reality Experience Highlighting the Social Injustices of Gender-Based Violence in the Muslim South-Asian Diaspora," arXiv (Cornell University), Apr. 2024, doi: 10.48550/arxiv.2404.15239.
- [2] M. Gunderson, "Visions of augmented reality in popular culture: Power and (un)readable identities when the world becomes a screen," May 2024, doi: 10.33767/osf.io/5u8md.
- [3] R. M. L. Silva, E. P. Cruz, D. K. Rosner, D. J. Kelly, A. Monroy-Hernández, and F. Liu, "Understanding AR Activism: An Interview Study with Creators of Augmented Reality Experiences for Social Change," in CHI Conference on Human Factors in Computing Systems, Apr. 2022, p. 1. doi: 10.1145/3491102.3517605.
- [4] C. Lin, "AR for Sexual Violence: Maintaining Ethical Balance While Enhancing Empathy," arXiv (Cornell University), Apr. 2024, doi: 10.48550/arxiv.2404.11305.
- [5] R. M. L. Silva et al., "With or Without Permission: Site-Specific Augmented Reality for Social Justice," p. 1, May 2024, doi: 10.1145/3613905.3636283.
- [6] A. Mehan, "Digital Feminist Placemaking: The Case of the 'Woman, Life, Freedom' Movement," Urban Planning, vol. 9, Dec. 2023, doi: 10.17645/up.7093.
- [7] S. Dory, "Male gaze: Augmented reality feminist intervention in a patriarchal space," Visual Arts Research, vol. 50, no. 2, pp. 103–115, Dec. 2024, doi: 10.5406/21518009.50.2.08.
- [8] M. Jopling et al., "Postdigital Citizen Science and Humanities: A Theoretical Kaleidoscope," Postdigital Science and Education, Jun. 2024, doi: 10.1007/s42438-024-00481-5.
- [9] A. Mehan, "Informal and revolutionary feminist placemaking," Frontiers in Sociology, vol. 9, Feb. 2024, doi: 10.3389/fsoc.2024.1347471.
- [10] Z. Hurley and K. Al-Ali, "Feminist Postdigital Inquiry in the Ruins of Pandemic Universities," Postdigital Science and Education, vol. 3, no. 3, p. 771, Sep. 2021, doi: 10.1007/s42438-021-00254-4.

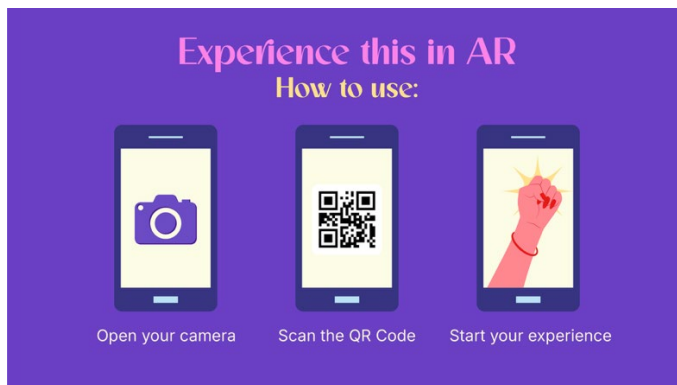


APPENDIX

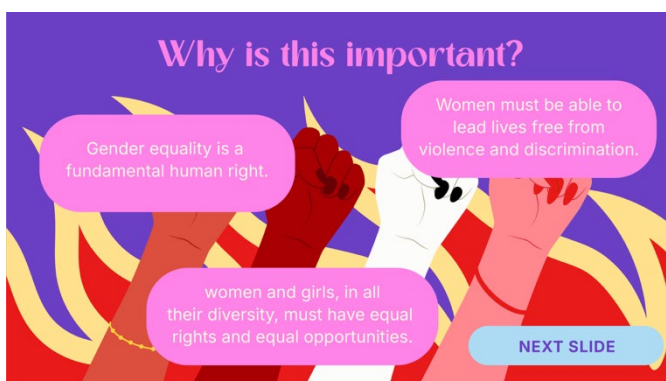
SCREENSHOTS OF AR EXPERIENCE



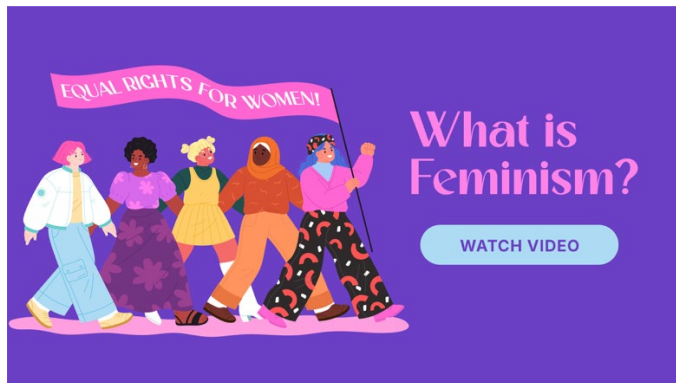
Title page (Introduction)



How to use the AR experience (Instructions)



Section on why learning this topic is important (Contains AR elements – to include QR code to scan)



What is Feminism (Contains AR elements – to include QR code to scan and viewers can watch video)



The phases of Feminism (Contains AR elements – to include QR code to scan and viewers can view animated elements that describe each Feminism wave)



Quiz section (Contains AR elements – to include QR code to scan and viewers will have to answer question in each section of the topics and a final quiz section)



QUANTIFYING THE LEAKY PIPELINE: A STATE-LEVEL MACHINE LEARNING AUDIT OF WOMEN'S ENGINEERING WORKFORCE ATTRITION IN INDIA

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ABSTRACT

In India, approximately 32% of female students are in undergraduate engineering programs, yet they only make up 3% of the STEM workforce. This represents a 93% loss of female students from secondary school to the work force. To explore this phenomenon, this study created a state-level Pipeline Leakage Index utilizing data from five different government datasets, by analysing Pipeline Leakage for each of the 36 states and Union Territories of India. Using Random Forest regression, the analysis demonstrated a high predictive accuracy ($R^2 = 0.926$) between the number of female students enrolled in engineering programs and the ones entering the workforce, thereby confirming that the leakage can be attributed to workforce entry and not to higher education access. An equity audit of the GATI identified a misallocation of GATI resources, with some of the highest need states having zero allocation, and the average Pipeline Leakage of GATI states being 2.43% lower than non-GATI states. Reallocation of Policy in accordance with data from the present study is recommended in alignment with the SDG 5 objectives.

Keywords: Women in STEM; Pipeline Leakage Index; Gender Parity Paradox; Machine Learning; Fairness Audit; GATI; India; SDG 5.

INTRODUCTION

India has produced 42.6% of female STEM graduates which is above the global average of 35%; however, the workforce remains only 20–30% female, with less than 14% in C-suite positions [1]. In addition, 93% of the potential female STEM workforce is lost between secondary school and the workforce, as derived from AISHE [2] and PLFS [3] data. Previous studies by IWWAGE (2024) [4] and EY (2026) [1] describe the disconnect nationally and outline high-level intervention areas but don't examine which states are the most impacted, what structural predictors they are impacted by, or whether government intervention reaches areas with the greatest need. To the authors' knowledge, no previous research has quantified pipeline leakage at the state level, identified structural predictive factors using machine learning, or audited geographic equity of a government STEM initiative using algorithmic fairness tools. This



research study fills these three gaps by creating the first state-level Pipeline Leakage Index across 36 states using five government data sources (AISHE, PLFS, SGDI, GATI, and UDISE+). The results show that the government has concentrated GATI efforts in states with lower levels of pipeline leakage, while six states with the most need have no GATI engagement; this has significant implications for how the DST and NITI Aayog allocate resources.

MATERIALS AND METHODS

DATA SOURCES

Five public datasets (2021–2025) formed the foundation for our study, containing enrolment data for schools and post-secondary institutions, workforce entry, and government programs available to students. Table 1 summarizes these sources, including extracted variables, collection periods, and geographical areas.

Table 1 – Dataset integration overview.

Source	Variables Extracted	Period	Coverage
AISHE 2021-22 [2]	Gender Parity Index (GPI), engineering enrolment (indirect est.)	2021-22	31 states
PLFS 2023-24 [3]	Female STEM workforce % (national constant: 3.27%)	2023-24	National
SDG India Index [5]	SDG 4 (Education), SDG 5 (Gender), SDG 8 (Work) scores	2023-24	36 states
UDISE+ 2024-25 [6]	Female secondary enrolment %, dropout rate, transition rate, GPI	2024-25	36 states
GATI Scheme (DST) [7]	Binary accreditation flag, institution count per state	2024	17 states

Different datasets spanning different years (2021-2025) were collected, according to various independent government release cycles (AISHE- academic year; PLFS- financial year; SDG Index- policy cycle; UDISE+ - school year). No single year contains all five datasets at the same time. These differences in temporal lengths are a limitation, and the data integration across all five datasets gives a picture of the current structural conditions instead of how one cohort would develop.

PIPELINE LEAKAGE INDEX

State-level estimates of female engineering enrolment were calculated by the following equation, $Female\ UG\ Eng\ \%_i = 29.12\% \times AISHE\ GPI_i$ using an indirect estimation methodology that is standard in UN and World Bank demographic research [8]. The Pipeline Leakage Index was calculated as- $Leak_i = Female\ UG\ Eng\ \%_i - 3.27\%$, using 3.27% as the national female STEM workforce constant from PLFS [3]. There was limited access to state disaggregated STEM workforce data without Nesstar Microdata; therefore, this was the primary limitation of the research. The median (26.41 pp.) was used as a binary high leak threshold.

PREDICTIVE MODEL



A Random Forest Regressor (n=100 trees, max_depth=10, random_state=42) was trained on 11 structural features of the variables included in the model (AISHE GPI[2]; SDG score(4,5,8) [5]; UDISE+ secondary metrics [6] - female enrolment rates, dropout rate, secondary transition rate, secondary GPI; GATI accreditation status and number of institutions [7]; UG-PG retention rate). A random 80/20 train/test split (24 training / 6 test states) was implemented. A Fairlearn MetricFrame [9] fairness audit was conducted on the binary Random Forest Classifier with GATI accreditation as the sensitive attribute.

Descriptive Statistics alone confirm the misallocation of GATI, while Random Forest feature importance further confirms that GATI's ability to make predictions is approximately 0.01% of the total AISHE GPI (6000 times less), which indicates that the scheme has no measurable effect on pipeline outcomes beyond poor geography.

RESULTS

NATIONAL FOUR-STAGE ATTRITION

Using datasets from thirty states with complete records, we calculated the percentage of female students progressing through the four pipeline stages (school to labour force), as represented in Table 2. It also depicts the percentage point drop-off at each stage and the cumulative loss from the first stage.

Table 2 - Four-stage pipeline attrition (national averages, 30 states).

Pipeline Stage	Female %	Drop from Prior Stage	Cumulative Attrition
Secondary Education (UDISE+) [2]	50.19%	- baseline	0%
UG Engineering (AISHE) [2]	32.12%	-18.06 pp. (36%)	36% lost
PG Engineering (AISHE) [2]	35.41%	+3.28 pp. (gain)	29% lost
STEM Workforce (PLFS) [3]	3.27%	-32.14 pp. (91%)	93% total

The sharpest decrease (32.14 pp., 91% attrition) occurs between PG and workforce, which is 1.8 times greater than the barrier to pre-enrolment (at 18.06 pp.). With 93% cumulative attrition from secondary education, the vacant pipeline is a result of failure to integrate individuals into the workforce rather than a lack of access to or means of education.

STATE-LEVEL VARIATION

The rate at which the pipeline leaks in 30 states with data ranges from the lowest (22.25%) in Odisha to the highest (60.40%) in Ladakh, which represents a difference of 2.7 times. The mean attrition rate across all states is 28.64 pp., the median is 26.41 pp., and the standard deviation is 7.33 pp. While recent trends indicate that the north-eastern states of Ladakh, Nagaland, Meghalaya and Mizoram and the state of Kerala are all producing a disproportionate number of women engineering graduates, rural



north-eastern states appear to face greater barriers to workforce integration than just access.

RANDOM FOREST: FEATURE IMPORTANCE AND THE GENDER PARITY PARADOX

A Random Forest regression model utilized 11 independent variables from 30 states and union territories to determine structural factors contributing most to pipeline leakage. Feature Importance Scores rank the relative strength of each predictor; Table 3 includes these rankings and the percentage of each variable's importance relative to the total score.

Table 3 - Random Forest feature importance (11 predictors, 30 states).

#	Feature	Importance	% Total	Source
1	aishe_gpi (Higher Ed GPI)	0.6486	64.86%	AISHE
2	sdg4 (Education Quality)	0.1819	18.19%	SDG Index
3	female_secondary_pct	0.0965	9.65%	UDISE+
4	sdg8 (Work & Economy)	0.0548	5.48%	SDG Index
5-9	Other UDISE+ / SDG metrics	0.0181	1.81%	Various
10	gati_accredited (binary)	0.0001	0.01%	GATI
11	ug_to_pg_retention	0.0000	0.00%	Derived

The AISHE GPI is 64.86%, which shows that Gender Parity Paradox exists. States having a greater number of female engineering students experience worse leakage. This is consistent with the principle that while the rate of participation in the workforce is held fairly constant at 3.27%, having additional female students creates a larger gap. The limiting factor in obtaining a job is entry into the workforce rather than access to higher education. The combined GATI feature importance is 0.14%, which goes to show that scheme has little measurable effect on outcomes, despite being active in 17 states. The model's R^2 of 0.926 and MAE of 0.97 pp are strong, however the training R^2 of 0.949 indicates mild overfitting which is expected as there were only 24 training states. Feature importance rankings remain interpretable regardless.

GATI FAIRNESS AUDIT

A fairness audit using Fairlearn's MetricFrame was conducted to determine if GATI accreditation relates to improved outcomes for women in engineering. By treating GATI status as a sensitive attribute, the audit allows for a direct comparison between accredited (n=17) and non-accredited states (n=19) across pipeline metrics. Table 4 illustrates differences in mean pipeline leakage, high-leakage rates, SDG 5 scores, classifier accuracy, and selection rates.

Table 4 - GATI fairness audit (Fairlearn MetricFrame, sensitive attribute: gati_accredited).

Metric	GATI States (n = 17)	Non-GATI (n = 19)	Signal
Mean Pipeline Leakage	27.50%	29.93%	GATI 2.43 pp. lower



Metric	GATI States (n = 17)	Non-GATI (n = 19)	Signal
High-Leak Rate (> median)	52.94%	31.58%	GATI 21.36 pp. higher
Mean SDG 5 (Gender Equality)	76.76	81.28	GATI 4.52 pts. lower
Classifier Accuracy	89%	83%	Acceptable disparity
Selection Rate (pred. high-leak)	44.4%	52.6%	8.2 pp. disparity

GATI exhibits reverse targeting: there are accredited organizations primarily in states with low average leakage; all six of the highest-need states have 0% coverage by accredited organizations: Ladakh (60.4%), Himachal Pradesh (35.5%), Nagaland (34.1%), Meghalaya (32.8%), Sikkim (32.0%) and Mizoram (27.5%). The paradox - GATI states have lower mean leakage but higher high-leak rate. GATI has targeted states with low leakage, such as Odisha (22.3%), as well as states with high leakage such as Kerala (38.6%) - this suppresses the overall mean of leakages while concentrating the high-need states in the pool of accredited organizations.

CONCLUSIONS

Using data collected from Indian institutions of higher education, this research quantifies, at the state level, the "pipeline" of women in engineering and provides several critical findings. First, there is a significant leak (26.41 pp.) in the pipeline from secondary education to the STEM workforce and an even greater level of attrition (93%) as compared with secondary school enrolled women migrating to the STEM workforce. Therefore, the post-graduation bottleneck constitutes the largest barrier to the flow of women into the workforce (32.14 pp.) and is 1.8 times greater than the pre-enrolment barrier. Consequently, the findings support a paradigm shift from enrolment initiatives to employment integration activities. Second, there is quantifiable misallocation of GATI, as evidenced by the fact that six of the highest-need states remain unserved by the scheme, and the combined predictive importance for them is only 0.14%. Third, the Gender Paradox shows that gains in enrolment do not increase retention without workforce and cultural changes to address these barriers.

State-level policy implications resulting from this study are: (1) The extension of GATI in Ladakh, Himachal Pradesh, Nagaland, Meghalaya, Sikkim and Mizoram where leakage rates are high & no coverage exists; (2) An emphasis on integrating graduates into the workforce via partnerships with employers, returnship programs and flexible working conditions; (3) To invest in both SDG 4 educational quality (18.19% feature importance) & SDG 8 economic development (5.48%) since they are the strongest evidence based systemic levers to reduce leakage from pipelines.

Primary limitations of the research include the application of the national PLFS constant of 3.27% due to lack of accessible state level STEM data; indirect estimation of female STEM enrolment through GPI modulation; small-N limitations; and temporal



inconsistencies across sources (2021-2025). Longitudinal pre-GATI/post-GATI data is necessary to establish causality. Future research should include access to AISHE disaggregated student-level data; qualitative research on employer perceptions; and establishing a comprehensive baseline to benchmark against for annual monitoring.

ACKNOWLEDGEMENTS

No funding has been provided for conducting this research. The public can access each dataset's location from the appropriate Indian government website. The author utilized Claude (created by Anthropic) to develop document structure and provide grammar help when needed. All content, analyses, and conclusions presented by the author are entirely the result of their projects.

REFERENCES

- [1] EY India, "Breaking the Code: The Rise of Women in India's STEM Landscape," EY India Report, January 2026.
- [2] Ministry of Education, Government of India, "All India Survey on Higher Education (AISHE) 2021-22," New Delhi: MoE, 2024. [Online]. Available: aishe.gov.in
- [3] MoSPI, "Periodic Labour Force Survey (PLFS) Annual Report 2023-24," New Delhi: NSO, 2024. [Online]. Available: mospi.gov.in
- [4] IWWAGE, "Women and Work: PLFS-Based Analysis of Female Workforce Participation," India Women, Work and Well-being Report, 2024.
- [5] NITI Aayog, "SDG India Index and Dashboard 2023-24," New Delhi: NITI Aayog, 2024. [Online]. Available: niti.gov.in
- [6] Department of School Education & Literacy, "UDISE+ 2024-25 Flash Statistics," New Delhi: MoE, 2025. [Online]. Available: education.gov.in
- [7] Department of Science & Technology, "GATI Scheme: Recommended List of Pilot Institutions," New Delhi: DST, 2022. [Online]. Available: dst.gov.in
- [8] United Nations Statistics Division, "Demographic Yearbook System: Methodology and Standards," New York: UN, 2019.
- [9] S. Bird, M. Dudik, R. Edgar, B. Horn, R. Lutz, V. Milan, M. Sameki, H. Wallach and K. Walker, "Fairlearn: A Toolkit for Assessing and Improving Fairness in AI," Microsoft Research Technical Report, MSR-TR-2020-26, 2020.



THE PRESENCE OF INCLUSIVE LANGUAGE IN ACADEMIC ENGINEERING CALLS FOR APPLICATIONS

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ABSTRACT

The present study analyzed the presence of inclusive language in academic calls for applications within the field of Engineering. Inclusive language is essential to promote equity and address the invisibility of marginalized groups. To this end, calls for faculty recruitment at higher education institutions (public selection processes), faculty accreditation in graduate programs, and research productivity fellowship calls (101 in total) were examined. The results revealed a low level of inclusive language implementation, with full adoption observed in 0% of faculty recruitment calls, 3.5% of accreditation documents, and 12.5% of research productivity fellowship calls. In conclusion, this practice has not yet been institutionally consolidated in the field studied, reinforcing the need for broader and more structural institutional actions.

Keywords: inclusive language; engineering; call for applications; equity.

INTRODUCTION

Engineering is a field marked by the underrepresentation of women. In Brazil, 31% of faculty members in higher education Engineering programs are women [1]. When analyzing graduate faculty, this figure decreases to 22% [1]. One of the main forms of recognition for Brazilian researchers is CNPq's Research Productivity Fellowship, also known as the PQ Fellowship. This prestigious fellowship is divided into levels, and its highest-level shows only 12% female representation in Engineering [1]. In this context, institutional policies are essential tools to fight the Scissors Effect and the Leaky Pipeline.

Among the past-due institutional policies to mitigate this scenario is the use of inclusive language, which aims to address discrimination and the invisibility of socially marginalized groups in forms of communication [2]. There are several techniques for its construction, including the use of terms and strategies other than the generic masculine (e.g., "people" instead of "mankind") [2]. In many Latin-based languages, such as Portuguese, Spanish, and French, nouns, articles, and adjectives are grammatically gendered, and the masculine plural traditionally serves as the generic form for mixed or unspecified groups (e.g., "the students" in Portuguese translates as "os alunos").



Similar gender-marking systems exist in languages such as German, Slavic languages (e.g., Polish, Russian), and Arabic.

It is important to emphasize that language is not merely a descriptive tool, but a symbolic device that legitimizes or delegitimizes social presence [3]. This recurrent use of the masculine as the default form may reinforce male-centered norms and contribute to the symbolic exclusion and reduced visibility of women and other gender identities in public and institutional communication. In this context, the objective of the present study is to analyze the presence of inclusive language in academic calls for applications within the field of Engineering, hypothesized as one of the barriers that prevent the entry and permanence of women.

MATERIALS AND METHODS

The study analyzes the presence of inclusive language in Engineering calls for applications from programs belonging to CAPES' Engineering area, which is divided into four fields: Engineering I, II, III, and IV. The analysis was conducted for three distinct groups of calls, aiming to identify the "leaks" in the academic research career: (1) faculty recruitment in higher education institutions (public competitive examinations), (2) accreditation in graduate programs (PPGs), and (3) research productivity fellowships (PQ fellowships). The selection, collection, and classification of the language used in the selected calls were carried out according to the classification presented in Table 1.

Table 1 – Classification of Inclusive Language in the Documents. Source: authors.

Classification	Description
Integral	The entire call for applications adopts inclusive language in a systematic, clear, and intentional manner.
Partial	Noticeable but non-systematic use of inclusive language, with sections of the main body of the call including expressions such as "he/she applicant" or "applicant person," and a mix of traditional and inclusive language throughout the text.
Occasional	Very limited use, restricted to specific cases, such as sections addressing maternity leave, breastfeeding, or women's rights; or present only in annexes.
Absent	Does not use any form of inclusive language in any part of the text.

Initially, we obtained the data of accredited faculty in Engineering PPGs, (then) publicly available in CAPES' Sucupira Platform [4]. However, the spreadsheets did not include information on the researchers' gender. Therefore, we inferred sex from first names using the tools GenderAPI and ChatGPT to reduce potential unconscious bias. The estimation of researchers' sex through names remains a limitation of the study, as it does not consider individual gender identity or non-binary individuals. Despite this, this strategy is commonly adopted in large datasets lacking self-reported gender identification, as done by Ross et al. [5].



We classified the PPGs by the percentage of female faculty members and selected a sample comprising the 10 programs with the highest and lowest proportions of women in each of the four Engineering fields, totaling 80 PPGs. Subsequently, we collected faculty accreditation calls from these programs, between August and December 2024, through institutional websites and by sending emails requesting the documents. At the end of the process, calls from 57 PPGs (71%) were obtained.

The 57 graduate programs analyzed were affiliated with 49 higher education institutions, encompassing institutions from all regions of Brazil. These institutions constituted the object of study to the evaluation of faculty recruitment calls in higher education institutions. The collection of public recruitment calls was carried out on the institutions' websites between June and July 2025, considering the most recent call available. In total, 36 calls were obtained. Finally, for the analysis of the PQ fellowships, we selected the most recent call available on the CNPq website in June 2025 [6]. This document contained eight calls related to Engineering programs within CAPES' Engineering area, which were analyzed.

RESULTS

Figure 1 presents the results found in the calls for graduate program accreditation, faculty recruitment, PQ fellowships, and overall, combining the three previous categories. Overall, 51.4% of the documents showed a complete absence of inclusive language, while only 2.9% adopted it fully. This result indicates that the adoption of inclusive language still occurs in a limited and inconsistent manner, even though this inclusivity measure requires very low human and financial resources.

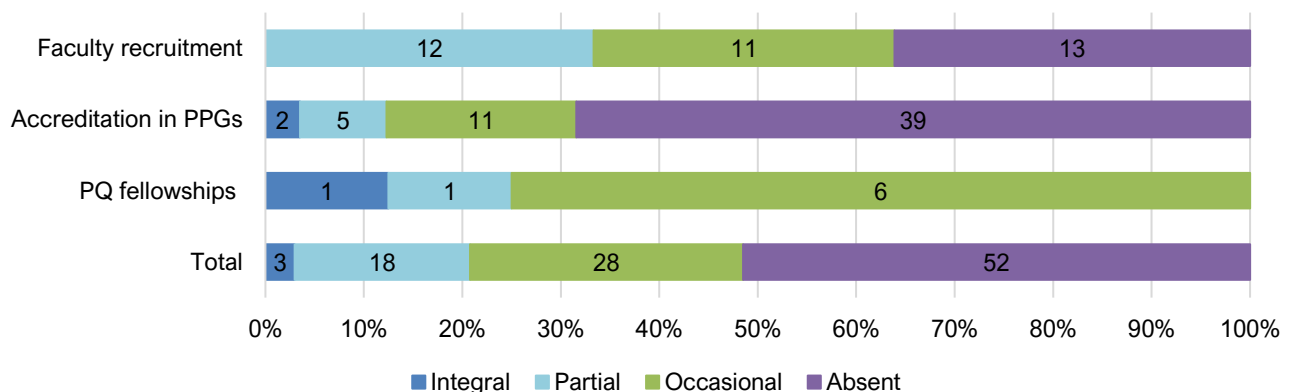


Figure 1 - Proportion of inclusive language classification in calls for faculty recruitment, accreditation in PPGs, and PQ fellowships. Source: authors.

Accreditation calls were the ones that least frequently presented inclusive language. This result may be related to the general disengagement of Engineering professionals with this topic. Engineering education predominantly comprises "hard sciences", with limited attention to knowledge from the Humanities and Social Sciences [7]. In addition,



there are constant demands for publications and productivity among faculty members affiliated with graduate programs. This context may lead to the neglect of important issues related to gender and minorities, such as the presence of inclusive language in official calls.

In the faculty recruitment calls, no document presented inclusion language in full, and the remaining categories showed only small percentage variations: 33% "Partial," 31% "Occasional," and 36% "Absent." Compared to the accreditation calls, there is a greater presence of inclusive language in public recruitment calls. However, the full adoption of such language remains a challenge. This absence is particularly relevant considering that faculty recruitment calls not only regulate internal selection processes but also serve as instruments of access to academic and scientific careers.

On the other hand, none of the PQ fellowship calls showed a complete absence of inclusive language, indicating a slight advancement. However, most of the documents (75%) were classified as "Occasional," demonstrating that their adoption still occurs in a limited and inconsistent manner.

CONCLUSIONS

The results indicate that, despite existing efforts, inclusive language has not yet been consolidated as a consistent institutional practice. By prioritizing generic masculine or adopting limited inclusion strategies, these documents contribute to the perpetuation of women's invisibility, especially in institutional spaces historically marked by gender inequality. In this way, the absence of inclusive forms in such texts may reinforce subtle barriers to women's entry and career advancement.

Therefore, systematically including women in official documents through language is not merely a stylistic detail, but a political act. In this context, one way to promote this change is through institutional deliberations that recommend and/or mandate the use of such language, imposed by higher governing bodies, such as the Ministry of Education. Meaningful changes will only be achieved through the engagement of all stakeholders involved. As a next step, our research group will investigate the presence of institutional gender equity policies in calls for applications.

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reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] I. F. Nery, "Por que tão poucas? Análise do Efeito Tesoura e Leaky Pipeline na carreira de mulheres pesquisadoras na engenharia," Dissertação (Mestrado em Engenharia Civil), 2025.
- [2] MGI, "Linguagem inclusiva," Ministério da Gestão e da Inovação em Serviços Públicos, 11 Julho 2023. [Online]. [Acesso em 10 Fevereiro 2026].
- [3] V. B. Santos, R. M. Freitag, R. Nascimento, E. S. Silva e T. S. Gois, "Linguagem inclusiva e comunicação não sexista na Universidade Federal de Sergipe," Revista do GELNE, 05 Outubro 2023.
- [4] CAPES, "Plataforma Sucupira," 2023. [Online]. Available: <https://sucupira.capes.gov.br/sucupira/>. [Acesso em 12 Julho 2023].
- [5] M. Ross, B. Glennon, R. Murciano-Goroff, E. Berkes, B. Weinberg e J. Lane, "Women are credited less in science than men," *Nature*, vol. 608, pp. 135-145, 22 Junho 2022.
- [6] CNPq, "Chamada CNPq Nº 18/2024 - Bolsas de Produtividade do CNPq," 2024. [Online]. [Acesso em 18 Julho 2025].
- [7] G. Barreto, "A necessária aproximação da engenharia com as ciências humanas," 2022. [Online]. [Acesso em 16 Dezembro 2025].



IN SILICO MODEL OF THE BONE HEALING PROCESS: ESTROGEN DECAY DURING MENOPAUSE

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ABSTRACT

The immune system regulates bone healing through complex cellular and molecular interactions that are strongly influenced by estrogen levels. During perimenopause, a decline in estrogen disrupts the balance between bone formation and resorption, impairing healing and increasing bone fragility. In this study, we extend an immune–bone interaction model based on nonlinear differential equations to incorporate estrogen depletion. The model simulates bone-healing dynamics under premenopausal and postmenopausal conditions. Numerical analyses show that reduced estradiol delays consolidation, decreases bone formation, and prolongs debris persistence. The framework provides qualitative and quantitative insights into immune–hormonal interactions and supports the development of strategies for postmenopausal osteoporosis.

Keywords: computational model; immune system; osteoporosis; estrogen; menopause.

INTRODUCTION

Gender differences are frequently neglected in research design, implementation, and reporting, limiting the generalizability of findings and their clinical applicability, particularly for women [1]. This bias extends to aging research, which remains predominantly centered on male subjects [2]. Such an imbalance is particularly concerning in conditions that disproportionately affect women, such as osteoporosis, characterized by reduced bone mineral density and microarchitectural deterioration, which leads to increased fragility and fracture risk [3], [4]. Although therapeutic advances have improved management, delayed healing and complications remain common [5].

Estrogens are key regulators of bone remodeling, maintaining tissue homeostasis by promoting formation and inhibiting resorption. The abrupt decline in estrogen levels



during postmenopause is strongly associated with increased osteoporosis incidence in women [6]. Due to hormonal reduction and cellular senescence, bone resorption surpasses formation, elevating fracture risk, particularly among postmenopausal women [7].

Understanding these mechanisms is challenging due to complex biological interactions. Advances in systems biology have enabled the development of computational models, particularly those based on ordinary differential equations (ODEs), capable of reproducing the temporal dynamics of bone remodeling [8],[9]. Within this framework, the present study aims to develop a mathematical model to simulate the influence of estrogen on bone remodeling during premenopausal and postmenopausal periods.

MATERIALS AND METHODS

The present study is based on a mathematical model of bone remodeling [10] that describes the inflammatory and repair phases of fracture healing. This extension enables the model to capture macrophage plasticity and the transition between pro-inflammatory and anti-inflammatory responses, which are essential for proper bone repair.

