ISSN: 2764-5886
e-ISSN: 2764-622X

Volume 9· N° 1 · January 2026

Journal of Bioengineering, Technologies and Health

An Official Publication of
SENAI CIMATEC

ISSN: 2764-5886 / e-ISSN 2764-622X

Volume 9 • Number 1 • January 2026

JOURNAL OF BIOENGINEERING TECHNOLOGIES AND HEALTH

An Official Publication of SENAI CIMATEC

EDITOR-IN-CHIEF
Leone Peter Andrade

PUBLISHED BY SENAI CIMATEC

January 2026
Printed in Brazil

JOURNAL OF BIOENGINEERING TECHNOLOGIES AND HEALTH

An Official Publication of SENAI CIMATEC

JOURNAL OF BIOENGINEERING TECHNOLOGIES AND HEALTH

Volume 9 • Number 1 **SUMMARY** *January 2026*

Original Articles

Systematic Review

The Journal of Bioengineering, Technologies and Health (JBTH) is an official publication of the SENAI CIMATEC University (Serviço Nacional de Aprendizagem Industrial - Universidade Centro Integrado de Manufatura e Tecnologia). It is published montly (January to December) in English by SENAI CIMATEC University – Avenida Orlando Gomes, 1845, Piatã, Zip Code: 41650-010, Salvador-Bahia-Brazil; phone: (55 71) 3879-5501. The editorial offices are at SENAI CIMATEC University.

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DOI:10.34178

ISSN: 2764-5886 / e-ISSN 2764-622X

COVER: Figure 3. SEM micrographs obtained for the Amazon River sediment sample. Potential Use of Amazon River Sediments in Civil Construction: Environmental and Socioeconomic Perspectives by Gleice Maria Araujo Ribeiro et al. J Bioeng. Tech. Health 2026;9(1):49.

A Bed-Management System Proposal for the Urgent and Emergency Care System of a Municipal Health Network in Brazil: Technical Proposal and System Architecture

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In many municipal networks, bed availability is still updated manually across non-interoperable systems, which causes delays, rework, and misallocation. This article presents a technical architecture and implementation blueprint for an Internet of Medical Things (IoMT)-enabled Emergency Medical Services (EMS) integrated real-time bed management system. Bed-mounted load cell sensors infer occupancy and temporary unavailability, reconcile these states with hospital information systems, and publish updates in real time to the bed management dashboard and to the Mobile Emergency Care Service (SAMU, Brazil's EMS). This replaces manual status calls and improves the accuracy and speed of bed availability communication. The approach aligns with the cybersociety and IoMT concepts and provides a continuous data stream for hospital quality indicators. In this proposal, the accumulation of data over time enables strategic analysis that supports resource optimization and continuous improvement in health services.

Keywords: Hospital Bed Management. Bed Allocation/Dispatch. Internet of Medical Things. Health Interoperability. Mobile Emergency Care Service.

Abbreviations: SAMU, Brazil's Mobile Emergency Care Service. EMS, Emergency Medical Services. ICU, Intensive Care Unit. PNHOSP, National Hospital Care Policy. SUS, Unified Health System. HIE, Health Information Exchange. NIR, Internal Dispatch Nucleus. NB-IoT, Narrowband Internet of Things. IoMT, Internet of Medical Things. API, Application Programming Interfaces.

Brazil's emergency and urgent care network is based on coordinated communication between mobile prehospital units such as the Mobile Emergency Care Service (SAMU), emergency medical dispatch and hospital networks. This coordination is prescribed by the National Hospital Care Policy (PNHOSP), which links entry points, emergency medical dispatch, and hospitals to organize access and bed occupancy within the Unified Health System (SUS) [1,2]. The destination of a critically ill patient is generally determined after the mobile unit contacts the medical dispatcher, who then consults the hospitals and checks the availability of beds. Hospital selection and prioritization are determined on a case-by-case basis depending on the type of emergency and hospital specialty. The heavy reliance on telephone calls and fragmented records leads to delays and rework, particularly when bed information is not updated promptly [3]. The health information exchange literature identifies the pre-hospital environment as a key area for data integration to reduce information gaps between the scene, the medical dispatcher, and the receiving hospital [4].

Within hospitals, creating Internal Dispatch Nuclei (NIR) to coordinate admissions, discharges, and surgical schedules has improved operational and care indicators and strengthened dialogue with medical dispatch centers [5]. However, inter-operability gaps between clinical and administrative systems and varying processes still limit visibility into real-time bed status and obstruct patient flow, especially in high-demand emergency departments [6]. These shortcomings delay destination decisions, extend waiting times at entry points, and create conflicts about receiving critically ill patients when occupancy is high. They underscore the need for digital solutions that continuously update bed availability, standardize information flows, and

Received on 10 October 2025; revised 28 December 2025.
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J Bioeng. Tech. Health 2026;9(1):1-8

integrate pre- hospital care, dispatcher, and hospital operations [3,4,6].

This paper proposes a real-time bed management system integrated into the municipal emergency and urgent care flow. The contributions are: (i) to outline a technical and organizational architecture focused on integration and automated bed status updates; (ii) to define interoperability and governance requirements aligned with PNHOSP; and (iii) to discuss how real-time data can shorten referral times, improve bed turnover, and ease overcrowding in emergency services [1-5].

Technologies in Emergency Medical Services

Internet of Medical Things (IoMT) encompasses clinical sensors, wearables, gateways, and interoperable platforms that connect prehospital settings (ambulances and medical dispatcher) to hospital environments such as emergency departments, urgent care units, intensive care units, and internal dispatcher nuclei (NIRs). In emergency medical services (EMS), IoMT supports early diagnosis and dispatch, navigation, and near real-time allocation of resources and beds[7]. Wearable and vital sign sensors, such as electrocardiograms (ECG), peripheral capillary oxygen saturation (SpO2), blood pressure, temperature, and capnography - enable continuous monitoring and issue alerts before hospital arrival. Prehospital transmission of 12-lead ECG within care pathways shortens revascularization times and improves outcomes in ST segment elevation myocardial infarction[8]. In hospitals, bed occupancy sensors and smart beds update bed management dashboards automatically, reducing under-reporting and human error [9,10].

The connectivity layer combines body area networks (WBAN) with low-power wide-area networks (LPWAN). Standards such as IEEE 802.15.6 and Bluetooth Low Energy are suitable for short-range, low-latency links on the patient's body, whereas LoRaWAN and NB-IoT extend coverage with high energy autonomy, useful for telemetry of assets and hospital infrastructure. Comparative studies indicate higher efficiency of 802.15.6 for WBAN use and advantages of LoRaWAN in range and power consumption [11]. Network design, however, must account for threats such as jamming and denial-of-service in LoRaWAN, applying specific countermeasures [12].

Interoperability depends on open standards capable of integrating prehospital and in-hospital care. HL7 FHIR, via RESTful APIs, standardizes the exchange of clinical resources; in the EMS context, NEMSIS structures prehospital care records and facilitates integration with emergency departments, regulation centers, and municipal data lakes [13,14]. Evidence from the literature on health information exchange and electronic health records suggests improved patient flow and operational indicators when information is available at the point of care [4 6,15].

To reduce latency and prioritize critical data, edge/fog-computing architectures perform local detection of events (such as arrhythmias and hypoxia) and offload the cloud, maintaining continuity of care during transport [16, 17]. Synchronous teleconsultation between field teams and specialists complements risk stratification, and unmanned aerial vehicles (drones) have been explored for delivering AEDs, blood products, and medications in hard-to-reach scenarios, provided they are integrated with CAD/AVL and regulatory requirements [18].

The expansion of this ecosystem increases the attack surface, requiring robust authentication, end-to-end encryption, key management, gateway hardening, secure firmware updates, and reliable audit trails, as highlighted by recent reviews on IoMT cybersecurity [19].

In Brazil, Ordinance No. 3,390/2013 (PNHOSP) designates the NIR as an institutional coordination body and the interface with medical dispatch centers, including bed management [20]. In practice, reliance on phone calls and outdated spreadsheets creates information asymmetry and delays in selecting the destination hospital. National studies show that coordination between medical dispatcher and bed management based on integrated information improves patient flow and critical time intervals [3,5]. In this context, IoMT contributes by automating bed status through sensing, exposing availability and constraints via FHIR-compatible APIs in near real time, transmitting prehospital clinical data (tele-ECG and vital parameters) to support risk classification and patient–specialty–resource matching, and integrating CAD/AVL with operational indicators (occupancy rate, length of stay, and turnover) [6].

This technical framework underpins data-driven regulation and supports this work's solution proposal, centered on integrating bed sensing, prehospital clinical telemetry, and interoperability via FHIR/NEMSIS in the context of the NIR and medical dispatch centers.

Emergency Care Systems in Brazil

Ordinance 3,390/2013 (PNHOSP) lays out guidelines for the hospital component of the Health Care Network and assigns the Internal Bed Regulation Unit (NIR) for centralized bed management and liaison with regulatory centers [21]. In emergency contexts, the success of this arrangement depends on reliable, timely information on bed availability and patient flow.

Well-implemented bed management systems optimize resource use, reduce waiting times, and improve care, affecting admissions, transfers, and discharges of critically ill patients [3]. A study in a Brazilian public university hospital found that the establishment of a NIR increased urgent and elective admissions, created norms and pathways for surgical patients, and improved bed planning, despite resistance to new routines [5].

Prehospital triage tools such as qSOFA, mRST, MEWS, and PRESEP do not identify all critically ill patients on their own, highlighting the need for integrated, real-time clinical and operational data to support decision making [22]. Governance analyzes note that regulatory frameworks are necessary but insufficient; Effective access to emergency care also requires metrics such as refusal rates, response times, and bed occupancy, and a robust information infrastructure for monitoring and transparency [23]. Integrating NIRs, regulation centers and prehospital services such as SAMU through interoperable real-time information systems is therefore a priority to equitably distribute demand, reduce delays and support clinical and logistical decisions [3,21].

Problems at the Regulation Interface

The interface where SAMU teams, regulation centers, and NIRs negotiate destinations, priorities, and beds suffers from information gaps and operational delays. Studies in municipal regulation centers reveal structural issues such as insufficient or inaccurate bed control, incorrect records, difficulties with SISREG, and breakdowns in the information flow between primary care and regulation [24]. These problems lead to delayed decisions, repeated requests, and loops that extend time to definitive care and increase queues at hospital doors.

Communication in the prehospital phase still relies mainly on voice channels, which are prone to noise and loss of context. SAMU services report frequent radio failures, inadequate operator training, and limited access to nursing coordination, all of which degrade the quality of clinical data used in regulation [25]. Lacking complete, standardized information, regulators can err on the side of caution (overtriage) or fail to identify hidden severity (undertriage), worsening the allocation of patients. Documentation and traceability of the regulatory process remain weak. Web-based regulation platforms in Brazil improve transparency and provide process indicators, but adoption can be uneven, leaving blind spots [26]. Our proposal aims to reduce delays and standardize data at the source, making supply and demand visible in real time. System-level interoperability between SAMU, NIR, hospital systems and SISREG is low, restricting automated exchange of operational and clinical data. The National Health Data Network (RNDS) uses the HL7 FHIR standard to define resources, profiles and APIs for secure clinical data exchange, offering a technical pathway to connect regulation with electronic health records and bed dashboards [27, 28]. Adoption remains uneven, and without adapter layers at the point of care, the standard does not yield data useful for minute-by-minute decisions.

These interface frictions manifest at hospital doors as crowding, access blocks and ambulance offload delays. Simplifying administrative tasks and accelerating discharge reduce the number of patients waiting in emergency departments and improve the connection between regulation and bed turnover [29]. The issue is thus less about absolute resource scarcity than about coordination and synchronising states across subsystems. Brazil's Urgent and Emergency Care Network already mandates integration between regulation complexes and entry points, with protocols and timely information as governance pillars [30]. Our proposal aligns with this framework by adding an integration layer linked to SAMU and NIR workflows that collects structured data at source (severity checklists, bed availability, temporary blocks), exposes them via FHIR-compatible APIs and supplies regulatory decision-making with operational telemetry (times, queues, refusals, occupancy). This reduces reliance on phone calls, free-text messages and manual records.

Proposed Solution

We propose an automated system that provides real-time availability of intensive care unit (ICU) beds to regulation centers and emergency medical services (EMS). A low-cost device attached to the hospital bed (a load cell in a simple waterproof enclosure) continuously infers bed occupancy and publishes state events. Operational categories follow Table 1 and are enriched through integration with clinical systems.

Architecture and Data Integration

Figure 1 shows narrowband Internet of Things (NBIoT) devices installed in beds transmit telemetry over licensed cellular networks directly to an Internet of Things (IoT) platform. The platform centralizes device identity and health management, data ingestion using message queueing telemetry transport (MQTT) and hypertext transfer protocol (HTTP), time series storage, rules and alerts, and exposes application programming interfaces (APIs) for upstream systems.

Regulation centers consume, through API, a consolidated real-time feed of bed availability and can issue actions through the platform, such as reserving a bed, triggering cleaning or linen services, or requesting device health checks. Communication with EMS is bidirectional: the regulation sends destination recommendations and receives prehospital status updates (en route, on scene, diversion). Where available, integrations with the hospital's Hospital Information System (HIS) or Electronic Medical Record (EMR) - admission, discharge, and transfer events and exam or procedure scheduling - or with the local bed management application enrich the interpretation of 'in movement', 'in transition' and 'discharged'. All traffic is encrypted and segregated via a private access point name (APN), keeping telemetry independent of the hospital's wired local area network (LAN) and providing a single source for dispatch, dispatch and audit across the network.

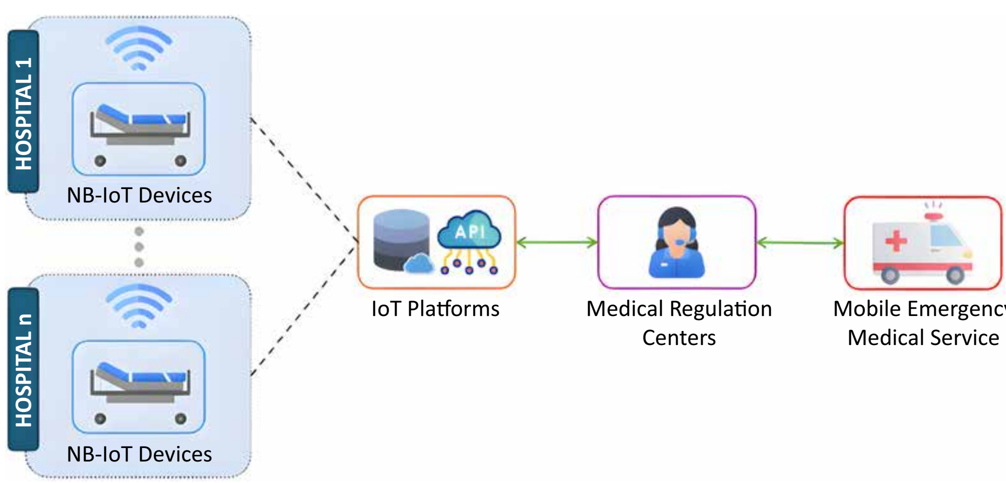
Connectivity

We adopted NB-IoT in licensed spectrum because it balances simplicity of deployment, total cost, and operational predictability in hospital environments. Unlike private LoRa/LoRaWAN (Long Range Wide Area Network) networks, the solution does not require the installation and maintenance of gateways, antennas or network servers, reducing capital expenditure (CAPEX) and technical complexity; each device only needs a NB- IoT module with SIM / eSIM to operate on the existing carrier infrastructure. Compared with a wired local area network, it avoids new Ethernet drops and switch ports per bed, as well as construction work and reconfiguration whenever beds are relocated (a common ICU practice), while also reducing exposed cabling,

Table 1. Improved bed statuses.