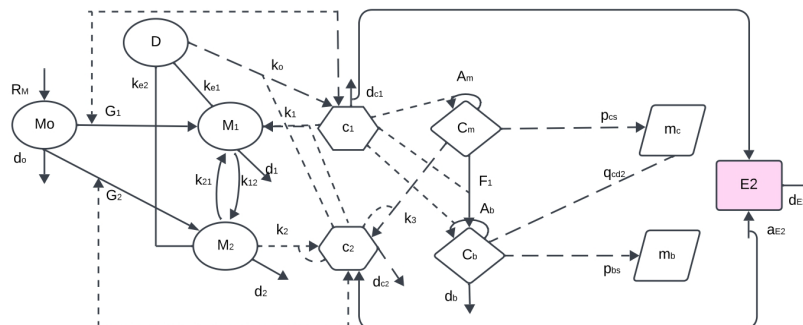


Figure 1 – Flow diagram of the proposed bone healing model.

The model, represented in Figure 1, consists of a system of nonlinear ordinary differential equations based on mass-action kinetics that describes the temporal dynamics of inflammation-driven bone healing. Bone debris (D) initiates inflammation by promoting macrophage recruitment and polarization (M_0 , M_1 , M_2), which regulate pro-inflammatory cytokines (C_1) and anti-inflammatory cytokines (C_a). This inflammatory cascade activates mesenchymal stem cells (C_m), which differentiate into osteoblasts (C_b), contributing to tissue formation. Fibrocartilage tissue (M_c) emerges as a transient repair phase before being replaced by newly formed bone tissue (M_b). Estradiol (E_2) modulates immune balance and enables simulation of pre-



and postmenopausal conditions. Parameter and initial conditions values were obtained from previously published *in silico*, *in vivo*, and *in vitro* studies involving both human and murine data. Parameters associated with estradiol were included to investigate its modulatory role in immune response and bone formation. Parameter ranges reflect biological variability and uncertainty and were considered in subsequent sensitivity analyses. The model was implemented in Python using the SciPy library for numerical integration.

RESULTS

The system is described by a set of eleven ordinary differential equations and was simulated over a period of 730 days (two years). The initial estradiol level (E_2) was set to 0.060 ng/mL, followed by a progressive decline to 0.030 ng/mL and 0.019 ng/mL, representing typical postmenopausal dynamics. Parameter estimation focused on the estradiol-related parameters, namely the production rate (ae_2) and degradation rate (de_2), while all other parameters were kept fixed. A Differential Evolution algorithm was employed to adjust these parameters in order to reproduce target estradiol levels. The objective function minimized the squared error between simulated and target values, and results from independent runs were recorded for further analysis.

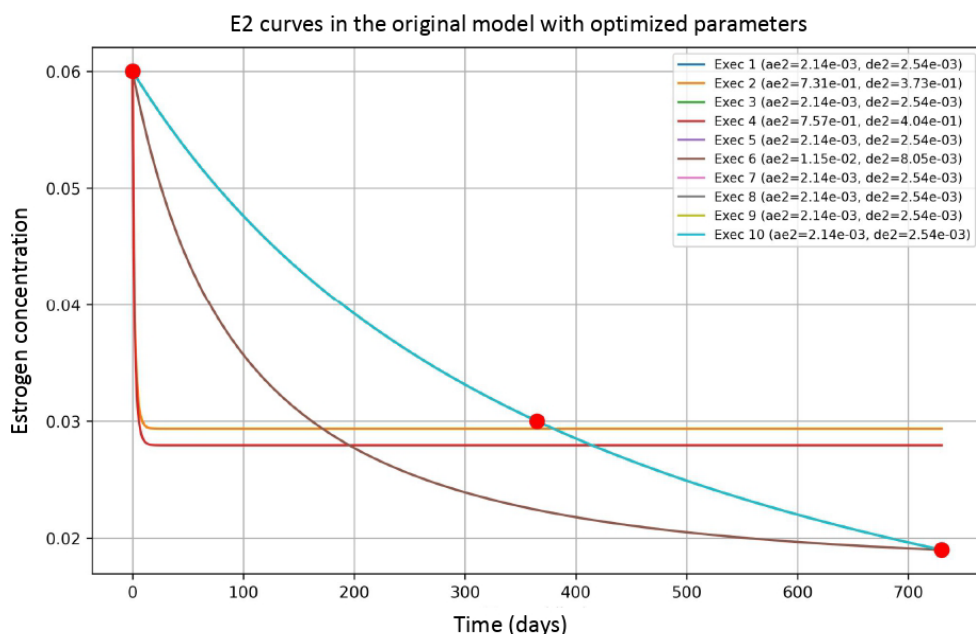


Figure 2 – Parameter estimation for estradiol.



CONCLUSIONS

This work presented a mathematical model to simulate the influence of estrogen on bone remodeling during premenopausal and postmenopausal periods. Alternative approaches in the literature include agent-based models, multiscale models, and multiphysics frameworks. Compared to these, the proposed mechanistic model offers greater interpretability and the ability to simulate physiological scenarios over time, although it relies on simplifying assumptions and literature-based parameters. As future work, we propose coupling the model with biomechanical simulations using the finite element method and exploring digital twin approaches for personalized analysis.

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REFERENCES

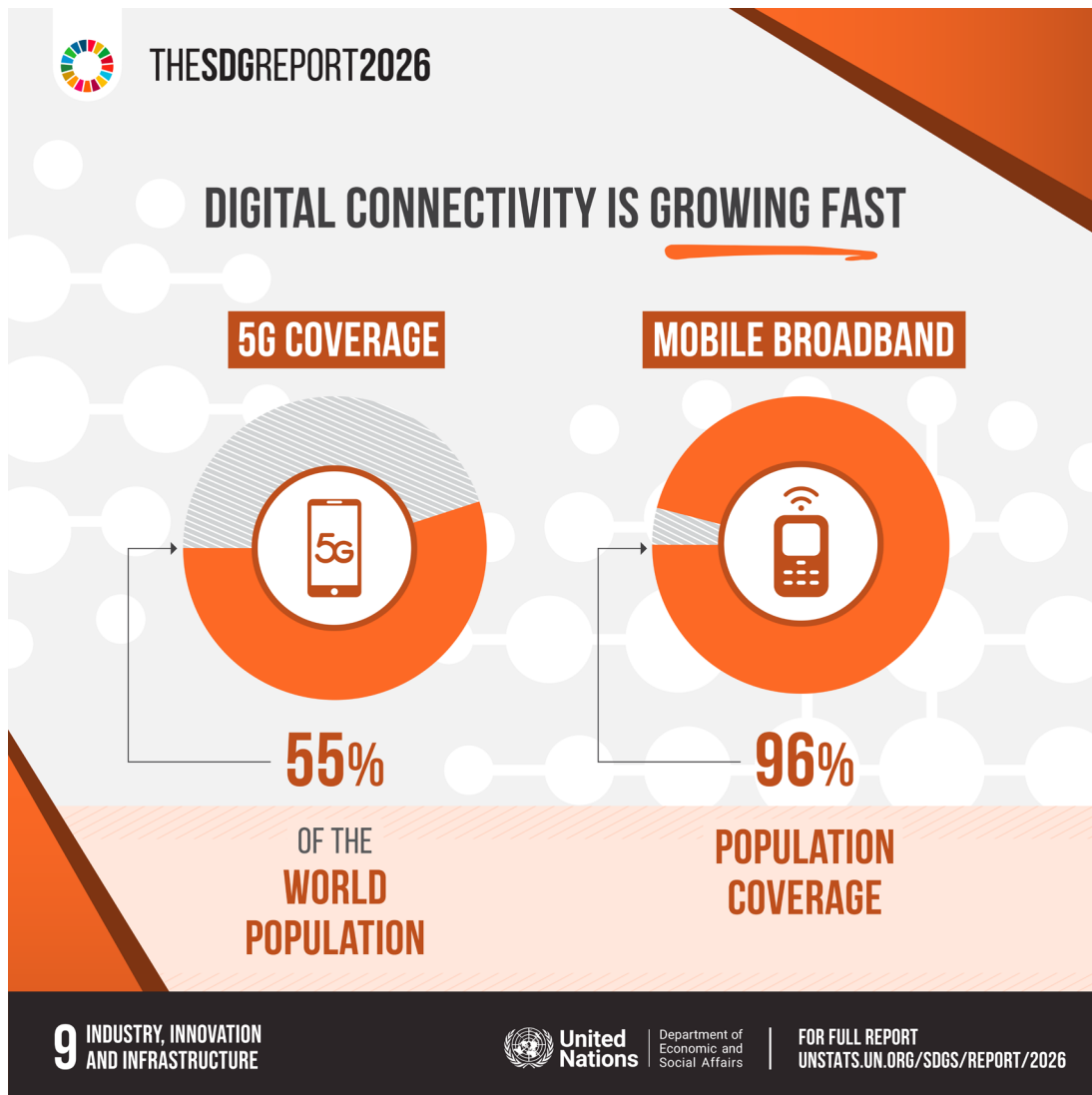
- [1] S. Heidari, T. F. Babor, P. De Castro, S. Tort, e M. Curno, "Publisher Correction: Sex and Gender Equity in Research: rationale for the SAGER guidelines and recommended use", *Res. Integr. Peer Rev.*, v. 9, n. 1, p. 15, dez. 2024, doi: 10.1186/s41073-024-00155-7.
- [2] Amelia Hill, "Why sex bias in labs means women are the losers in research into ageing", *Why sex bias in labs means women are the losers in research into ageing*, 22 de junho de 2024. Accessed on January 26th, 2026. Available in: <https://www.theguardian.com/science/article/2024/jul/22/sex-bias-labs-women-losers-research-ageing>
- [3] C. A. Mallio *et al.*, "Phantomless Computed Tomography-Based Quantitative Bone Mineral Density Assessment: A Literature Review", *Appl. Sci.*, v. 14, n. 4, p. 1447, fev. 2024, doi: 10.3390/app14041447.
- [4] E. Karlafti, K. Lampropoulou-Adamidou, S. Tournis, G. Trovas, e I. K. Triantafyllopoulos, "Effect of estrogen on bone cells: what is new?", *J. Res. Pract. Musculoskelet. Syst.*, v. 03, n. 04, p. 113–122, dez. 2019, doi: 10.22540/JRPMS-03-113.
- [5] L. Claes, S. Recknagel, e A. Ignatius, "Fracture healing under healthy and inflammatory conditions", *Nat. Rev. Rheumatol.*, v. 8, n. 3, p. 133–143, mar. 2012, doi: 10.1038/nrrheum.2012.1.
- [6] S. Kondoh *et al.*, "Estrogen receptor α in osteocytes regulates trabecular bone formation in female mice", *Bone*, v. 60, p. 68–77, mar. 2014, doi: 10.1016/j.bone.2013.12.005.
- [7] E. Noirit-Esclassan *et al.*, "Critical Role of Estrogens on Bone Homeostasis in Both Male and Female: From Physiology to Medical Implications", *Int. J. Mol. Sci.*, v. 22, n. 4, p. 1568, fev. 2021, doi: 10.3390/ijms22041568.
- [8] B. Ji, Y. Zhang, C. Zhen, M. J. Fagan, e Q. Yang, "Mathematical modelling of bone remodelling cycles including the NF κ B signalling pathway", *Comput. Biol. Med.*, v. 107, p. 257–264, abr. 2019, doi: 10.1016/j.combiomed.2019.03.003.



- [9] C. H. Lo, E. Baratchart, D. Basanta, e C. C. Lynch, "Computational modeling reveals a key role for polarized myeloid cells in controlling osteoclast activity during bone injury repair", Sci. Rep., v. 11, n. 1, p. 6055, mar. 2021, doi: 10.1038/s41598-021-84888-1.
- [10] I. Trejo, H. Kojouharov, e B. Chen-Charpentier, "Modeling the Macrophage-Mediated Inflammation Involved in the Bone Fracture Healing Process", Math. Comput. Appl., v. 24, n. 1, 2019, doi: 10.3390/mca24010012.



GOAL 9: BUILD RESILIENT INFRASTRUCTURE, PROMOTE INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION, AND FOSTER INNOVATION



Source: UN's The Sustainable Development Goals Report 2026



TECHNICAL FEASIBILITY OF USING STEEL SLAG AS RAILWAY BALLAST

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ABSTRACT

This study evaluates the technical feasibility of using treated steel slag as railway ballast. Tests included physical and mechanical. The slag presented high apparent density (3,122 kg/m³), low water absorption (2.0%), and apparent porosity of 5.5%, this last one exceeding normative limits. Mechanical performance was superior to natural crushed stone, with lower Treton toughness (9.6%) and Los Angeles abrasion (20.3%) indices. Mechanical analysis indicates that steel slag, despite higher initial fragmentation, rapidly stabilizes and exhibits greater residual strength with reduced progressive degradation, whereas natural crushed stone shows continuous degradation under loading, leading to increased fines generation and accelerated loss of track structural capacity. The mixture shows intermediate behavior, combining rapid initial settlement with residual strength, which may benefit long-term performance and cost-effectiveness.

Keywords: Steel slag; Ballast; Aggregate; Waste.

INTRODUCTION

The steel industry plays a crucial role in the global scenario by supplying inputs to various sectors, although steel production also entails the generation of large volumes of solid, liquid, and gaseous waste [1, 2]. Among these residues is steel slag; blast furnace slag is generated during the chemical reduction process of iron ore that occurs in the production of pig iron [3]. Basic oxygen furnace and electric arc furnace slags are by-products of the conversion of iron into steel [4].

Railways play a crucial global role in the transportation of freight and passengers, being one of the most efficient logistics modes due to their ability to move large volumes with lower environmental impact compared to other transport modes [5]. However, railway construction has environmental impacts, particularly due to the use of ballast composed of natural rock aggregates, which intensifies mining activity, a well-known polluting practice [6] [7].

A strategy to achieve sustainability in railway ballast is the use of waste materials as aggregates. Among the materials studied for this purpose, steel slag stands out,



having shown promising results from mechanical and physical perspectives [8]. In addition, the use of steel slag contributes to carbon sequestration, ranging from 73.1 to 250 kg CO₂/tonne slag [9].

Although several studies have evaluated the feasibility of steel slag as a ballast material, technical challenges and debates regarding its application still persist. Thus, the present study aims to provide technical data and detailed analyses on the performance of steel slag, contributing to the effective application of this sustainable alternative to conventional ballast.

MATERIALS AND METHODS

To carry out this study, two main samples were used: one steel slag sample, with eight months of carbonation, originating from the basic oxygen furnace process, and one gneiss crushed stone sample.

The physical characterization of the materials included apparent specific gravity, apparent porosity, and water absorption tests, conducted in accordance with ABNT NBR 5564, as well as the expansion test, performed following DNIT 113/2009. For mechanical characterization, samples of slag, crushed stone, and a mixture composed of 50% of each material were evaluated. This 50/50 mixture was adopted based on a recommendation from the company, given the lack of prior studies on this proportion. The Treton impact resistance test was carried out in accordance with ABNT NBR 5564. To analyze the evolution of fine generation, after each test the material was homogenized and the test was repeated, with the procedure carried out four times. The Los Angeles abrasion test was conducted according to DNIT 451/2024. Similarly to the Treton test, after each test the material was homogenized and the procedure was successively repeated until more than 50% of the sample presented a particle size smaller than 19 mm. The mechanical tests were repeated in order to relate the generation of fine material to the durability of the ballast.

RESULTS

The results of the physical tests, apparent specific gravity, apparent porosity, water absorption, and expansion, are organized in Table 1. Regarding the crushed stone, all evaluated parameters meet the regulatory limits. Conversely, for the steel slag, it is noted that the apparent porosity (5.5%) significantly exceeds the established limit, while the water absorption (2.0%) reaches the maximum allowable threshold. Such indices may compromise the durability of the sleepers, as higher moisture retention in the aggregate favors water accumulation at the base of the structure. Furthermore, these factors directly influence the electrical resistivity of the material, facilitating the formation of preferential conductivity paths. Furthermore, the low expansion value (1.2%) may be associated with the material's carbonation time; it is likely that the



material was already stabilized at the time of testing and that the curing process performed was effective.

Table 1 - Physical characterization. Source: authors.

	Apparent specific gravity (kg/m ³)	Apparent porosity (%)	Water absorption (%)	Expansion (%)
Gneiss	2847	0.4	0.1	-
Steel slag	3122	5.5	2.0	1,2
Std. Limit	≥2600	≤2.0	≤2.0	≤3.0

The mechanical test results are presented in Table 2. The crushed stone showed the poorest performance in both tests, with a Treton toughness index of 21.8% and a Los Angeles abrasion index of 21.6%. In contrast, the steel slag exhibited the best performance in the Treton test, with a value of 9.6%, indicating greater resistance to fragmentation; however, in the Los Angeles abrasion test, it showed a result close to that of the natural aggregate, with an index of 20.3%. Finally, the mixture presented a Treton index slightly higher than that of the slag, at 10.8%, and achieved the best performance in the Los Angeles abrasion test, with a value of 18.3%, demonstrating greater resistance to both impact and abrasive wear.

Table 2 - Mechanical characterization. Source: authors.

	Treton (%)	Los Angeles Abrasion (%)
Gneiss	21.8	21.6
Steel slag	9.6	20.3
Mixture	10.5	18.3
Limit	≤25	≤30

To analyze how the applied energy influences the generation of fine material, a scatter plot was developed using the test results, for both the Treton impact test (Figure 1a) and the Los Angeles abrasion test Figure 1b.

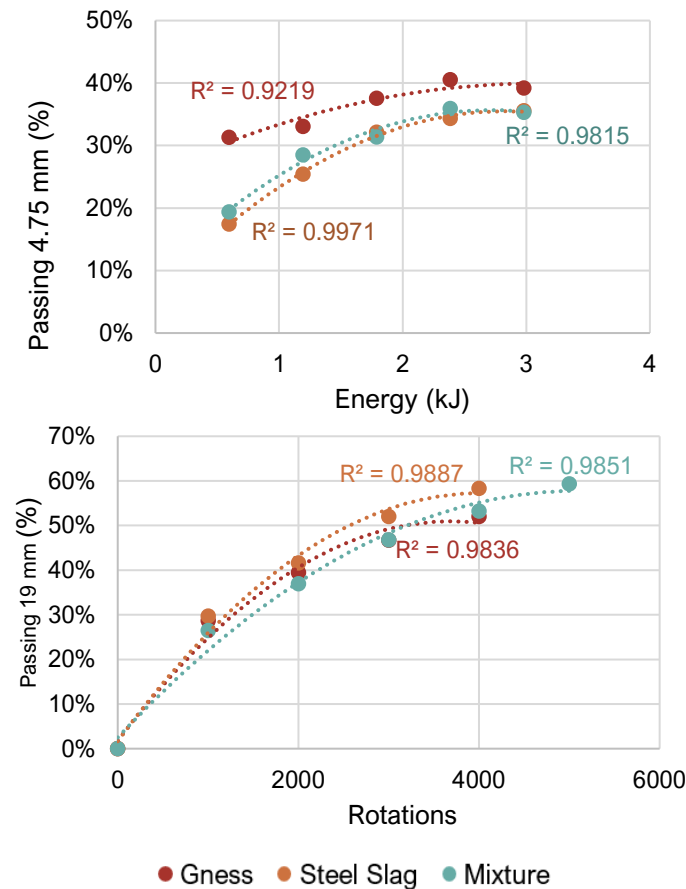


Figure 1 - Relationship between fine material and energy. a) Treton; b) Los Angeles abrasion. Source: authors.

In the Treton test, the crushed stone showed lower fragmentation during the initial impacts, indicating greater initial resistance to breakage; however, it maintained progressive fragmentation as energy was applied. In contrast, the slag exhibited high fragmentation during the first impacts, followed by a marked reduction in the fragmentation rate and subsequent stabilization of the material. In the Los Angeles abrasion test, the slag showed higher fines generation during the initial revolutions, while the natural aggregate exhibited a slightly lower initial rate and a more pronounced reduction throughout the test, indicating stabilization. Overall, the results indicate that slag is more susceptible to initial fragmentation, natural aggregate shows greater initial resistance, and the mixture combines both behaviors, resulting in more gradual and controlled degradation.

CONCLUSIONS

With regard to physical aspects, the slag showed inferior performance in terms of apparent porosity and water absorption, which may negatively affect sleeper durability. These parameters favor moisture retention in the ballast, creating a



constantly humid environment that may promote fungal growth in the case of wooden sleepers and may intensify corrosion processes in steel sleepers. From the mechanical analysis, it can be concluded that although the slag exhibits greater initial fragmentation, its behavior tends toward rapid stabilization, resulting in high residual strength and lower progressive degradation. In contrast, natural crushed stone, despite showing lower initial fragmentation, demonstrates a continuous tendency toward degradation under loading, which promotes the cumulative generation of fines, ballast fouling, and an accelerated reduction in the structural capacity of the track. The mixture exhibits intermediate behavior between slag and natural aggregate, suggesting rapid initial settlement combined with the maintenance of residual strength. This characteristic can be advantageous in applications where long-term performance and cost-benefit considerations are relevant. As a suggestion for future work, full-scale tests are recommended, as well as a detailed analysis of the electrical conductivity of the material.

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REFERENCES

- [1] N. C. C. Lobato, "Gerenciamento de resíduos sólidos da indústria," p. 143, 2014.
- [2] P. S. L. d. Carvalho, P. P. D. Mesquita e E. D. G. Araújo, "Sustentabilidade da siderurgia brasileira: eficiência energética, emissões e competitividade," BNDES Setorial, nº 41, pp. 181-236, março 2015.
- [3] B. Kumar, S. Hazra, M. Sahoo, P. Pal, M. Paliwal e S. Nag, "Blast Furnace Slag Formation Prediction Model Using Classical Thermodynamics," Steel Research International, vol. 95, 2024.
- [4] Y. Lan, Q.-c. Liu, F. Meng, D.-l. Niu e H. Zhao, "Optimization of magnetic separation process for iron recovery from steel slag," Journal of Iron and Steel Research, Internacional, vol. 24, nº 2, pp. 165-170, 2017.
- [5] R. R. Pecharromán, Á. J. López-López, A. P. Cucala e A. Fernández-Cardador, "Riding the Rails to DC Power Efficiency: Energy efficiency in dc-electrified metropolitan railways," EEE Electrification Magazine, vol. 2, nº 3, pp. 32-38, 2014.
- [6] A. H. M. Merheb, "Análise mecânica do lastro ferroviário por meio de ensaios triaxiais cíclicos.," São Paulo, 2014.



- [7] A. L. Leite, I. G. Freitas, E. B. Oliveira e M. T. Marino, "Atividade mineradora e impactos ambientais em uma empresa cearense," em Os Desafios da Geografia Física na Fronteira do Conhecimento., 2017, pp. 7282-7286.
- [8] L. Soranço, C. Katrine, V. Alves, S. Oliveira, V. Alves, G. Marques e J. Mendes, "Reaproveitamento de resíduos como lastro ferroviário: uma revisão sistemática e análise crítica no contexto brasileiro," Transportes, em revisão, 2025.
- [9] K. S. Couto, "Investigação ambiental e financeira do uso de agreado siderúrgico como lastro em pavimentos ferroviários," Juiz de Fora, 2025.
- [10] G. M. d. Sousa, "Estudo experimental de escória de aciaria para fins de caracterização tecnológica como material de lastro ferroviário em vias sinalizadas," Ouro Preto, 2007.



CONTROL-TO-EVIDENCE GRC FOR CLOUD SERVICES IN AUSTRALIA: OPERATIONALISING PRIVACY AND CYBERSECURITY ASSURANCE THROUGH CONTINUOUS CONTROL VALIDATION

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ABSTRACT

As Australian organisations move more services to the cloud, they are under growing pressure to show that privacy and cybersecurity protections are not only documented, but also working in practice. However, governance is often still based on policies, spreadsheets, and periodic checks, which can miss rapid changes in cloud environments. This extended abstract proposes a Control-to-Evidence (C2E) GRC model that connects governance requirements with practical cloud controls and continuously produced evidence. The model draws on Australian privacy reform developments, APRA CPS 234 assurance expectations, and the structures provided by ISO/IEC 27001 and ISO/IEC 27701. Rather than treating evidence as something collected only for audits, C2E treats evidence generation as part of everyday governance design. It links governance inputs, control requirements, cloud implementation mechanisms, evidence signals such as configuration changes, approvals, and remediation timelines, and audit-ready evidence packs. The paper offers a practical model for helping organisations maintain credible, up-to-date assurance in fast-changing cloud settings, with broader implications for resilient digital infrastructure and safer digital services.

Keywords: Governance, Risk and Compliance (GRC); privacy governance; cybersecurity assurance; cloud security; continuous monitoring.

INTRODUCTION

Australia's critical services increasingly depend on cloud-based platforms and third-party technology supply chains. In parallel, the Attorney-General's Department has published the Privacy Act Review Report, signalling stronger expectations for accountability and governance in personal information handling [1]. For APRA-regulated entities, CPS 234 requires information security capabilities commensurate with threats and emphasises assurance of control design and operating effectiveness, including controls managed by related parties and third parties [2].

Despite these expectations, many governance programs rely on periodic attestations and retrospective evidence collection, which can be difficult to reconcile with



configuration drift and rapid deployment cycles in cloud environments. Continuous monitoring guidance frames this as an assurance problem that requires ongoing visibility into security posture and control effectiveness to support risk decisions [3]. This paper addresses the gap by proposing a governance-to-operations model that links policy obligations to continuous control validation and evidence production.

MATERIALS AND METHODS

The C2E model is developed using a standards-to-controls synthesis approach grounded in three governance layers. First, Australian privacy reform material is treated as a governance input that shapes privacy accountability expectations for organisations processing personal information. Second, CPS 234 is used to specify assurance expectations for security control effectiveness and third-party coverage. Third, ISO/IEC 27001 and ISO/IEC 27701 are used to structure management system alignment for security and privacy governance, ensuring that obligations can be operationalised as auditable control objectives and measurable artefacts [4], [5], [6].

C2E defines a traceability chain from governance inputs to control catalogues and cloud implementations, and from implementations to evidence signals and evidence packs. Evidence design follows continuous monitoring principles where evidence is produced through operational telemetry and control state inspection rather than assembled only during audits Figure 1 summarises the C2E pipeline.

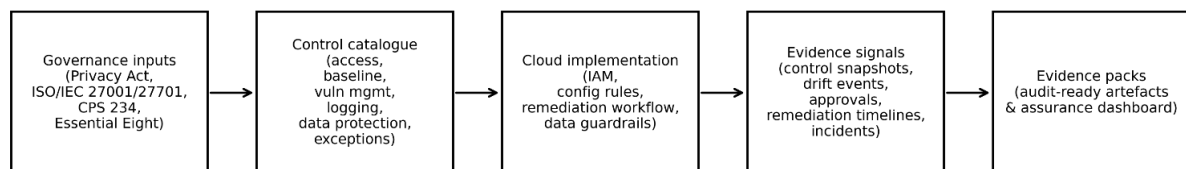


Figure 1 – Control-to-Evidence (C2E) GRC pipeline.

RESULTS

Framework proposal

C2E is formalised as a five-stage pipeline that links governance inputs to continuously validated control states and audit artefacts. Governance inputs (privacy reform expectations, prudential assurance obligations, and ISO management system controls) are translated into a control catalogue expressed as verifiable control intents. These intents are implemented through cloud mechanisms (e.g., identity and access enforcement, configuration rules, encryption enforcement, secure logging configuration) and validated through evidence signals that capture both steady-



state compliance and change events (e.g., drift detection, exception approvals, remediation timestamps). Evidence packs are defined as structured collections that bind control intent, implementation configuration, validation signals, and accountability records, enabling audit readiness without ad hoc evidence gathering.

DISCUSSION

The model responds directly to CPS 234's emphasis on demonstrating control effectiveness, including for controls operated by third parties, by specifying what continuous evidence should exist and how it can be linked to governance intent [2]. It also aligns with the broader objective of continuous monitoring programs that treat monitoring and measurement as ongoing risk management functions rather than episodic compliance activities [3]. The approach is designed to be cloud-agnostic at the governance layer while allowing heterogeneous implementation, which is relevant for Australian organisations operating multi-cloud and outsourced service environments. C2E reframes assurance as operational discipline: governance decisions are made testable, and audit claims become verifiable against persistent evidence.

CONCLUSIONS

C2E reframes GRC as a control-to-evidence system that supports privacy and cybersecurity assurance in cloud environments that change continuously. By aligning Australian governance expectations with ISO management system structures and continuous monitoring principles, the model supports more defensible assurance and more practical audit readiness for GRC, security assurance, and cloud security contexts. Its implications extend beyond compliance efficiency. For organisations, it can strengthen decision-making by giving leaders more timely and reliable visibility into whether important controls are working, drifting, or awaiting remediation. For regulators, auditors, and customers, it can improve trust by making assurance claims more transparent and easier to verify. More broadly, adopting this kind of model can contribute to more resilient digital infrastructure and safer digital services by reducing the gap between what organisations say they do and what their systems are actually doing. Future work can apply C2E in organisational pilots and assess impacts on audit effort, drift detection, remediation timeliness, and stakeholder confidence in assurance outcomes.

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REFERENCES

- [1] T. Yanagawa, V. Agarwal, Y. Watanabe, L. DeGenaro, and A. Sailer, "A Secure Framework for Continuous Compliance across Heterogeneous Policy Validation Points," in Proceedings of the IEEE International Conference on Cloud Computing (CLOUD), 2024, pp. 176–182.
- [2] F. Angermeir, J. Fischbach, F. Moyón, and D. Méndez, "Towards Automated Continuous Security Compliance," in Proceedings of the ACM/IEEE International Symposium on Empirical Software Engineering and Measurement (ESEM), 2024.
- [3] F. Moyón, F. Angermeir, and D. Méndez, "Industrial Challenges in Secure Continuous Development," in Proceedings of the International Conference on Software Engineering: Software Engineering in Practice (ICSE-SEIP), 2024.
- [4] Australian Prudential Regulation Authority (APRA), Prudential Standard CPS 234: Information Security, 2019.
- [5] Australian Government (Attorney-General's Department), Privacy Act Review Report, 2023.
- [6] NIST, Information Security Continuous Monitoring (ISCM) for Federal Information Systems and Organizations, NIST SP 800-137, 2011.



OPERATIONALISING TRUSTWORTHY ML UNDER CHANGE: AN EVALUATION-TO-MONITORING (E2M) ASSURANCE LOOP FOR DRIFT, ACCOUNTABILITY, AND GOVERNANCE EVIDENCE

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ABSTRACT

Machine Learning (ML) systems are increasingly deployed in high-change environments where dataset shift and concept drift can degrade model validity after deployment. While monitoring dashboards are common, many deployments do not preserve evaluation baselines as governance evidence nor connect monitoring signals to accountable decision pathways. This extended abstract proposes an Evaluation-to-Monitoring (E2M) assurance loop that links pre-deployment evaluation artefacts to post-deployment drift monitoring, incident response, and evidence packs suitable for assurance. The approach builds on established concept drift literature and aligns governance artefacts with NIST's AI Risk Management Framework. The contribution is a practical blueprint for ML engineering and analytics teams to manage model risk under change with clear accountability and auditable artefacts, supporting SDG 9 and SDG 13.

Keywords: MLOps governance; concept drift; model monitoring; trustworthy AI; analytics assurance.

INTRODUCTION

Deployed ML systems operate under non-stationarity: data distributions and underlying relationships can shift due to operational changes, seasonality, environment, behaviour, and policy interventions. Concept drift research frames this as a foundational challenge and motivates detection and adaptation strategies across the lifecycle [1].

Organisations also face increased expectations to manage AI risks with transparency, accountability, and documentation. The NIST AI Risk Management Framework provides a widely adopted structure for identifying, measuring, and managing AI risks and emphasises lifecycle governance and evaluation of system trustworthiness characteristics over time [2]. Yet many production systems separate model evaluation from monitoring and do not maintain traceable artefacts linking baseline assumptions, drift events, decisions, and remediation. E2M addresses this gap by

structuring monitoring as an assurance loop that produces governance-ready evidence as part of operational practice.