Code	Status	Description
0000	Out of service	Device communication failure.
0001	Occupied	Bed currently being used by a patient.
0010	Vacant	Bed is suitable for use and is not currently occupied by a patient.
0011	Reserved	Reserved bed.
0100	Patient out for procedure	Bed is empty, but the patient is undergoing a procedure or exam away from the bed.
0101	Patient in transfer	Patient is being transferred to another hospital ward. Bed will be available soon.
0110	Patient discharged	The patient has been discharged. Bed will be available soon

Figure 1. Architecture overview showing bed sensing and data integration



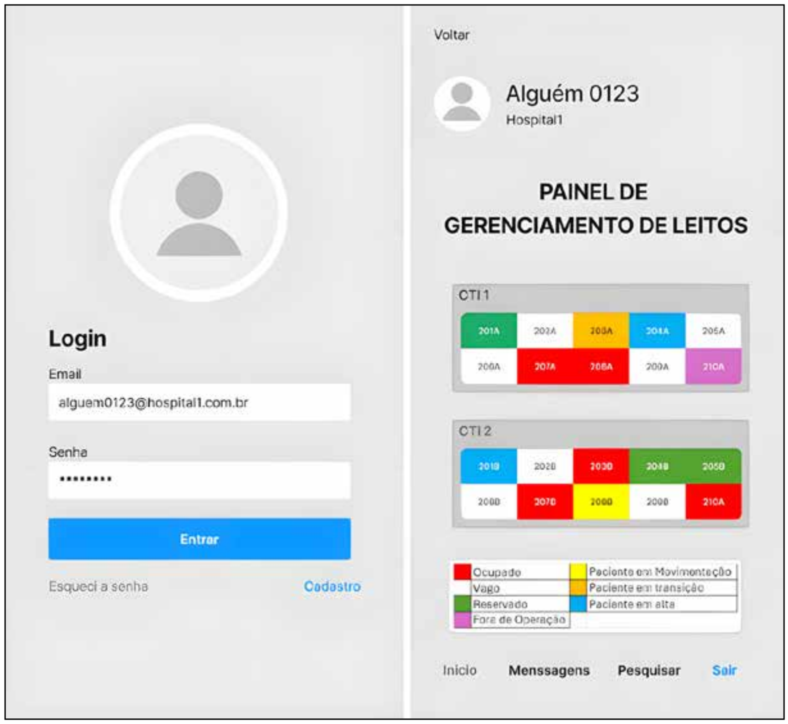
which benefits hygiene and electrical safety. Operationally, telemetry remains independent of the hospital's internal LAN, minimizing the impact of LAN maintenance or incidents and simplifying multhospital governance. Traffic is encrypted and segmented through a private APN, reducing the attack surface of the clinical network (HIS / EMR) and strengthening logical isolation. Connectivity costs shift to operational predictable (OPEX) per device, well-suited to the low-volume, periodic messaging profile of bed telemetry, while licensed indoor coverage under carrier management improves reliability in complex areas.

Operational Orchestration

The local dashboard (Figure 2) displays occupancy and movements in real time, flags device faults, highlights above normal movement or transition times, and, after discharge, automatically triggers cleaning and linen services to prepare the bed.

In the central repository, the regulation sees a consolidated view of availability and receives destination recommendations based on availability, distance, and specialty. Upon confirmation, the system notifies the selected hospital to reserve the

Figure 2. Local bed management dashboard.



bed and anticipate emergency provisions (staff allocation and equipment preparation), reducing phone calls and door-to-ICU time.

<u>Indicators and Continuous Improvement</u>

Two main axes are recommended. Flow and access (Dispatch/EMS): bed confirmation time, door-to-ICU time, reservation diversion or cancelation rate, and adherence to system recommendations. Capacity and efficiency: ICU occupancy, bed turnover, length of stay (median and tail), bed turnaround time after discharge, and nonclinical unavailability. Stratify by hospital, unit, and shift and set targets with dashboard alerts to enable rapid adjustments.

Conclusion

The implementation of automated systems for ICU bed management represents a significant advance in the efficiency of health services, particularly in urgent and emergency contexts. The proposal described in this article offers a low-cost and robust solution capable of automating bed status updates, reducing reliance on manual interventions, and minimizing delays and errors in patient care coordination. Furthermore, the centralization of data in a single system, accessible to SAMU's regulatory physicians, eliminates the need for manual verifications and phone calls, optimizing bed allocation and accelerating the availability of specialized resources.

Although this work presents an innovative technical architecture, the absence of empirical results is acknowledged as a limitation that reduces the robustness of the discussion. As next steps, laboratory prototypes will be developed to validate load cell measurement accuracy, NB-IoT transmission reliability, and integration with hospital information systems. In parallel, computational simulations of bed occupancy and regulation scenarios will be conducted to evaluate reductions in response time and the expected impact on operational indicators.

Additionally, case studies in collaboration with hospitals and regulation centers will enable pilot implementations at small scale, allowing the collection of practical metrics such as bed confirmation time, divergence rate, door-to-ICU time, and effects on occupancy rate. A qualitative validation process with SAMU regulatory physicians and hospital managers is also planned, through structured interviews and surveys, to assess the applicability and acceptance of the proposed solution.

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Study of Compressive Strength and Water Absorption in 3D Printed PLA Scaffolds for Bone Regeneration

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This work investigates the use of polylactic acid (PLA) scaffolds manufactured by 3D printing (FDM) for bone tissue engineering, in order to overcome the limitations of treatments for bone defects. The aim was to evaluate the influence of different extrusion temperatures (180°C and 200°C) and filling rates (40%, 60% and 80%) on the water absorption and compressive strength of the structures. For this purpose, PLA scaffolds were printed and subjected to water absorption (ASTM D570) and compressive strength tests (ASTM D695-10). The results showed a clear inverse correlation between the properties: increasing the filler increased the mechanical strength but reduced the water absorption capacity. Scaffolds with 40% filler showed the highest absorption (up to 90.48%), while those with 80% exhibited the highest strength and lowest absorption (10.69%). The temperature of 200°C promoted a slight increase in mechanical strength due to better fusion between the layers. It is concluded that adjusting the printing parameters allows the properties of scaffolds to be modulated, balancing mechanical support and functional porosity to optimize performance in specific biomedical applications.

Keywords: Tissue Engineering. Bone Regeneration. Scaffolds. FDM.

Abbreviations: PLA, Polylactic acid. FDM, Fused Filament Deposition. WE, Wet Sample. WD, Dry Sample. ASTM, American Society for Testing and Materials.

The high incidence of bone defects caused by infections, tumors and bone loss due to trauma, which significantly affect patients' quality of life and impact society as a whole, means that bone tissue is more commonly used for transplantation and treatment of bone defects worldwide [1]. This tissue is metabolically active and, depending on the defect, is capable of selfhealing without surgical intervention [2], as it is made up of collagen, the mineral hydroxyapatite, a mixed organic component (type 1 collagen, lipids and non-collagenous proteins) and water [1-4]. However, studies show that larger bone defects require invasive surgical intervention to aid the healing process. To overcome these challenges, tissue engineering has advanced in studies aimed at developing scaffolds produced from biomaterials by 3D printing, with the aim of helping to regenerate bone tissue [2-5]. Tissue engineering depends on understanding the biological mechanisms that regulate cell proliferation and differentiation, and the use of scaffolds is fundamental for providing structural and functional support to cells in this process. Conventional scaffold manufacturing techniques have limitations in terms of the precision of pore size and geometry, as well as interconnectivity and mechanical strength. 3D printing has emerged as a promising technique, enabling the production of complex biomimetic structures with high precision. Advanced 3D printing strategies make it possible to manufacture platforms ranging from the millimeter to the nanometer scale, although production time increases as the complexity of the project grows. 3D structures can be created, called scaffolds, capable of mimicking the extracellular matrix, promoting an ideal microenvironment for cell

Received on 5 October 2025; revised 20 December 2025.
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J Bioeng. Tech. Health 2026;9(1):9-14

adhesion, proliferation and differentiation, with the potential to form functional tissues [4,5]. The ideal scaffold for bone fracture recovery must be produced from a bioactive, biodegradable, biocompatible biomaterial with adequate mechanical strength for the implantation site and osteogenic potential. One of the successful polymers to meet these properties is the use of polylactic acid (PLA). PLA is a thermoplastic, biocompatible and biodegradable biopolymer, widely used in biomedical applications for tissue regeneration and controlled drug release. It also has low elasticity and high tensile strength. However, it is hydrophobic, non-bioactive and has a low degradation rate [1-3]. The main objective of this research is to present a study on the use of PLA in the manufacture of scaffolds by 3D printing, intended for application in injured or fractured bone tissue, using two melting temperatures (180 °C and 200 °C) in order to evaluate the influence on the formation of the scaffolds and three filling rates (40, 60 and 80%) in order to study the influence on the rate of water absorption and compressive strength.

Materials and Methods

For the production of the scaffolds, we used polylactic acid (PLA) filament, purchased from 3D Slim Tecnologia Comercio de Equipamento, with a density of 1.24 g/cm^3, a melting temperature of 185 °C and a glass transition temperature (Tg) of 60 °C.

Scaffolds Design and Printing

The scaffolds were designed using 3D modeling software (CAD) with dimensions of 10×10 mm. The internal filling pattern selected was zigzag. The model file was then exported in STL format and processed in Ultimaker Cura slicing software. The specimens were additively manufactured on a Creality CR-10 3D printer using the Fusion Deposition Modeling (FDM) technique. During printing, the table temperature was kept constant at 50 °C and the printing speed was set at 50.0 mm/s. Two nozzle extrusion temperatures were tested, 180 °C and 200 °C, and three different fill rates: 40%, 60% and 80%.

Water Absorption Test

The water absorption test was carried out in triplicate for each group of samples according to ASTM D570. The specimens were immersed in water at a temperature of 24 °C for a period of 48 hours. The absorption capacity was calculated as the ratio of the difference between the weight of the wet sample (Ww) and the weight of the dry sample (Wd), and the weight of the wet sample, shown in Equation 1.

$$Water\ absorption\ (\%) = \frac{W_w - W_d}{W_w} \times 100\% \qquad (1)$$

Compression Resistance Test

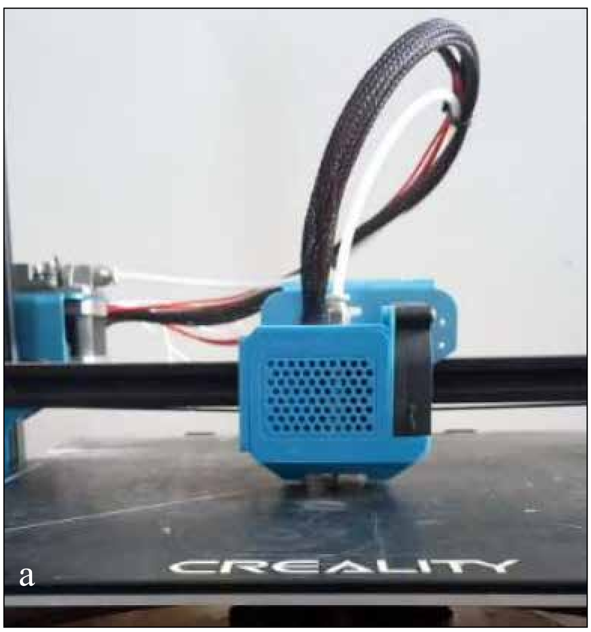
The mechanical properties of the scaffolds were assessed using compression tests in accordance with ASTM D695-10. The tests were carried out on an EMIC universal testing machine, model DL10000, equipped with a 10 kN load cell. The load application speed during the test was 1.0 mm/min. The results were analyzed in order to correlate the maximum stress withstood and the relative deformation with the different printing parameters (temperature and filling percentage).

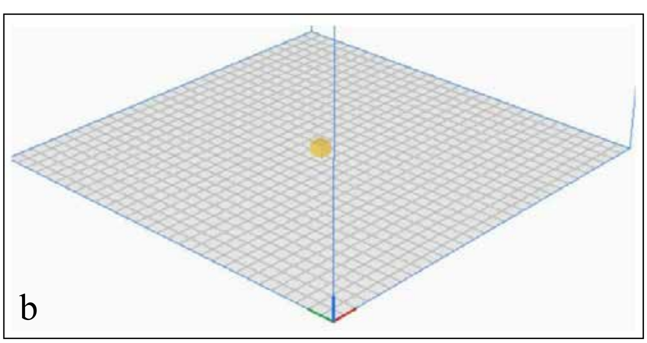
Results and Discussion

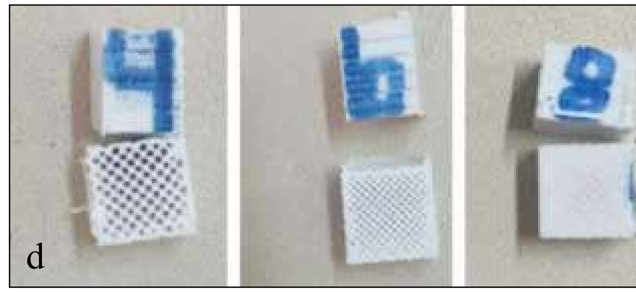
Scaffolds Printing

The three-dimensional images generated in the slicing software allowed a detailed spatial analysis of the geometry designed in all directions and planes. The qualitative evaluation indicated that the spatial architecture modeled for the samples was reproduced with high fidelity during most of the manufacturing process. However, it was observed that the upper layers tended to "close" the pores. To guarantee the functionality of the scaffold, which depends on a porous and interconnected structure, the printing process was intentionally interrupted when it reached between 90% and 94% of its completion, thus preserving the desired architecture (Figure 1).

Figure 1. Printer producing the specimens (a), image of the Ultimaker Cura during slicing (b), the parts with 40%, 60% and 80% printed at .180°C (c) and 200°C (d)





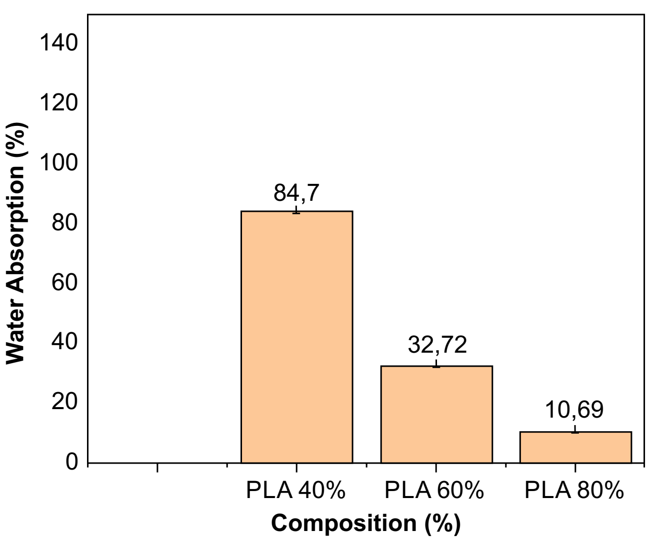


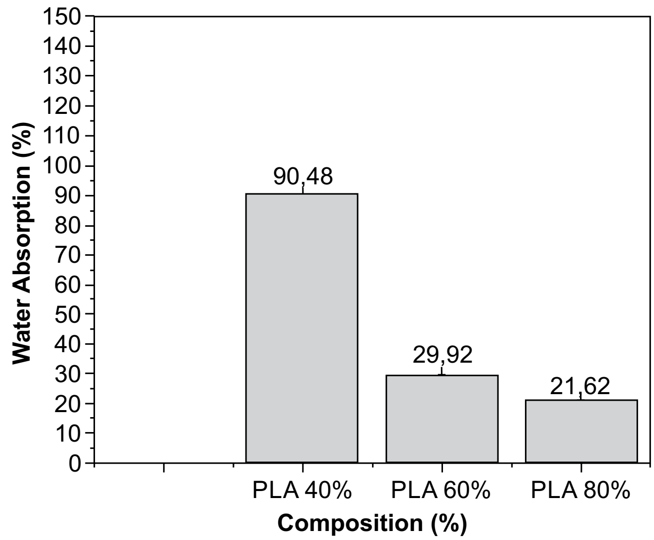
Water Absorption Tests

The water absorption test is essential for assessing a scaffold's potential to interact with the biological environment, influencing cell adhesion and nutrient transportation. Figure 2 shows the results of this test, graphically illustrating how varying the percentage of filler and the printing temperature impacted on the water retention capacity of PLA scaffolds.

Analysis of the water absorption tests showed a inverse correlation between the percentage of filling and the water absorption capacity. The scaffolds with 40% filling, the lowest density tested, had the highest average water absorption values, registering 84. 7 ± 0, 59% for the 180°C temperature and 90. 48 ± 0, 41% for 200°C. This behaviour is to be expected, since a lower fill density results in greater internal porosity and a more significant volume of interconnected voids, maximizing the surface area available for interaction with water and, consequently, its retention. As the filling percentage increases to 60% and 80%, water absorption progressively decreases, as evidenced by the values of 32. 72 ± 0, 46% and 10. 69 ± 0, 34% and 29. 92 ± 0, 35% and 21. 62 ± 0, 48%, at 180°C and 200°C, respectively. The increase in material density creates more compact structures, with a smaller pore volume and less accessibility to water penetration, which naturally restricts capillarity and reduces water retention capacity. The influence of printing temperature was also observed, as scaffolds printed at 200°C generally showed slightly different absorption than those produced at 180°C. This can be attributed to better cohesion and fusion between the layers at

Figure 2. Percentage of water absorption of scaffolds printed at: (a) 180° C and (b) 200° C.





higher temperatures, which can alter the surface roughness and internal morphology of the pores, influencing the interaction with water. Just as fill density has been shown to be a determining factor for mechanical properties [6-7], it is clear that this same structural parameter dictates physical properties, such as fluid absorption.

Compressive Strength Test

Figures 3 and 4 show the test being carried out on the scaffolds and the visual aspect after the test, allowing a qualitative analysis of the deformation and failure mode of the structure, which complements the quantitative stress and strain data.

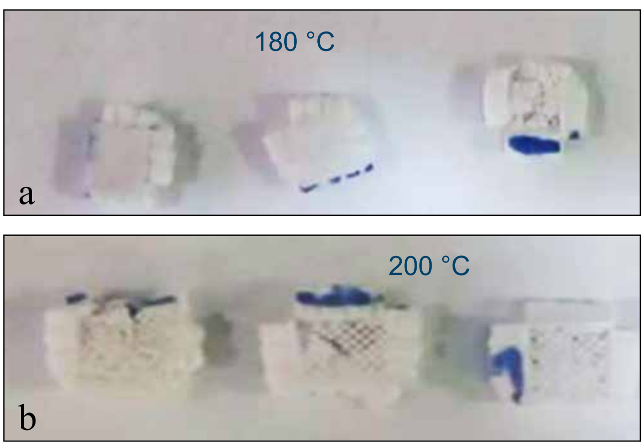
The results obtained showed that the compressive strength of PLA scaffolds increased significantly with the increase in the percentage of filler, ranging from 40% to 80%, as pointed out by works such as Dave and colleagues (2019) [6] and Silva and colleagues (2019) [7], the density of filler is one of the most influential parameters in the mechanical behavior of parts manufactured by FDM. A higher percentage of filler results in a more solid internal structure with a smaller volume of voids, giving greater rigidity and, consequently, a greater capacity to withstand compressive loads [8,9].

Figure 5 shows a comparison of the results between compression tests for PLA scaffolds. The bars represent the Maximum Stress supported by each specimen, while the line indicates the Relative Deformation at Maximum Stress. The nomenclature of the samples on the horizontal axis specifies the percentage of fill (A4 = 40%, A6 = 60%, and A8 = 80%) and the printing temperature (180°C or 200°C).

Analysis of the compression test graph (Figure 5) shows that the maximum stress values increased progressively as the fill went from 40% to 80%. For the samples printed at 200°C, the maximum stress was noticeably higher in the parts with 80% fill compared to those with 40% and 60%. This behavior is crucial for bone tissue engineering, where scaffolds must offer mechanical support similar to bone tissue in order for there to be adequate cell regeneration. The ability to modulate mechanical strength by adjusting the filler, as demonstrated, is essential for mimicking the properties of specific tissues, such as trabecular bone, as discussed by Baptista and Guedes (2021) [10]. The influence of printing temperature, a critical parameter in additive manufacturing, proved to be complex. The data obtained suggests that the extrusion temperature of 200°C favored the integrity of the layers, resulting in slightly higher mechanical strength values compared to

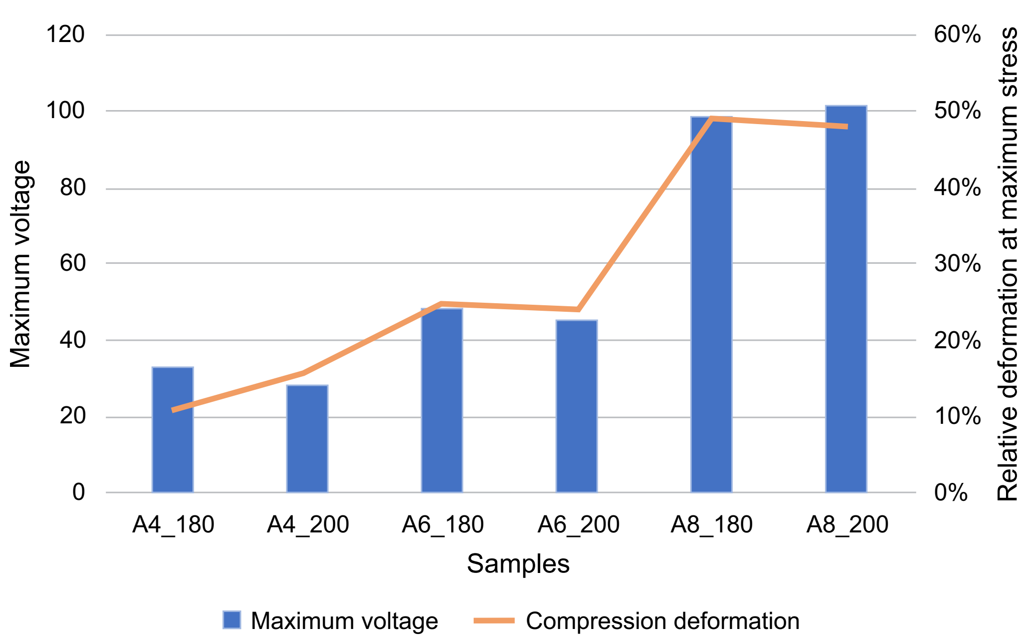
Figure 3. Compressive strength test of scaffolds.

Figure 4. Samples after the compression test: (a) 180 °C e (b) 200 °C.



180°C. This phenomenon is attributed to better fusion between the filaments, which reduces voids and improves adhesion between the layers, a behavior validated by Baptista and Guedes (2021) [10] in their studies. However, the same authors warn that excessively high temperatures can compromise the dimensional accuracy of the part, which reinforces the observation that this parameter must be strictly controlled to guarantee both the mechanical stability and geometric fidelity of the scaffold. It is important to note the inverse correlation observed between the compression and water absorption results. The data shows that the scaffolds with the lowest filling (40%), which had the lowest compressive strength, were the ones with the highest water absorption capacity (up to 90.48% at 200°C). On the other hand, the scaffolds with 80% filling, which withstood the highest compressive stress, showed the lowest rate of water absorption (10.69% at 180°C). This inverse relationship is a direct consequence of the microarchitecture of the scaffolds, which is dictated by the percentage of filling. A structure with high porosity (low filling) has a large volume of interconnected voids, which facilitates the penetration and retention of fluids, but at the same

Figure 5. Comparative graph of the compression test results for PLA scaffolds.



time represents a structural discontinuity that reduces the ability to withstand mechanical loads. Conversely, a dense structure (high fill) offers greater integrity and cross-sectional area to resist compression, but has fewer pores available for water absorption. Applications that require high load-bearing may need denser scaffolds, while applications that prioritize maximum cell-material interaction and nutrient transport may benefit from greater porosity, albeit with lower mechanical strength. The ability to modulate this balance by adjusting printing parameters, such as filling, is one of the main findings of this work and is in line with the literature exploring the customization of scaffolds for biomedical purposes [7,9,10].

Conclusion

Based on the results, it can be concluded that the filling percentage of scaffolds has an inverse influence on water absorption and compressive strength. Structures with less filling (40%) showed greater porosity and, consequently, greater water absorption, but lower mechanical strength. On the other hand, denser scaffolds (80%) had lower absorption capacity and higher compressive strength. The printing temperature also affected performance, with 200 °C favoring a slight increase in mechanical strength. These findings reinforce the importance of adjusting the filler and printing temperature to balance mechanical and absorption properties, according to the specific demands of biomedical applications.

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Ecotoxicological Evaluation of Aquatic Environment Contamined by Diesel and Biodiesel Using *Daphnia similis* as Test Organism

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This study aimed to evaluate the ecotoxicity of an aquatic environment contaminated with Diesel S10 and Biodiesel B100, using *Daphnia similis* as the test organism. For this purpose, ecotoxicological tests were performed based on the ABNT NBR 12713 standard, during which the Daphnia were exposed to different test solutions of the fuels for 24 and 48 hours. The results demonstrated that exposure to Diesel S10 caused significantly more severe effects than exposure to Biodiesel B100. These data highlighted that Diesel S10 has a higher toxic potential in aquatic environments than Biodiesel B100.
Keywords: Ecotoxicity. Diesel. Biodiesel. *Daphnia similis*.

Due to the growing energy demand, the use of fossil fuels, such as diesel, has intensified. However, the high cost of these fuels and their significant environmental impacts have driven the search for cleaner and more sustainable alternatives [1]. The continued use of these fuels raises concerns about their environmental impact, affecting both the atmosphere and the flora and fauna. In this context, aquatic ecosystems are particularly vulnerable to contamination, whether from pollutants emitted through engine exhausts or from fuel spills during maritime transport [2,3].

Fossil fuels, particularly diesel, which is widely used in maritime transport, can have serious environmental impacts on aquatic ecosystems. Diesel contains chemicals that, when released into the environment, can degrade water quality, compromising not only the ecological balance of bodies of water, but also the health of the species that inhabit these environments [4]. The impact on water quality after a diesel spill may be related to the presence of polycyclic aromatic hydrocarbons (PAHs), known for their high toxic and carcinogenic potential. The severity of this impact varies according to the solubility of PAHs in water: low molecular weight PAHs are more soluble and volatile, while high molecular weight PAHs are more persistent in the marine environment [4,5].

In this context, fuels derived from renewable sources are gaining prominence due to their lower environmental impact. Biodiesel has emerged as a more strategic alternative to minimize the impacts caused by the use of fossil fuels, highlighting a possible rapid degradation of its components in an aqueous medium and has become an increasingly adopted option [1,6]. It's crucial to assess the impact of fuels of this nature to mitigate the possible adverse effects they may cause in aquatic environments.

Thus, ecotoxicological tests have proven to be extremely useful for investigating spills in aquatic environments. They allow for a more detailed analysis of the impacts, with emphasis on the use of Daphnia as an effective bioindicator [2,7].

Therefore, ecotoxicological tests with Daphnia are highly significant, since these organisms are widely used to assess toxicity and water quality. Daphnia are microcrustaceans of the order Cladocera, with sizes ranging from 0.5 to 5.0 mm, and are widely used in ecotoxicological tests due to their ease of cultivation and accessibility. Among the species used, *Daphnia magna* and *Daphnia similis* are the most common. It should be noted that *Daphnia similis* is particularly

Received on 18 October 2025; revised 28 December 2025.
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J Bioeng. Tech. Health 2026;9(1):15-20

suitable for tropical climates, where it adapts well to environmental conditions [8].

In this context, this study sought to evaluate the toxicity of an aquatic environment contaminated by diesel and biodiesel, using *Daphnia similis* as a test organism.

Materials and Methods

The method employed in this study involved conducting acute ecotoxicological tests with *Daphnia similis*, adhering to the guidelines outlined in standard NBR 12713 (Aquatic Ecotoxicology — Acute Toxicity — Test Method with Daphnia spp) [9]. The test fuels comprised pure Diesel S10 and Biodiesel B100.

For each fuel, a contaminated solution (effluent) was prepared by mixing 10 microliters of the fuel with 100 mL of the organisms' culture medium.

The purpose of preparing this effluent was to simulate a fuel spill scenario in an aquatic environment. Following the standard's guidelines, five test solutions (doses) were created, each with a specific concentration of the contaminated solution, to assess the toxicity of S10 and B100 on Daphnia. These concentrations were determined based on preliminary analyses involving the exposure of Daphnia to various fuel levels.

The test doses were prepared using the successive dilution method (Figure 1), which involves diluting the most concentrated solution by 50% in the culture medium, starting from the previous dose to create progressively lower levels of contamination. Consequently, the test solutions for Diesel S10 ranged from 0.00024% to 0.000015%, while those for Biodiesel B100 ranged from 0.00012% to 0.0000075%.