MATERIALS AND METHODS

E2M is defined as a lifecycle loop with four coupled artefact streams: baseline evaluation artefacts, drift-aware monitoring signals, accountable decisions, and evidence packs. Concept drift theory informs monitoring design by distinguishing distribution shift from changes in predictive relationships and error behaviour, motivating signals beyond single performance metrics [3].

Governance alignment is informed by the AI RMF's emphasis on measurable risk management, organisational accountability, and documentation that supports continuous improvement [4]. Under E2M, evaluation baselines are preserved as explicit reference artefacts (e.g., acceptance thresholds and error analyses). Monitoring signals detect divergence from baseline assumptions and trigger triage pathways (e.g., rollback, retraining, exception approval) with named owners. Evidence packs are defined as structured artefacts that include baseline results, monitoring alerts, ownership decisions, remediation actions, and post-incident reviews. Figure 1 presents the E2M loop as a numbered sequence to clarify the order of assurance activities from baseline evaluation to monitoring, remediation, and evidence generation.

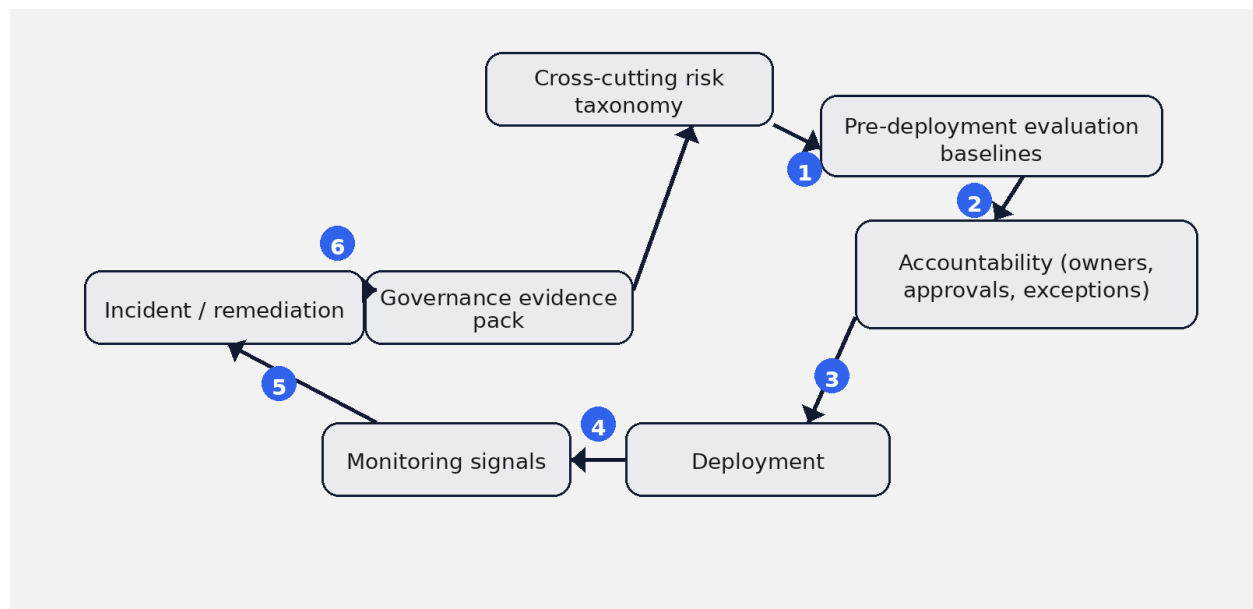


Figure 1 - Numbered Evaluation-to-Monitoring (E2M) loop shown as a high-resolution image

RESULTS

Framework proposal



E2M operationalises monitoring as assurance by binding pre-deployment evaluation to post-deployment decision-making. Baselines become explicit governance artefacts that provide a stable reference for interpreting monitoring signals, while drift events are treated as governance-relevant changes requiring accountable action rather than purely technical anomalies. Evidence packs unify baseline assumptions, monitoring records, and remediation decisions into a coherent assurance record that is suitable for internal governance review and external scrutiny.

Illustrative walkthrough. Consider a utility provider using an ML model to forecast peak service demand during summer. (1) Before deployment, the team records baseline evaluation artefacts such as accuracy, calibration, error patterns, and acceptance thresholds for high-temperature periods. (2) These baselines are assigned to accountable owners who define escalation rules, approval points, and acceptable exceptions. (3) Once deployed, the model is monitored in production. (4) Monitoring signals then track prediction error, input drift, and unusual changes in weather-related demand patterns against the approved baseline. (5) If a heatwave produces sustained drift, the issue is triaged through incident and remediation actions such as threshold review, rollback, or retraining. (6) The resulting governance evidence pack combines the baseline results, drift alerts, ownership decisions, remediation actions, and post-incident review, allowing the organisation to explain what changed, who acted, and why the response was appropriate.

DISCUSSION

E2M aligns operational practice with the AI RMF emphasis on lifecycle risk management by making measurement, documentation, and accountability explicit outputs of routine MLOps operations [4]. It also reduces the common gap where monitoring exists but does not support defensible decisions when models degrade [5]. The assurance framing is applicable to analytics used for sustainability-linked decisions and climate-exposed services because it treats environmental change as a first-class condition of deployment, consistent with the non-stationarity challenges discussed in concept drift literature [6]. E2M does not prescribe a specific toolkit; instead, it specifies artefact requirements that can be met using varied engineering stacks, enabling adoption across organisations.

CONCLUSIONS

E2M provides a practical governance-aware blueprint for monitoring ML systems under change. It strengthens accountability and audit readiness while remaining compatible with common ML engineering workflows. The approach supports SDG 9 by strengthening trustworthy digital infrastructure and SDG 13 by improving reliability of analytics used in change-exposed contexts. Future work can validate E2M through



applied implementations and evaluate impacts on incident response time, retraining decisions, and governance transparency.

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REFERENCES

- [1] C. Amrit and A. K. Narayanappa, "An analysis of the challenges in the adoption of MLOps," *Journal of Innovation & Knowledge*, vol. 10, no. 1, 2025.
- [2] J. Gama, I. Žliobaitė, A. Bifet, M. Pechenizkiy, and A. Bouchachia, "A survey on concept drift adaptation," *ACM Computing Surveys*, vol. 46, no. 4, 2014.
- [3] NIST, *Artificial Intelligence Risk Management Framework (AI RMF 1.0)*, NIST AI 100-1, 2023.
- [4] G. F. dos Santos Silva, "Strategies for detecting and mitigating dataset shift in machine learning applications," *Artificial Intelligence in Medicine*, 2025.
- [5] J. Hatherley, "A moving target in AI-assisted decision-making: dataset shift ...," *Ethics and Information Technology*, 2025.
- [6] E. Breck, S. Cai, E. Nielsen, M. Salib, and D. Sculley, "The ML Test Score: A rubric for ML production readiness and technical debt reduction," in *Proceedings of KDD*, 2017.



SIMULATION OF A SALES PLATFORM COMMERCIAL FUNNEL FOR IDENTIFYING BOTTLENECKS

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ABSTRACT

The growing market competitiveness requires companies to strengthen their decision-making processes, especially in critical areas such as business intelligence and sales. This study demonstrates the application of simulation techniques based on metrics collected from the Marketing and Sales teams of an e-commerce company specializing in sales platforms, using FlexSim software. Through the analysis of key performance indicators (KPIs) and the construction of simulation scenarios, the research sought to understand the behavior of the outbound commercial flow involving business intelligence, sales development representatives (SDR) and sales closer, focusing on process conversion. The research used a quantitative approach, based on data collection and interpretation of KPIs for one month, and the model simulated 30 days of operation. The simulation outcomes revealed a bottleneck in the SDR stage, where the accumulation of qualified leads impacted the sales cycle. The results confirm the relevance of simulation techniques as a diagnostic and decision-support tools, capable of reducing waiting times, shortening sales cycles, and increasing predictability.

Keywords: bottleneck; performance indicator; process simulation; sales funnel.

INTRODUCTION

The current growing market competitiveness, coupled with rapidly changing consumer behavior, has increased the need for more robust and predictive analytics within companies. To observe metrics in isolation is insufficient to predict future scenarios or fully understand the impact of business variables on results, which represents a limitation when addressing the importance of analysis for competitive advantage [1].

Simulation techniques have been used for reproducing, testing, and evaluating the behavior of commercial systems in controlled environments. Simulated models provide a more accurate representation of processes dynamics, supporting the understanding of complex phenomena and enabling analyses that would be unfeasible through observation alone [2].



Particularly, system dynamics models can act as decision support tools for marketing managers, allowing them to compare the effectiveness of different strategies, such as market entry, and to communicate the logic and results of the system to decision makers. When developed with direct input from managers, such models reinforce the importance of data-driven approaches to guide decisions in scenarios of high uncertainty and competition [3].

The FlexSim was selected because it enables the graphical modeling of process flows, resource allocation, waiting lines, and scenario analysis, allowing a more detailed understanding of how operational constraints affect sales performance. Thus, the software supports not only process visualization, but also the identification of bottlenecks and the evaluation of improvement alternatives before changes are implemented in practice.

The objective of this study was to demonstrate the application of sales funnel simulation techniques to identify bottlenecks, based on metrics collected from the Marketing and Sales teams of an online e-commerce company, using FlexSim software.

MATERIALS AND METHODS

COMPANY PROFILE

The study was conducted at an e-commerce company specializing in sales platforms. Three teams were considered for simulation, each with different responsibilities and workloads. The Commercial Intelligence team, responsible for qualifying leads, consisted of four employees working six hours a day. The SDR team, responsible for making initial contact with leads and scheduling partnership meetings, included one analyst and one intern, working eight and six hours a day, respectively. The Closer team, whose role is to conclude partnerships and finalize the company's commercial process, operated with a standard workload of eight hours per day.

DATA COLLECTION

Data were obtained through the observation and interpretation of dashboards and KPIs for September/25, from which the expressions for each stage of the process were derived and used as input parameters for the discrete-event simulation model, making it possible to represent the dynamics of the commercial funnel, including stage transitions, variable processing behavior, and the effects of capacity limitations, as shown in Table 1.

Table 1 – Statistical distributions of employees' performance.

Process	Distribution	Process time	Unit	Observation
Lead qualification T1	Normal	(5.50, 0.05)	Hours	4.40 leads/day
Lead qualification T2	Normal	(5.00, 0.10)	Hours	4.80 leads/day



Lead qualification T3	Normal	(0.59, 0.10)	Hours	3.54 leads/day
Lead qualification T4	Normal	(0.43, 0.10)	Hours	2.58 leads/day
Call SDR 1	Normal	2.59	Hours	8.58 leads/day
Call SDR 2	Normal	8.32	Hours	2.87 leads/day

To enable monthly forecasts, data was normalized considering continuous daily activity throughout the month. Average hourly performance per employee was calculated based on metrics for qualified leads, calls made, meetings scheduled, and leads converted.

The Closer's processing time was set at 10 hours, which is considered average availability for meetings with closers plus meeting duration. The Commercial Intelligence team was represented with different arrival intervals, since they are responsible for generating leads and feeding the queues of qualified leads, scheduled meetings and converted leads. SDRs and Closers were modeled as processors, with processing times based on the number of calls during the period. Different processing times and conversion rates were applied to simulate transitions between stages.

RESULTS

SIMULATION ANALYSIS

An overview of process performance, from lead qualification to final conversion, is provided in Table 2, together with the results of the commercial flow simulation for September/2025.

Table 2 – Results of the 30-day simulation in units.

Qualified leads	Scheduled meetings	Converted leads	Leads with no interest or no response
Initial scenario			
466	48	30	330
Simulated Scenarios with 3 SRD			
466	57	43	402

During the period analyzed, 466 leads were qualified, representing the total volume of opportunities entering the pipeline after the initial filter by the Business Intelligence team. Of these, 48 advanced to the stage of scheduling meetings with the SDR team. This drop between stages reflects a significant attrition rate in the funnel, possibly associated with factors such as contact unavailability, communication difficulties, or initial misalignment with the value proposition. Even though such losses are common in real business processes, they also highlight opportunities for improvement in the initial interaction or response time.



Among the meetings scheduled, 30 leads were successfully converted into customers, demonstrating positive performance by the sales closers in finalizing opportunities that reached this stage. Although this number is lower than the total number of meetings scheduled, it reflects the natural behavior of consultative sales, in which not all interactions result in immediate conversion.

In contrast, 330 leads were classified as uninterested or unresponsive, representing the largest share of the flow and highlighting a common pattern in commercial operations, especially when targeting broad or heterogeneous audiences.

The results reinforce the value of simulation as a diagnostic and decision support tool. By reproducing the actual behavior of the commercial process, the model enables the identification of bottlenecks, the evaluation of the efficiency at each stage, and the design of interventions capable of increasing conversion rates and optimizing resources allocation.

The overall conversion rate from qualified leads to converted customers was 6.44%. However, the simulation revealed an accumulation of queues at the qualified leads stage, generating an excessive workload for the SDRs, with 103 leads not reaching them. These findings suggest that adding an additional SDR could mitigate (Table 2) the observed bottleneck, even considering the longer processing time of SDR 2 due to his recent entry into the role.

The use of FlexSim helped clarify this behavior by making queue accumulation and resource overload visible throughout the simulated period. Rather than relying only on isolated KPIs, the model provided a systemic view of the relationship between arrival rates, service times, and conversion outcomes.

When comparing the results, it can be seen that the process flow is more fluid, with reduced waiting times and a conversion rate of 9.23%. In the proposed scenario, with the addition of another member to the SDR team, the average lead cycle time was reduced by 28.4%, indicating an increase in operational efficiency.

CONCLUSIONS

The simulation applied to the sales platform company confirmed that FlexSim software is an effective tool for analyzing and optimizing sales funnel processes. Through computer modeling, the simulation allowed the identification of bottlenecks in the SDR phase. These findings highlight the relevance of simulation as a decision-support tool, reinforcing its potential to guide managerial actions in dynamic and competitive environments. Therefore, it is recommended that the company adopt simulation periodically, mainly to evaluate new team configurations and variations in demand.



DECLARATION OF AI-ASSISTED TOOLS

"The author used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication."

REFERENCES

- [1] T. H. Davenport, J.G. Harris. "Competing on Analytics: The New Science of Winning". Boston: Harvard Business School Press, 2007.
- [2] A. M. Law, W. D. Kelton. "Simulation Modeling and Analysis". 3. ed. New York: McGraw-Hill, 2000.
- [3] P. Otto. "A system dynamics model as a decision aid in evaluating and communicating complex market entry strategies". *Journal of Business Research*, vol. 61, p. 1173–1181, 2008.



“SAFE-AND SUSTAINABLE-BY-DESIGN” ENGINEERING OF NANO-ENABLED UV FILTERS: A MINI REVIEW

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ABSTRACT

Mineral nano-UV filters such as TiO₂ provide strong UV attenuation, but UV excitation generates reactive oxygen species (ROS) via interfacial redox reactions. Reported "risk signals" diverge because photoreactivity is conditional, governed by phase/defects, surface accessibility, dispersion state, and test geometry. This review synthesises safe-and-sustainable-by-design (SSbD) strategies, focusing on coating-based photopassivation as the most mature industrial lever for suppressing charge transfer. We distil design rules linking coating continuity, thickness, chemistry, and durability to ROS suppression, and map trade-offs in optical performance, aesthetics, and formulation compatibility. QD/heterostructure approaches are discussed as lower-readiness alternatives. Finally, we argue that film-state validation coupling SPF/UVA protection with oxidative potential under use-relevant UVI/dose conditions offers a practical pathway for reproducible benchmarking and scalable deployment of safer mineral UV filters.

Keywords: SSbD, UV filter, photocatalysis, sunscreen, evaluation

INTRODUCTION

Sunscreens must reduce UV dose to skin while remaining stable, spreadable, and cosmetically acceptable. Many organic filters photochemically degrade under sunlight, and growing scrutiny over systemic and environmental exposure has accelerated the adoption of mineral filters, particularly TiO₂ and ZnO, for their strong UV attenuation and photostability.

These mineral nanoceramics, however, generate electron-hole pairs under UV excitation that can trigger reactive oxygen species (ROS) via interfacial redox chemistry, oxidising formulation components and elevating biological and



environmental risk signals. Critically, "photoactivity" is not a fixed property: it depends on phase, defects, surface accessibility, dispersion state, and whether testing is conducted in suspensions or realistic films, a mismatch that drives a persistent translation gap. The Safe-and-Sustainable-by-Design (SSbD) framework [1] addresses this by requiring evaluation across the full material lifecycle, including synthesis efficiency, environmental fate, and ecotoxicity.

This review frames the solution as interface engineering: charge transfer to reactive surface sites can be suppressed by tuning phase/defects and applying durable passivation coatings. Defensible safety claims require paired evidence: (i) broad-spectrum optical protection in film form and (ii) controlled oxidative potential under use-relevant conditions.

MATERIALS AND METHODS

A scoping review was conducted to map SSbD strategies for nano-enabled UV filters and identify measurement gaps limiting industrial translation. Searches across Scopus, Web of Science, and Google Scholar combined terms for mineral UV filters (TiO₂, ZnO, nano, sunscreen), photoreactivity endpoints (ROS, photocatalysis, radical generation, dye degradation), and mitigation approaches (coatings/passivation, surface functionalisation, doping/defect control, heterostructures). Studies were prioritised where photoreactivity was quantified under reported irradiation conditions. Evidence was synthesised into mechanism-to-design rules and assessed for scalability, coating integrity, formulation compatibility, and film-state relevance.

RESULTS

PHOTOREACTIVITY AS A CONDITIONAL PROPERTY

Engineered nanoceramic UV filters outperform coarse mineral pigments because nanoscale design improves transparency, dispersion, and formulation stability while preserving strong UV attenuation[2],[3]. However, these same materials can still generate ROS under UV and reported risk signals vary widely across studies (Table 1). The divergence is driven by phase/defect chemistry, surface accessibility, aggregation state, and most decisively, test geometry (dilute suspensions vs applied films) [4],[5]. As a result, ROS rankings from proxy photocatalysis assays may not predict behaviour in sunscreen films, where microstructure and local oxygen/water access control interfacial kinetics.

Table 1 Properties of current nanoceramic UV filters



Material	Bandgap	Protection	Safety Profile	Key References
TiO ₂ (Rutile)	3.0-3.2 eV	UVA-II, UVB	Lower ROS than anatase; requires passivation	[6],[7],[8]
ZnO (Wurtzite)	3.1-3.4 eV	UVA-I, UVA-II, UVB	Can generate ROS under UV and can dissolve, releasing Zn ²⁺ in some conditions	[9],[10],[11]

COATINGS AS THE INDUSTRIAL SAFE-BY-DESIGN LEVER

Surface coatings are the dominant industrial route to moderating TiO₂ photoreactivity because they directly suppress interfacial charge transfer [12],[13]. Coatings suppress ROS by separating TiO₂ from reactants, reducing adsorption of redox-active species, and shifting surface band bending/trap accessibility so carriers recombine rather than reaching reactive sites. Silica and alumina shells are widely used because they can markedly reduce photocatalytic indicators, but effectiveness depends on shell continuity and thickness [14],[15]. Critically, passivation is not “free”: thicker shells can reduce ROS yet also lower UV attenuation per unit TiO₂ and alter dispersion and film aesthetics. The strongest evidence links ROS endpoints to optical performance and durability in the film state, not in suspensions. From an SSbD perspective, coating strategies must also be assessed for the environmental fate of shell materials (e.g. silica/alumina) in rinse-off scenarios, the resource intensity of coating synthesis, and the ecotoxicity of breakdown products, dimensions that complement, but are distinct from, ROS suppression efficacy.

LOWER-TRL ALTERNATIVES: QD/HETEROSTRUCTURES

QDs and heterostructures are proposed to expand spectral coverage and to buffer or divert redox pathways, but they represent multiple design intents rather than a single approach. Two recurring architectures are (i) QD encrusted TiO₂ surfaces (discontinuous nanodomain layers)[16] and (ii) ligand/matrix-immobilised ^{QD}TiO₂ hybrids designed to regulate interfacial charge transfer and improve durability [17]. Translation remains lower-TRL (Technology Readiness Level) because these systems introduce new failure modes (ligand oxidation, matrix photodegradation, permeability changes) and because “antioxidant” behaviour can invert under UV depending on composition and environment. Therefore, QD strategies must be evaluated using explicit film state ROS/oxidative capacity testing under relevant irradiation and formulation conditions.



VALIDATION UNDER USE: INTEGRATING SPF WITH UVI

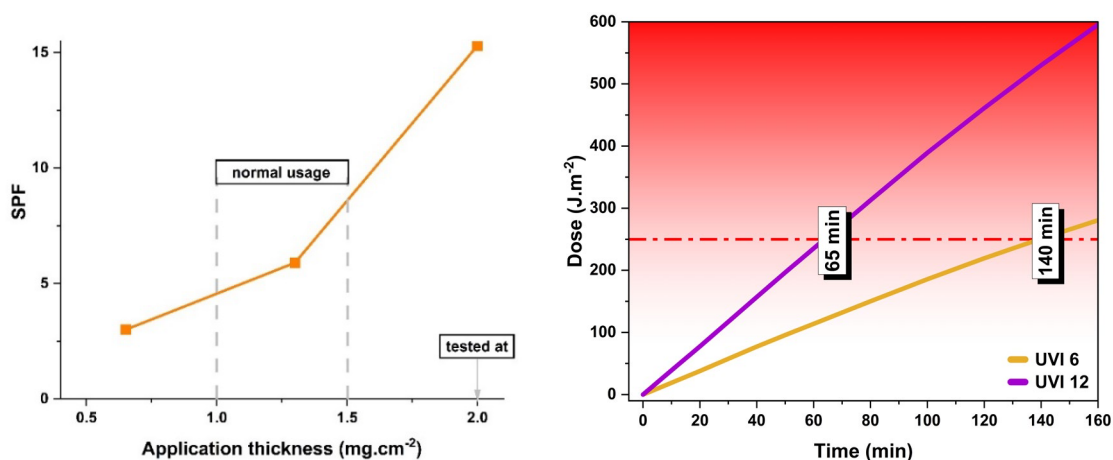


Figure 1 (Left) Variation in SPF with applied thickness and (Right) Variation of accumulated UV dose with UVI

SPF and UVA protection metrics remain the regulatory anchor, but they do not fully capture real world protection, as performance depends on film thickness, uniformity, and evolution over use. In vitro, film based spectrophotometric methods are more translational than solution-based testing because they capture scattering/absorption effects and film microstructure. A persistent gap is in application behaviour: consumers typically apply substantially less than the 2 mg·cm⁻² used in standard testing, resulting in large protection shortfalls (Figure 1)[18],[19]. Integrating realistic application rates with UV Index (UVI) and dose provides a physically meaningful framework for screening formulations under high-irradiance conditions and for treating reapplication as dose management rather than a fixed time rule [19]. For SSbD mineral systems, the defensible endpoint is convergent evidence: stable film state spectral protection plus controlled oxidative potential under use relevant dose conditions.

CONCLUSIONS

Mineral nano-UV filters can be both highly effective and demonstrably safer, but only when safety is treated as an engineered interface outcome rather than an intrinsic material label. Variability in photoreactivity and "risk signals" is driven less by the TiO₂ core than by surface accessibility, defect chemistry, dispersion state, and test geometry, making film-state, formulation-relevant evaluation essential.

Coating-based photopassivation remains the most translation-ready pathway: durable silica/alumina or hybrid shells suppress ROS while preserving UV protection, provided shell continuity, thickness, and integrity are controlled. QD/heterostructure approaches are promising but lower-TRL, with outcomes sensitive to band alignment, environmental conditions, and degradation pathways.



To bridge the translation gap, a dual-evidence framework coupling film-state optical protection with oxidative potential testing under use-relevant UV doses is needed. Embedding this within an SSbD approach, integrating lifecycle sustainability, environmental fate, and circularity alongside hazard criteria, aligns mineral UV filter development with emerging EU regulatory expectations, supporting scalable deployment of safer products and advancing SDG 3 and SDG 9.

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REFERENCES

- [1] C. Caldeira et al., "Safe and sustainable by design chemicals and materials - Framework for the definition of criteria and evaluation procedure for chemicals and materials," JRC Publications Repository. Accessed: Apr. 09, 2026. [Online]. Available: <https://publications.jrc.ec.europa.eu/repository/handle/JRC128591>
- [2] C. Cole, T. Shyr, and H. Ou-Yang, "Metal oxide sunscreens protect skin by absorption, not by reflection or scattering," *Photodermatology, Photoimmunology & Photomedicine*, vol. 32, no. 1, pp. 5–10, 2016, doi: 10.1111/phpp.12214.
- [3] N. Serpone, D. Dondi, and A. Albini, "Inorganic and organic UV filters: Their role and efficacy in sunscreens and suncare products," *Inorganica Chimica Acta*, vol. 360, no. 3, p. 794, 2007.
- [4] K. Bogusz, M. Tehei, M. Lerch, S. X. Dou, H. K. Liu, and K. Konstantinov, "TiO₂/(BiO)₂CO₃ nanocomposites for ultraviolet filtration with reduced photocatalytic activity," *Journal of Materials Chemistry C*, vol. 6, no. 21, pp. 5639–5650, 2018, doi: 10.1039/c8tc01330f.
- [5] A. Morlando et al., "Development of CeO₂ nanodot encrusted TiO₂ nanoparticles with reduced photocatalytic activity and increased biocompatibility towards a human keratinocyte cell line," *Journal of Materials Chemistry B*, vol. 8, no. 18, pp. 4016–4028, 2020, doi: 10.1039/d0tb00629g.
- [6] S. M. Araki and A. R. Baby, "New Perspectives on Titanium Dioxide and Zinc Oxide as Inorganic UV Filters: Advances, Safety, Challenges, and Environmental Considerations," *Cosmetics*, vol. 12, no. 2, p. 77, Apr. 2025, doi: 10.3390/cosmetics12020077.
- [7] K. Sharma, K. M. Dixon, G. Münch, D. Chang, and X. Zhou, "Ultraviolet and infrared radiation in Australia: assessing the benefits, risks, and optimal exposure guidelines," *Front Public Health*, vol. 12, p. 1505904, Dec. 2024, doi: 10.3389/fpubh.2024.1505904.
- [8] N. Serpone, "Sunscreens and their usefulness: have we made any progress in the last two decades?," *Photochem Photobiol Sci*, vol. 20, no. 2, pp. 189–244, Feb. 2021, doi: 10.1007/s43630-021-00013-1.
- [9] S. O. Mohammed, M. M. H. Khalil, I. M. El-Sewify, and A. Radwan, "Nd-doped CuO/ZnO and ZnO/CuO heterojunctions for simultaneous UV blocking and malachite green



- detoxification," Sci Rep, vol. 15, no. 1, p. 34063, Sep. 2025, doi: 10.1038/s41598-025-13945-w.
- [10] A. Elbrolesy, Y. Abdou, F. A. Elhussiny, and R. Morsy, "Novel Green Synthesis of UV-Sunscreen ZnO Nanoparticles Using Solanum Lycopersicum Fruit Extract and Evaluation of Their Antibacterial and Anticancer Activity," J Inorg Organomet Polym, vol. 33, no. 12, pp. 3750–3759, Dec. 2023, doi: 10.1007/s10904-023-02744-3.
- [11] H. S. Kapare, M. Bhosale, P. Karwa, D. Kulkarni, R. Bhole, and S. Labhade, "Phyto-Assisted Synthesis and Investigation of Zinc Oxide Nanoparticles for Their Anti-Aging, Sun Protection and Antibacterial Activity," Cosmetics, vol. 12, no. 6, p. 238, Dec. 2025, doi: 10.3390/cosmetics12060238.
- [12] "MT-100SJTV by Sunjin Beauty Science (formerly Sunjin Chemical) - Personal Care & Cosmetics." Accessed: Apr. 03, 2025. [Online]. Available: <https://www.ulprospector.com/en/asia/PersonalCare/Detail/3858/6611594/MT-100SJTV>
- [13] Sunjin Beauty Science, "Technical Data Sheet SUNZNO." Jul. 2021. [Online]. Available: www.sunjinbs.com
- [14] M.-C. Le, T.-H. Le, T.-H. Bui Thi, Q.-D. Nguyen, T.-H. Do Thi, and M.-N. Tran Thi, "Synthesizing and Evaluating the Photocatalytic and Antibacterial Ability of TiO₂/SiO₂ Nanocomposite for Silicate Coating," Front. Chem., vol. 9, Sep. 2021, doi: 10.3389/fchem.2021.738969.
- [15] T. A. Egerton, "The Influence of Surface Alumina and Silica on the Photocatalytic Degradation of Organic Pollutants," Catalysts, vol. 3, no. 1, pp. 338–362, Mar. 2013, doi: 10.3390/catal3010338.
- [16] N. P. Cooray, R. C. Das, P. J. Barker, M. Lerch, J. H. Kim, and K. Konstantinov, "The inhibition of photocatalytic activity of rutile nanoparticles via surface encrustation with La(OH)₃ quantum dots," J. Mater. Chem. B, May 2025, doi: 10.1039/D5TB00114E.
- [17] J. Zhou, Y. Liu, J. Tang, and W. Tang, "Surface ligands engineering of semiconductor quantum dots for chemosensory and biological applications," Materials Today, vol. 20, no. 7, pp. 360–376, Sep. 2017, doi: 10.1016/j.mattod.2017.02.006.
- [18] B. Diffey, "Sunscreen isn't enough," Journal of Photochemistry and Photobiology B: Biology, vol. 64, no. 2, pp. 105–108, Nov. 2001, doi: 10.1016/S1011-1344(01)00195-6.
- [19] N. P. Cooray, E. Li, K. Konstantinov, M. Lerch, and P. J. Barker, "The dynamic behaviour of sunscreens under in-service conditions.," Journal of Photochemistry and Photobiology B: Biology, vol. 230, p. 112435, May 2022, doi: 10.1016/j.jphotobiol.2022.112435.



LIFE CYCLE ASSESSMENT OF SUGARCANE RESIDUE-BASED GEOPOLYMERS MORTARS: EFFECTS OF PRECURSOR PROCESSING

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ABSTRACT

This study evaluates the environmental performance of SCBA-based geopolymer mortars through a systematic literature review and Life Cycle Assessment conducted in SimaPro 10.2.0.0, using a gate-to-gate approach with a functional unit of 1 ton and the ReCiPe 2016 Midpoint H method. Global warming potential ranged from 51.2 to 185 kg CO₂ eq, while fine particulate matter formation and mineral resource scarcity varied by up to fourfold across formulations. Higher impacts were associated with multi-step thermal pre-treatments and elevated sodium silicate dosages, whereas minimal processing and reduced activator contents yielded the lowest profiles. Results demonstrate that alkaline activator composition, particularly sodium silicate content, outweighs calcination severity as the primary environmental driver, confirming that sustainability depends on integrated optimization of processing and mix design.

Keywords: Geopolymer mortar; Sugarcane bagasse ash; Life cycle assessment; waste; construction

INTRODUCTION

Improper biomass waste disposal is a major environmental challenge in agricultural production, causing odors, water contamination, and risks to human health, including infectious, respiratory, and ocular diseases. It is also linked to risks to human health, including infectious, respiratory, and ocular diseases. It is estimated that for every 1,000 kg of sugarcane processed, approximately 220–300 kg of straw, 260–330 kg of bagasse, and 35–40 kg of mill sludge are generated [1].

The sugar-energy sector has strong potential for residue valorization in sustainable cement-based composites. Partial cement replacement with sugarcane bagasse ash (SCBA) improves mechanical performance and durability in UHPC [2]. However, the integration of environmental and energy impacts of pre-treatment processes with mixture design parameters has not been systematically addressed in the literature. Therefore, this study combines a systematic review and LCA to assess how precursor



processing and mix proportions jointly influence the environmental performance of SCBA-based geopolymer mortars.

MATERIALS AND METHODS

A systematic review of the Scopus database (2001–2025) was conducted to identify studies on SCBA-based geopolymer mortars. Only journal articles, conference papers, and book chapters reporting pre-treatment parameters (time, temperature, and equipment) for drying, calcinating, grinding, and sieving, along with mix proportions, were included.

The LCA was conducted following internationally recognized methodological guidelines, using SimaPro software (version 10.2.0.0) with the Agri-footprint 6.3 and Ecoinvent 3.10 databases. The system boundary was defined as “gate-to-gate”, considering exclusively the laboratory-scale geopolymer preparation stages. The functional unit was set at 1 ton as the basis for quantifying material and energy flows. In this analysis, precursors were assumed to carry zero environmental burden as by-products of existing industrial processes. The inventory focused solely on energy-related processing impacts based on literature data, as shown in Table 1.

Table 1 – Energy consumption of pretreatment processes for geopolymer mortars and their mix proportion. Source: authors.

Article	Precursors	Drying	Sieving	Grinding	Calcinating	Mixing	Total	Mix Proportion
Ardhira et al. [3]	SCBA + FA + GGBFS	N/A	N/A	N/A	6,15 kWh; N/A; 700 °C.	10 min; 0,63 kWh	6,78 KWh	Water: 67.980 cm ³ FA: 207,69 Kg GGBFS: 103,85 Kg SCBA: 34,62 Kg Sand: 446,23 Kg NaOH: 69,18 Kg Na ₂ SiO ₃ : 70,45 Kg
Zafar et al. [4]	SCBA + FA	22 kWh/t [5] = 1,01 KWh	11 kWh/t [6] = 0,51 KWh	39 kWh/t [7] = 1,80 KWh	7,22kWh; 240min; 800 °C.		11,17 KWh	Water: 33.580 cm ³ FA: 414,75 Kg SCBA: 46,08 Kg Sand: 460,84 Kg Na ₂ SiO ₃ : 22,37 Kg NaOH: 22,38 Kg
Murugesan et al. [8]	SCBA + GGBFS + MW	22 kWh/t [5] = 0,63 KWh	11 kWh/t [6] = 0,31 KWh	N/A	N/A		1,57 KWh	Water: 44.730 cm ³ GGBFS: 257,35 kg SCBA: 28,59 kg MW: 114,38 kg NaOH: 57,19 kg Na ₂ SiO ₃ : 40,25 kg Sand: 457,51 kg
Castaldelli et al. [9]	SCBA + FA	22 kWh/t [5] = 1,11 KWh	N/A	45,6 kWh/t [6] = 2,30 KWh	5,76kWh; 120min; 650 °C + Silica sand fusion [10] [11] = 14,97 KWh		24,77 KWh	Water: 90.970 cm ³ FA: 151,55 Kg SCBA: 50,51 Kg Sand: 606,18 Kg KOH: 40,82 Kg Silica Sand: 23,39 Kg Potassium hydroxide: 36,58 Kg



Pereira et al. [12]	SCBA + BFS	N/A	11 kWh/t [6] = 0,66 KWh	15,2 kWh/t [6] = 0,91 KWh	N/A		2,2 KWh	Water: 108.020 cm ³ BFS: 180,42 kg SCBA: 60,13 kg NaOH: 29,40 kg Na ₂ SiO ₃ : 20,65 kg Sand: 601,38 kg
Afriansya et al. [13]	SCBA + FA	N/A	N/A	N/A	5,30kWh; 120min; 600 °C		5,93 KWh	Water: 35.500 cm ³ FA: 309,5 kg BA: 16,3 kg Fine aggregate: 521,2 kg Na ₂ SiO ₃ : 93,1 kg NaOH sólido: 17,9 kg SP: 6,5 kg

FA: Fly Ash; **GGBFS:** Ground Granulated Blast Furnace Slag;

MW: Marble Waste; **BFS:** blast furnace slags; **SP:** Superplasticizer; **N/A:** Not applicable.

The calcination energy demand was modeled using the muffle furnace configuration proposed by Castro et al. [14], considering heating and isothermal holding phases. Heating energy was calculated from nominal power and ramp time, based on a constant rate of 10 °C · min⁻¹ and the temperature difference between ambient and target conditions. During holding, power input was assumed to offset conductive heat losses through the furnace walls, estimated by Fourier's law using equivalent thermal resistance and heat transfer area. Total energy corresponds to the sum of both phases. Sample homogenization was assumed to occur in a 5 hp, 220 V concrete mixer for 10 min.

RESULTS AND DISCUSSION

Figure 1 shows the percentage contribution of geopolymer mortars across ReCiPe 2016 Midpoint (H) impact categories, where values are normalized to the highest impact in each category. Table 2 highlights those with the highest environmental burdens.

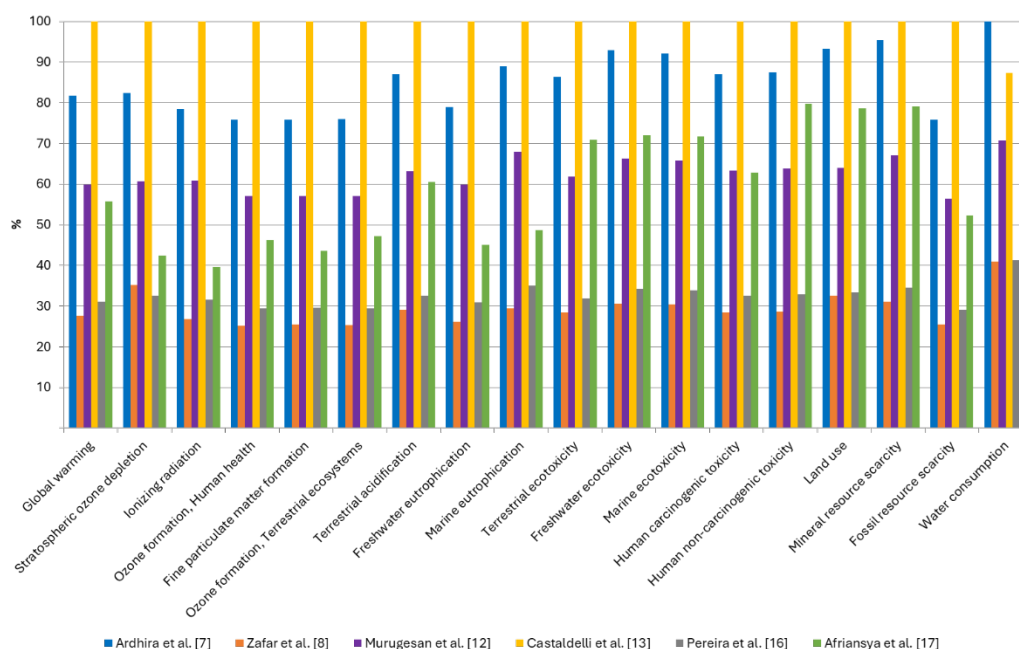


Figure 1 – Comparative Environmental Impact of Geopolymer Mortar

Table 2 – Key environmental indicators of SCBA-based geopolymer mortars. Source: authors.

Article	Global Warming [kg CO ₂ eq]	Fine particulate matter formation [kg PM _{2.5} eq]	Mineral resource scarcity [kg Cu eq]	Water consumption [m ³]
Ardhira et al. [3]	152	0,257	0,648	2,37
Zafar et al. [4]	51,2	0,0863	0,211	0,973
Murugesan et al. [8]	111	0,194	0,456	1,68
Castaldelli et al. [9]	185	0,339	0,679	2,07
Pereira et al. [12]	57,4	0,1	0,235	0,978
Afriansya et al. [13]	103	0,147	0,537	1,55

Castaldelli et al. [9] exhibited the highest impacts across nearly all categories, driven by the cumulative burden of multiple energy-intensive pre-treatment stages, as shown in Table 1, combined with K₂O- and SiO₂-based activators associated with substantial upstream production loads. In contrast, Pereira et al. [12] and Murugesan et al. [8] presented the most favorable profiles, with values ranging from 25 to 65% across most categories. Pereira et al. [12] benefited from the absence of thermal treatment, with SCBA processing limited to sieving and 50 minutes of milling, alongside low activator dosages (NaOH: 29.40 kg/t; Na₂SiO₃: 20.65 kg/t). Murugesan et al. [8] achieved similar results by eliminating calcination and incorporating marble waste, thereby reducing both thermal and raw material-related burdens.

Zafar et al. [4] showed a seemingly counterintuitive outcome. Despite the most intensive calcination at 800 °C for 4 hours, moderate impacts were observed due to low activator dosages (Na₂SiO₃: 22.37 kg/t; NaOH: 22.38 kg/t). Conversely, Afriansya et al. [13], despite milder calcination at 600 °C for 2 hours, exhibited elevated impacts



in non-carcinogenic toxicity, marine ecotoxicity, and mineral resource scarcity, driven by the highest Na_2SiO_3 content among all formulations (93.1 kg/t).

CONCLUSIONS

LCA results indicate that the environmental performance of SCBA-based geopolymer mortars is controlled by pre-treatment intensity and alkaline activator composition, with sodium silicate as the main impact driver. Formulations with minimal processing and low activator dosages achieved the best profiles, confirming SCBA's potential as a sustainable precursor when processing and mix design are jointly optimized.

REFERENCES

- [1] P. Paulose and P. Kaparaju, "Anaerobic mono-digestion of sugarcane trash and bagasse with and without pretreatment," *Industrial Crops and Products*, vol. 170, 15 October 2021.
- [2] W. M. Shaban, A. M. Heniegal, M. Amin, A. M. Zeyad, I. S. Agwa and H. H. Hassan, "Effect of agricultural wastes as sugar beet ash, sugarcane leaf ash, and sugarcane bagasse ash on UHPC properties," *Journal of Building Engineering*, vol. 98, 1 December 2024.
- [3] P. Ardhira, S. K. Shukla and D. Sathyan, "Synthesis of geopolymer mortar from biomass ashes and forecasting its compressive strength behaviour," *Case Studies in Construction Materials*, vol. 21, December 2024.
- [4] I. Zafar, K. Rashid, M. Ahmad and M. Ltifi, "Thermo-chemico-mechanical activation of bagasse ash to develop geopolymer based cold-pressed block," *Construction and Building Materials*, vol. 352, 17 October 2022.
- [5] R. Manohar and R. Velraj, "Bagasse Dryer," *International Journal of Applied Engineering Research*, vol. 10, 2015.
- [6] Y. Bayapureddy, K. Muniraj and M. r. G. Mutukuru, "Enhancing material properties of agro-industrial waste sugarcane bagasse ash—Way towards sustainable development," *Sustainable Futures*, vol. 7, June 2024.
- [7] G. C. Cordeiro, P. V. Andreão and L. M. Tavares, "Pozzolanic properties of ultrafine sugar cane bagasse ash produced by controlled burning," *Heliyon*, vol. 5, October 2019.
- [8] T. Murugesan, R. Vidjeapriya and A. Bahurudeen, "Development of Sustainable Alkali Activated Binder," *Sugar Tech*, vol. 22, p. 885–895, 18 April 2020.
- [9] V. Castaldelli, J. Moraes, J. Akasaki, J. Melges, J. Monzó, M. Borrachero, L. Soriano, J. Payá and M. Tashima, "Study of the binary system fly ash/sugarcane bagasse ash (FA/SCBA) in $\text{SiO}_2/\text{K}_2\text{O}$ alkali-activated binders," *Fuel*, vol. 174, pp. 307–316, 15 June 2016.
- [10] S. Tetteh, G. Juul, M. Järvinen and A. Santasalo-Aarnio, "Improved effective thermal conductivity of sand bed in thermal energy storage systems," *Journal of Energy Storage*, vol. 86, 10 May 2024.
- [11] R. BEERKENS, "ANALYSIS OF ELEMENTARY PROCESS STEPS IN INDUSTRIAL GLASS MELTING TANKS - SOME IDEAS ON INNOVATIONS IN INDUSTRIAL GLASS MELTING," *Ceramics-Silikaty*, vol. 52, pp. 206–217, 9 October 2008.



- [12] A. Pereira, J. L. Akasaki, J. L. Melges, M. M. Tashima, L. Soriano, M. V. Borrachero, J. Monzó and J. Payá, "Mechanical and durability properties of alkali-activated mortar based on sugarcane bagasse ash and blast furnace slag," *Ceramics International*, vol. 41, pp. 13012-13024, December 2015.
- [13] R. Afriansya, P. Astuti, V. S. Ratnadewati, J. Randisyah, T. Y. Ramadhona and E. A. Anisa, "INVESTIGATION OF SETTING TIME AND FLOWABILITY OF GEOPOLYMER MORTAR USING LOCAL INDUSTRY AND AGRICULTURE WASTE AS PRECURSOR IN INDONESIA," *International Journal of GEOMATE*, vol. 21, pp. 64-69, Nov 2021.
- [14] G. G. P. D. Castro, G. J. d. S. N. Rezende, L. F. Maciel and L. V. d. A. d. Almeida, "Metodologia construtivista: dimensionamento e fabricação de um forno tipo mufla de alto desempenho," *Brazilian Journal of Development*, vol. 5, no. 11, 2019.



ANALYSIS AND ASSESSMENT OF VARIOUS MODALITIES IN GROUP VIDEO EMOTION RECOGNITION USING DEEP LEARNING APPROACHES

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ABSTRACT

We present the first group facial emotion recognition (FER) study on original Indian cinematic content spanning a 52-year temporal gap. Three novel annotated datasets are constructed from Ittefaq (1969, B&W, suspense thriller), 420 IPC (2021, RGB, mystery-drama), and Taarak Mehta Ka Ooltah Chashmah (2008+, RGB, TV sitcom), covering six emotion classes with balanced distributions. Real-time emotion recognition from video is critical for live deployment in security surveillance, driver monitoring, and interactive media, where frame-level latency must be minimised and audio or text may be unavailable. We propose MicroDCSA, a lightweight dual-stream architecture combining EfficientNet-B0 + Bidirectional GRU (spatial stream) with SE-ResConv + BiGRU (motion stream), fused via a novel Bidirectional Cross-Stream Attention (CSA) mechanism. Cultural domain knowledge—rooted in Indian Navarasas performance tradition—is embedded through FACS-adapted annotation, temporal windowing encoding onset–apex–offset dynamics, and Focal Loss with class weighting. MicroDCSA_v4 (2.15M params) achieves 74.44% accuracy on Indian B&W cinema, outperforming ResNet-50 (25.6M, 11.9× larger) by +3.33 pp with AUC = 0.9317. HybridMDv7 achieves 69.60% cross-domain average across all three cinematic eras, surpassing ResNet-50 by +3.50 pp.

Keywords: Group Emotion Recognition, Dual-Stream, Cross-Stream Attention Network, Real-Time Video Analysis, Facial Expression Recognition, Transfer Learning, Indian Cinema, BiGRU, Domain Adaptation.

INTRODUCTION

Video emotion recognition (VER) is a cornerstone of affective computing, essential for healthcare monitoring, public safety surveillance, and emotionally-aware virtual assistants. Real-world deployment is challenged by fluctuating lighting, occluded faces, and absent audio streams. Indian performance tradition, rooted in the classical Navarasa system of nine emotional states, differs systematically from Western theatrical norms—yet all major FER benchmarks (FER2013, AffectNet, RAF-DB, CK+) feature predominantly Western subjects, creating systematic underperformance in Indian contexts. This research addresses both gaps: constructing the first Indian cinematic FER benchmark spanning 52 years and proposing MicroDCSA—a visual-



only real-time architecture embedding cultural domain knowledge—validated across five experimental scenarios.

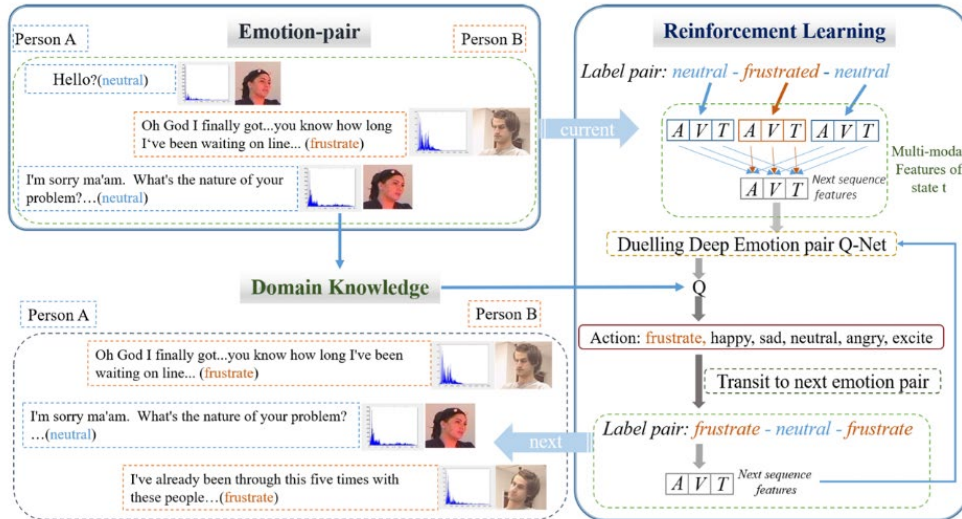


Figure 1 – Overview of base model architecture ERLDK. Adapted from [8].

LITERATURE REVIEW

Emotion recognition has evolved from static CNN analysis to multimodal Transformer systems. Zhang et al. [8] proposed ERLDK using Dueling DQN + GRU + Domain Knowledge module (55.29% wF1 on IEMOCAP) but requires all three modalities and was untested on Indian content. Chaudhari et al. [6] showed Vision Transformers improve occluded-face FER; Bhagat et al. [7] established CNN-FER baselines. No prior work evaluates on Indian cinematic content or 52-year cross-era temporal domain shift—the central contribution of this paper. Critical challenges persist around real-time inference, cross-cultural generalisation, and robustness under missing modality conditions [5].

DATASET CONSTRUCTION

We constructed three original datasets spanning a 52-year range. All share FACS annotation adapted for Indian Navarasa conventions (calibrated per genre: understated in 1969 thriller; naturalistic in 2021 drama; exaggerated comedic in TV sitcom), T=10 temporal windowing (step=2, capturing onset→apex→offset dynamics), and SEED=42 stratified 70/15/15 splits.



Figure 2 – Dataset samples. Left: Ittefaq (1969, B&W). Centre: 420 IPC (2021, RGB). Right: Taarak Mehta (2008+, TV RGB).

Table 1 – Indian cinematic FER datasets. Six emotion classes: Neutral, Sad, Fear, Angry, Happy, Surprise.

Dataset	Year	Colour	Genre	Total Samples	Per Class	Split 70/15/15
Ittefaq	1969	B&W	Suspense Thriller	600	100	420 / 90 / 90
420 IPC	2021	RGB HD	Mystery-Drama	1,549	100	1,277 / 272 / 272
Taarak Mehta	2008+	RGB	TV Sitcom	1,824	304	1,268 / 274 / 274

PROPOSED ARCHITECTURE: MICRODCSA

Stream A – Spatial: EfficientNet-B0 (5.3M params) extracts 1280-dim features per frame → 2-layer BiGRU (hidden=256) + 4-head temporal attention → context $B \times 512$ + spatial residual $B \times 1280$.

Stream B – Motion: Frame differences $\Delta f_t = f_t - f_{t-1}$ (grayscale) → scratch SE-ResConv CNN (4 blocks, 32→64→128ch) → 3-layer BiGRU (hidden=128) → domain-invariant motion trajectory features.

Bidirectional CSA Fusion: $s' = \text{MHA}(Q=\text{spatial}, K=\text{motion}, V=\text{motion}) + s$; $m' = \text{MHA}(Q=\text{motion}, K=s', V=s') + m$. Domain Adapters (per dataset) + Focal Loss + Hierarchical Cross-Entropy embed cultural domain knowledge at training level.

RESULTS AND DISCUSSION

A. SCENARIO 1 – SINGLE-DOMAIN: ITTEFAQ (B&W 1969)

MicroDCSA_v4 (2.15M) achieves 74.44% accuracy, AUC=0.9317, outperforming ResNet-50 (25.6M, 11.9× larger) by +3.33 pp with 100% Neutral recall. Temporal modelling of expression trajectories dominates on B&W cinema where static ImageNet texture features degrade severely.

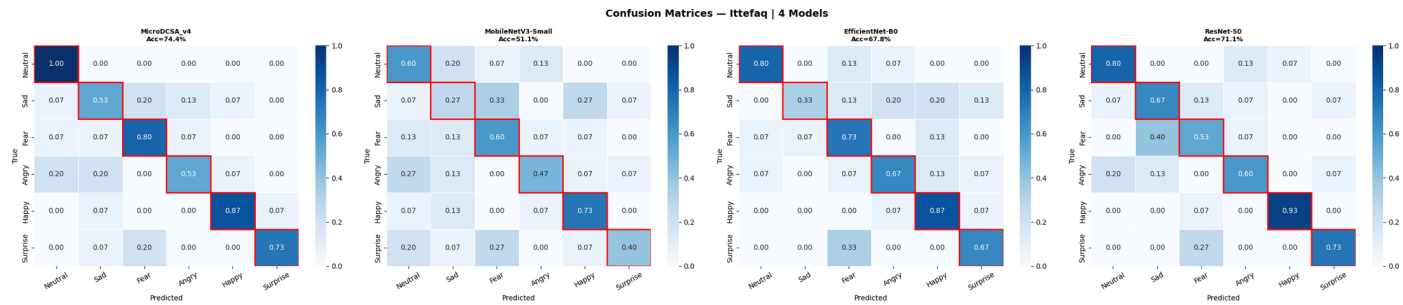


Figure 3 – Confusion matrices: S1 Ittefaq (4 models). MicroDCSA_v4: 74.44%, 100% Neutral recall.

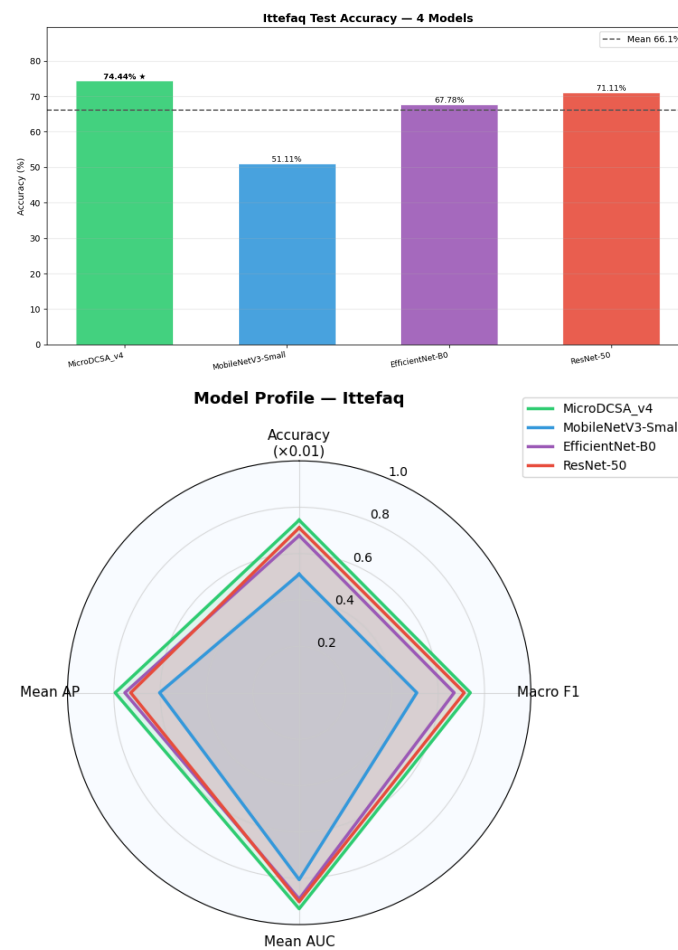


Figure 4 – Left: Overall accuracy comparison S1. Right: Radar chart – MicroDCSA_v4 (green) leads Accuracy, F1, AUC, AP on Ittefaq.

Table 2 – Scenario 1 results (Ittefaq B&W). ★ = proposed model.

Model	Params	Accuracy	Macro-F1	mAUC	mAP
★ MicroDCSA_v4	2.15M	74.44%	0.7388	0.9317	0.7942
ResNet-50	25.6M	71.11%	0.7126	0.9016	0.7272



EfficientNet-B0	5.3M	67.78%	0.6690	0.8898	0.7524
MobileNetV3-S	2.5M	51.11%	0.5077	0.8062	0.6024

B. SCENARIO 2 – CROSS-DOMAIN: ITTEFAQ → 420 IPC (B&W → RGB)

ResNet-50 (91.54%) outperforms HybridMDv6 (90.44%) when training data exceeds 1,200 samples—pretrained ImageNet capacity dominates at scale. Key rule: small data (<600) → temporal wins; large data (>1200) → pretrained wins. HybridMDv6 achieves 100% Happy and 95.6% Fear cross-domain.

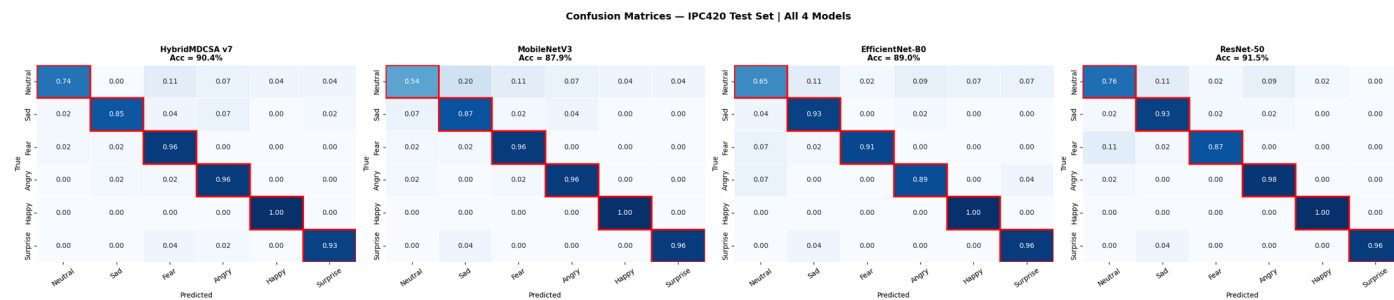


Figure 5 – Confusion matrices: S2 cross-domain Ittefaq→IPC420. HybridMDCSA: 90.4%, ResNet-50: 91.5%.

C. SCENARIOS 3–5 – MULTI-DOMAIN & BOOST TRAINING

MicroDCSA_MD (2.23M, Option D: Replay Buffer + Domain Adapters + Dynamic Loss) achieves 84.52% average across all three simultaneous domains, with 93.00–96.88% full-dataset accuracy—matching ResNet-50 (25.6M) at 13.5× better parameter efficiency. HybridMDv7 (Strategy A+B+C: Taarak Mehta + 25% Ittefaq + 25% IPC420 batch mixing) achieves the best cross-domain average of 69.60%, +3.50 pp over ResNet-50—demonstrating BiGRU temporal features bridge the 52-year cinematographic gap.

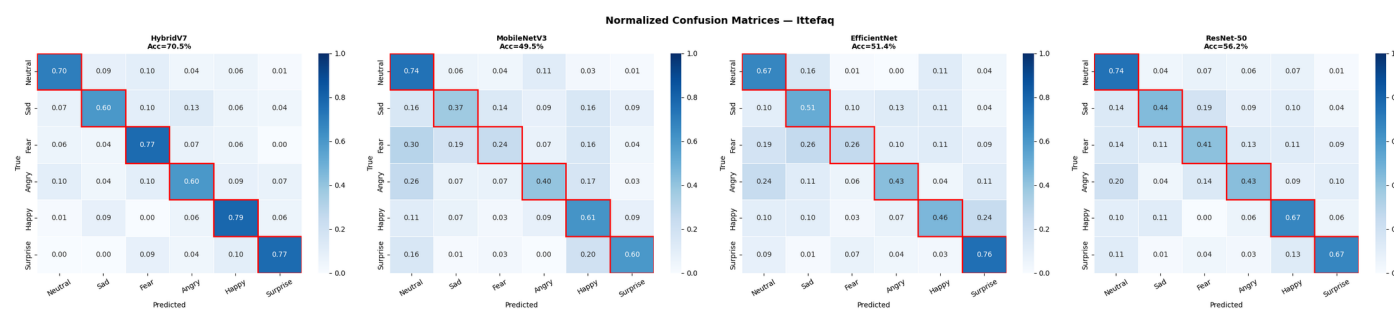


Figure 6 – Confusion matrices: S5 A+B+C boost, Ittefaq cross-domain. HybridMDv7: 70.5% vs ResNet-50: 56.2%.

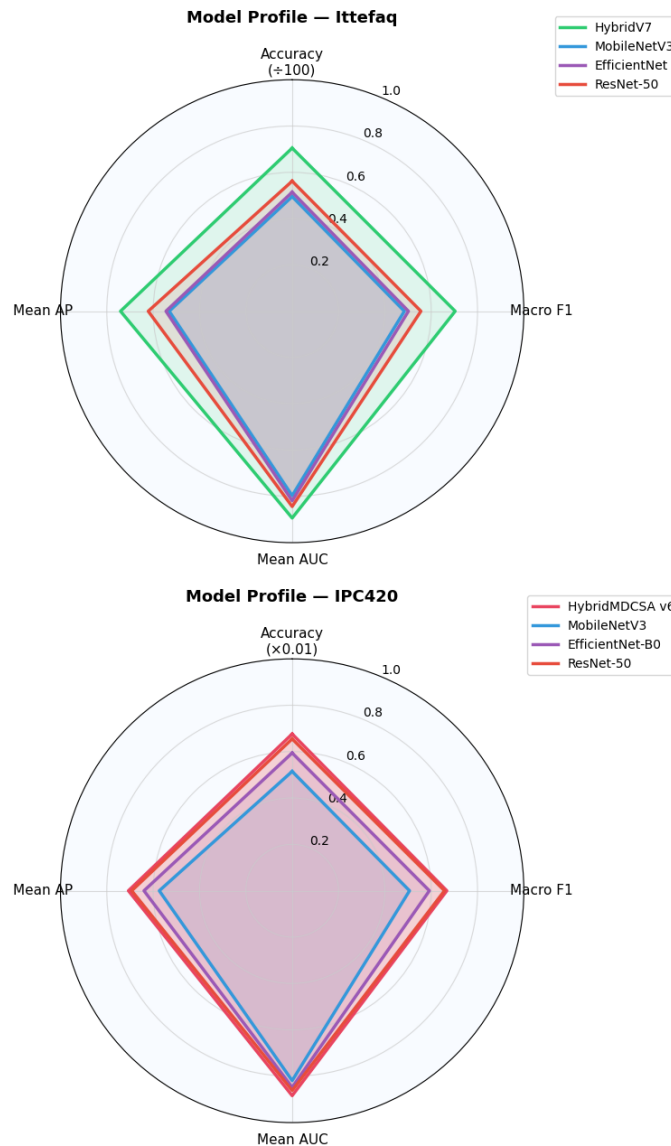


Figure 7 – Radar charts. Left: S5 Ittefaq – HybridMDv7 (green) outperforms all models. Right: S2 IPC420 cross-domain model profiles.