Thus, the test with *Daphnia similis* was conducted with 24-hour and 48-hour exposure periods, under the temperature (18 to 22°C), pH (7 to 7.6), and photoperiod (16 hours light/8 hours dark) conditions specified by the standard. In this setup, the test was performed in triplicate, with each replicate containing 10 organisms and 50 mL of the test solution (Figure 2), along with triplicate controls using pure culture solution.

As a supplementary analysis of the ecotoxicological test involving *Daphnia similis*, the calculation of the EC50 (Median Effective Concentration) was performed. EC50 estimates the concentration required to cause an adverse effect (immobility and mortality) in 50% of the exposed organisms. This determination was made using the Trimmed Spearman-Karber (TSK) statistical model, which generates a dose- response curve based on empirical values within the range of the tested solutions. The model assesses the extreme high and low effects, disregards these points, and estimates the EC50 based on the intersection of the resulting curve. Notably, in this study, the model was implemented using the RStudio software, using the drc package, specifically developed for

Figure 1. Preparation of test solutions.

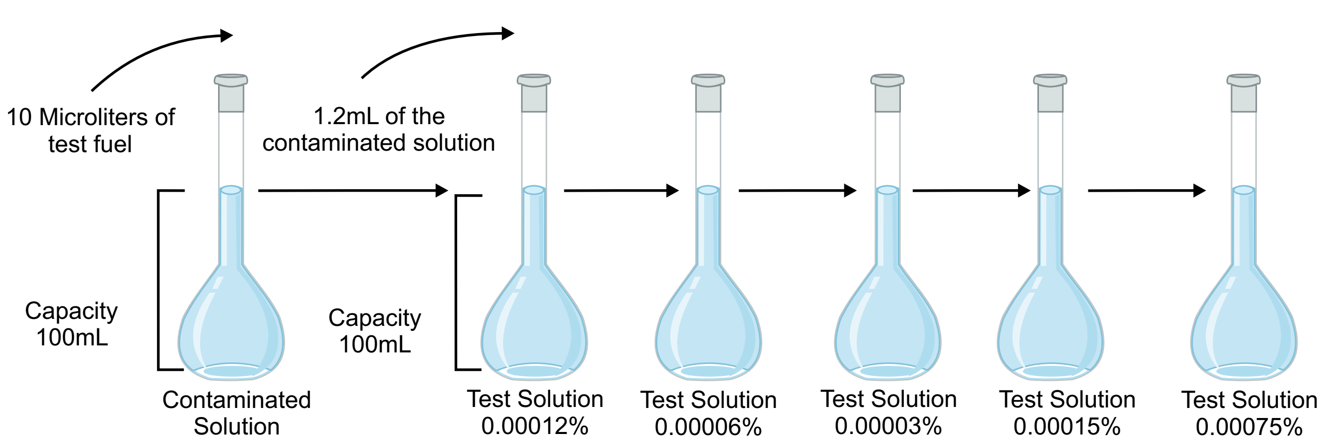
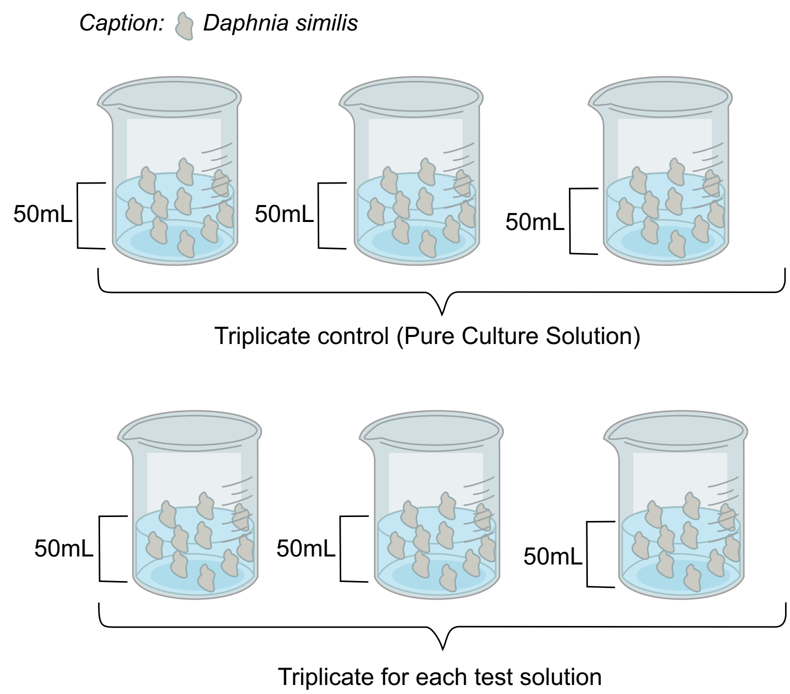


Figure 2. Acute ecotoxicological test design.



non-linear regression and dose-response analyses in ecotoxicological data.

Results and Discussion

The results presented in this section detail the effects observed in *Daphnia similis* after 24 and 48 hours of exposure (Figures 3 and 4). These findings illustrate the behavior of the organisms during the experiment with different concentrations of the contaminated solutions of Diesel S10 and Biodiesel B100.

The results highlight that the effects observed in organisms exposed to Diesel S10 were more severe compared to those exposed to Biodiesel B100. According to Müllerand colleagues (2019) [10], the water-soluble fraction of diesel was found to be more toxic than that of biodiesel when assessed with *Daphnia magna*, leading to marked reductions in reproduction, longevity, and growth. These findings align with the present results, where Biodiesel B100 showed a lower toxic effect compared to Diesel S10, reinforcing its reduced ecotoxicological potential.

<u>Specifically, Daphnia exposed to Diesel</u>

S10 exhibited 100% immobility within 48 hours at concentrations ranging from 0.00006% to 0.00024%. In contrast, exposure to Biodiesel B100 resulted in immobility only at higher concentrations, without reaching 100% immobility even at the highest concentration of 0.00012%. This indicates that Diesel S10 has a higher toxic potential compared to Biodiesel B100, impacting the organisms more significantly and rapidly. However, it is crucial to evaluate the toxicity of these substances at various dilutions to understand their contamination profile in aquatic environments in spill scenarios.

In this context, the immobility data from the assay were analyzed using RStudio software to calculate the EC50 for each fuel (Figures 5 and 6), for the established exposure periods. This process was essential for assessing and confirming the toxicity of these substances based on the observed effects in the experiment.

Based on the results, the EC50 (48 hours) for Diesel S10 was identified to be between

Figure 3. Results for Diesel S10 Test Solutions in *Daphnia similis*: a) 24h, b) 48h.

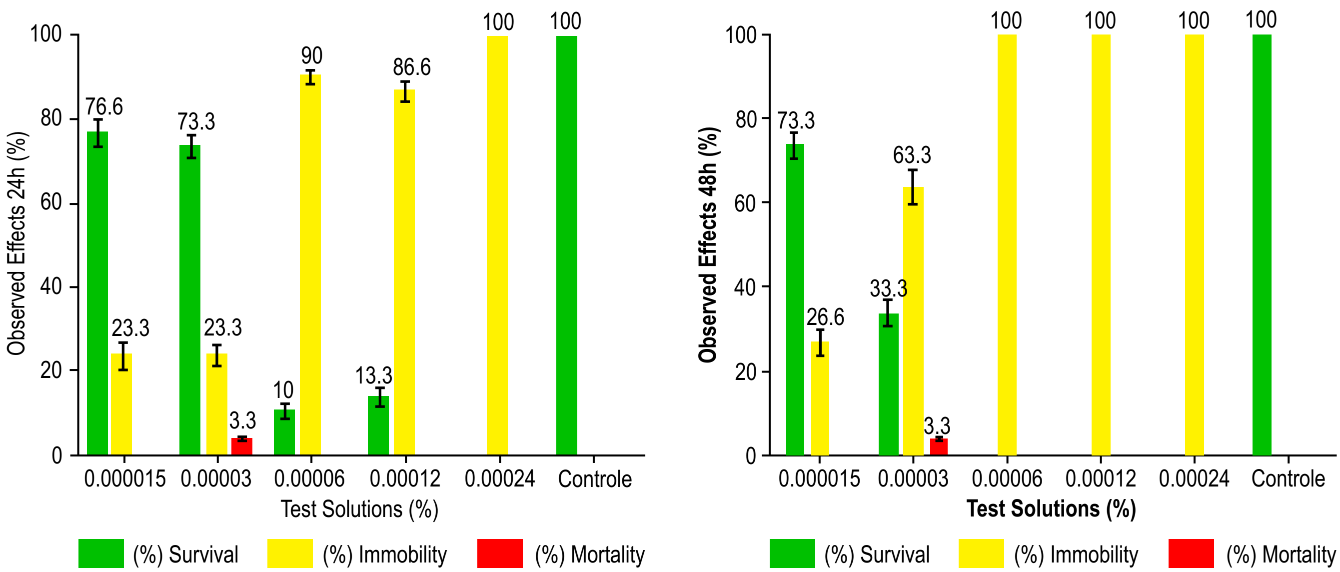
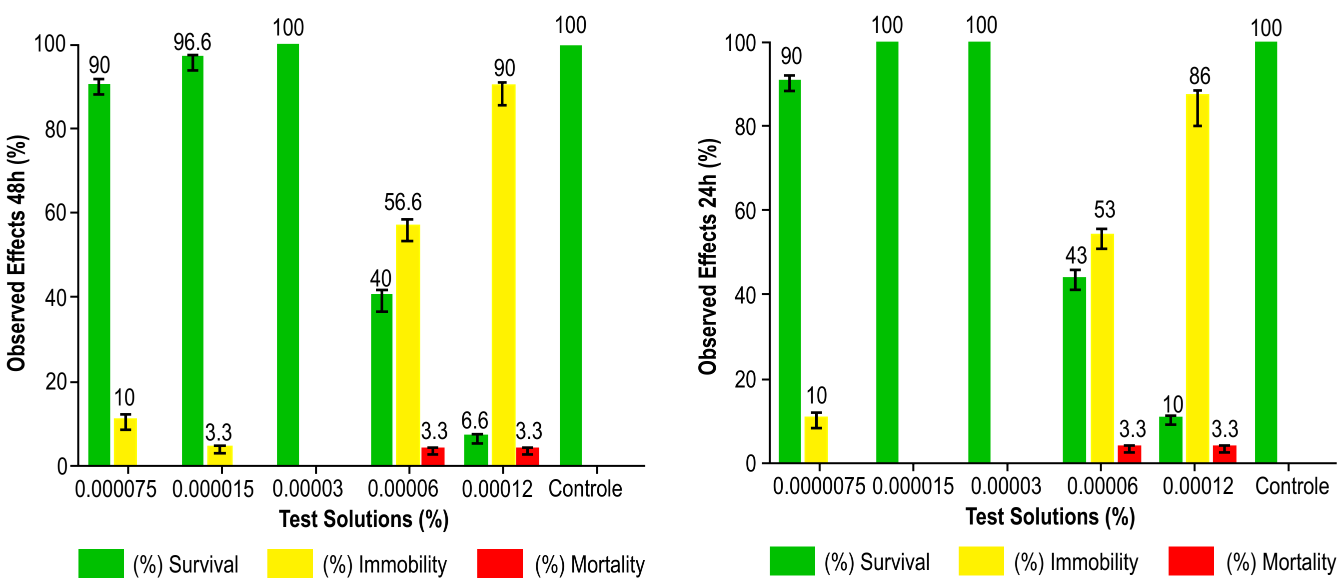


Figure 4. Results for biodiesel B100 test solutions in *Daphnia similis*: a) 24h, b) 48h.



0.000015% and 0.00006%, while for Biodiesel B100, it ranged from 0.00003% to 0.00006%. These findings align with the observed effects in the experiments, showing that the lower EC50 for Diesel S10 is associated with its higher toxicity in aquatic environments, as it impacts organism health at lower concentrations. This analysis is illustrated by the dose-response curves, where the curve for Diesel S10 is steeper, indicating a faster effect on Daphnia. In contrast, Biodiesel B100 takes longer to affect the organisms, suggesting lower toxicity in aquatic settings.

This work emphasized the calculation of EC_{50}, a parameter that reflects the concentration required to impair mobility in half of the exposed *Daphnia similis*. However, determining LC_{50} in parallel could provide complementary insights, as it specifically quantifies lethality. Including both

Figure 5. EC50 Results for Diesel S10 in *Daphnia similis*: a) 24h, b) 48h

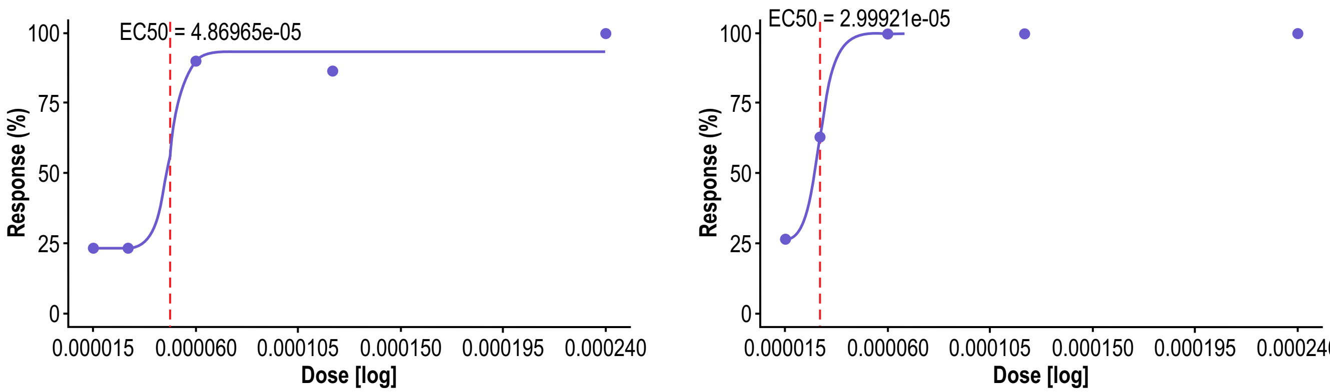
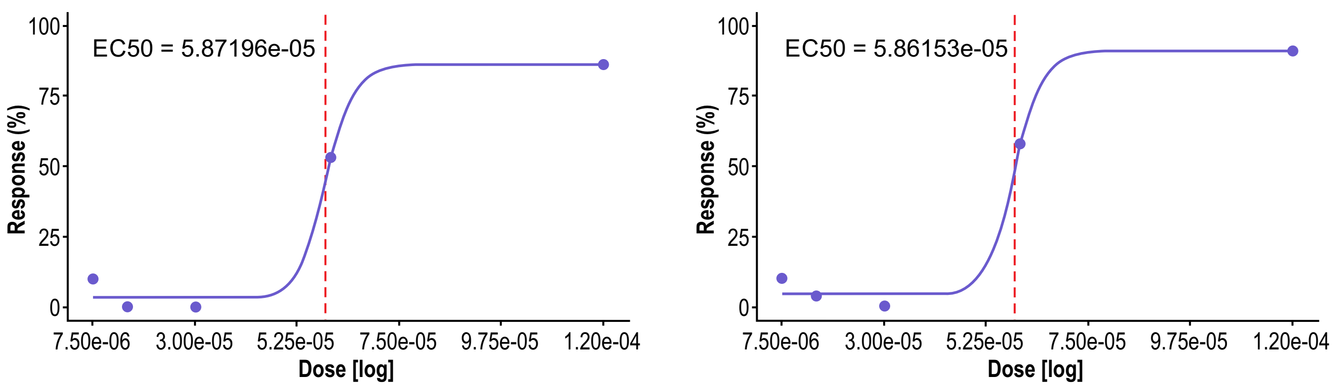


Figure 6. EC50 Results for Biodiesel B100 in *Daphnia similis*: a) 24h, b) 48h



endpoints in future assessments would strengthen the reliability of ecotoxicological studies and enable a broader understanding of acute fuel toxicity.

Conclusion

The results of this study revealed significant differences in the toxicity of the culture medium solution for *Daphnia similis* contaminated with Diesel S10 and Biodiesel B100. The analyses demonstrated that Diesel S10 has a considerably higher toxic potential, leading to complete immobility of the organisms within the first 48 hours of exposure to test solutions ranging from 0.00006% to 0.00024%. In contrast, Biodiesel B100 showed a less pronounced toxic effect, requiring higher concentrations to induce immobility.

These findings are supported by the EC50 calculations, which indicated a significantly lower EC50 value for Diesel S10 compared to Biodiesel B100. This reinforces the conclusion that Diesel S10 may pose a higher toxicity risk in aquatic spill scenarios, consistent with the existing literature. The study also highlighted the need for further research with various dilutions and experimental conditions to gain a deeper understanding of the contamination profiles and the potential ecotoxicological risks associated with these fuels.

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Sustentoy: A Pedagogical Manual for Building Toys with Recyclable Materials

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This study investigates the impact of a pedagogical activity involving the construction of toys from recyclable materials on the development of socioemotional and cognitive skills, with a focus on consolidating soft skills among high school students in technical education. The main objective was to stimulate creativity, teamwork, concentration, problem-solving, and manual dexterity through interdisciplinary workshops aligned with educational guidelines emphasizing sustainability and student protagonism. A descriptive quantitative method was used, with data collected via questionnaires administered to first-year technical students during integrated workshops. The activity involved collaborative prototyping of sustainable toys, combining discussions on environmental awareness with practical tasks focused on planning, designing, and assembling products from discarded materials. Results indicated promotion of creativity, improvement in motor coordination, and enhancement of social sensitivity, as students collaborated effectively and adapted to challenges during toy construction. The project strengthened responsibility, engagement, and teamwork while fostering empathy and reflection on sustainable practices. Some students showed difficulty maintaining focus, suggesting the need for adjustments such as dividing tasks into smaller stages and incorporating reflective pauses. Overall, participants expressed motivation to engage in future projects, demonstrating the effectiveness of manual, creative, and cooperative practices for fostering socioemotional competencies. These findings highlight the value of experiential, interdisciplinary approaches for strengthening soft skills, promoting environmental education, and preparing students to face contemporary societal challenges in line with the Brazilian National Common Curricular Base (BNCC).

Keywords: Creativity. Soft Skills. Environmental Education. Collaborative Learning. Motor Skills.

In the context of the New High School (NEM), there is a growing demand for active methodologies that promote student protagonism and the integral development of students [1]. However, many technical education students still face challenges related to the lack of stimulation of creativity, concentration, teamwork, and the development of fine motor skills, especially in more theoretical courses or those excessively mediated by screens [2,3].

The school routine, often centered on content-heavy and digital materials, tends to reduce the space for practical, collaborative, and creative experiences that integrate different knowledge and skills [1,2,4].

Received on 28 October 2025; revised 15 December 2025.
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J Bioeng. Tech. Health 2026;9(1):21-25

The World Health Organization highlights that children and adolescents should spend less time sitting and more time engaged in playful and active experiences, benefiting their physical, cognitive, and socioemotional development [5].

In this scenario, the Sustentoy project proposes the creation of sustainable and recyclable toys, aimed at technical education students, as an interdisciplinary learning tool. The proposal seeks to encourage creativity, collaboration, and environmental awareness, while developing practical and psychomotor skills through the construction of toys made with recyclable materials. This approach allows the integration of knowledge areas such as Arts, Science, Environment, and Technology, promoting a more active and meaningful experience in the teaching-learning process [6,7].

These proposals are also in line with the updated version of the Brazilian National Common Curricular Base, which emphasizes competencies such as responsibility, empathy, and critical thinking [1,8]. This approach also responds to the demands of the Fourth Industrial Revolution, which requires education to develop adaptable, creative, and technology-integrated skills [9].

Sustentoy is based on the guidelines of the National Common Curricular Base (BNCC) and the formative itineraries of the New High School, allowing the customization of activities according to students' interests and the possibilities of the school context. The toy construction will be carried out collaboratively, stimulating teamwork, creative reasoning, and reflection on sustainability, conscious consumption, and the circular economy [1,7].

The Sustentoy project proposal arises as a response to the need for pedagogical strategies that stimulate creativity, concentration, teamwork, and the development of practical skills in technical education students [2, 3, 10]. In an increasingly digitalized educational context, it is essential to offer concrete experiences that foster meaningful learning, autonomy, and youth protagonism [1,3,11].

Research shows that socioemotional skills such as teamwork, perseverance, and adaptability have a significant impact on academic and professional success, being as important as cognitive abilities [12].

By proposing the construction of toys with recyclable materials, the project acts from the perspective of environmental education, the development of socioemotional skills, and citizenship formation, by encouraging the reuse of resources and the practice of the circular economy [1,7]. The manual and collaborative activity also strengthens student engagement and promotes interdisciplinarity, favoring learning that goes beyond formal content and connects with contemporary society's challenges [6,7,13].

The approach favors the development of general competencies from the BNCC, such as critical thinking, empathy, responsibility, and cultural repertoire, in addition to integrating relevant technical and practical knowledge for professional training [1,9,13].

Develop an interactive digital manual with sustainable and recyclable toys, aimed at Technical Education students, to stimulate creativity, teamwork, concentration, and the development of motor skills, in an interdisciplinary way and aligned with the BNCC and the formative itineraries of the New High School.

- Stimulate students' creativity and artistic expression through the construction of recyclable toys;
- Promote collaborative work among students, strengthening socioemotional skills and coexistence abilities;
- Develop motor and practical skills, contributing to active and concrete learning;
- Encourage the reuse of materials and reflection on conscious consumption and sustainability;
- Integrate different knowledge areas interdisciplinarily, especially Arts, Environment, Science, and Technology;
- Align the proposed activities with the BNCC components and the NEM formative itineraries, favoring meaningful and contextualized learning.

Materials and Methods

This study is characterized as a descriptive quantitative research, using numerical data to analyze participants' perceptions about interdisciplinary practical activities. This method was chosen to objectively measure perceptions in a comparable way, identifying patterns and trends in the results. The technical procedure corresponds to field research conducted in the school environment through integrated workshops within the Curricular Unit (UC) Research and Experience of Professions.

The target population consisted of first-year students of the New High School (NEM) in 2024, enrolled in the technical courses of Biotechnology, Mechatronics, and Systems Development. All students in these classes participated in the workshops, constituting a census sampling. Additionally, visitors to the exhibition were invited to answer an external questionnaire, forming a distinct respondent group.

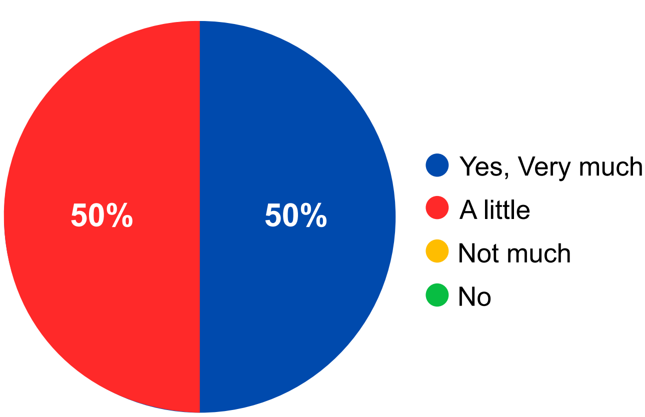
Data collection was carried out through digital questionnaires made available via Microsoft Forms, limited to students participating in the workshops and visitors to the internal exhibition held at the institution.

The adoption of project-based learning methodologies allows the development of 21st-century skills, fostering autonomy, problem-solving, and collaboration [15].

The integrated workshops followed these steps:

1. Formation of heterogeneous groups based on students' skills and interests.
2. Presentation of real challenges related to social and environmental problems, emphasizing sustainability and solutions for low-income contexts.
3. Practical execution using simple and low-cost materials, prioritizing manual prototyping.
4. Correlation with industrial innovation by simulating prototypes applicable to real production sector issues.
5. Final presentation of prototypes in an internal exhibition open to the school community and external visitors.

Figure 1. Answers to the question "Did making the toy help you think creatively?"



Results and Discussion

The analysis of data collected through the questionnaire applied to high school students revealed relevant aspects in the development of socioemotional and cognitive skills, especially those associated with soft skills, through the toy-making activity.

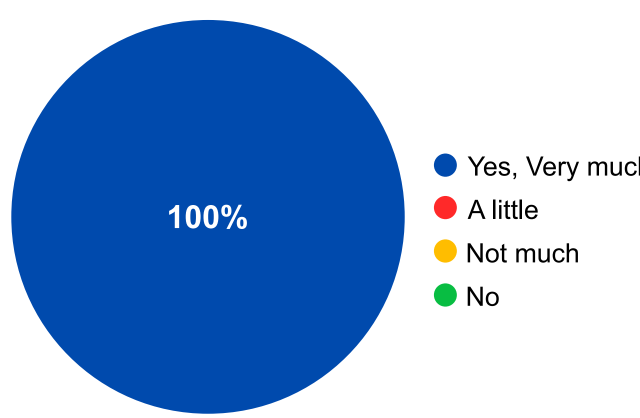
When asked about the stimulation of creativity, half of the participants stated that creating the toy helped them a lot to think creatively, while the other half reported that this occurred to a lesser extent (Figure 1). This result indicates that the activity promoted creative thinking for all participants, although at different levels of intensity.

Regarding the development of manual skills, all students responded positively, either directly ("Yes") or emphatically ("Of course"), confirming that the activity contributed to improving motor coordination and practical dexterity (Figure 2).

As for the ability to maintain focus until completing the task, most students stated they managed to concentrate "a little," while a smaller portion answered "no" (Figure 3). This indicates that there is still some difficulty in sustaining attention during practical activities, pointing to the need for pedagogical strategies that foster concentration.

When asked whether the experience influenced the way they think about helping other people,

Figure 2. Answers to the question "Do you think making the toy helped improve your skills with manual work?"



most answered "a little," while a smaller portion responded "not much" (Figure 4). This suggests that the collaborative experience fostered some degree of social reflection and empathy, although moderately.

Finally, all participants expressed interest in joining more projects related to environmental care (Figure 5), reinforcing the potential of this methodology to engage students in socio-environmental causes.

Based on these results, the project outlined the following expected outcomes:

- Stimulation of creativity as a tool for innovative problem-solving;
- Development of concentration and persistence in practical activities;
- Promotion of empathy and collaborative thinking;
- Strengthening of teamwork and interpersonal communication skills.

These findings reinforce the importance of pedagogical proposals that integrate manual and collaborative practices to develop soft skills, which are essential for the personal and professional growth of high school students.

Studies in technical education contexts confirm that project-based learning fosters socioemotional skills and enhances student engagement [17].

Conclusion

The toy-making activity proved effective in developing socioemotional and cognitive skills in high school students, particularly soft skills such as creativity, collaboration, empathy, and innovative thinking. It also enhanced motor coordination and manual dexterity, essential for overall development. However, some students faced challenges in maintaining focus, indicating the need for strategies that foster attention and persistence.

The collaborative process promoted social sensitivity and increased motivation for environmental projects, highlighting the potential

Figure 3. Answers to the question "Was it easy or difficult to stay focused until finishing the toy?"

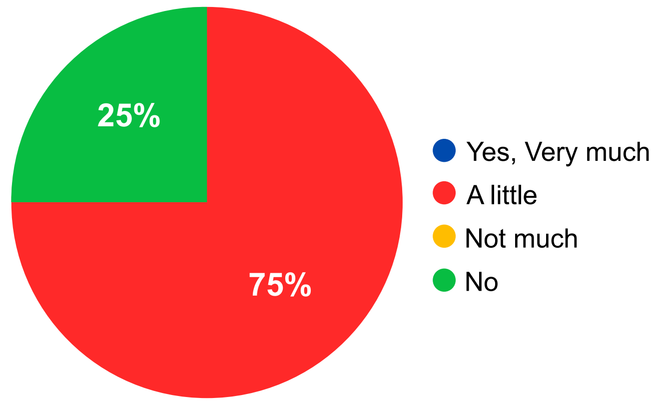


Figure 4. Answers to the question "Did this experience make you think differently about helping other people?"

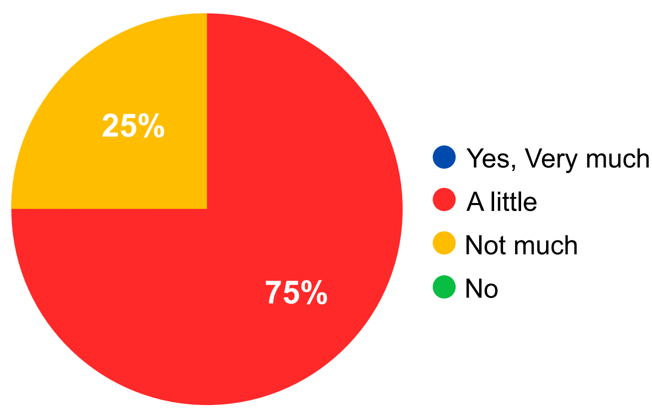
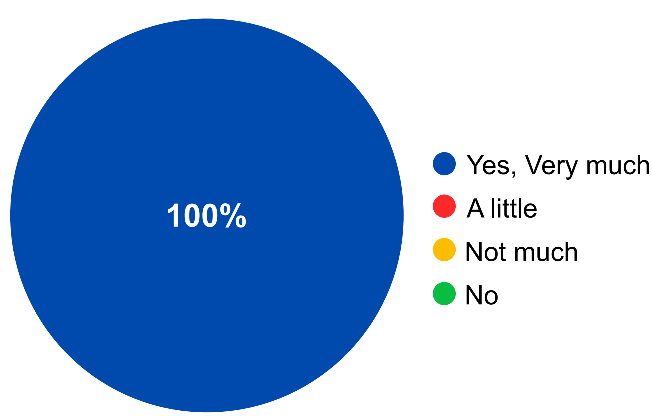


Figure 5. Answers to the question "Would you like to take part in more projects that encourage caring for the environment?"



of this methodology to encourage youth socio-environmental protagonism. These results reinforce the importance of integrating manual, creative, and cooperative practices in education, as advocated by Morin [16], to shape students capable of acting in a complex world.