Table 3 – All 5 scenarios summary. ★ = scenario winner.

Scenario	Best Model	Key Result
S1: Single-domain Ittefaq	★ MicroDCSA_v4	74.44% Acc AUC=0.9317 beats ResNet-50 (+3.33pp, 11.9× fewer params)
S2: Ittefaq→IPC420	ResNet-50	91.54% (large data → pretrained ImageNet capacity wins)
S3: Multi-domain (Option D)	★ MicroDCSA_MD	84.52% avg 93–97% full 13.5× efficiency vs ResNet-50
S4: Tarak→All cross-domain	★ HybridMDv6	62.02% cross avg +1.18pp vs ResNet-50



S5: A+B+C Boost ★ HybridMDv7 69.60% cross avg | +3.50pp vs ResNet-50 | bridges 52yr gap

CONCLUSIONS

The Dual-Stream Attention Network (MicroDCSA) delivers robust real-time visual emotion recognition on Indian cinematic group videos across a 52-year temporal span. Three findings are validated: (1) temporal BiGRU features are more domain-invariant than static ImageNet features across colour-space boundaries; (2) data scale determines optimal architecture—temporal models win at small scale (<600), pretrained at large scale (>1200); (3) the 52-year cross-era gap is bridgeable via lightweight mix-replay training. MicroDCSA_v4 achieves 74.44% (+3.33 pp over ResNet-50 at 11.9× fewer parameters); HybridMDv7 achieves 69.60% cross-domain average (+3.50 pp)—providing an accurate, efficient, and culturally-grounded solution for next-generation group emotion recognition.

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REFERENCES

- [1] J. Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection," 2016 IEEE CVPR, pp. 779–788.
- [2] K. Batzner et al., "EfficientAD: Accurate Visual Anomaly Detection at Millisecond-Level Latencies," 2024 IEEE/CVF WACV, pp. 127–137.
- [3] K. Deshpande et al., "Anomaly detection in surveillance videos using transformer based attention model," arXiv:2206.01524, 2022.
- [4] J. Zhao et al., "R1-Omni: Explainable Omni-Multimodal Emotion Recognition with Reinforcing Learning," arXiv:2503.05379, 2025.
- [5] Y. Wu et al., "A Comprehensive Review of Multimodal Emotion Recognition: Techniques, Challenges, and Future Directions," Biomimetics, vol. 10, no. 7, 418, 2025.
- [6] A. Chaudhari et al., "ViT FER: Facial Emotion Recognition with Vision Transformers," Appl. Syst. Innov., vol. 5, no. 4, 80, 2022.
- [7] D. Bhagat et al., "Facial Emotion Recognition (FER) using CNN," Procedia Comp. Sci., vol. 235, pp. 2079–2089, 2024.
- [8] K. Zhang et al., "Real-Time Video Emotion Recognition Based on Reinforcement Learning and Domain Knowledge," IEEE TCSVT, vol. 32, no. 3, pp. 1034–1047, 2022.
- [9] C. Busso et al., "IEMOCAP: Interactive emotional dyadic motion capture database," Proc. 5th LREC, 2008, pp. 3352–3355.



- [10] A. Vaswani et al., "Attention is All You Need," Advances in NeurIPS, vol. 30, 2017, pp. 5998–6008.
- [11] K. Han et al., "GhostNet: More Features from Cheap Operations," Proc. IEEE/CVF CVPR, 2020, pp. 1580–1589.
- [12] X. Wang et al., "Adaptive Dual-Stream Network for Video Emotion Recognition," IEEE Trans. Multimed., vol. 24, pp. 1120–1132, 2022.
- [13] S. Sabir et al., "Time-Distributed CNN-LSTM for Video-Based FER," IEEE Access, vol. 11, 2023.
- [14] M. Tan and Q. V. Le, "EfficientNet: Rethinking Model Scaling for CNNs," in Proc. ICML, 2019.
- [15] K. He et al., "Deep Residual Learning for Image Recognition," in Proc. CVPR, 2016, pp. 770–778.



SAFER SUN PROTECTION THROUGH NON-TRANSITION METAL OXIDE -BASED UV FILTERS

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ABSTRACT

Concerns regarding the photocatalytic activity and associated cytotoxicity of transition metal oxide nanoparticles, such as TiO₂, have driven the search for safer inorganic UV filters. In this study, cerium(III) phosphate (CePO₄)-based nanomaterials were investigated as non-photocatalytic alternatives for sunscreen applications. Pure and composite systems were evaluated for UVB attenuation, photocatalytic activity, cytotoxicity, and phototoxicity using HaCaT cells. Compared to TiO₂, CePO₄-based materials exhibited comparable UV protection with significantly reduced photocatalytic activity. Cytotoxicity and phototoxicity assays confirm high cell viability under both dark and UV conditions. These findings highlight CePO₄ as a promising next-generation UV filter with improved safety and photostability.

Keywords: Sunscreen; Biocompatible; UV filter; CePO₄; Metal oxide, Nanocomposite.

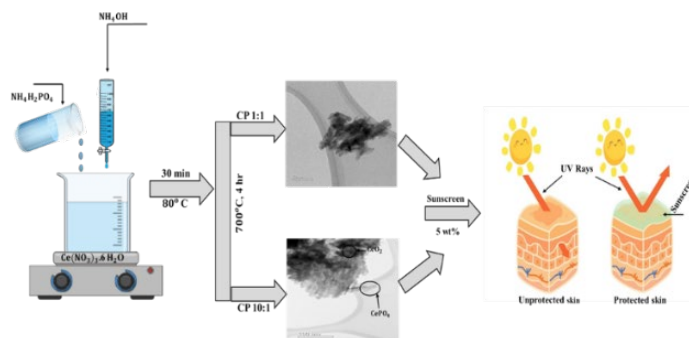


Figure 1: Graphical Abstract

INTRODUCTION

Skin cancer is a growing public health concern, with numerous studies linking ultraviolet (UV) radiation exposure to an increased risk of skin cancers, including melanoma [1]. UV radiation, particularly UVB (280–320 nm), is a potent carcinogen responsible for acute sunburn and, with repeated exposure, melanoma development [2]. Sunscreens typically contain a combination of organic and inorganic compounds that absorb and/or scatter UV radiation, thereby shielding human skin from harmful exposure [3]. However, organic UV filters suffer from photoinstability and may induce



allergic reactions upon UV exposure, making inorganic UV filters—owing to their chemical stability and cost-effectiveness—a preferred alternative [4,5].

To date transition metal-based oxides like TiO₂, ZnO and Fe₂O₃ proven effective as photoprotective materials, with TiO₂ being the most popular UVB blocker in commercial sunscreens [6]. Despite their high UV attenuation efficiency, TiO₂ nanoparticles exhibit strong photocatalytic activity which can lead to the formation of reactive oxygen species (ROS) on the skin surface, posing potential health risks [7]. These concerns highlight the urgent need for non-photocatalytic and biocompatible alternatives to conventional transition metal oxide-based UVB filters.

Cerium phosphate is a polymorphic material that crystallizes in a rhabdophane-type hexagonal structure at low temperatures and a monoclinic phase at higher temperatures, existing in both Ce(III) and Ce(IV) oxidation states [8]. This study presents a comprehensive evaluation of cerium phosphate-based compounds as safer alternatives to commercial TiO₂, focusing on UV protection efficiency, photostability, and biocompatibility.

MATERIALS AND METHODS

CePO₄ nanoparticles and CePO₄-CeO₂ nanocomposite were synthesized via co-precipitation method followed by thermal treatment. Morphology and microstructure were analyzed using scanning electron microscopy (SEM, JEOL JSM-7500FA, 10 kV) and transmission electron microscopy (TEM, JEOL JEM-F200), with elemental composition confirmed by energy-dispersive spectroscopy (EDS, JED-2300 detector). Cytotoxicity and phototoxicity were assessed using human keratinocyte (HaCaT) cells before and after UV exposure.

Non-irradiated in vitro SPF values were calculated using Equation (1) [4]:

$$SPF = \frac{\sum_{400}^{290} E_{\lambda} S_{\lambda}}{\sum_{400}^{290} E_{\lambda} S_{\lambda} T_{\lambda}} \quad (1)$$

RESULTS

Cerium phosphate nanomaterials exhibited strong UVB absorbance and markedly lower photocatalytic activity than TiO₂, mitigating potential oxidative stress during UV exposure (**Figure 2**). At equivalent loading, in vitro SPF measurements showed comparable intrinsic sun protection to TiO₂.

Transmission electron microscopy (TEM) revealed that pristine CePO₄ nanoparticles possessed a rod-like morphology, with diameters ranging from 5–16 nm and lengths between 10–54 nm, yielding an average particle size of 24.99 ± 1.11 nm. Selected area electron diffraction (SAED) patterns confirmed the crystalline monoclinic orthophosphate structure, while STEM-EDS mapping verified uniform



elemental distribution in both pure CePO_4 and $\text{CePO}_4\text{-CeO}_2$ composite systems (**Figure 3**).

Cytotoxicity and phototoxicity (**Figure 4**) assays demonstrated superior biocompatibility of cerium phosphate-based materials compared to rutile TiO_2 , as evidenced by higher HaCaT cell viability and no significant increase in cell death following UV exposure. After 24 h treatment without irradiation, cell viability at 100 mg/L remained high for CePO_4 ($95 \pm 1\%$), $\text{CePO}_4\text{-APTMS}$ ($87 \pm 3\%$) and $\text{CePO}_4\text{-CeO}_2$ ($90 \pm 2\%$) whereas rutile TiO_2 exhibited reduced viability ($81 \pm 2\%$). The low cytotoxicity of CePO_4 is attributed to the extremely low solubility of monazite-type cerium phosphate and the absence of free cerium ion release, which minimizes cellular stress. Under solar irradiation, rutile (TiO_2) nanoparticles showed the highest phototoxicity, with cell viability declining significantly to $69 \pm 1\%$ after 15 min at 100 mg/L. In contrast, CePO_4 and $\text{CePO}_4\text{-CeO}_2$ maintained cell viability above 86% across all tested concentrations and irradiation times, indicating pronounced photoprotective behavior. This effect is primarily attributed to the strong UV-shielding capability of CePO_4 , while the incorporation of CeO_2 , known for its antioxidant properties, may further enhance cellular protection.

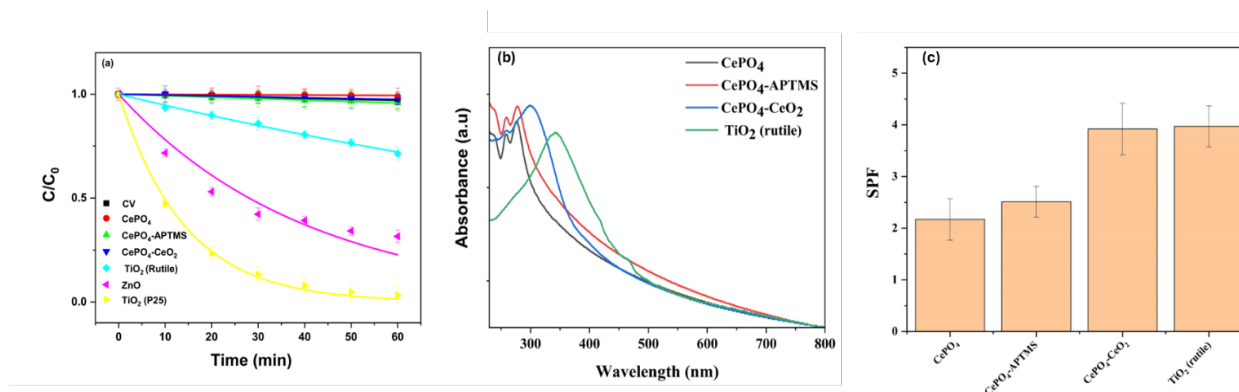


Figure 2 - Comparison of (a) Photocatalysis, (b) UV-vis absorbance and (c) SPF value of the prepared samples with commercial TiO_2 (rutile).

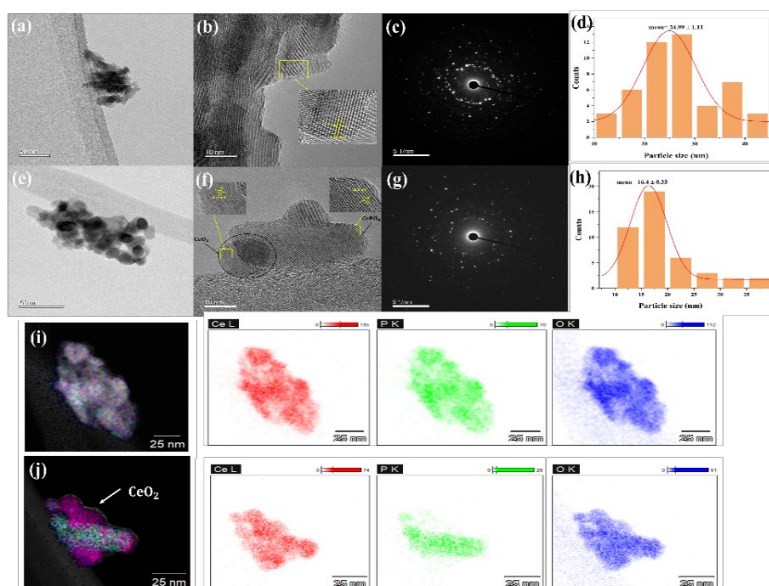


Figure 3 - TEM, HRTEM, SAED, particle size distribution curve and EDS mapping of pure CePO_4 (a-d, i) and $\text{CePO}_4\text{-CeO}_2$ composite (e-h, j) respectively.

Although all materials exhibited dose-dependent reductions in viability, the effect was most pronounced for rutile (TiO_2).

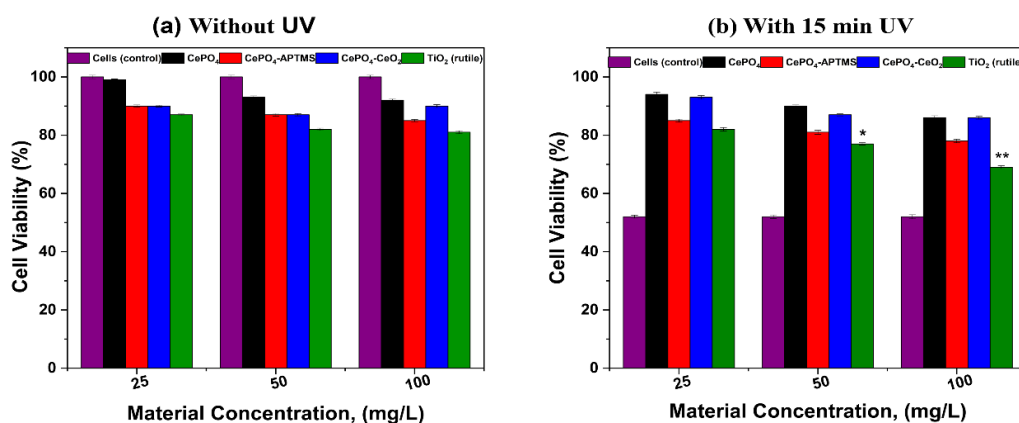


Figure 4 - Average HaCaT cell viability after 24 h incubation with CePO_4 , $\text{CePO}_4\text{-APTMS}$ and $\text{CePO}_4\text{-CeO}_2$, (a) without UV irradiation and (b) after 15 min UV irradiation at an intensity of 6 mW cm^{-2} . Compared with cells (control)* and ** refer to $p < 0.05$ and $p < 0.01$, respectively.



CONCLUSIONS

Overall, CePO₄-based materials demonstrated superior biocompatibility and photoprotective performance compared to TiO₂, highlighting their potential as safer and more effective inorganic UV filters for sunscreen applications.

REFERENCES

- [1] D.S. Rigel, Cutaneous ultraviolet exposure and its relationship to the development of skin cancer, *Journal of the American Academy of Dermatology*, 58 (2008) S129-S132.
- [2] T.V. Torbati, V. Javanbakht, Fabrication of TiO₂/Zn₂TiO₄/Ag nanocomposite for synergic effects of UV radiation protection and antibacterial activity in sunscreen, *Colloids and Surfaces B: Biointerfaces*, 187 (2020) 110652.
- [3] M.A. C. Teixeira, C. Piccirillo, D.M. Tobaldi, R.C. Pullar, J.A. Labrincha, M.O. Ferreira, P.M. L. Castro, M.M. E. Pintado, Effect of preparation and processing conditions on UV absorbing properties of hydroxyapatite-Fe₂O₃ sunscreen, *Materials Science and Engineering: C*, 71 (2017) 141-149.
- [4] M. Chaki Borrás, R. Sluyter, P.J. Barker, K. Konstantinov, S. Bakand, Y₂O₃ decorated TiO₂ nanoparticles: Enhanced UV attenuation and suppressed photocatalytic activity with promise for cosmetic and sunscreen applications, *Journal of Photochemistry and Photobiology B: Biology*, 207 (2020) 111883.
- [5] T.G. Smijs, S. and Pavel, Titanium dioxide and zinc oxide nanoparticles in sunscreens: focus on their safety and effectiveness, *Nanotechnology, Science and Applications*, 4 (2011) 95-112.
- [6] A. Morlando, M. Chaki Borrás, Y. Rehman, S. Bakand, P. Barker, R. Sluyter, K. Konstantinov, Development of CeO₂ nanodot encrusted TiO₂ nanoparticles with reduced photocatalytic activity and increased biocompatibility towards a human keratinocyte cell line, *Journal of Materials Chemistry B*, 8 (2020) 4016-4028.
- [7] S.M. Solaiman, J. Algie, S. Bakand, R. Sluyter, V. Sencadas, M. Lerch, X.-F. Huang, K. Konstantinov, P.J. Barker, Nano-sunscreens – a double-edged sword in protecting consumers from harm: viewing Australian regulatory policies through the lenses of the European Union, *Critical Reviews in Toxicology*, 49 (2019) 122-139.
- [8] T.O. Kozlova, D.N. Vasilyeva, D.A. Kozlov, I.V. Kolesnik, M.A. Teplonogova, I.V. Tronev, E.D. Sheichenko, M.R. Protsenko, D.D. Kolmanovich, O.S. Ivanova, A.E. Baranchikov, V.K. Ivanov, A Comparative Study of Cerium(III) and Cerium(IV) Phosphates for Sunscreens, *Molecules*, 2024.



BARRIERS FOR THE IMPLEMENTATION OF INNOVATION IN BRAZILIAN CIVIL CONSTRUCTION

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ABSTRACT

This study investigates the barriers associated with different types of innovation implementation in the Brazilian construction industry. A systematic review of 100 case studies published between 2015 and 2024 was conducted to classify innovations and identify implementation challenges. The findings reveal significant asymmetries across innovation types. Technological innovations face the highest concentration of obstacles, particularly related to cost/investment, lack of training, resistance to change, and data/systems management. Cost and training deficits emerge as systemic barriers affecting all innovation categories. Managerial innovations are predominantly constrained by cultural resistance and skill gaps, while process innovations encounter comparatively lower barrier intensity. The results indicate that financial and human-capital limitations constitute structural constraints to innovation diffusion in the Brazilian construction context. The study contributes empirical evidence to the debate on innovation implementation in emerging economies, highlighting the need for coordinated institutional and organizational responses.

Keywords: Construction Industry; Innovation; Case Study; Barriers; Challenges; Emerging Economies.

INTRODUCTION

Innovation is widely recognized as a key mechanism to improve efficiency, sustainability, and competitiveness in any industry [1, 2]. In the construction sector, innovation may involve technological solutions, new materials, digital tools such as BIM and AI, process redesign, or managerial practices [3]. However, its implementation remains challenging



due to structural characteristics of the sector, including project fragmentation, cultural resistance, limited technical training, and financial constraints [4, 2].

Although the literature brings examples in mapping innovation initiatives, identifying drivers, and examining performance impacts in the construction industry [2, 3, 4], most studies focus primarily on describing implemented solutions or assessing their outcomes. Less attention has been given to systematically analyzing the barriers faced during implementation, particularly in relation to different innovation categories. This gap is especially relevant in developing countries, where structural and institutional constraints may shape distinct patterns of resistance and resource limitations.

Understanding how barriers vary is therefore essential to advance a more realistic and context-sensitive perspective on innovation adoption in the Brazilian construction sector. In this context, this study aims to analyze how implementation barriers differ across innovation types in the Brazilian construction industry, based on a systematic review of case studies.

MATERIALS AND METHODS

This research utilized a qualitative, exploratory systematic review of case studies. The search was conducted in March 2025 via Google Scholar using the Portuguese string: “(estudo de caso) AND (“construção civil” OR “construtora”) AND (“inovação” OR “inovações”)”. From approximately 500 initial titles, 100 studies were selected on the implementation of innovation across the construction value chain. Only studies published between 2015 and 2024 were considered, focusing on the Brazilian context and necessarily configured as case studies of technologies that were effectively implemented. Data extraction and coding, followed by manual verification, enabled the classification of innovations according to the four-domain model proposed by Wang, Xu, and Liu [3], as well as the identification and categorization of reported implementation barriers. Barrier frequencies were calculated based on the number of studies reporting each category.

The four-domain model structures construction innovation into: (i) Technological Innovation, which encompasses the adoption of new technologies, materials, digital tools (such as BIM), and on-site construction methods; (ii) Process Innovation, related to improvements in workflows, supply chain integration, business models, and interorganizational collaboration; (iii) Managerial Innovation, which includes changes in management practices, waste management, procurement strategies, and project delivery methods; and (iv) Innovation Management, focused on organizational capabilities, knowledge management, innovation mechanisms, and drivers or barriers that influence innovation performance.



RESULTS

Figure 1 illustrates the relationship between innovation categories and reported implementation challenges. Of the 100 studies analyzed, 50 were classified as Technological Innovation, 24 as Managerial Innovation, 15 as Process Innovation, and 11 as Innovation Management. Innovation management initiatives present the lowest reported obstacle levels, with resistance to change standing out as the predominant barrier. Two interpretations are possible: either such practices remain less developed and therefore less exposed to implementation friction, or technological and operational innovations receive greater visibility in the literature, concentrating reported challenges in those domains. This concentration may also reflect the sector's low innovation maturity level, with firms prioritizing immediate technological and operational solutions over structured innovation management practices.

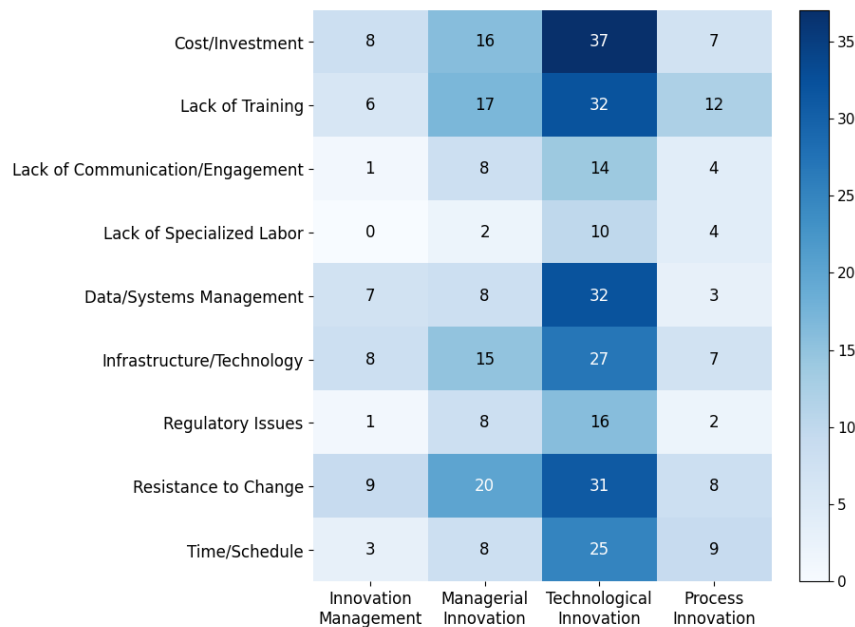


Figure 1 – Relationship Between Innovation Classification and Challenge mentioned. Source: authors.

In this context, technological innovations consistently present higher barrier frequencies across nearly all categories, particularly cost/investment, lack of training, resistance to change, and data/systems management. This pattern suggests that capital-intensive and infrastructure-dependent innovations may amplify structural weaknesses within the sector, especially in contexts characterized by limited financial capacity and uneven digital maturity. Regulatory gaps may further restrict their diffusion by limiting access to financing and formal market acceptance.

In contrast, managerial innovations display a barrier pattern predominantly shaped by resistance to change and lack of training. Although financial constraints are present, organizational and cultural factors appear more decisive in this category.



These findings indicate that initiatives focused on governance, procurement strategies, waste management, and business management depend heavily on internal alignment, leadership engagement, and workforce adaptation, reinforcing the role of organizational culture as a critical implementation variable.

Finally, process innovations present a more concentrated barrier profile, primarily associated with lack of training and time/schedule constraints, while showing moderate exposure to cost-related obstacles. This suggests that workflow improvements, supply chain adjustments, and business model adaptations demand fewer large-scale infrastructural investments but remain strongly conditioned by human-capital development and operational coordination.

Across all innovation types, three barriers stand out as the most recurrent: resistance to change (68% of studies), cost/investment constraints (68%), and lack of training (67%). Resistance to change reflects both managerial reluctance to adopt new approaches and workforce resistance driven by perceived risks, skill gaps, and job security concerns. Cost-related barriers indicate the financial limitations associated with adopting new technologies and processes, particularly in a sector characterized by restricted access to capital. Meanwhile, training deficits highlight gaps in workforce qualification, limiting the effective implementation and scaling of innovation. Together, these factors indicate that financial and human-capital limitations are not isolated difficulties but systemic constraints shaping the innovation landscape in the Brazilian construction industry.

CONCLUSIONS

The findings demonstrate that implementation barriers vary significantly according to innovation type. Technological innovation is disproportionately constrained by financial, infrastructural, and digital limitations, whereas managerial initiatives are primarily challenged by cultural resistance and workforce qualification gaps. Process innovations and Innovation Management are represented in a smaller number of studies, which limits direct comparison of overall barrier intensity.

The recurring presence of cost and training barriers across all innovation categories suggests that innovation challenges in the Brazilian construction industry are structural rather than incidental. Without addressing financial capacity and human-capital development, innovation efforts are likely to remain fragmented and incremental.

By empirically mapping these barriers, this study contributes to the understanding of innovation implementation dynamics in emerging economies and underscores the need for integrated strategies that combine technological investment with organizational and institutional strengthening. These findings reinforce that innovation policy in emerging economies must address systemic capacity constraints rather than focusing exclusively on technological diffusion.



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The authors used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] McKinsey Global Institute, "Reinventing Construction: A Route to Higher Productivity," 2017.
- [2] S. I. Egwunatum e J. C. Oboreh, "Factors Limiting Knowledge Management among Construction Small and Medium Enterprises," *Journal of Engineering, Project, and Production Management*, vol. 12, nº 1, pp. 25-38, 2022.
- [3] N. Wang, Z. Xu e Z. Liu, "Innovation in the construction sector: Bibliometric analysis and research agenda," *Journal of Engineering and Technology Management*, vol. 68, p. 14, 2023.
- [4] F. Albuquerque, A. S. Torres e F. T. Berssaneti, "Lean product development and agile project management in the construction industry," *Revista de Gestão*, vol. 27, nº 2, pp. 135-151, 2020.



ASSESSMENT OF CONSTRUCTION INNOVATION ECOSYSTEMS: A SCOPING REVIEW

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ABSTRACT

The of innovation ecosystems in the construction industry constitutes a methodological challenge due to sector fragmentation, the diversity of stakeholders, and the dependence on institutional and regional contexts. This study aims to map and analyze the approaches used to assess the maturity of these ecosystems, with a view to adaptation to the Brazilian context. A scoping review was conducted following the PRISMA-ScR protocol, with searches carried out in the Scopus, Web of Science, and SciELO databases. After the selection stages, 10 studies comprised the final sample. The results reveal high heterogeneity in objectives, methods, and indicators, with a predominance of composite indices, social network analyses, and quantitative metrics, as well as a strong geographical concentration of research in China. A limited incorporation of qualitative dimensions related to governance and collaboration was observed. We concluded that there are no universally applicable models, and methodological adaptations are therefore necessary.

Keywords: Innovation ecosystem; Performance assessment; Maturity indicators; Construction industry.

INTRODUCTION

Innovation is understood as the implementation of new products, processes, or methods capable of generating economic and social value [1]. It thus plays a central role in economic development and organizational competitiveness. This phenomenon depends on interactions among multiple actors, often organized according to the quadruple helix logic, involving industry, government, universities, and society [2]. These interactions configure innovation ecosystems, dynamic environments characterized by knowledge sharing and the collective generation of value [3],[4].

In the construction industry, innovation progresses at a slower pace compared to other industrial sectors, due to productive fragmentation, low integration among agents, and limited investment in research and development [5]. The assessment of innovation ecosystems in this context is particularly complex, as it involves interdependent technological, organizational, and institutional dimensions [6]. Analyses often prioritize quantitative indicators that are easy to measure, capturing



only tangible outcomes while neglecting essential qualitative factors related to governance and collaboration [7].

In this scenario, this study aims to identify how innovation ecosystems in the construction industry have been evaluated globally, with a view to methodological adaptation to the Brazilian context.

METHODOLOGY

The study is characterized as a scoping review aimed at mapping approaches for assessing the maturity of innovation ecosystems in the construction industry. The review followed the guidelines of the PRISMA-ScR protocol, which is suitable for emerging and multidisciplinary topics in which there is not yet a consolidated methodological consensus.

Searches were conducted in the Scopus, Web of Science, and SciELO databases, without temporal restriction, considering publications in English and Portuguese. Strategies combining terms related to innovation ecosystems, assessment, metrics, and the construction industry were used. After duplicate removal, studies were screened based on titles and abstracts according to predefined eligibility criteria, including explicit focus on innovation ecosystems, application of maturity assessment approaches, and relevance to the construction sector. Seventeen studies were selected for full-text review, resulting in 10 articles in the final sample.

Data extraction was carried out using structured spreadsheets, covering variables such as objectives, geographical context, methods, indicators used, and reported challenges. The synthesis was performed through descriptive analysis and conceptual groupings.

RESULTS

CHARACTERIZATION OF THE STUDIES

The analyzed studies present high methodological and thematic heterogeneity, reflecting the multidimensional nature of innovation ecosystems. A predominance of research conducted in China is observed, along with an increase in publications from 2020 onward, indicating a still emerging field. The analyses cover different subareas, including management, digital technologies, materials, and broad sectoral assessments.

The selected studies focus on four categories in the construction sector: general construction (2); management and organization (2); technologies in construction (5); and materials and components (1). Figure 1 presents the temporal distribution and countries associated with the selected publications. In total, the review covered 10 analytical subunits, including: Fang et al. [8]; Chen et al. [9]; Ivanova e Belikova [10];



Xue et al. [11]; Yang, Wu and Zheng [12]; Zhang et al. [13]; Erikshammar, Gull and Stehn [14]; Liu et al. [15]; Wu, Li and Teng [16].

INDICATORS AND ASSESSMENT METHODS

The review identified a broad set of indicators organized into five main dimensions:

- Social network structure (e.g., centrality, density, and network diameter);
- Resource allocation (e.g., R&D expenditure as a percentage of GDP and firm-level R&D financial indicators);
- Innovation output (e.g., number of registered patents and high-tech firms);
- Human capital (e.g., proportion of R&D personnel relative to total employees and number of qualified professionals per capita);
- Technological maturity (e.g., BIM adoption rates in projects and firms' level of digitalization).