To overcome the challenges identified, future applications should include measures such as dividing tasks into smaller stages, adding reflective pauses, diversifying activities, rotating group compositions, and incorporating peer feedback. Such practices can maximize the benefits of the methodology, ensuring stronger impacts on students' socioemotional and cognitive development.

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Morphological Development of Agave Under Different Planting Layouts

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Agave is a perennial xerophytic plant with CAM metabolism, adapted to arid and semiarid regions. This species represents a promising option for the utilization of Brazil's northeastern semiarid, a region scarcely explored for cultivation due to adverse edaphoclimatic conditions. Despite the widespread ornamental use of agaves and succulents, little is known about seedling production characteristics, especially regarding nutrition in the early months of establishment. Therefore, this study aimed to plant Agave seedlings from suckers and bulbils. The field experiment was conducted in Conceição do Coité - BA, in a 255 m² experimental area arranged in a randomized block design (9 × 4), using *Agave sisalana* seedlings from suckers and bulbils, as well as hybrid 11648 seedlings from bulbils measuring 30 cm in length. Results showed that proper management, including fertilization and irrigation, is essential for Agave development. Bulbils demonstrated greater vigor and morphological performance, with a possible growth peak observed at 270 days after planting.
Keywords: Bulbils. Suckers. *Agave sisalana*.

Sisal (*Agave sisalana*) is a perennial xerophytic plant with CAM metabolism, adapted to arid and semi-arid regions, cultivated primarily for fiber extraction from its leaves. Its growth is slow, with the first harvest for decortication typically occurring three years after planting. These characteristics make sisal a promising option for the Brazilian northeastern semiarid, a region underutilized for cultivation due to adverse edaphoclimatic conditions such as high temperatures and low rainfall [4].

Although agaves and succulents are widely used in landscaping, little is known about their seedling production characteristics, particularly regarding nutritional aspects during early growth.

Despite limited exploration, fertilization with mineral nutrients has shown excellent results and should be encouraged for application to other species, whether grown in confined or open environments [5].

The objective of this work was to evaluate the morphological development of Agave as a function of different management strategies, including fertilization and irrigation, as well as the type of propagule used, aiming to identify the most efficient combinations for vegetative growth over six months of evaluation.

Received on 12 October 2025; revised 20 December 2025.
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J Bioeng. Tech. Health 2026;9(1):26-31

Materials and Methods

The experiment was conducted at CIMATEC Sertão, located in Conceição do Coité - BA, using *Agave sisalana* seedlings from suckers and bulbils measuring 30 cm in length (Figure 1).

Figure 1. Experimental crop located at the CIMATEC Sertão unit, in the municipality of Conceição do Coité, Bahia.

A 255 m² area (17 × 15 m), fallow for about three years after grass cultivation, was used. Prior to the experiment, the area was mowed mechanically, plowed once, and harrowed once. The blocks and plots were then marked, with four blocks spaced 3.0 m apart.

Soil pH correction and fertilization were performed based on prior soil analysis pH (Potential of hydrogen in the soil) 5.3; OM (Organic matter) 1.25%; P (Phosphorus) 24 mg/dm³; K (Potassium) 69 mg/dm³; Ca (Calcium) 1.7 cmol/dm³; Mg (Magnesium) 0.8 cmol/dm³.

The conventional planting system included treatments (Table 1) with and without irrigation, arranged in a randomized block design with ten treatments and four replications.

At the end of the experiment, the morphological characteristics height (cm), diameter (mm), number of leaves, and leaf length and width. Measurements were taken at 180, 210, 270, and 360 days after planting.

The results obtained were subjected to analysis of variance (ANOVA), and the means were compared using the F-test at a 5% significance level. Statistical analyses were performed using Statistica® v.10.0 software.

Table 1. Description of the treatments (TRAT), including Number of rows (Nº R), Spacing (S), Propagule type (PT), and Irrigation (IRR).

TRAT	Nº R	S	PT	IRR
T0	2	3x1x1	SUC	No
T1	2	3x1x1	SUC	No
T2	2	3x1x1	BB	No
T3	1	3x1	SUC	No
T4	1	3x1	BB	No
T5	1	3x1	SUC	Yes
T6	1	3x1	BB	Yes
T7	2	3x1x1	SUC	Yes
T8	2	3x1x1	BB	Yes
T9	2	3x1x1	BB	Yes

*BB: Bulbils; SUC: Suckers. T0 to T8: Seedlings of *Agave sisalana*; T9: Agave Hybrid 11648.

Results and Discussion

Height

Statistically significant differences were observed in Agave plant height between treatments over time. At 180 and 210 days after planting, treatments T1, T2, T4, T5, T6, T8, and T9 differed significantly from the control (T0). At 270 days, the differences were maintained in treatments T2, T4, T6, T8, and T9, all composed of bulbils, regardless of the layout type or irrigation use, reinforcing the role of propagule type on height growth. At 360 days, treatments T1, T2, T4, T6, and T8 outperformed T0, indicating that the positive influence of bulbils persists over time and that propagule type has a greater effect on plant growth than irrigation.

The improved height results observed in treatments using bulbils can be attributed to the superior morphophysiological characteristics of these propagules.

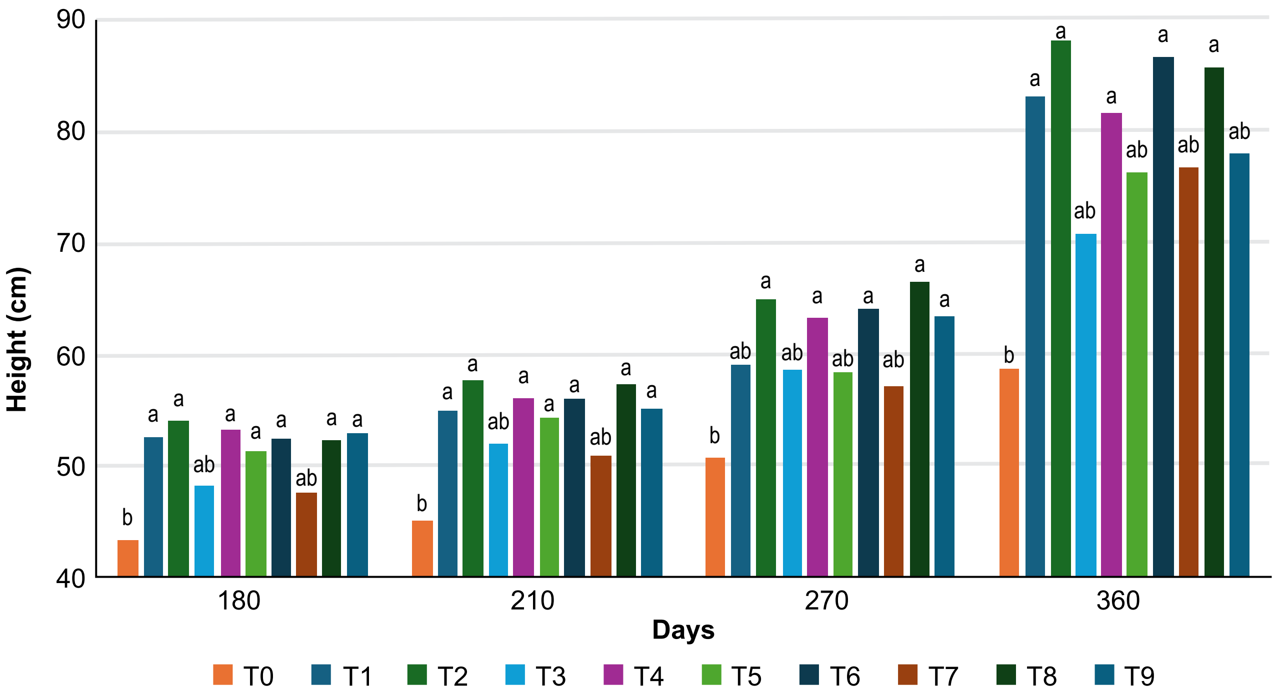
According to a study with *Agave angustifolia*, bulbils showed greater uniformity in size compared to suckers, in addition to developing roots more quickly than shoots from rhizomes. These factors may explain the greater vigor and, consequently, the better development of plants grown from bulbils [2]. Figure 2 demonstrates a gradual increase in height over time in all treatments evaluated. After 270 days, more pronounced growth is observed in most treatments, indicating a possible peak in vegetative development during this period.

Diameter

For T9, composed of propagation by bulblets of hybrid 11648 and with irrigation, showed a statistically significant difference in relation to the control (T0) at 180, 270 and 360 days after planting for the diameter variable (Figure 3).

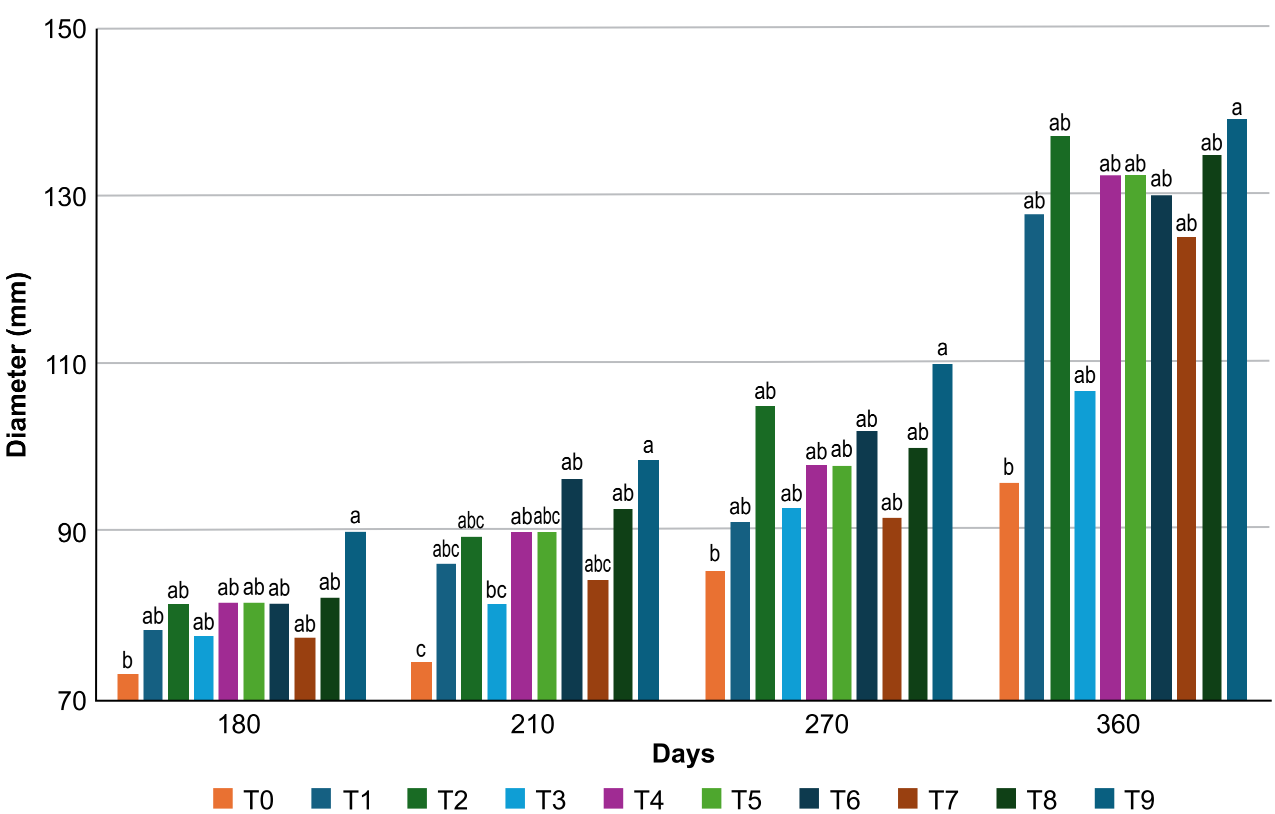
Over 210 days, in addition to the difference between T9 and T0, a statistical difference was

Figure 2. Average height (cm) of *A. sisalana* plants among treatments.



*Means followed by the same letter in the column do not differ statistically from each other, according to the F test at 5% probability.

Figure 3. Averages for the diameter (mm) of *A. sisalana* plants, among treatments.



* Means followed by the same letter in the column do not differ statistically from each other, according to the F test at 5% probability.

also observed between T9 and T3. T9 had higher averages, while T3, consisting of suckers and without irrigation, did not differ statistically from T0, both with the lowest averages observed.

Leaf Number (Unit)

As shown in Figure 4, T9 showed a statistically significant difference at all evaluation times, highlighting the positive effect of the interaction between the use of improved genetic material, irrigation, and adequate nutrition. At 270 days after planting, in addition to the statistical difference between T9 and the other treatments, T2 and T8 performed better than T3. The main distinction between these treatments lies in the type of propagule and water management: T2 and T8 used bulbils with or without irrigation, while T3 was managed with suckers and without irrigation.

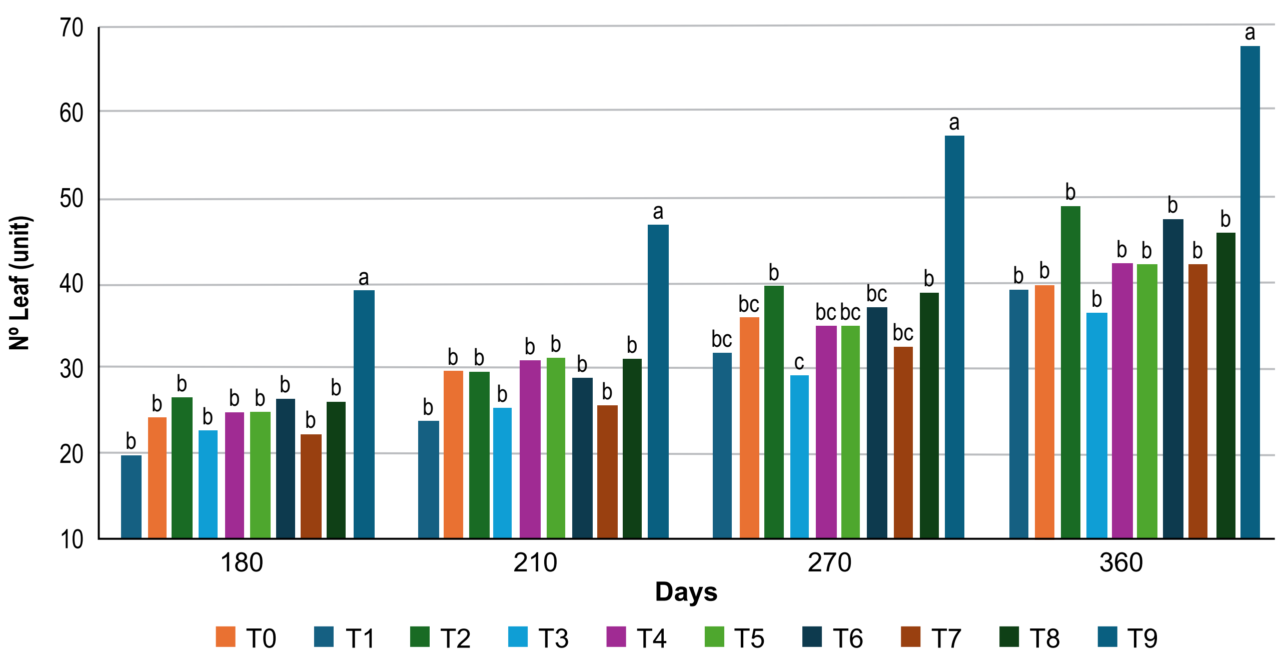
The double-row arrangement proved to be the most efficient strategy for increasing leaf number in Agave cultivation. The results also indicated that bulbils outperformed suckers, regardless of irrigation. This behavior can be explained by Agave's high water resilience, typical of plants with CAM metabolism, whose efficient water conservation physiology allows cultivation even under conditions of low water availability [1].