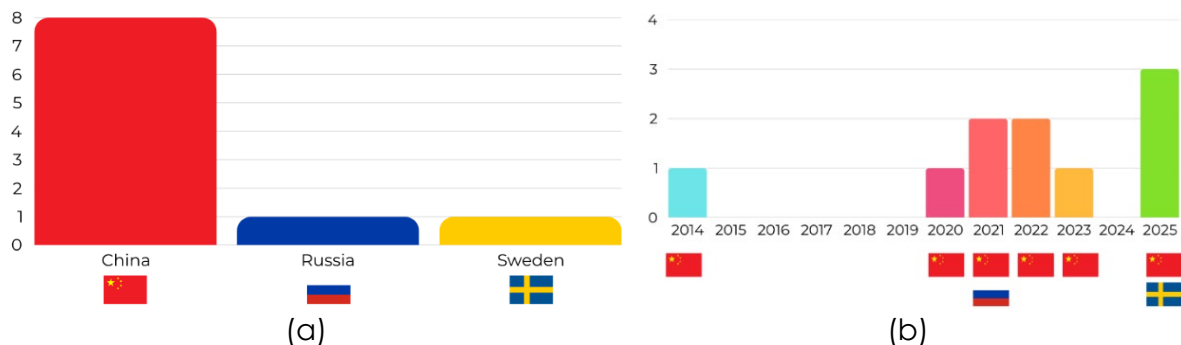


Figure 1 - Bibliometrics: (a) temporal evolution and (b) countries of publication.

Quantitative metrics predominate, whereas qualitative indicators (particularly those related to governance and innovation culture) are less frequent. Most indicators exhibit cross-cutting relevance across different thematic axes, especially those associated with network analysis and resource allocation. In contrast, highly sector-specific metrics (such as BIM applications in construction) are confined to thematic categories.

Methodological operationalization depends largely on data availability, relying on secondary governmental databases, firm-level information, or primary data collection. Consequently, the selection and measurement of indicators tend to be context-dependent, reflecting disparities in data transparency, institutional maturity, and the degree of ecosystem consolidation across different regional settings. The most frequently employed methods include social network analysis, multicriteria techniques, statistical modeling, and composite index construction. The limited emergence of new theoretical models suggests that the field remains in a stage of methodological consolidation, making the definition of a minimum set of common indicators an essential step toward advancing both theoretical development and the practical assessment of innovation ecosystems in the construction sector.



CONCLUSIONS

The review shows that there is no universal model for assessing innovation ecosystems in the construction industry, with predominant approaches combining quantitative indicators, network analyses, and multicriteria methods. The results reinforce the need to integrate technological, organizational, and institutional dimensions for more robust diagnoses.

Methodological adaptation should consider data limitations, regional heterogeneity, and structural characteristics of the sector. The combination of social network analyses with multicriteria methods emerges as a promising alternative for the development of applicable maturity indices. The study contributes to the systematization of a still fragmented field and provides support for the development of assessment models aligned with national specificities.

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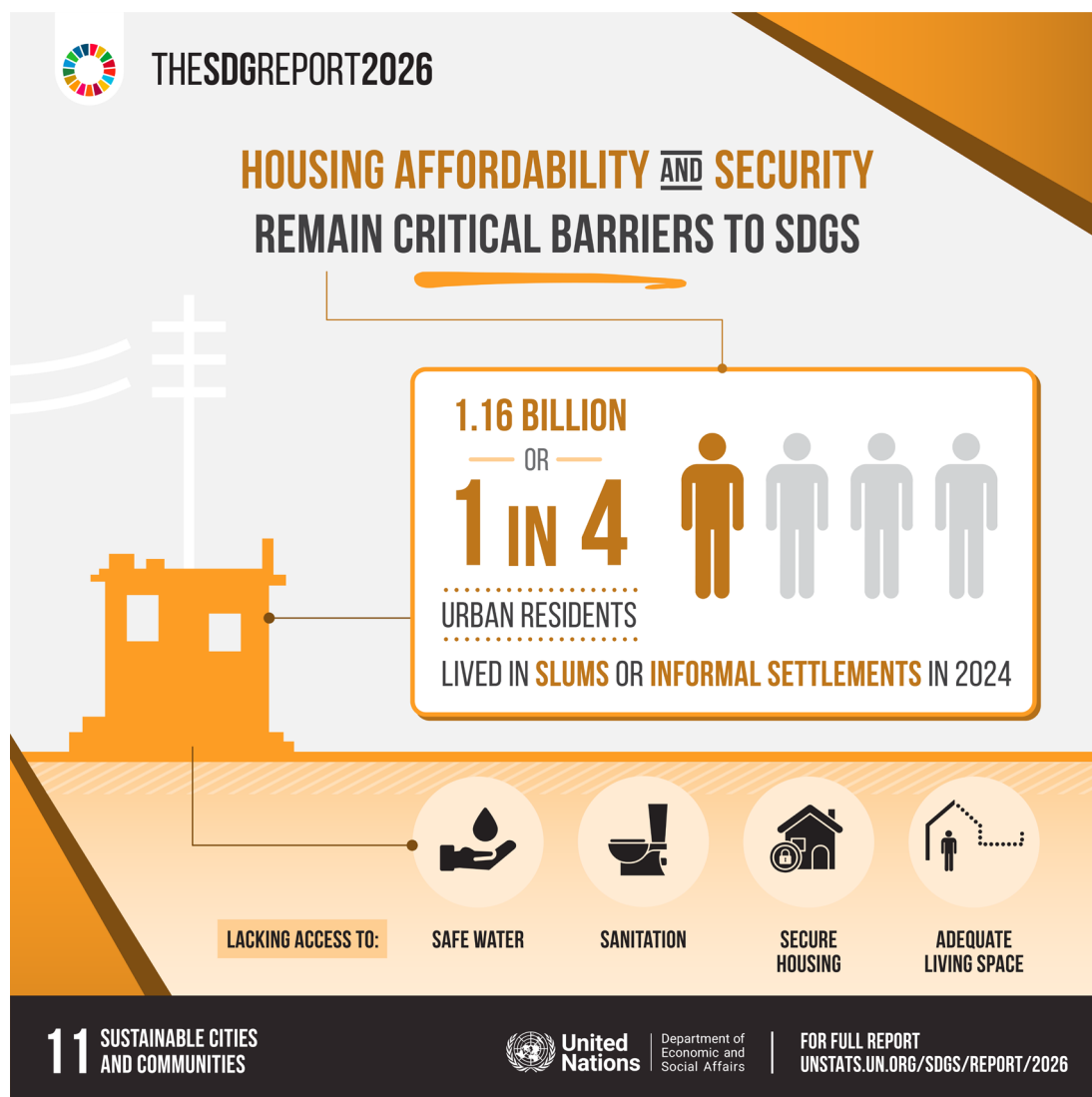
REFERENCES

- [1] T. Myjak, "Theoretical and practical dilemmas of defining the concept of innovation," *Management and Administration Journal*, vol. 61, n° 134, 2024.
- [2] J. Kolehmainen, J. Irvine, L. Stewart, Z. Karacsonyi, T. Szabó, J. Alarinta e A. Norberg, "Quadruple Helix, Innovation and the Knowledge-Based Development: Lessons from Remote, Rural and Less-Favoured Regions," *Journal of the Knowledge Economy*, vol. 7, pp. 23-42, 2015.
- [3] E. Torling e P. C. Resende Junior, "Uma Discussão sobre o Papel das Universidades nos Ecossistemas de Inovação," em TMS ALGARVE 2018 – Tourism & Management Studies International Conference TMS ALGARVE 2018 – Tourism & Management Studies International Conference, 2018.
- [4] R. Adner, "Match Your Innovation Strategy to Your Innovation Ecosystem," *Harvard Business Review*, 2006.
- [5] Weissmann e J. Watanabe, "Research on Innovative Practices of Civil Engineering Construction," *International Academic Journal of Innovative Research*, vol. 10, n° 4, pp. 25-30, 2023.



- [6] Y. Xu e Y. Li, "A bibliometric review of innovation ecosystem," *Systems Research and Behavioral Science*, vol. 42, n° 4, pp. 978-995, 2024.
- [7] L. Silva e M. Hoffmann, "Program assessment in innovation ecosystems," *Revista Pensamento Contemporâneo em Administração*, vol. 14, n° 03, 2020.
- [8] C. Fang, H. Ma, Z. Wang e G. Li, "The sustainable development of innovative cities in China: Comprehensive assessment and future configuration," *Journal of Geographical Sciences*, vol. 24, pp. 1095-1114, 24 10 2014.
- [9] H. Chen, Z. Jin, Q. Su e G. Yue, "The roles of captains in megaproject innovation ecosystems: the case of the Hong Kong-Zhuhai-Macau Bridge," *Engineering, Construction and Architectural Management*, vol. 28 (3), pp. 662-680, 06 02 2020.
- [10] O. Ivanova e S. Belikova, "Assessment of the innovation ecosystem reproductive potential," em IV International Scientific Conference "Construction and Architecture: Theory and Practice of Innovative Development", Rostov-on-Don, 2021.
- [11] X. Xue, X. Tan, Q. Huang, H. Zhu e J. Chen, "Exploring the Innovation Path of the Digital Construction Industry Using Mixed Methods," *Buildings*, vol. 12 (11), 01 11 2022.
- [12] X. Yang, D. Wu e Z. Zheng, "Research on the Relationship between Construction 4.0 and Construction Firm's Performance: Based on the Mediating Role of Technological Innovation Capability," *Mathematical Problems in Engineering*, vol. 2022 (1), 25 08 2022.
- [13] R. Zhang, T. Chen, Y. Zhang e Z. Wang, "Exploring differences in level of construction innovation: an empirical analysis in China," *Environmental Science and Pollution Research*, vol. 30, pp. 48179-48200, 08 02 2023.
- [14] J. Erikshammar, A. Gull e L. Stehn, "Innovation ecosystems beyond construction projects - a case study of Swedish cross laminated timber building networks," *Wood Material Science & Engineering*, vol. 20 (5), pp. 968-980, 15 07 2024.
- [15] H. Liu, H. Zheng, Q. Ju, M. J. Skibniewski e M. Wang, "Temporal-Spatial Evolution of BIM-Based Collaborative Innovation Network: Evidence from Patents in China's Construction Industry," *Journal of Management in Engineering*, vol. 41 (5), 13 06 2025.
- [16] J. Wu, L. Li e B. Teng, "Research on synergistic development paths of intelligent construction and construction industrialization- A case study of Shenyang, China," *Journal of Building Engineering*, 15 05 2025.

GOAL 11: MAKE CITIES AND HUMAN SETTLEMENTS INCLUSIVE, SAFE, RESILIENT AND SUSTAINABLE



Source: UN's The Sustainable Development Goals Report 2026



IS “SUSTAINABLE” CONSTRUCTION AND DEMOLITION WASTE REUSE IN BRAZIL A MEASURED OUTCOME OR JUST A LABEL?

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ABSTRACT

This study reviews Brazilian scholarly publications from the last decade on the sustainable reuse of construction and demolition waste (CDW) in building construction, auditing how sustainability is evaluated. A systematic screening of CAPES Periódicos (2016-2025) identified 240 records, with 20 applied experimental studies retained. Results show growing interest after 2021 and a strong technical emphasis on aggregate substitution, with promising mechanical performance but recurring challenges related to porosity and water absorption. Sustainability is mostly framed through environmental arguments, with limited integration of economic and social indicators. The review highlights the need for standardized characterization, multidimensional metrics, and policy aligned frameworks to support circular economy implementation in Brazil.

Keywords: systematic literature review; circular economy; recycled aggregates; material recycling.

INTRODUCTION

The construction sector is a major global consumer of natural resources and energy and a significant generator of solid waste [1]. In Brazil, construction and demolition waste (CDW) includes fragments from construction, renovation, and demolition activities [2]. Although national evidence indicates that about 61% of construction waste mass is potentially reusable or recyclable, only around 10% is actually recycled, revealing a persistent gap between potential and practice [3]. This mismatch contributes to environmental and social impacts such as improper disposal, drainage obstruction, and public health risks [4]. Sustainability, however, extends beyond environmental aspects, encompassing economic and social pillars as well [5]. While Brazilian research increasingly proposes technical applications for CDW in building materials, it remains unclear whether sustainability is being assessed through



integrated indicators across these pillars or merely cited as a motivation. Therefore, this study reviews scholarly publications from the last decade on the sustainable reuse of CDW in building construction, critically examining how sustainability is evaluated in studies produced, published, and disseminated in Brazil.

METHODS

The literature review was conducted on 4 August 2025, covering Brazilian publications from 2016 to 2025. The search was performed through the Brazilian CAPES Periódicos Portal (as it indexes scholarly publications disseminated in Brazil), focusing on studies addressing the reuse of construction and demolition waste (CDW) as a sustainable alternative in the building sector. The search strings were applied in Portuguese using: *(resíduos da construção civil OR resíduos da construção e demolição OR "RCD") AND (reutilização OR reaproveitamento OR reciclagem)*, which means *(construction waste OR construction and demolition waste OR "CDW") AND (reuse OR recovery OR recycling)*.

The screening process followed the systematic workflow proposed by Ferenhof et al. [6]. Initially, 240 documents were identified. Studies were selected through successive stages of title, abstract, and full-text reading. To be included, papers needed to (i) address CDW incorporation within the construction/building context, (ii) consist of applied experimental research rather than review studies, and (iii) report laboratory investigations proposing new products or reuse applications for CDW. After the final screening, 20 studies were retained.

RESULTS

Figure 1 summarizes Brazilian scholarly outputs on CDW reuse in buildings from 2016 to 2024. Publication volume is skewed toward the later years, with 25% of the studies published in 2016-2020 versus 75% in 2021-2024. Although 2025 publications existed at the time of the search, none met the refinement and inclusion criteria adopted in this review. Studies are regionally concentrated in the Southeast (35%) and South (20%), consistent with Brazil's most populous and industrialized areas, where construction activity and CDW generation are higher. Most papers treat CDW generically (60%), with limited compositional characterization, while a smaller share examines more specific CDW streams or modified mixes.

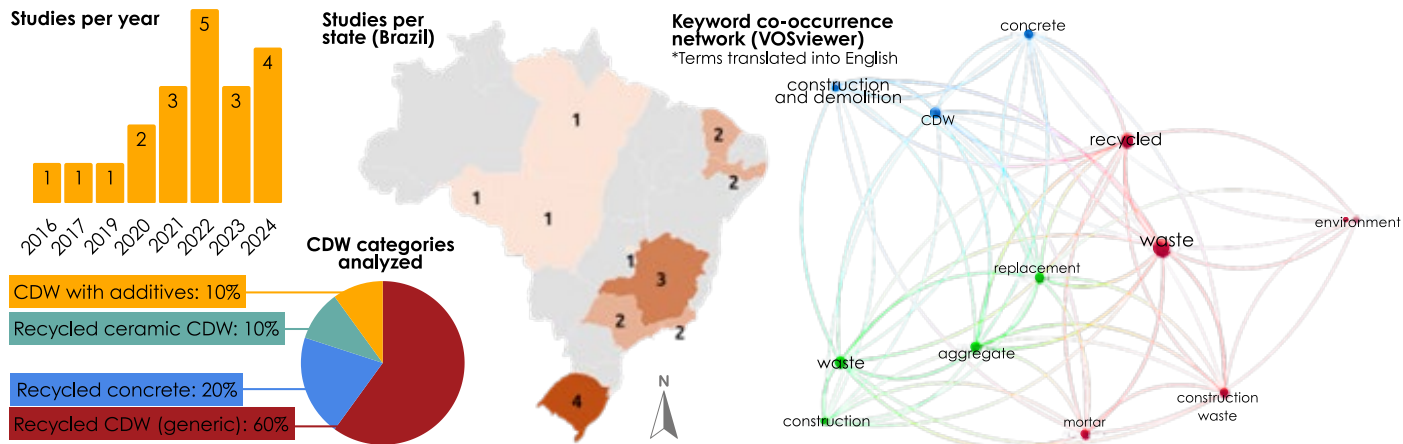


Figure 1 – Brazilian CDW studies overview: trends, locations, categories, and keyword network. Source: authors.

The keyword co-occurrence network reinforces a predominantly engineering and materials oriented discourse, reflecting that the Brazilian literature has primarily advanced through technical feasibility assessments. Overall, the reviewed studies converge in showing that CDW can achieve promising mechanical performance under controlled replacement limits and mix adjustments. For instance, concrete with recycled coarse aggregates has been reported to reach strengths comparable to conventional mixes, with 50% replacement achieving 28.36 MPa versus 28.37 MPa in the reference material [7]. At the same time, recurring challenges remain, particularly the higher porosity and water absorption of recycled aggregates, which may require additional cement or stricter quality control, constraining broader standardization and replication [8].

Within this predominantly technical framing, “environment” appears only peripherally as the sole explicit sustainability related term in the keyword co-occurrence network (Figure 1), suggesting that sustainability is mainly interpreted through an environmental lens rather than evaluated through integrated environmental, economic, and social pillars. Full-text screening reinforces this mismatch, since many papers label the approach as “sustainable” while reporting limited indicators beyond mechanical performance and material substitution. Consistent with the broader context of high resource use and waste generation in construction [1] and the recycling gap highlighted by national data [3], the Brazilian literature reviewed here still tends to treat sustainability as a rationale, not as a measured outcome.

From an environmental perspective, most studies highlight reduced landfill disposal and lower demand for virgin materials [9], yet rarely quantify avoided emissions, processing impacts, or logistical burdens, even though irregular disposal continues to generate significant environmental and public health risks [4]. Economically, cost savings are frequently suggested but seldom supported by objective indicators such as cost-benefit ratios or net savings, despite evidence that recycled aggregates may



increase water absorption and cement demand, directly affecting mixture costs [8]. The social dimension is even less developed, usually limited to generic references to job creation, without measurable assessments of social impact or equity, although sustainability inherently requires the integration of environmental protection, social justice, and economic development [5].

These gaps have clear technical and strategic implications: without standardized CDW characterization, durability evaluation, and integrated sustainability metrics, reuse practices remain small-scale and vulnerable to short-term decision-making, falling short of the circular economy framework embedded in Brazilian regulation [10]. Moreover, durability related evidence remains scarce, since few studies assess long term performance under aggressive exposure or service life conditions, which is essential for sustainability claims in real buildings. Future research should therefore incorporate quantitative environmental assessment (e.g., life cycle analysis), robust economic evaluation, verifiable social indicators, and clearer reporting of waste composition, in order to move from demonstrated technical feasibility toward a truly comprehensive sustainability strategy capable of supporting public policies, fiscal incentives, and industrial upscaling of CDW reuse in Brazil [9].

CONCLUSIONS

By mapping what circulates in Brazilian academia on the “sustainable” reuse of CDW in building construction, this review showed that research still prioritizes technical feasibility, while sustainability assessment remains mostly environmental and poorly integrated with economic and social evidence. Consequently, sustainability is often claimed rather than demonstrated through comparable metrics, durability, or life cycle reporting. Future studies should generate indicators that support standards and ranking of alternatives, and public policy should tie permitting, incentives, and procurement to verified performance. Establishing reference datasets and certification for recycled CDW streams, and embedding life cycle criteria in public housing procurement, are key steps. Further reviews should also expand this scope to include international publications by Brazilian scholars and broader Latin American and global panoramas, enabling benchmarking across contexts. Ultimately, reviews of this nature are essential to transform academic discourse into auditable evidence that can guide circular economy policies and scalable implementation.

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REFERENCES

- [1] F. Krausmann, C. Lauk, W. Haas e D. Wiedenhofer, "From resource extraction," em *Global Environ.*, 1 ed., 2018, pp. 131-140.
- [2] CONAMA, "Conselho Nacional do Meio Ambiente," 2002.
- [3] SINIR, "Sistema Nacional de Informações Sobre a Gestão de Resíduos Sólidos," 2019. [Online]. Available: <https://sinir.gov.br/relatorios/nacional/>. [Acesso em 20 6 2025].
- [4] R. Nogueira, "Eu Ambientalista," 2013. [Online]. Available: <https://euambientalista.blogspot.com/2013/02/recuperacao-de-areas-degradadas-pela.html>. [Acesso em 06 Junho 2025].
- [5] I. Mikhailova, "SUSTENTABILIDADE: EVOLUÇÃO DOS CONCEITOS TEÓRICOS E OS PROBLEMAS DA MENSURAÇÃO PRÁTICA," *Rev. Econ. Desenv.*, nº 16, 2004.
- [6] H. A. Ferenhof e R. F. Fernandes, "Desmistificando uma revisão de literatura como base para redação científica: Método SSF," *Revista ACB*, vol. 21, pp. 550-563, 2016.
- [7] L. Bernardon, J. L. Waechter, R. d. A. Silva, R. T. Lermen e J. F. Novaes, "Avaliação da substituição total de areia natural por RCC em argamassa de assentamento," *Revista Arq IMED*, pp. 173-192, Dezembro 2020.
- [8] P. M. Borges, E. Rigo, E. Possan e J. J. d. O. Andrade, "Captura de carbono em argamassas produzidas com agregado reciclado de resíduo de construção e demolição," *ConReSol*, pp. 1-13, 2023.
- [9] ABRECON, "PESQUISA SETORIAL ABRECON," São Paulo, 2020.
- [10] PNRS, "Política Nacional de Resíduos Sólidos," em LEI Nº 12.305, 2010.



INVEST EARLY OR PAY THE ELECTRICITY BILL? FINANCIAL AND ENVIRONMENTAL TRADE-OFFS OF WALL SYSTEMS IN BRAZIL

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ABSTRACT

This study evaluates the economic and environmental payback between construction costs and electricity bills in low-income housing. A 40 m² house was modeled across three Brazilian climates (Canela-cold, Brasília-mild, and Petrolina-warm), comparing cast-in-place concrete walls (CW) and load-bearing concrete masonry units (CMU). EnergyPlus simulations were combined with national datasets to quantify upfront costs, embodied CO₂, and operational thermal performance. CW consistently reduced initial costs (~55%), while CMU reduced embodied CO₂ (~47%). Thermal performance was climate-sensitive: CW lowered Thermal Load (TL) by ~30% in Canela, whereas CMU reduced TL by ~45% in Brasília and ~57% in Petrolina. In warmer climates, operational savings yielded financial paybacks of 14.1 years (Brasília) and 4.6 years (Petrolina), with immediate carbon advantages. The findings support climate-adapted, performance-based social housing policies that integrate affordability and carbon criteria.

Keywords: energy efficiency; environmental impact; concrete wall; CMU; life cycle assessment.

INTRODUCTION

The construction sector has environmental impacts due to high resource and energy use and linked greenhouse gas emissions [1] making low-carbon materials and improved envelope thermal performance key mitigation solutions. Because HVAC systems often forms a major share of building energy demand, envelope upgrades can reduce HVAC loads, cutting operating costs and the total environmental footprint.

In Brazil, wall systems for low-income housing schemes typically use load-bearing concrete masonry units (CMU) and cast-in-place concrete walls (CW). Although CWs may show lower kgCO₂ in some inventories, this varies and rests on key arrangements (total material volume, cement content/additions, and finishing layers/mortar) [2]. Thermal behavior also differs: the CMUs hollow blocks add resistance via air cavities, while CWs offer more thermal mass and, consequently, thermal inertia [3].

In this scenario, the present study combines climate variability and regional costs to estimate the payback of these systems relative to their thermal efficiency. For this purpose, we assess CMU and cast-in-place CWs in a dwelling across three Brazilian cities, linking national databases for upfront cost and embodied CO₂ with energy simulations to quantify cost, thermal, and CO₂ outcomes, and to quantify the trade-off between upfront investment and long-term operational savings.

METHODS

This study combines thermo-energy simulations with cost and CO₂ assessments to compare two wall systems in a 40 m² apartment located in three Brazilian climates: Canela (cold), Brasília (mild), and Petrolina (warm). The reference model (Figure 1) represents a unit in a four-story multifamily building (four units per floor) with living room, kitchen, bathroom, and two bedrooms. Two commonly used wall systems were analyzed (Table 1): (1) cast-in-place concrete walls (CW) and (2) load-bearing concrete masonry units (CMU).



Figure 1 – Assessed building. Source: authors.

Table 1 – Systems' thermal transmittance (U) and thermal capacity (TC). Source: authors.

System	Description (indoors → outdoors)	U (W/(m ² ·K))	TC (kJ/(m ² ·K))
Concrete Wall (CW)	Concrete wall (15cm)	3.6	300.0
Masonry Wall (CMU)	Cement mortar plaster (2.5cm) + CMU ((14×19×39)cm) with 1 cm bricklaying mortar joint (vertical and horizontal) cm + render (2.5cm)	2.2	174.7



Roof (both walls)	Gypsum ceiling (1.5cm) + air gap (20cm) + concrete slab (10cm) + air gap (20cm) + fibercement tile (0,6cm)	2.1	233
Floor (both walls)	Porcelain tile (1cm) + adhesive mortar (0,5cm) + cement subfloor (3cm) + concrete slab (10cm)	2.7	174.7

Thermal performance was assessed using the Thermal Load (TL) method to estimate the primary HVAC energy demand, following NBR 15575 [4]. Lower TL values indicate better thermal performance. TL was converted to operating cost and CO₂ emissions using local electricity tariffs (Canela: R\$ 0.822/kWh; Brasília: R\$ 0.827/kWh; Petrolina: R\$ 0.769/kWh [5]) and Brazil's average emission factor for Feb. 2025 (28.9 kg CO₂/MWh) [6]. Simulations were run in EnergyPlus v22.1. Costs were obtained from the Brazilian National System for Construction Cost and Index Research (SINAPI) monthly spreadsheets for December 2025 at the state level. Material CO₂ emissions were sourced from the Brazilian Construction Environmental Performance Information System (Sidac), which reports cradle-to-gate manufacturing impacts for Brazil without state-level disaggregation.

RESULTS

Table 2 shows that CW consistently has ~55% lower initial cost than CMU across all cities, while CMU reduces embodied CO₂ by ~47%. Thus, the trade-off is clear: CW minimizes upfront expenditure, whereas CMU lowers manufacturing emissions. Thermal performance, however, is climate-dependent. In Canela (cold), CW also reduces TL by ~30%, becoming dominant with instant financial payback. Yet, because CW has higher embodied CO₂, its carbon payback reaches 52.1 years. Considering that residential buildings are typically designed for ~50 years of service life, this suggests that embodied differences may only be offset near the end of the building's lifespan in colder climates. In Brasília (mild), CMU lowers TL by ~45%, yielding a 14.1-year financial payback and instant carbon payback. In Petrolina (warm), TL reductions reach ~57%, shortening financial payback to 4.6 years, also with instant carbon advantage. In hot climates, operational savings rapidly compensate higher investments and reinforce environmental gains.

Table 2 – Results for each assessed system, criterion, and city. Source: authors.

City	Wall sys.	R\$/m ² (1)	kgCO ₂ /m ² (1)	R\$ (2)	kgCO ₂ (2)	TL (kWh/y ear)	TL (R\$/year)	TL (kgCO ₂ / year)	R\$ payback	CO ₂ payback
Canela (cold)	CW	107.3	38.0	11050.9	3914.0	2782.3	2287.0	80.4	instant	52.1 years
	CMU	235.2	20.2	24226.6	2080.6	4000.3	3308.2	115.6		
Brasília (mild)	CW	104.7	38.0	10781.5	3914.0	3058.1	2529.1	88.4	14.1 years	instant
	CMU	259.1	20.2	26682.4	2080.6	1696.3	1402.9	49.0		
Petrolina	CW	99.6	38.0	10258.2	3914.0	8264.0	6355.1	238.8	4.6 years	instant



(warm)	CMU	261.4	20.2	26926.9	2080.6	3544.6	2725.8	102.4
(1) Values per m ² of wall.								Best-performing system
(2) Values considering the total area of walls (103 m ²).								Worst-performing system

Overall, the “best” system depends on climate and life-cycle perspective. In Brazil, where CW housing is widespread, post-occupancy studies report frequent thermal discomfort with implications for vulnerable groups [7]. Therefore, climate-adapted envelope selection is essential to balance affordability, emissions, and long-term adequacy within a 50-year building horizon. Thus, low initial impacts may not ensure long-term adequacy when thermal inefficiencies increase cooling demand or intensify heat stress. In very hot Brazilian climates such as Petrolina, passive strategies and improved envelope performance can mitigate overheating and reduce HVAC dependence, although mechanical cooling may still be required during peak periods. From a sustainability and equity perspective, climate-adapted envelope choices can lower emissions and household energy burdens, supporting more resilient and socially responsive housing policies.

CONCLUSIONS

This study assessed the cost, embodied CO₂, and thermal performance of CW and CMU systems in a small-scale dwelling across three Brazilian climates. CW consistently reduced upfront costs (~55% lower), while CMU reduced embodied CO₂ (~47%) and markedly lowered HVAC thermal loads in warmer locations (~45–57% TL reduction), yielding financial paybacks of 14.1 years in Brasília and 4.6 years in Petrolina, with instant carbon advantages in both cases. In Canela, CW remained economically dominant but required a long carbon payback (52.1 years). These results indicate that envelope selection should be climate-sensitive, balancing upfront burdens against long-term operational performance within a typical 50-year building lifespan. Policy-wise, the findings support performance-based social housing guidelines that integrate regional climate, affordability, equity, and carbon criteria. Limitations include the single dwelling typology, two wall systems, and three cities; future research should expand to additional regions, building types, envelope components, and future climate scenarios. Overall, the study provides an integrated economic–environmental–thermal framework to guide more resilient, equitable, and low-carbon envelope decisions in Brazil.

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edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] C. d. M. N. Lopes, V. F. Mendes, D. R. Garcia e J. C. Mendes, "Residues in cement-based composites: Occurrence mapping in Brazil," *Case Stud Constr Mater*, vol. 18, p. e01763, 2023.
- [2] V. F. Mendes, P. E. Arcanjo, M. P. C. Tavares e J. M. Mendes, "Balancing cost, thermal performance, and environmental impact: a study on materials for masonry systems in Brazil," *ENARC+*, vol. 9, pp. 1-6, 2025.
- [3] R. Lamberts, A. P. Melo, M. A. Triana, L. G. Eli e A. F. Krelling, "Análise de custo/benefício de parâmetros de eficiência energética em Habitações de Interesse Social," *Eficiência Energética para o Desenvolvimento Urbano Sustentável (EEDUS)*, 2020.
- [4] ABNT, "NBR 15575 - Edifícios Residenciais - Desempenho," Rio de Janeiro, 2023.
- [5] ANEEL, "Ranking da Tarifa Residencial," 2025. [Online]. Available: <https://portalrelatorios.aneel.gov.br/luznatarifa/rankingtarifas>. [Acesso em 8 2 2026].
- [6] MCTI, "MCTI publica fatores de emissão de CO2 da geração de energia elétrica no Brasil para 2025," 2025. [Online]. Available: <https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/noticias/2025/06/mcti-publica-fatores-de-emissao-de-co2-da-geracao-de-energia-eletrica-no-brasil-para-2025>. [Acesso em 8 2 2026].



THE VULNERABLE POPULATION IS PAYING THE BILL: INFLUENCE OF WALL PROPERTIES ON THE ELECTRICITY CONSUMPTION IN BRAZILIAN SOCIAL HOUSING

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ABSTRACT

With more extreme heat waves, increasing energy costs and energy consumption records, the thermal performance of buildings is becoming more crucial in Brazil, especially among vulnerable communities. This study examines how the thermal performance of two wall types affects air-conditioning electricity use and costs in Brazilian social housing, by comparing the two most widely used wall systems: reinforced concrete (RC) and concrete masonry unit (CMU). A representative single-story dwelling was simulated in 12 cities spanning the national bioclimatic zones. Results showed that large performance gaps between RC and CMU walls do not necessarily yield large bill savings: the largest reduction in air-conditioning use (35%) corresponded to annual savings of R\$ 886.90. Conversely, when the alternative wall system provided only moderate reductions in space-conditioning demand relative to CMU, the associated electricity-bill savings were substantial; in one region, a 28% reduction resulted in annual savings of R\$ 1,832.80, equivalent to more than one national minimum monthly wage. Overall, envelope choices should be assessed in terms of electricity bills, since climate and local tariffs can amplify or dampen the cost relevance of thermal performance.