The data indicate that T9 presented the highest number of leaves in all evaluated periods, standing out from the others. At 270 days after the start of the experiment, Treatments 2 and 8 also stood out among the conventional treatments, demonstrating significantly superior performance. In contrast, T0 (control) maintained the lowest values throughout the period (Figure 3).

Leaf Width

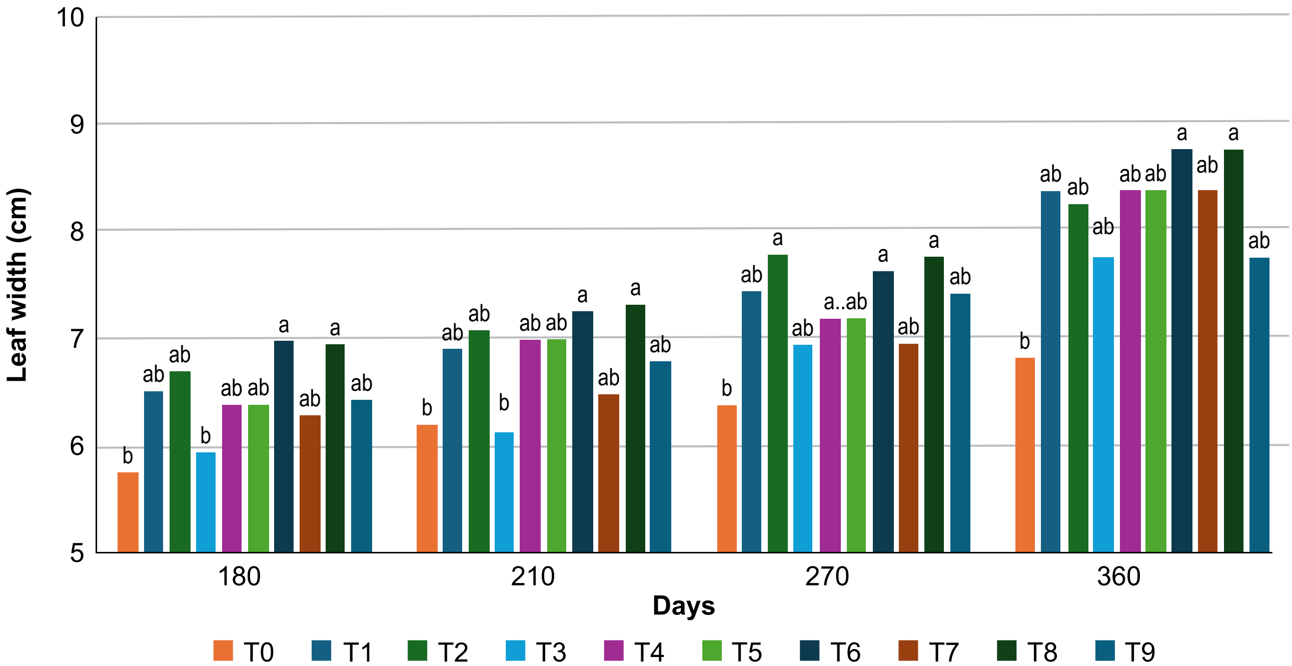
Statistically significant differences between treatments were observed throughout the evaluated periods for the variable leaf width. At 180 and 210 days, treatments T6 and T8, both consisting of bulbils under irrigation, presented higher averages compared to the control (T0) and T3, it is using suckers and grown without irrigation. At 270 days, treatments T2, T6, and T8 differed statistically from T0, all consisting of bulbils, regardless of planting arrangement and irrigation use (Figure 5).

Figure 4. Average leaf number (unit) of *A. sisalana* plants, among treatments.



* Means followed by the same letter in the column do not differ statistically from each other, according to the F test at 5% probability.

Figure 5. Average leaf width (cm) of *A. sisalana* plants, between treatments.



* Means followed by the same letter in the column do not differ statistically from each other, according to the F test at 5% probability.

Over 360 days, treatments T6 and T8 maintained the highest mean values and showed statistically significant differences compared to T0. These results indicate that the main factor responsible for the observed differences in leaf width was the type of propagule used, with bulbils performing better than suckers, regardless of irrigation and row arrangement.

In a study evaluating the production potential of *A. sisalana* under three irrigation conditions in Pakistan, they found that the treatment subjected to higher irrigation was the least efficient, resulting in lower plant height, fewer leaves, and smaller leaf area, suggesting possible negative effects of excess water, such as soil saturation and physiological stress [3]. The control treatment without irrigation, however, showed satisfactory results, especially regarding leaf diameter, demonstrating the species' high drought resistance, a hallmark of plants with Crassulacean acid metabolism (CAM).

Leaf length

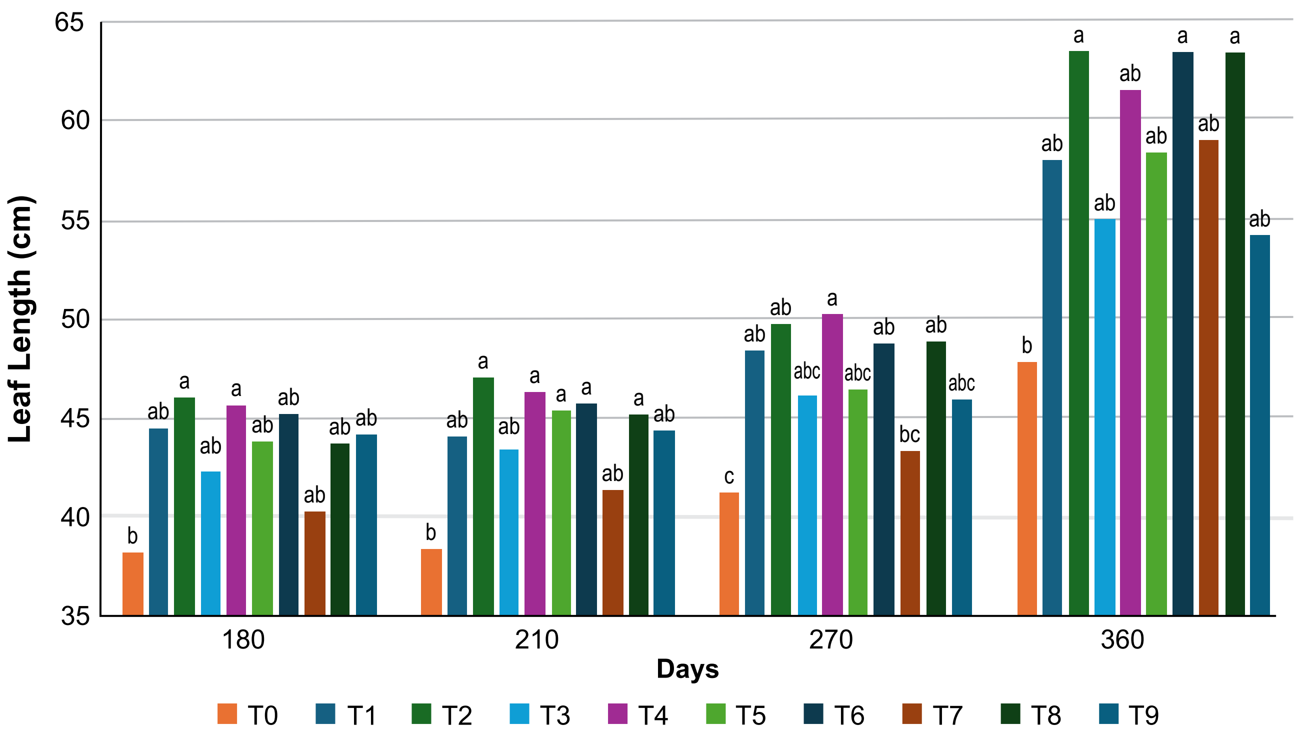
As shown in Figure 6, at 180 days, treatments T2, consisting of bulbils and grown without irrigation, showed a higher mean than the control T0, suggesting better performance of this type of propagule, regardless of planting arrangement. At 210 days, treatments T2, T4, T5, T6, and T8 differed significantly from T0. Of these, only T5 used suckers, reinforcing the superiority of bulbils, even under different water conditions.

At 270 days, T4 (bulbils without irrigation) had the highest average, statistically different from T0 and T7, the latter irrigated and composed of suckers, reinforcing the influence of propagule type on plant performance. Finally, at 360 days, treatments T2, T6, and T8, all using bulbils, had the highest average values, with significant differences compared to T0, demonstrating that bulbils provided better development regardless of irrigation.

Conclusions

The control (T0), without fertilization and irrigation, presented the lowest values in all morphological variables evaluated compared to the other treatments, demonstrating that the lack

Figure 6. Average leaf length (cm) of *A. sisalana* plants across treatments.



* Means followed by the same letter in the column do not differ statistically from each other, according to the F test at 5% probability.

of management significantly limits the vegetative development of Agave. This reaffirms that the adoption of good management practices such as fertilization and soil amendment, used in the other treatments, plays a fundamental role in the vegetative development of the crop. Another point observed was that plants from bulbils showed greater development and vigor regardless of arrangement and irrigation, indicating a promising alternative for promoting greater productivity. Furthermore, 270 days after planting, more significant growth was observed in most variables and treatments, indicating the possibility of a peak in vegetative growth at this stage of Agave development, indicating a strategic time for intensified management.

Acknowledgement

The authors would like to acknowledge Shell Brazil and ANP for the strategic support provided through regulatory incentives for Research, Development & Innovation. We also acknowledge EMBRAPII and Senai CIMATEC for the encouragement and funding.

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Structural Analysis and Optimization of a Baja Vehicle's Engine Support Using the Finite Element Method

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This work presents the structural analysis of the engine package in a BAJA prototype. Three distinct design configurations were evaluated: (1) the initial engine package; (2) the engine package without the firewall tube; and (3) the engine package without the vertical tubes. Simulations encompassed assessment of deformations, Von Mises stresses, combined tensile/compressive stresses, and buckling modes. All configurations demonstrated satisfactory performance, with high safety factors and stresses well below the yield strength of AISI 1020 steel, the material selected for its favorable mechanical properties, machinability, and widespread structural use in the automotive sector. Configuration (2) achieved a mass reduction of 1.04%, while configuration (3) reduced mass by 0.78%, both maintained the required structural integrity and performance for the intended application.
Keywords: Structural Optimization. Engine Package. Finite Element Method. ANSYS. Buckling.
Abbreviations: BLC, Overhead Lateral Cross member. CLC, Upper Lateral Cross Member. FABup, Fore-Aft Bracing Members. FEM, Finite Element Method. RRH, Rear Roll Hoop. SAE, Society of Automotive Engineers.

In automotive design, especially for off-road vehicles such as Baja SAE prototypes, every structural component required careful engineered to ensure performance, safety, and lightweight construction. In this context, the engine package served as a key structural connection, linking engine to the vehicle structure and must support not only its weight but also the dynamic loads generated during operation, such as vibrations and torques,as reported by Shigley and colleagues [1].

Therefore, optimizing this structure involved balancing strength and mass variations, to achieve a mid-term between durability and performance [2], often using softwares.

The structural analysis of mechanical components using the finite element method (FEM) has become established as an essential tool in engineering design development. This method enables the simulation of structural performance under different loading conditions, allowing the pre-validation of a concept, optimizing the time and resources required for physical testing as reported by Mac Donald [6]. Among the most relevant parameters evaluated in the simulations were deformations, Von Mises stresses, and buckling modes [3].

The Von Mises stress represented widely used criterion for predicting the failure of ductile materials, such as steel, and is based on distortion energy. For materials such as AISI 1020 steel, which exhibits yield strength of approximately 351.57 MPa, failure typically occurs when the equivalent stress reaches about 60% of that value, according to the safety criterion adopted [2].

Another critical aspect for automotive structures is buckling, a structural instability caused by compressive loads, whose occurrence depended on the component's geometry, boundary conditions, and material properties [4]. Buckling analysis in ANSYS employed critical load factors to predict the multiplier of the applied load required to reach the first buckling (unstable) mode.

Furthermore, structural fatigue is also considered in many assessments. Components subjected to cyclic loading were evaluated for service life, especially in automotive applications where vibrations and repetitive loads are constant [5]. In the present study, the observed stresses remained sufficiently low to ensure infinite life of the

Received on 17 October 2025; revised 21 December 2025.
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structure, according to the Goodman Curve criteria which according to Norton [2] is conservative, but it keeps close to the experimental data.

Finally, structural optimization focused on reducing mass without compromising the integrity of the system. Weight reductions were particularly important in mobility projects such as off-road vehicles where performance and energy efficiency are directly affected.

The objective of this study was to conduct a comprehensive structural analysis of the engine package using ANSYS simulations, with the aim of optimizing its geometry and mass while preserving the mechanical integrity of the assembly.

The chosen software for the present study was ANSYS, because it has all the tools necessary for the analysis, and its web support.

Materials and Methods

The simulation modeled the engine as a concentrated mass of (32 kg) placed at its center of mass (Figure 1).

A torque of 30 N·m was applied at the engine package mounting points, with constraints imposed on the central differential supports, this torque was based on the engine's maximum torque. The material selected was AISI 1020 steel and the finite-element model used beam-type (1D) elements with a mesh size of 20 mm. The sequence of the steps are shown in Figure 2.

The engine package comprises four attachment points secured with bolts. In the simulation, the applied torque corresponded to the engine's maximum output and was applied at the output shaft location. Structural constraints were imposed

Figure 1. Engine package.