Keywords: climate-responsive design; energy poverty; electricity tariffs; social interest housing.

INTRODUCTION

Thermal performance describes a building's ability to maintain indoor thermal comfort under external climatic variations and is influenced by local climate and the adopted construction systems [1]. In recent decades, limitations in passive design, particularly



in hot climates, have increased reliance on active cooling systems, a trend intensified in Brazil by high electricity costs that disproportionately affect low-income households. For many occupants, the key question is not whether a system performs better in relative terms, but whether it reduces substantially the monthly electricity bill associated with air-conditioning [5]. Within this context, this study evaluates how thermal-performance improvements in a representative Social Interest Housing (SIH) dwelling translate into air-conditioning electricity use and bills across Brazilian two main construction systems and bioclimatic regions.

METHODS

The case study is a single-story, single-family dwelling representative of SIH, with approximately 40 m², two bedrooms, a living room, a kitchen, and one bathroom. This residential typology is widely adopted in large-scale housing developments across Brazil. As seen in Figure 1, two external wall systems were evaluated: concrete masonry unit walls (CMU) and reinforced concrete walls (RC). These systems are among the most commonly used in SIH buildings in Brazil and are applied across diverse bioclimatic contexts.

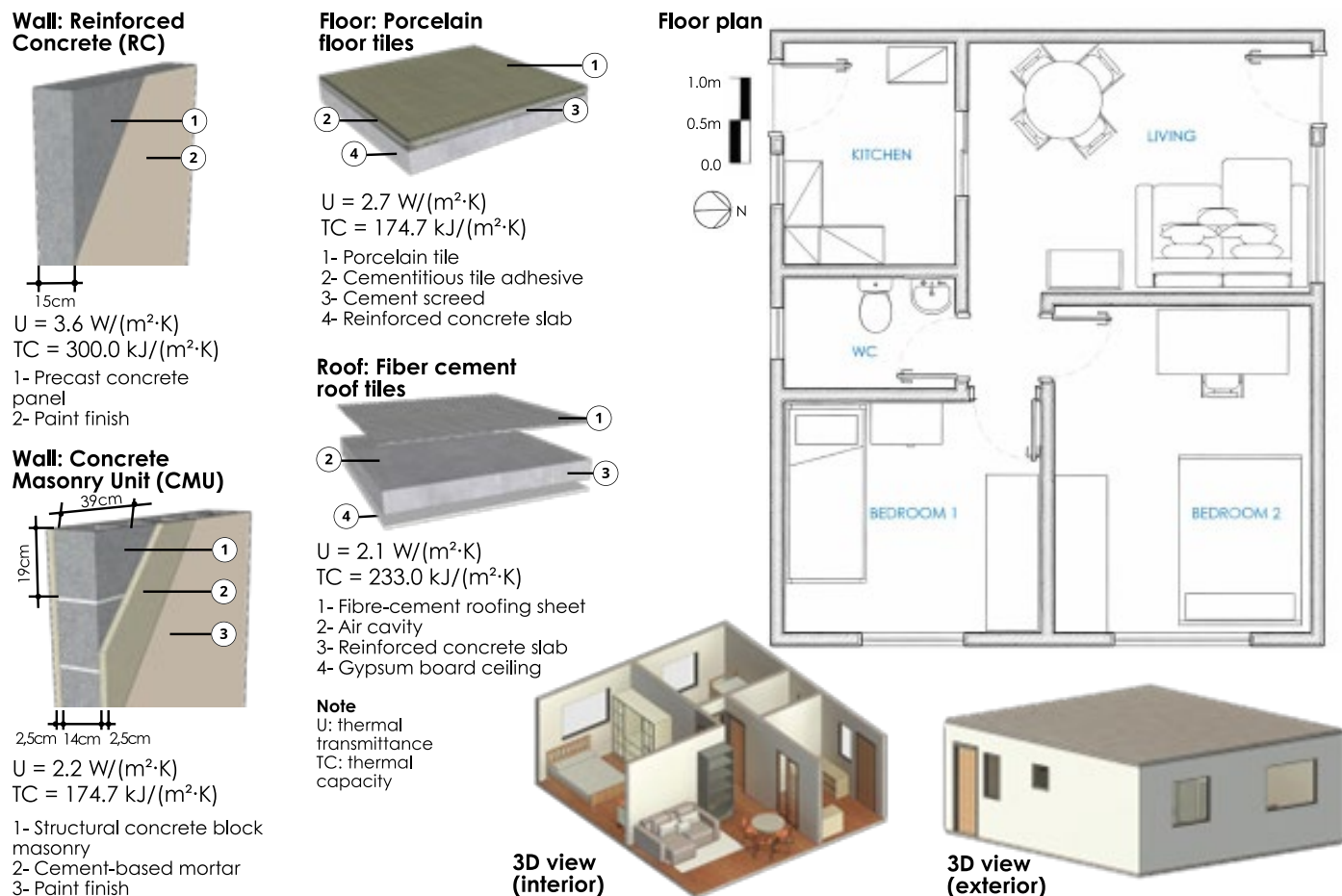




Figure 1 – Construction systems and building studied. Source: authors.

All modeling and simulations were performed in accordance with the Brazilian standard NBR 15575 [2], using annual building thermal loads (air-conditioning setpoint temperatures: 21 and 23 °C). EnergyPlus software was used to simulate building thermal performance in 12 Brazilian cities, each representative of a bioclimatic zone (BZ) and its subdivisions, encompassing climates from “very cold with severe winters” (1R) to “very hot and dry” (6B) [3]. Conventional electricity tariffs (R\$/ kWh) for each location were obtained from official Brazilian sources [4], and EnergyPlus thermal-load outputs were converted from annual air-conditioning electricity use (kWh) to the associated costs (R\$).

RESULTS

Figure 2 indicates that RC walls achieved superior thermal performance in only 25% of the analyzed BZs, with improved performance primarily observed in colder climates (BZs 1R, 1M, and 2R). This behavior is associated with the high thermal capacity (TC) of RC (300.0 kJ/(m²·K) vs. 174.7 kJ/(m²·K) of CMU), which contributes to reduced indoor temperature fluctuations, despite RC presenting nearly twice the thermal transmittance (U) of CMU walls (3.6 W/(m²·K) vs. 2.2 W/(m²·K)). In warmer climates (BZs 2M to 6B), CMU walls consistently exhibited superior thermal performance. The lower U of CMU walls resulted in reduced heat gains through the building envelope and lower cooling thermal loads, leading to more efficient air-conditioning operation.



Figure 2 – Thermal simulation results. Source: authors.

The largest thermal-performance difference occurred in BZ 3B (35%) and the smallest in BZ 2M (3%), with larger performance gaps generally leading to greater differences in annual energy costs. In warmer zones, CMU-related savings often approached or



exceeded the national minimum wage (R\$1,621.00), while in colder zones they typically remained below R\$1,000.00 (R\$83.30/month).

These results show that thermal performance must be assessed alongside local tariffs, as climate and energy costs determine its impact on affordability. In Brazil's hotter and more vulnerable regions, envelope choices directly affect household expenses. Thus, the "best" wall system depends not only on thermal metrics but on their interaction with climate and tariffs. SIH guidelines should therefore adopt climate- and tariff-sensitive criteria to reduce long-term energy burdens and improve living conditions.

CONCLUSIONS

The findings show that thermal-performance improvements of 3%–35% in air-conditioning demand translate into electricity-bill savings (R\$ 1,401.50–R\$ 7,861.60), depending on climate and tariffs. This highlights that envelope decisions in SIH should be assessed not only by thermal metrics but also by their impact on affordability. Strategies such as solar orientation, window sizing and placement, shading, and high-reflectance finishes can reduce cooling demand, often at lower upfront cost than material substitution alone. Integrating envelope materials with passive design in economic evaluations strengthens climate-adapted public housing guidelines and performance-based requirements that consider operational costs in vulnerable regions. Future research should examine additional housing layouts, envelope solutions, adaptive comfort scenarios, dynamic tariffs, and climate projections, alongside post-occupancy monitoring to capture behavioral and equity effects. Overall, the study supports equitable SIH policies that lower long-term energy burdens and improve thermal comfort across Brazilian climates.

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REFERENCES

- [1] R. Lamberts, A. P. Melo, M. A. Triana, L. G. Eli e A. F. Krelling, "Análise de custo/benefício de parâmetros de eficiência energética em Habitações de Interesse Social," *Eficiência Energética para o Desenvolvimento Urbano Sustentável (EEDUS)*, 2020.
- [2] ABNT, NBR 15575 - Residential buildings - Performance", Rio de Janeiro, Brazil, 2023.
- [3] ABNT, NBR 15220 - Thermal performance of buildings, Rio de Janeiro, Brazil, 2022.



- [4] ANEEL, "Ranking da Tarifa Residencial," 2025. [Online]. Available: <https://portalrelatorios.aneel.gov.br/luznatarifa/rankingtarifas>. [Acesso em 8 2 2026].
- [5] D. R. Garcia, V. F. Mendes, C. F. Moraes, M. M. Q. Cabral, I. B. A. R. Silva e J. C. Mendes, "Climate change, thermal comfort, and low-income residences: Insights from post-occupancy evaluations of concrete wall buildings in Brazil," *Sustainable Energy Technologies and Assessments*, vol. 86, p. 104847, 2026.



ON THE ROLE OF SOLUTION REPRESENTATION IN MULTI-OBJECTIVE OPTIMIZATION FOR BUILDING PERFORMANCE DESIGN

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ABSTRACT

This study evaluates how individual encoding strategies influence multi-objective optimization performance in discrete building envelope design, an aspect rarely examined in building performance studies. A search space of 28,224 envelope combinations was optimized using R-NSGA-III considering ten objectives, including thermal performance, cost, and embodied CO₂. Three encoding schemes were compared using Hypervolume (HV), IGD+, and Spacing indicators. Gray code achieved the highest HV (0.964505) and lowest Spacing (0.095300), improving HV by 2.2% and reducing Spacing by 17% compared to binary encoding. The findings demonstrate that representation choice significantly affects convergence and diversity behavior, reinforcing the methodological importance of carefully selecting encoding strategies to enhance robustness in multi-objective building optimization.

Keywords: evolutionary algorithms; gray code encoding; buildings; climate-resilient buildings.

INTRODUCTION

The growing demand for energy-efficient and climate-resilient buildings has strengthened the integration of building energy simulation and multi-objective optimization methods. In multi-objective building performance analysis, multiple and often conflicting thermal, economic, and environmental criteria must be evaluated simultaneously to support robust envelope design decisions [1]. Evolutionary algorithms do not operate directly on physical design alternatives but on encoded representations of candidate solutions. Each envelope configuration must therefore be translated into a chromosome structure that enables selection, crossover, and mutation operations [2]. The encoding strategy defines how discrete construction



alternatives are mapped into the search space and determines how neighboring solutions are generated during the evolutionary process.

Although objective formulation and algorithm selection are widely discussed, the representation of individuals remains a critical yet underexplored factor that can significantly influence convergence behavior, diversity preservation, and Pareto front approximation. Therefore, this study investigates how alternative encoding strategies affect the performance of multi-objective optimization in building performance analysis.

METHODS

The optimization framework adopted in this study followed the structure previously proposed by Silva [8], including surrogate modeling and multi-objective optimization. However, the primary focus of the present work is to evaluate the most suitable individual representation strategy. For this reason, the machine learning and optimization workflow are only briefly described, with greater emphasis placed on the encoding schemes and their impact on search performance.

The design space comprised 28,224 possible envelope combinations generated from the discrete selection of wall, roof, and floor alternatives for a given house. Each individual represents a unique combination of these components. The decision variables are categorical and discrete, encoding construction systems characterized by thermal properties, upfront cost, and embodied CO₂.

A total of ten objective functions were considered. Thermal performance metrics included Thermal Load, Degree-Hours, Thermal Autonomy, and Thermal Resilience, each evaluated under both present climate conditions and future climate projections, resulting in eight climate-dependent objectives. In addition, upfront cost and embodied CO₂ were included as economic and environmental objectives. The objective functions were formulated to improve thermal performance while simultaneously minimizing cost and CO₂ emissions.

Optimization was performed using the reference-point-based evolutionary algorithm R-NSGA-III. Selection, crossover, and mutation operators followed the configuration defined by Silva [8] and were kept identical across all encoding strategies to ensure a fair comparison. The algorithm was executed for a fixed number of generations (81), as determined by Optuna-based hyperparameter tuning. To account for the stochastic nature of evolutionary algorithms, each encoding strategy was evaluated over ten independent runs.

Three encoding strategies were compared. In the discrete encoding, each gene directly stores an integer corresponding to a construction alternative, maintaining a direct genotype–phenotype mapping [2]. In the binary encoding, each decision variable is represented as a binary string, allowing genetic operators to operate at the



bit level [1]. In the Gray code encoding, integer values are converted into Gray representation, in which consecutive values differ by only one bit [2]. This encoding modifies the bit-level representation while preserving the same feasible solution set.

The performance of each encoding strategy was evaluated using three multi-objective quality indicators: Hypervolume (HV), IGD+, and Spacing [3]. HV quantifies the volume of objective space dominated by the approximated Pareto front; higher values indicate better convergence and broader coverage of the trade-off surface. IGD+ measures the average distance between the obtained solutions and a reference Pareto front; lower values indicate better convergence accuracy. Spacing assesses the uniformity of distribution among non-dominated solutions; lower values indicate better diversity and more regular spread along the Pareto front. Results were reported as mean $\pm$ standard deviation across the ten independent runs. The most suitable encoding strategy was identified based on higher HV and lower IGD+ and Spacing values, reflecting a superior balance between convergence and diversity.

RESULTS

As seen in Table 1, the comparison among the three evaluated representations (discrete integer, binary, and Gray code) reveals significant differences in optimization performance according to the HV, IGD+, and Spacing indicators, computed over ten independent runs. Among the evaluated strategies, the Gray code representation achieved the best overall performance. It obtained the highest mean HV (0.964505), representing an improvement of approximately 2.2% over binary encoding and 0.5% over discrete encoding, indicating superior approximation of the ideal Pareto front and broader coverage of the objective space. Additionally, it presented the lowest Spacing value (0.095300), reducing solution dispersion by nearly 17% compared to binary encoding and about 6% compared to discrete encoding, suggesting a more uniform distribution of non-dominated solutions along the front [2].

Table 1 – Performance comparison of encoding strategies based on Hypervolume (HV), IGD+, and Spacing metrics (mean $\pm$ standard deviation). Source: authors.

Encoding strategies	HV (mean $\pm$ SD)	IGD+ (mean $\pm$ SD)	Spacing (mean $\pm$ SD)
Discrete integer	0.959858 $\pm$ 0.000156	0.013501 $\pm$ 0.001420	0.014643 $\pm$ 0.002470
Binary	0.944149 $\pm$ 0.000013	0.018073 $\pm$ 0.000196	0.114499 $\pm$ 0.000230
Gray code	0.964505 $\pm$ 0.000143	0.014643 $\pm$ 0.002470	0.095300 $\pm$ 0.000155

Although the discrete integer representation achieved the lowest IGD+ value (0.013501), indicating a slightly closer average distance to the reference front, this advantage was accompanied by higher irregularity in solution distribution (Spacing = 0.101037), reducing diversity along the obtained Pareto set [3]. In contrast, the binary encoding produced the weakest performance across all metrics, presenting the



lowest HV (0.944149) and the highest Spacing (0.114499), indicating less diverse fronts, poorer convergence, and reduced robustness across runs.

These findings are consistent with the theoretical behavior expected from each encoding scheme. Gray code preserves locality by ensuring that consecutive integer values differ by only one bit, promoting smoother transitions in the search space and reducing disruptive mutations [2]. This property supports more structured exploration of discrete solution spaces and contributes to the generation of stable and well-distributed Pareto fronts. In contrast, traditional binary encoding is more prone to abrupt phenotypic changes caused by small genotypic variations, which may impair convergence and diversity, particularly in discrete problems with correlated variables, as observed in this study.

Overall, the systematic evaluation of encoding strategies demonstrates that representation choice significantly affects multi-objective optimization performance in discrete building design problems. The identification of Gray code as the most suitable encoding enhances the methodological robustness of the proposed framework, improving convergence behavior and solution distribution. As a result, subsequent multi-objective analyses can be conducted with greater methodological consistency, supporting more reliable and well-optimized design decisions in building performance applications.

CONCLUSIONS

This study aimed to evaluate how different encoding strategies influence the performance of multi-objective optimization in discrete building envelope design. Among the tested representations, Gray code achieved the best overall results, presenting the highest Hypervolume (0.964505) and the lowest Spacing (0.095300), improving HV by approximately 2.2% and reducing Spacing by nearly 17% compared to binary encoding. Although the discrete representation obtained the lowest IGD+ (0.013501), Gray code provided the most balanced convergence and diversity performance. These findings enhance the robustness of multi-objective optimization in building performance analysis by demonstrating the critical role of representation choice. As a limitation, the evaluation was restricted to a single case study and fixed algorithm parameters. Future research should investigate encoding performance across different building typologies, larger design spaces, and alternative evolutionary algorithms.

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using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

- [1] A. S. Cruz, L. R. Caldas, V. M. Mendes, J. C. Mendes e B. E. G. Leopoldo, "Multi-objective optimization based on surrogate models for sustainable building design: A systematic literature review," *Building and Environment*, vol. 266, p. 112147, 2024.
- [2] A. F. Silva, *Otimização multiobjetivo para seleção de materiais de construção*, Final-year project: Ferderal Unviersity of Juiz de Fora (Brazil), 2026.
- [3] J. Monteiro, A. Pedro e A. J. Silva, "A Gray Code model for the encoding of grid cells in the Entorhinal Cortex," *Neural Computing and Applications*, vol. 34, pp. 2287-2306, 2022.
- [4] H. Ishibuchi, L. M. Pang e K. Shang, "Effects of dominance modification on hypervolume-based and IGD-based performance evaluation results of NSGA-II," *Proceedings of the Genetic and Evolutionary Computation Conference*, pp. 679-687, 2023.
- [5] E. Zitzler, K. Deb e L. Thiele, "Comparison of multiobjective evolutionary algorithms: Empirical results," *Evolutionary computation*, vol. 8, n° 2, pp. 173-195, 2000.
- [6] A. Halim, I. I. Hanif e S. Das, "Performance assessment of the metaheuristic optimization algorithms: an exhaustive review," *Artificial Intelligence Review*, vol. 54, n° 3, pp. 2323-2409, 2021.



MICROALGAE AND *BACILLUS ARYABHATTAI* AS COMPLEMENTARY BIOINPUTS FOR SUSTAINABLE CROP PRODUCTION

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ABSTRACT

Population growth has increased wastewater generation and environmental impacts. Native microalgae offer a sustainable alternative by removing nutrients and producing biomass that can be used as biofertilizer. Plant growth-promoting rhizobacteria (PGPR) also enhance crop growth and stresses tolerance. This study evaluated the combined effect of microalgae and rhizobacteria in *Amaranthus* plants. Microalgae application increased the photosynthetic rate and dry matter accumulation, and their combination with *Bacillus aryabhattai* further improved photosynthetic performance, with no significant differences between bacterial doses. These effects are likely linked to improvements in plant nutritional status promoted by *B. aryabhattai* inoculation.

Keywords: wastewater; microalgae; rhizobacteria.

INTRODUCTION

Population growth has increased wastewater generation, releasing effluents rich in nutrients, and pollutants. Although conventional treatment in Wastewater Treatment Plants (WWTPs) removes solids and pathogens, microalgae have emerged as a sustainable complementary approach. They efficiently remove nutrients and contaminants while generating biomass with biofertilizer potential, contributing to circular economy strategies and Sustainable Development Goals (SDGs). Cultivated in systems such as High-Rate Algal Ponds (HRAPs), they assimilate nutrients and sequester CO₂. Their biomass can partially replace chemical fertilizers by supplying nutrients and bioactive compounds that improve soil quality [1].

Bioinputs such as Plant Growth-promoting Rhizobacteria (PGPR), further enhance sustainable agriculture. *Bacillus aryabhattai* promotes plant growth through phytohormone production, improved nutrient availability, and stress tolerance [2]. In this study, *B. aryabhattai* CMAA 1363 (Auras®) was combined with microalgae to evaluate its effects on biomass production, gas exchange, and nutrient status of *Amaranthus cruentus*, a nutritionally valuable crop [3] [4].



MATERIALS AND METHODS

EFFLUENT COLLECTION AND MICROALGAE CULTIVATION

Domestic wastewater was collected from the Wastewater Treatment Plant (WWTP) in Candeia district, Bauru-SP, after UASB treatment. The pre-treated effluent, still rich in nutrients, was used as a culture medium for native microalgae. An inoculum was cultivated under controlled conditions (12 h photoperiod, 25–32 °C) for 12 days and then transferred to a High-Rate Algal Pond (HRAP) at 10% inoculum (15 L) and 90% effluent (135 L). After 7 days of cultivation, the biomass was allowed to settle for 7 days, separated from the supernatant, dried at 65 °C, ground, and stored for plant application.

AMARANTH CULTIVATION CONDITIONS

Seeds of *A. cruentus* cv. BRS Alegria were sown in 4-L plastic pots containing a substrate mixture of 1 part Carolina® commercial substrate and 2 parts vermiculite (1:2 v/v). Plants were maintained under natural photoperiod in a greenhouse (18.9 °C and 33.2 °C). Four treatments were applied: T1: substrate + 0 g microalgae + 0 mL bioinput; T2: substrate + 4 g dried microalgae + 0 mL bioinput; T3: substrate + 4 g dried microalgae + 5 mL bioinput and T4: substrate + 4 g dried microalgae + 10 mL bioinput. Microalgae were first applied at sowing and mixed superficially. Auras® bioinput was diluted (5 or 10 mL in 100 mL water per pot) and applied 16 days after sowing. A second microalgae application occurred 26 days after sowing.

GAS EXCHANGE MEASUREMENTS

Gas exchange was measured weekly from day 22 after sowing using an infrared gas analyzer (IRGA – LCpro, ADC BioScientific Ltd., UK). Measurements were performed between 8–10 a.m. under ambient conditions. Photosynthetically active radiation of 900 $\mu\text{mol m}^{-2} \text{s}^{-1}$ was provided by a light source attached to the leaf chamber. A/Ci ratio was used to estimate instantaneous carboxylation efficiency.

DRY MASS DETERMINATION AND QUANTIFICATION OF MACRO AND MICRONUTRIENT CONTENTS IN THE LEAVES

Plants were harvested and separated into leaves and stems. Samples were dried at 65 °C and weighed to determine shoot dry mass. Leaves samples were ground, and nutrients analyzed according to [5].

RESULTS

GAS EXCHANGE AND DRY MASS



Addition of microalgae increased gas exchange characteristics (Fig.1). Treatments with microalgae and microalgae + *B. aryabhattai* showed significantly higher photosynthetic rates than the control. Treatment 4 (10 mL bioinput) showed the highest rates, indicating a synergistic effect. Microalgae also increased shoot dry mass, especially leaf mass. Inoculation with *B. aryabhattai* significantly increased biomass compared to microalgae alone, with no difference between 5 and 10 mL doses. The absence of a dose-dependent response between 5 and 10 mL at the end of the experiment suggests that the beneficial effects of *B. aryabhattai* reached a plateau over time, with the lower dose being sufficient to maximize biomass accumulation under the experimental conditions. This suggests that plant-microbe interactions reached an effective equilibrium over time, beyond which additional inoculum did not further enhance biomass production.

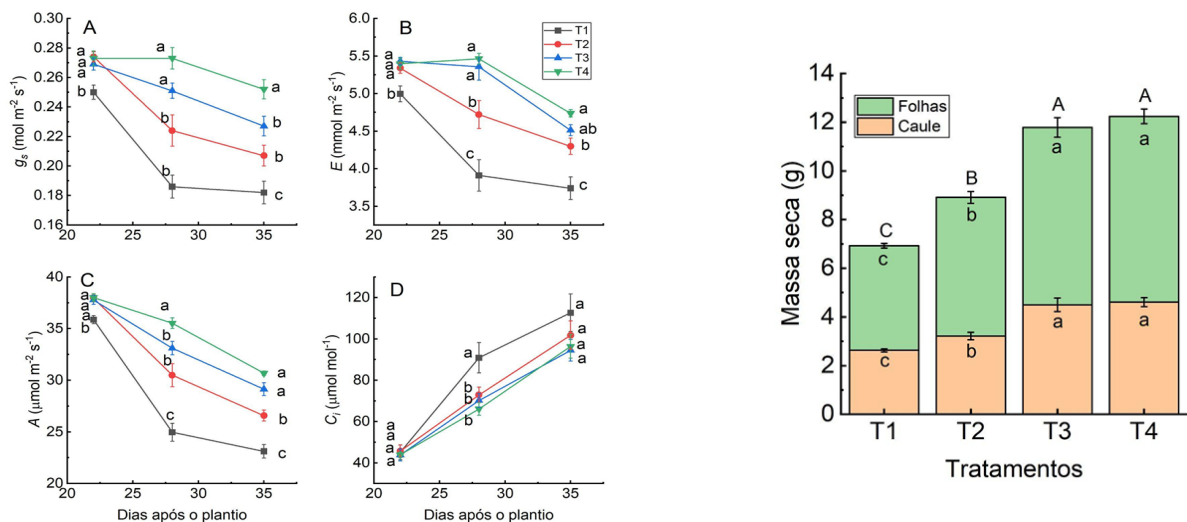


Figure 1 – Left panel: Stomatal conductance (g_s , A), transpiration rate (E , B), net photosynthetic rate (A , C), and substomatal CO_2 concentration (C_i , D). Right panel: Shoot dry mass partitioning of *Amaranthus cruentus* plants grown under microalgae application and *Bacillus aryabhattai* inoculation. Values represent means $\pm$ standard error ($n = 10$). Different lowercase letters indicate significant differences ($P < 0.05$) among organs, whereas uppercase letters indicate significant differences among treatments for total shoot dry mass. Treatments are described in the Materials and Methods section.

LEAF NUTRIENT CONTENT

Microalgae biomass contained high N, Cu, Fe, and Zn, reflected in higher leaf concentrations. Treatments with *B. aryabhattai* increased Fe, Mn, and Zn, especially T4.



Table 1 – Nutrient content of microalgae and amaranth plant leaves. The analysis was done in duplicate. Source: authors.

	Macronutrients (g kg ⁻¹)					Micronutrients (mg kg ⁻¹)					
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Microalgae	55	8.7	10	10	3.2	12.9	36	32	4,408	104	220
T1	15.8	8	22	9	16	5	27	8	72	56	45
T2	21.8	7.6	21	7	17.2	4.3	23	10	77	56	47
T3	21.9	8	22	9	18	4	25	10	76	60	49
T4	22.2	8	23	6	16	5	24	11	88	75	57

CONCLUSIONS

Microalgae and *B. aryabhattai* showed a synergistic effect, evidenced by increased photosynthesis and shoot dry mass in amaranth, especially in Treatment 4. Microalgal biomass showed potential as a biofertilizer, and its association with the rhizobacterium enhanced nutrient uptake resulting in higher dry matter production. Overall, integrating microalgae and *B. aryabhattai* represents a promising strategy to increase crop productivity and promote sustainable agriculture.

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REFERENCES

- [1] A. K. A. Suleiman, K. S. Lourenço, C. Clark e R. L. Luz, "From toilet to agriculture: Fertilization with microalgal biomass from wastewater impacts the soil and rhizosphere active microbiomes, greenhouse gas emissions and plant growth", *Resour., Conservation Recycling*, vol. 161, 2020.
- [2] G. G. Shailendra Singh, "Plant Growth Promoting Rhizobacteria (PGPR): Current and Future Prospects for Development of Sustainable Agriculture", *J. Microbial & Biochem. Technol.*, vol. 07, n. ° 02, 2015. Consult. 2026-02-28.
- [3] Empresa Brasileira de Pesquisa Agropecuária (Embrapa), "Embrapa destaca diferenciais do bioinsumo CMAA 1363 na Agrishow 2022," Portal Embrapa, 2022. [Online]. Available: <https://www.embrapa.br/busca-de-noticias/-/noticia/70257581/embrapa-destaca-diferenciais-do-bioinsumo-cmaa-1363-na-agrishow-2022>. [Accessed: Feb. 28, 2026].

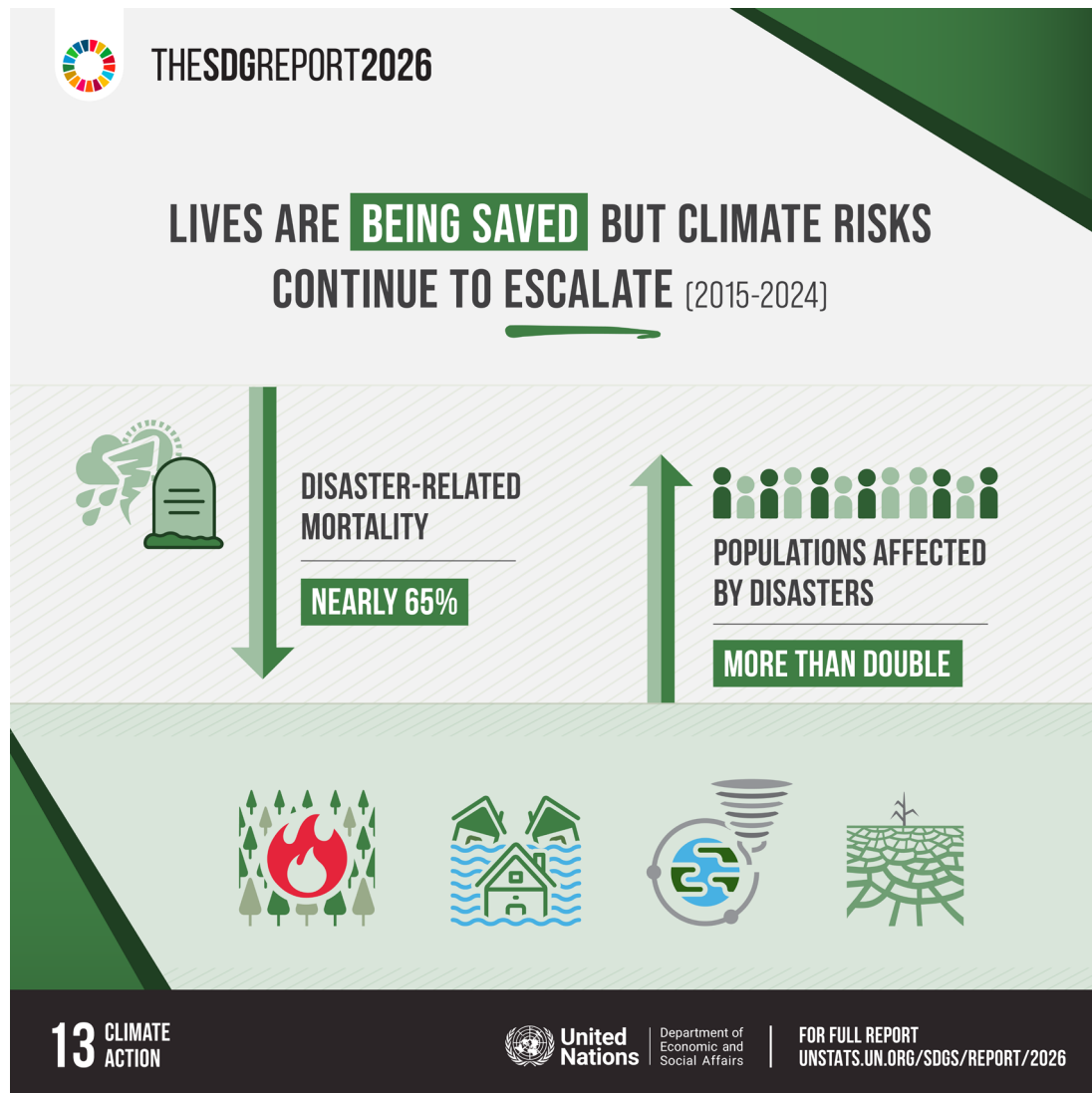


- [4] R. Spehar, "Amaranth BRS Alegria: alternative for diversification of cropping systems," Pesquisa Agropecuária Brasileira, Embrapa, 2007. [Online]. Available: <https://apct.sede.embrapa.br/pab/article/view/6621>. [Accessed: Feb. 28, 2026].

- [5] Ministério da Agricultura, Pecuária e Abastecimento, Manual de Métodos Analíticos Oficiais para Fertilizantes e Corretivos. Brasília, Brazil: MAPA, 2017. [Online]. Available: https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/fertilizantes/legislacao/manual-de-metodos_2017_isbn-978-85-7991-109-5.pdf. [Accessed: Feb. 28, 2026].



GOAL 13: TAKE URGENT ACTION TO COMBAT CLIMATE CHANGE AND ITS IMPACTS



Source: UN's The Sustainable Development Goals Report 2026



SIREN: A CONCEPTUAL FRAMEWORK FOR MULTIMODAL NEUROPHYSIOLOGICAL EARLY WARNING OF HEAT STRAIN

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ABSTRACT

Rising ambient temperatures are increasing the incidence of heat-related illness across occupational, operational, and home healthcare settings. Contemporary neuroscience and psychophysiology suggest that such events are not abrupt failures but reflect progressive network strain—the cumulative overload of interacting autonomic, thermal, and neuroregulatory systems. \ Systems-level understanding has not yet been translated into field-deployable approaches for early detection, with current monitoring technologies relying on subjective reporting or single-parameter sensing that typically identify risk only at late stages. Presented is a conceptual framework that reconceptualises heat strain as a multimodal, network-level phenomenon and proposes that early physiological decompensation can be detected through coordinated changes across externally measurable signals. The framework integrates insights from neuroscience, wearable biosensing, and engineering to define a signal-fusion approach for identifying deviation from individual baseline states. SIREN (Signal-Integrated Resilience Early-warning Neurodiagnostic) is introduced as a translational instantiation of this framework, implemented as a lightweight, textile-integrated sensing platform designed to capture multimodal physiological data—including heart rate, heart rate variability, electrodermal activity, skin temperature, motion, and emerging biochemical markers—within a closed-loop architecture capable of delivering adaptive support cues. By linking network-based models of physiological strain to wearable, multimodal sensing systems, this work reframes heat-risk detection as a problem of cumulative system dynamics rather than single-parameter thresholds. Positioned as climate-adaptation infrastructure, the framework aims to support earlier intervention, improved workforce resilience, and alignment with Sustainable Development Goals related to health, industry innovation, and climate action.

Keywords: Heat strain; climate adaptation; wearable textiles; multimodal sensing; resilience; early warning; SDGs



INTRODUCTION

Climate change is intensifying heat exposure and increasing the burden of heat-related illness across occupational and operational settings [1–3]. In defence, emergency services, mining, and other heat-exposed industries, physiological failure rarely occurs without warning; rather, it reflects progressive overload across autonomic, thermal, and neuromuscular systems [10,12]. Yet current risk management remains largely reactive, depending on self-report, visible symptoms, or consumer-grade devices that monitor a narrow set of parameters and are not designed for continuous wear under uniforms or protective equipment [4,5]. Recent advances in neuroscience and psychophysiology suggest that failure in complex biological systems is better understood as “network strain”, or the cumulative overload of interconnected regulatory systems rather than the breakdown of a single component [8–10]. In such models, internal dysregulation is mirrored by coordinated changes in external physiological markers, providing accessible, non-invasive windows into otherwise hidden system stress [10–12]. Applied to heat strain, this implies that early physiological decompensation is unlikely to be captured by any single sensor, but instead emerges as a multimodal pattern spanning autonomic, thermal, and motor domains [4,5,10]. Signal-Integrated Resilience for Early-warning Neurodiagnostic (SIREN), also referred to as the 2nd Skin Resilience Monitor, is proposed to address this gap through a textile-integrated, mission-critical approach that prioritises prediction over description. By embedding multiple validated indicators of heat strain directly into a washable base layer, SIREN is intended to detect early physiological decompensation before collapse occurs and to support timely, low-burden interventions (e.g., rest, hydration, guided breathing). This work positions SIREN as climate-adaptation infrastructure for human systems, aligning with SDG 11 (Sustainable Cities & Communities), and also SDG 13 (Climate Action), SDG 9 (Industry, Innovation and Infrastructure). This paper develops a conceptual framework that reconceptualises heat strain as a network-level phenomenon and proposes multimodal physiological sensing as its observable signature. SIREN is introduced as a translational embodiment of this framework, demonstrating how these principles can be operationalised in a wearable system.

CONCEPTUAL FRAMEWORK

SYSTEM ARCHITECTURE

SIREN is conceived as a lightweight, textile-integrated garment to be worn beneath standard uniforms, work clothing, or comfortably within home healthcare settings. Core design constraints will include durability under heat, perspiration, load carriage and laundering, local data storage, and compliance with operational safety and battery standards. The anticipated competitive advantage will derive from signal



fusion rather than reliance on any single biomarker. The sensing stack will integrate multimodal domains indicative of heat strain and physiological load, including heart rate (HR), heart rate variability (HRV), electrodermal activity (EDA), skin temperature gradients, and motion/postural stability, with an extensible pathway toward sweat-based biochemical markers [4–7,10,11]. Higher-fidelity prototypes are expected to accommodate neurophysiological channels (e.g., EEG, fNIRS, EMG) for research validation [8,9,13]. A low-power embedded processor will be used to perform real-time feature extraction and fusion to estimate physiological load and detect deviation from safe or individual baseline states. This design is informed by the principle that external physiological markers can mirror internal system-level strain, providing accessible, non-invasive readouts of cumulative overload [8–12]. In neuropsychiatric contexts, such markers have been shown to parallel internal network dysregulation; SIREN extends this logic to heat strain by treating autonomic, thermal, and motor signals as coupled indicators of emerging physiological failure rather than independent variables [10–12]. SIREN is not presented as a finished device, but as a translational instantiation of a conceptual framework linking network-level physiological strain to multimodal wearable detection.

CLOSED-LOOP OPERATION AND PERSONALISATION

Unlike passive monitoring systems, SIREN is designed to implement a closed-loop paradigm. When pre-set or personalised thresholds are crossed, the garment is intended to activate adaptive support cues to assist thermoregulatory recovery. This approach is motivated by evidence that effective regulation of strained biological systems requires engagement of autonomic and subcortical processes, rather than reliance on purely cognitive or retrospective feedback. Over time, the prototype is expected to establish individual baselines, enabling person-specific detection. In this way, SIREN functions as an adaptive, learning-oriented prototype supporting early, proactive risk mitigation.

ILLUSTRATIVE COMPARISON

SIREN is intended to be comparable to current commercial wearable systems used for heat and workload monitoring, while extending beyond them by shifting detection into a closed-loop, multimodal framework. Existing solutions typically rely on single or narrow sensing domains and provide primarily passive, descriptive monitoring. In contrast, SIREN is proposed to advance the state of the art through multimodal signal fusion, textile integration, and closed-loop adaptive support, with the additional objective of enabling future integration of biochemical marker readout.

Table 1 illustrates how current wearable systems align with or diverge from the proposed framework. As illustrated, current devices are generally implemented as external accessories (e.g., watches, straps, or patches), focus on limited sensing modalities, and prioritise



retrospective or descriptive analytics. SIREN, by comparison, is conceived as a textile-integrated base layer designed for continuous wear, combining multiple physiological domains into a unified sensing architecture and supporting real-time, adaptive responses to emerging strain. Rather than replacing existing devices, SIREN is intended to address their structural limitations by reframing heat-risk detection as a systems-level problem of cumulative network strain, requiring coordinated interpretation across multiple physiological domains rather than reliance on single-parameter thresholds.

Capability	Current Wearables	SIREN
• Sensing	Single / limited signals	Multimodal signal fusion
• Integration	External devices (watch/strap/patch)	Textile-integrated base layer
• Monitoring	Passive, descriptive	Closed-loop, adaptive
• Durability	Limited to moderate	Designed for heat, sweat, washing
• Novelty	Established sensors	Pathway to biochemical markers

CONCLUSIONS

This work presents a conceptual framework that reconceptualises heat strain as a problem of cumulative, network-level physiological overload rather than single-parameter failure. Within this framework, SIREN is introduced as a prototype design—a textile-integrated, closed-loop system that operationalises multimodal sensing and adaptive response for early detection of physiological and neurophysiological strain in climate-exposed environments. By translating network-strain models from neuroscience into wearable, field-deployable architectures, the framework addresses a critical gap between theory and practice and supports earlier, more actionable intervention prior to collapse. This work also advances a more inclusive approach to system design, explicitly responding to gender biases in protective equipment that can amplify risk. By challenging reductionist paradigms, it promotes monitoring systems that better reflect the diversity and complexity of human responses under stress. Future work will focus on prototype development, validation, and real-world evaluation across operational settings.



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REFERENCES

- [1] F. O. Alele, B. S. Malau-Aduli, E. O. Malau-Aduli e M. J. Crowe, "Epidemiology of exertional heat illness in the military: A systematic review of observational studies," *International Journal of Environmental Research and Public Health*, vol. 17, no. 19, p. 7037, 2020.
- [2] S. A. Lewandowski, M.-A. Kioumourtzoglou e J. L. Shaman, "Heat stress illness outcomes and annual indices of outdoor heat at U.S. Army installations," *PLOS ONE*, vol. 17, no. 11, p. e0263803, 2022.
- [3] M. Romanello et al., "The 2025 report of the Lancet Countdown on health and climate change," *The Lancet*, 2025.
- [4] Y. Yang e W. Gao, "Wearable and flexible electronics for continuous molecular monitoring," *Chemical Society Reviews*, vol. 48, pp. 1465–1491, 2019.
- [5] J. Kim, A. S. Campbell, B. E.-F. de Ávila e J. Wang, "Wearable biosensors for healthcare monitoring," *Nature Biotechnology*, vol. 37, pp. 389–406, 2019.
- [6] Y. Shi et al., "Washable textile biosensors enabled by nanostructured oxides with fast ion diffusion," *Device*, vol. 2, no. 11, p. 100503, 2024.
- [7] L. Zhou et al., "An autonomous fabric electrochemical biosensor for efficient health monitoring," *National Science Review*, vol. 12, no. 6, p. nwaf155, 2025.
- [8] J. F. Cavanagh e M. J. Frank, "Frontal midline theta and error-related activity as biomarkers of anterior cingulate engagement in attention and cognitive control," *Frontiers in Human Neuroscience*, vol. 8, p. 69, 2014.
- [9] R. T. Thibault et al., "EEG resting-state biomarkers of psychiatric disorders," *Frontiers in Human Neuroscience*, vol. 12, p. 521, 2018.
- [10] A. H. Kemp et al., "Heart rate variability and its relationship to prefrontal-autonomic regulation in stress and depression," *Journal of Affective Disorders*, vol. 122, nos. 1–2, pp. 80–86, 2010.
- [11] V. C. Goessl, J. E. Curtiss e S. G. Hofmann, "The effect of heart rate variability biofeedback training on stress and anxiety: A meta-analysis," *Applied Psychophysiology and Biofeedback*, vol. 42, pp. 1–13, 2017.
- [12] G. Tan et al., "Heart rate variability (HRV) and posttraumatic stress disorder (PTSD): A pilot study," *Psychiatry Research*, vol. 187, nos. 1–2, pp. 89–94, 2011.
- [13] S. Cortese et al., "Neurofeedback in ADHD: Meta-analyses on theta/beta ratio training," *European Child & Adolescent Psychiatry*, vol. 25, no. 5, pp. 389–402, 2016.



- [14] N'deo, G., Curtin, M., & Price, R. (2019). Women, PPE and Performance: A Review of Fit, Function, and Gender Bias in Safety Equipment. *International Journal of Occupational Safety and Ergonomics*, 25(3), 389–399.



WASTE-BASED SUPPLEMENTARY CEMENTITIOUS MATERIALS IN BRAZIL: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

Portland cement production significantly contributes to global greenhouse gas emissions, particularly due to clinker manufacturing. In Brazil, traditional supplementary cementitious materials (SCMs), such as fly ash and ground granulated blast furnace slag, face limitations in long-term availability. This study aimed to identify the waste materials most frequently investigated as SCMs by Brazilian researchers through a bibliometric analysis. Fifteen waste materials were identified, among which sugarcane bagasse ash, construction and demolition waste, glass waste, and ceramic waste emerged as the most studied. The findings indicate that waste valorization plays a central role in supporting sustainable and low-carbon pathways for the Brazilian cement sector.

Keywords: supplementary cementitious materials; waste valorization; sugarcane bagasse ash; bibliometric analysis; circular economy.

INTRODUCTION

Portland cement production accounts for approximately 7% of global anthropogenic greenhouse gas emissions [1, 2], with 60–70% of these emissions arising from clinker manufacturing, the main component of cement [3]. In response, the cement industry has sought to reduce clinker content using supplementary cementitious materials (SCMs), which may be natural materials or industrial by-products with latent hydraulic or pozzolanic activity [4]. In Brazil, ground granulated blast furnace slag and fly ash are the most commonly used SCMs. However, their availability is limited and expected to decline, particularly in the case of fly ash, due to ongoing decarbonization of the energy sector [1].

In this context, the use of waste materials as SCMs represents a promising alternative, with the potential to reduce production costs, mitigate environmental impacts associated with cement and SCM manufacturing, and divert waste from landfills [5, 4]. Numerous studies have identified residues such as agricultural ashes, glass waste, and construction and demolition waste as potential SCMs, although their practical application remains limited [5, 6]. Therefore, this study aims to identify, through a

bibliometric analysis, the waste materials most frequently investigated as SCMs by Brazilian researchers, contributing to a better understanding of their availability and feasibility and supporting long-term decarbonization strategies in the cement industry.

MATERIALS AND METHODS

We conducted a bibliometric analysis using the Scopus database to identify waste materials most frequently investigated by Brazilian researchers as SCMs. The search was performed on February 26, 2025, in the "title/abstract/keywords" field using the query: *((residue OR waste OR tailings) AND ("supplementary cementitious material" OR SCM OR pozzolan OR "cement replacement"))*. We included only final-stage journal articles, while review papers and conference proceedings were excluded to ensure the inclusion of primary studies. The search was limited to Brazil, with no restriction on publication year, resulting in 213 documents.

The bibliometric data were analyzed using VOSviewer (version 1.6.20). To identify the most studied SCMs, we conducted a co-occurrence analysis of author keywords using the full counting method, with a minimum threshold of two occurrences per keyword. Among the 598 keywords initially identified, 131 met this criterion. After grouping synonymous terms and excluding generic expressions, non-waste materials, and by-products not used as clinker replacements, we identified 15 distinct waste materials with potential application as SCMs.

RESULTS

We analyzed the 131 keywords to identify the SCMs most frequently researched by Brazilian authors, resulting in the identification of 15 waste materials with potential application as SCMs. Table 1 presents these residues ordered by keyword co-occurrence.

Table 1 – Most studied waste materials as SCM in Brazil

Waste material used as SCM	Sum of keyword occurrences
Sugarcane bagasse ash	11
Construction and demolition waste	9
Glass waste	8
Ceramic waste	7
Bauxite residue (red mud)	6
Ornamental stone waste	6
Iron ore tailing	5
Rice husk ash	5
Water treatment sludge	5
Bamboo leaf ash	4
Fly ash	4



Waste material used as SCM	Sum of keyword occurrences
Porcelain polishing residue	3
Silica fume	3
BOF steel slag	2
Spent FCC catalyst	2

The four most studied materials are sugarcane bagasse ash (SCBA), construction and demolition waste (CDW), glass waste, and ceramic waste. Snellings, Suraneni, and Skibsted [5] classify these as emerging SCMs, i.e., materials gaining relevance in local and global markets and whose production processes are generally well established.

SCBA showed the highest number of occurrences. Its high amorphous silica content provides good pozzolanic properties [7] and its prominence in Brazilian studies is likely related to Brazil's position as the world's largest sugarcane producer [8]. CDW has traditionally been used as recycled aggregate, but recent studies focus on its fine fraction ($<150 \mu\text{m}$), which can act as filler or exhibit pozzolanic activity after appropriate treatment [9]. Glass waste is mainly composed of amorphous silica and therefore presents natural reactivity [9]. Ceramic waste shows pozzolanic behavior when finely ground due to amorphous phases formed during sintering [5].

In addition to emerging SCMs, future SCMs [5] were also identified, that is, materials with promising potential but still requiring further research and development, such as red mud, iron ore tailings, and BOF steel slag. The presence of these materials reinforces the interest of the Brazilian scientific community in exploring unconventional alternatives in the field of SCMs.

Regarding the most traditional SCMs, such as fly ash and ground granulated blast furnace slag, only fly ash appears among the most studied wastes, and with only four occurrences. Most of the analyzed articles were published in the last ten years, when these materials were already technically consolidated and widely applied. This may explain the shift in academic interest toward alternative and emerging waste materials that remain underexplored.

Furthermore, there is a trend toward reduced availability of these traditional SCMs in the coming years [1]. In response, part of the cement industry has shifted toward alternative binders such as calcined clay [1]. However, its large-scale adoption requires additional thermal energy and the extraction of natural clay deposits, raising concerns about energy demand and resource depletion [1]. Given Brazil's large availability of agricultural, mining, and construction residues with demonstrated SCM potential [6], investing in waste valorization may represent a more resource-efficient and context-specific strategy to support clinker reduction and circular economy goals.



CONCLUSIONS

Among the 15 identified residues, sugarcane bagasse ash, construction and demolition waste, glass waste, and ceramic waste stand out as the most investigated and strategically relevant materials in Brazil. Their prominence reflects both material availability and increasing scientific interest in emerging SCMs capable of partially replacing clinker. The findings highlight waste valorization as a key strategy for advancing sustainable and low-carbon pathways in the Brazilian cement sector, while also indicating the need for continued research to support technical standardization and large-scale implementation.

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REFERENCES

- [1] SNIC, "Roadmap tecnológico do cimento: potencial de redução das emissões de carbono da indústria do cimento brasileira até 2050," Sindicato Nacional da Indústria do Cimento, Rio de Janeiro, 2019.
- [2] D. K. Panesar, D. Kanraj e Y. Abualrous, "Effect of transportation of fly ash: Life cycle assessment and life cycle cost analysis of concrete," *Cement and Concrete Composites*, vol. 99, pp. 214-224, 2019.
- [3] K. L. Scrivener, V. M. John e E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO₂ cement-based materials industry," *Cement and Concrete Research*, vol. 114, pp. 2-26, 2018.
- [4] P. K. Mehta e P. J. M. Monteiro, "Concreto Microestrutura, Propriedade e Materiais," IBRACON, São Paulo. 2^a ed, 2014.
- [5] R. Snellings, P. Suraneni e J. Skibsted, "Future and emerging supplementary cementitious materials," *Cement and Concrete Research*, vol. 171, p. 107199, 2023.
- [6] C. M. N. Lopes, V. F. Mendes, D. R. Garcia e J. C. Mendes, "Residues in cement-based composites: Occurrence mapping in Brazil," *Case Studies in Construction Materials*, vol. 18, p. e01763, 2023.
- [7] M. J. Khalil, M. Aslam e S. Ahmad, "Utilization of sugarcane bagasse ash as cement replacement for the production of sustainable concrete – A review," *Construction and Building Materials*, vol. 270, p. 121371, 2021.



- [8] Conab, Acompanhamento da safra brasileira de cana-de-açúcar. Safra 2024/25 3º levantamento, Brasília: Companhia Nacional de Abastecimento, 2024.
- [9] T. F. Baggio, E. Possan e J. J. d. O. Andrade, "Physical-chemical characterization of construction and demolition waste powder with thermomechanical activation for use as supplementary cementitious material," Construction and Building Materials, vol. 437, p. 136907, 2024.



FLOODINTEL: BRIDGING THE FLOOD DATA GAP WITH GENERATIVE AI AND DEEP LEARNING BENCHMARKING

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ABSTRACT

Advancements in deep learning have revolutionized object detection, yet data scarcity remains a significant hurdle in high-risk scenarios like flood response due to environmental and accessibility constraints. This study conducts a comparative analysis of five architectures including YOLO11, Faster R-CNN, RetinaNet, DETR, and RF-DETR. Utilizing a synthetic dataset of 7,182 generative AI-produced images and expanded to 12,207 via augmentation, the models are trained to detect flooded houses. Evaluations reveal that YOLO11 (82.6 FPS, 0.967 mAP@0.5) and RF-DETR (78.7 FPS, 0.968 mAP@0.5) yield the superior balance between computational efficiency and detection precision. These findings highlight critical performance trade-offs, providing a framework for deploying robust, real-time computer vision systems in disaster management contexts where empirical data is limited. To ensure practical utility, models trained on synthetic data were validated against real-world flood imagery, demonstrating strong generalizability and promising performance.

Keywords: Artificial Intelligence; Deep-learning Algorithms, FloodIntel, Flood Response, Object Detection.

INTRODUCTION

Floods remain among the most frequent and devastating natural disasters globally, causing significant socio-economic damage [1],[2],[3]. Traditional manual response methods often lack scalability and coordination [4],[5], driving the need for automated deep learning (DL) object detection. DL detectors can be classified into three main categories which include the Single-stage Detectors, Region Proposal-based Detectors (also known as Two-stage Detectors) and Transformer-Based Detectors [6], [7]. While models like YOLO, Faster R-CNN, and DETR have excelled in



sectors like agriculture and medicine [8],[9],[10], their performance in flood response remains under-investigated due to data scarcity and inconsistent benchmarking.

Therefore, this paper aims to bridge the gap by evaluating five algorithms on a standardized dataset of synthetic aerial images. Building on initial research using YOLOv8 and the FloodIntel framework [5], this study focuses on three primary objectives:

- *Benchmarking for Disaster Response:* This study aims to address the lack of domain-specific benchmarks by assessing how well each algorithm performs in such scenarios.
- *Synthetic Data Utilization:* Our study aims to utilize generative AI (gen-AI) to overcome real-world data acquisition challenges, such as privacy concerns and environmental risks.
- *Balancing Accuracy and Speed:* This paper intends to provide empirical evidence on inference speed versus detection precision to support time-critical decision-making for government agencies and emergency responders.

METHODOLOGY

DATASET PREPARATION AND PREPROCESSING

To overcome data scarcity, a synthetic dataset was created using four generative AI platforms: Freepik, Adobe Firefly, Canva, and Flux AI. Prompts were designed to simulate Malaysian urban and rural flood scenarios from an orthographic (top-down) perspective, aligning with future UAV-based deployments. After filtering for realism and perspective, 7,182 images were manually annotated via Roboflow for the 'building' class. To enhance model generalization and mitigate spatial bias, techniques (flipping, rotation, grayscale) were applied. The final dataset comprised 12,207 images, resized to 416×416 pixels and partitioned into a 70:20:10 ratio for training, validation and testing.

OBJECT DETECTION MODEL SELECTIONS

Five architectures were evaluated to benchmark the trade-offs between computational efficiency and detection precision. Single-stage detectors, YOLO11s and RetinaNet, were selected for their real-time capabilities; YOLO11s utilizes C3k2 blocks for lightweight inference, while RetinaNet employs Focal Loss to manage class imbalances [11]. To achieve higher localization accuracy in dense residential areas, the two-stage Faster R-CNN (ResNet-101-FPN) was included for its robust Region Proposal Network (RPN) [12]. The study also assesses transformer-based paradigms through DETR and RF-DETR. These models replace traditional anchor boxes with global attention mechanisms. Specifically, RF-DETR integrates region-aware attention modules, offering a sophisticated balance of high-precision and real-time inference suitable for disaster response [13]. These models were carefully selected to provide a



representative benchmark on disaster-response efficacy across primary detection paradigms.

EVALUATION METRICS

Training was conducted on a Google Colab A100 GPU environment. Performance was rigorously quantified using standard metrics: mAP@0.5 and mAP@0.5:0.95 for precision across IoU thresholds, F1 Score for classification balance, and Frames Per Second (FPS) to assess operational readiness for real-time disaster monitoring. This multi-metric approach ensures the selected models are validated for both scientific rigor and practical field utility. While mAP is utilized as the primary metric for architectural benchmarking across all models, additional operational metrics (Precision, Recall, and F1-score) are provided for the leading models to evaluate their suitability for real-time disaster response

RESULTS

Table 1 – Performance Comparison of Models.

Algorithm	mAP@0.5	mAP@[0.5,0.95]	Precision	Recall	F1-score	FPS
YOLO11	0.967	0.776	0.965	0.843	0.900	82.6
RetinaNet	0.881	0.617	0.881	0.900	0.891	79.7
Faster R-CNN	0.940	0.660	N/A	N/A	N/A	25.0
DETR	0.907	0.624	N/A	N/A	N/A	16.6
RF-DETR	0.967	0.757	0.923	0.919	0.921	78.7

Table 2 – Summary of Algorithms.

Algorithm	Architecture Type	Backbone	Speed	Accuracy
YOLOv11	Single Stage	Custom CNN	82.6	0.967
RetinaNet	Single Stage	ResNet 50 FPN	79.7	0.881
Faster R-CNN	Two Stage	ResNet 101 FPN	25.0	0.940
DETR	Transformer Based	ResNet50	16.6	0.907
RF-DETR	Trasnformer Based	DINOv2	78.7	0.967

Experimental results as illustrated in Tables 1 and 2 reveal distinct trade-offs between computational efficiency and detection precision across the five architectures. YOLO11 emerged as the most efficient model, achieving the highest inference speed (82.6 FPS) and the superior mAP@0.5:0.95 (0.776), making it the premier candidate for real-time edge deployment. Conversely, RF-DETR achieved the peak mAP@0.5 (0.967) along with YOLO11, demonstrating superior capability in localizing small or partially submerged rooftops whereas RetinaNet and DETR struggled to perform. While two-stage (Faster R-CNN) and standard transformer (DETR) architectures provided robust localization, their significantly lower speeds (25.0 and 16.6 FPS) limit their utility in time-critical disaster response. In contrast, the optimized RF-DETR (78.7 FPS) effectively

bridges the gap between accuracy and speed. Validation on actual flood imagery are performed as shown in Figure 1 and it yielded promising results, confirming that the synthetic training pipeline produces models with comparable real-world generalizability. YOLO11 attained mAP@0.5 and mAP@0.5:0.95 scores of 0.331 and 0.194, whereas RF-DETR demonstrated strong performance with scores of 0.966 and 0.748. Ultimately, these findings suggest that while YOLO11 is optimal for immediate situational awareness, RF-DETR is preferable for high-precision post-disaster assessments.



Figure 1 – Validation of Results on Real-world Images.

CONCLUSIONS

This study provides a comprehensive benchmark of YOLO11, RetinaNet, Faster R-CNN, DETR, and RF-DETR for detecting flood-affected houses using synthetic aerial imagery. Results identify YOLO11 (prioritizing speed) and RF-DETR (prioritizing accuracy) as the optimal architectures for disaster response. By leveraging generative AI to overcome data scarcity, this research demonstrates that synthetic datasets can effectively train high-performing models. Furthermore, this work supports SDG 13 by advancing AI-driven climate resilience tools. Future efforts include optimizing these models for edge deployment in real-time systems to further enhance emergency response capabilities as well as exploring deeper into the domain gap between synthetic training environments and the complex, unpredictable conditions of real-world flood scenarios.

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REFERENCES

- [1] J. Rentschler, M. Salhab, and B. A. Jafino, "Flood exposure and poverty in 188 countries," *Nat. Commun.*, vol. 13, no. 1, p. 3527, Jun. 2022, doi: 10.1038/s41467-022-30727-4.
- [2] H. Basri, S. Syakur, A. Azmeri, and E. Fatimah, "Floods and their problems: Land uses and soil types perspectives," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 951, no. 1, p. 012111, Jan. 2022, doi: 10.1088/1755-1315/951/1/012111.
- [3] "Floods," World Health Organization. Accessed: Sep. 15, 2023. [Online]. Available: https://www.who.int/health-topics/floods#tab=tab_1
- [4] H. S. Rosmadi, M. F. Ahmed, M. Bin Mokhtar, and C. K. Lim, "Reviewing Challenges of Flood Risk Management in Malaysia," *Water (Basel)*, vol. 15, no. 13, p. 2390, 2023, doi: <https://doi.org/10.3390/w15132390>.
- [5] J. Teoh, Z. B. Zulkoffli, K. M. Yap, and H. S. Chua, "Exploring Generative AI for YOLO-Based Object Detection to Enhance Flood Disaster Response in Malaysia," *IEEE Access*, vol. 12, pp. 173686–173699, 2024, doi: 10.1109/ACCESS.2024.3498893.
- [6] H. Vaidwan, N. Seth, A. S. Parihar, and K. Singh, "A study on transformer-based Object Detection," in *2021 International Conference on Intelligent Technologies (CONIT)*, IEEE, Jun. 2021, pp. 1–6. doi: 10.1109/CONIT51480.2021.9498550.
- [7] S. Y. Mohammed, "Architecture review: Two-stage and one-stage object detection," *Franklin Open*, vol. 12, p. 100322, Sep. 2025, doi: 10.1016/j.fraope.2025.100322.
- [8] A. Thulaseedharan and L. P. P. S., "Deep Learning based Object Detection Algorithm for the Detection of Dental Diseases and Differential Treatments," in *2022 IEEE 19th India Council International Conference (INDICON)*, IEEE, Nov. 2022, pp. 1–7. doi: 10.1109/INDICON56171.2022.10040109.
- [9] N. Hoanh and T. V. Pham, "Focus-Attention Approach in Optimizing DETR for Object Detection from High-Resolution Images," *Knowl. Based. Syst.*, vol. 296, p. 111939, Jul. 2024, doi: 10.1016/j.knosys.2024.111939.
- [10] S. Sharif, M. O. Ali, and Kamaruzzaman, "Bone Tumor Detection using Faster R-CNN," in *2024 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON)*, IEEE, Nov. 2024, pp. 23–26. doi: 10.1109/BECITHCON64160.2024.10962759.
- [11] L. He, Y. Zhou, L. Liu, W. Cao, and J. Ma, "Research on object detection and recognition in remote sensing images based on YOLOv11," *Sci. Rep.*, vol. 15, no. 1, p. 14032, Apr. 2025, doi: 10.1038/s41598-025-96314-x.
- [12] H. H. I. Alhussein and A. A. Mohammedbaker Qazzaz, "License Plate Detection and Recognition Using Faster RCNN," 2025, pp. 173–186. doi: 10.1007/978-981-97-7603-0_17.
- [13] I. Robinson, P. Robicheaux, and M. Popov, "RF-DETR [Computer software]."