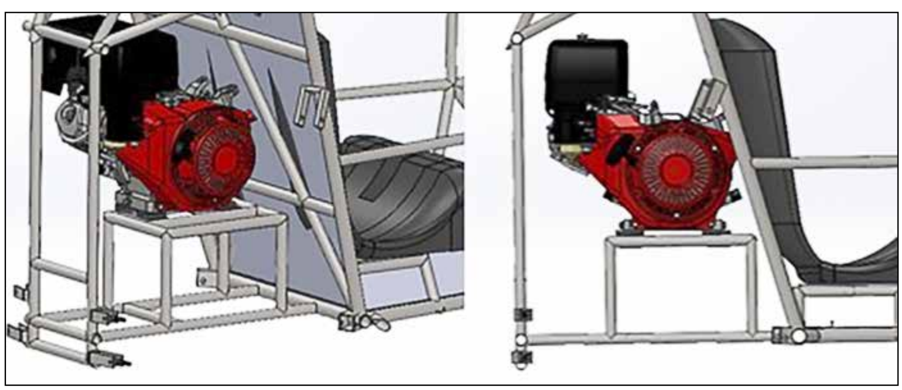
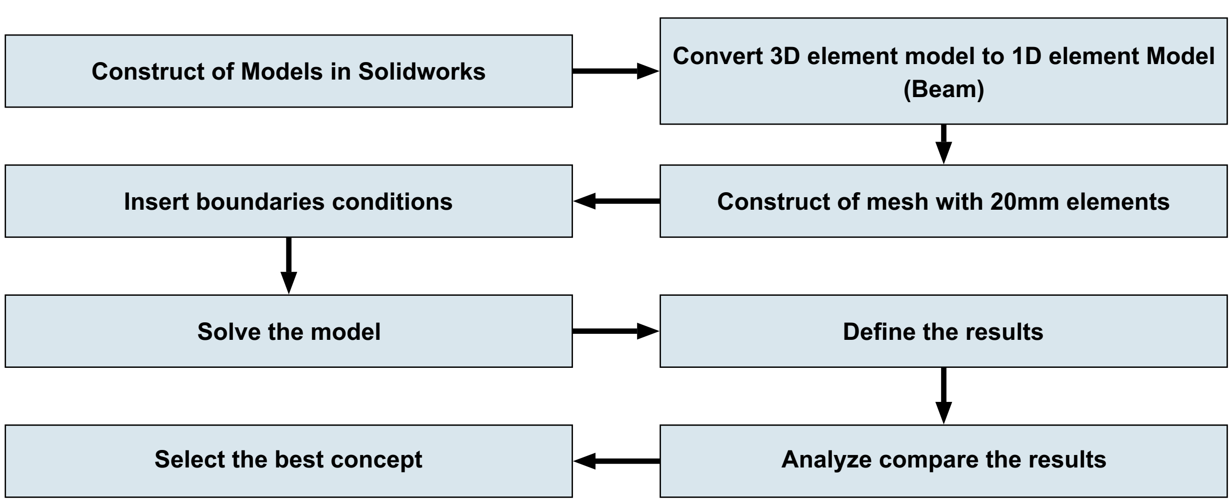
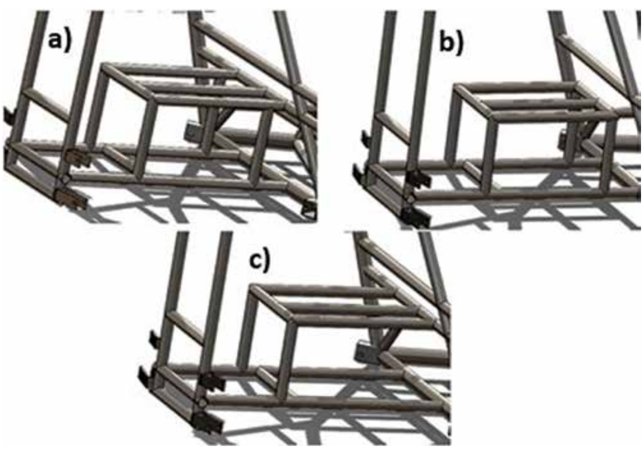


Figure 2. Visual representation of the method.



at the central differential attachment points, which are also secured by four bolts at a lower position on the chassis (Figure 3). This attachment location was selected because the differential serves as the primary component connecting the wheels to the vehicle structure; thus, the reaction forces resulting from the engine torque are transmitted through it.

Figure 3. Comparative view of the 3 engine package configurations: a) Engine Package 1, b) Engine Package 2, and c) Engine Package 3.



The three engine package was: Engine package 1, which has the anchorage in the firewall and in the bottom tubes. Engine package 2, which has the anchorage only in the bottom tubes, and the Engine package 3, which has the anchorage only in the firewall.

The analyses performed consisted of static and buckling studies aimed at evaluating the stress and deformation states across the different engine package configurations. The buckling analysis was used to identify the critical modes of structural instability. Critical modes were defined as those exhibiting the lowest buckling coefficient, i.e., the modes that indicate instability under the smallest applied load to the structure.

Results and Discussion

For this study, there were three results from each engine package. The total deformation, which shows how the body deforms based on the load. The Von Mises stress, that is a combination of the axial stress and shear stress, based on the Von Mises Ellipse. And the Buckling modes, which is the bending of a beam, or in this case, a chassis member, by compression, the number analyzed in this result is the buckling factor, that is a multiplier load that leads to the buckling mode.

Engine Package 1

The maximum deformation of the chassis was 0.00687 mm, concentrated in the upper-rear section of the chassis, specifically at the junction between the Rear Roll Hoop (RRH) and Overhead Lateral Cross member (BLC). On the engine package, the maximum deformation was 0.00598 mm, concentrated at the torque application point.

The highest stress was also located at the torque application point, being caused mainly by the bending tendency of the engine motion. The stress at this point was 7.615 MPa, resulting in a safety factor of 26.36 based on the criteria used by Robert Norton, thus there was a good margin for refinement of this chassis component (Table 1, Figure 4). The critical buckling mode occurred with a load factor of 9128, i.e., the torque would need to be increased by a factor of approximately 9.000 times to produce this buckling mode, indicating structural stability. The critical buckling mode developed in Upper Lateral Cross member (CLC) and in the Fore-Aft Bracing members (FABups). These values were used as the reference condition for the support selected for optimization.

Engine Package 2

In this model, the maximum deformation of the engine package was 0.00521 mm, an improvement compared to the first model. Conversely, because fewer attachments were positioned on the chassis, the chassis maximum deformation increased to 0.0083 mm, and was distributed across all upper chassis members. Stresses decreased slightly while remaining concentrated at the engine fastening point.

Figure 4. Deformation, Von Misses stress and critical buckling modes of engine package 1.

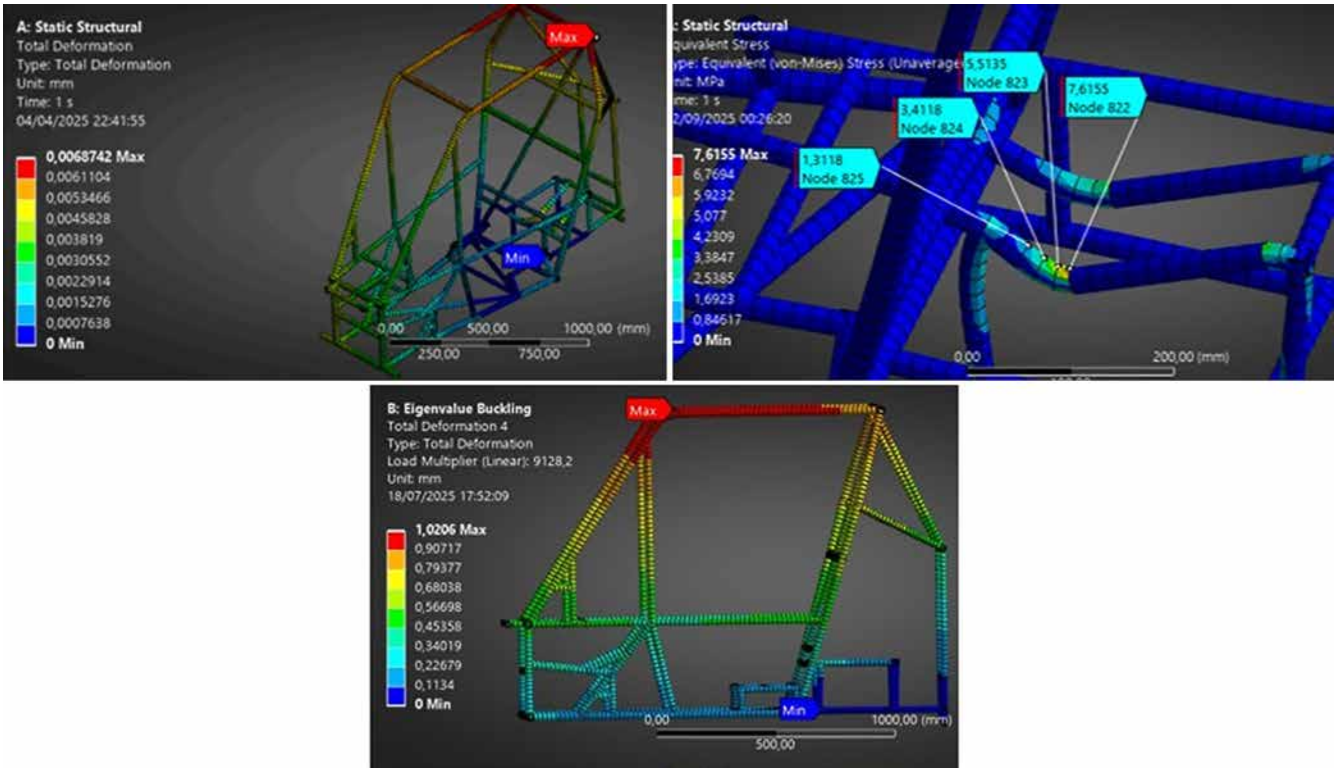


Table 1. Stress engine package 1.

Engine Package 1	
Stress (MPA)	**Node**
7.6155	822
3.4118	824
5.5135	823
1.3118	825

The peak stress reached 6.9778 MPa, corresponding to a safety factor of 30.13, as observed in Table 2, and Figure 5. The critical buckling load factor was lower than in the first model but still far from a critical condition (7049), which also indicates structural safety. This buckling mode occurs in the front portion of the engine package.

Engine Package 3

This configuration exhibited larger deformations both in the chassis, reaching a 0.08080 mm, and in the engine package, reaching 0.04958 mm, nearly one hundred times higher than the others package options. Despite this, the result could still be acceptable if a substantial mass reduction were achieved. Stresses retained a similar distribution, with the maximum at the engine fastening point; in this case the peak stress was 7.9 MPa, corresponding to a safety factor of 25.31 (Table 3, Figure 6). The critical buckling load factor for this configuration was the lowest of all, 5489, which was still well above the threshold for buckling failure but considerably smaller than the other cases. This buckling mode was

Table 2. Stress engine package 2.

Engine Package 2	
Stress (MPA)	**Node**
7,1244	517
5,2812	518
3,4400	519
1,6074	520

Figure 5. Deformation, Von Misses stress and critical buckling modes of engine package 2.

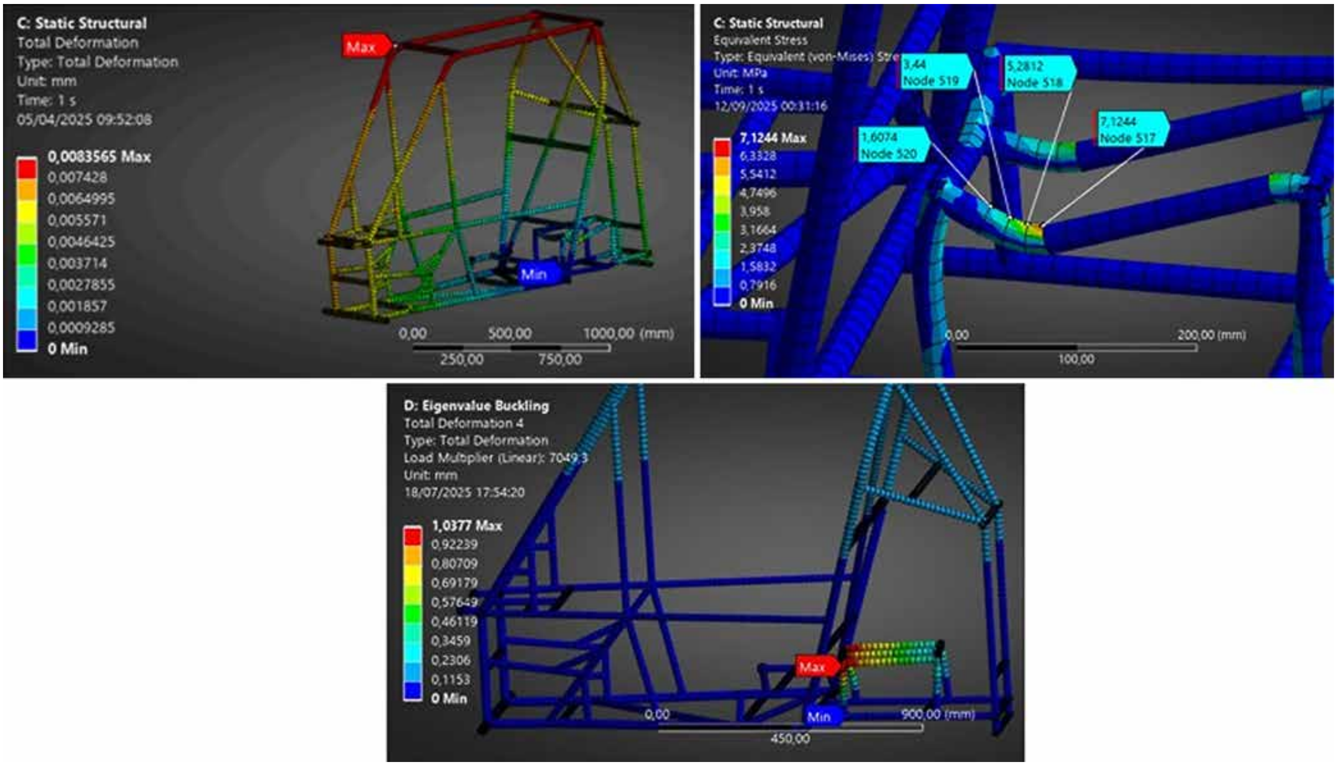


Table 3. Stress engine package 3.

Engine Package 3	
Stress (MPA)	**Node**
7,9777	818
6,7451	819
5,5196	820
4,3070	821

concentrated mainly in the rear transverse bar, due to the absence of rear support on the chassis.

Comparative Analysis of the Engine Package Configurations

Based on the results, a comparison was made of the total mass of each chassis configuration using Solidworks, and the configuration that presents the best balance between load performance and mass was selected. The percentage mass reduction is given relative to the initial model, which was Engine Package 1. Table 4 presents the comparison of the values. Therefore, engine package configuration 2 was selected for the vehicle, as it provided the highest percentage reduction in mass while resulting in only minor increases in stress and deformation. Furthermore, configurations 1 and 3, which include a mounting point directly attached to the panel against which the driver rests, would transmit higher vibration levels to the driver's body, thereby compromising the overall ergonomics of the vehicle.

Conclusions

The three configurations meet the mechanical strength and stability criteria. The second configuration (2) proved most advantageous, showing the largest mass reduction and the highest safety factor. However, when the assembly was evaluated together with the chassis, interference was observed between the engine package and the driveshaft arm; therefore, the package position must be modified and the simulations repeated accounting for the 4x4 drivetrain geometry.

Figure 6. Deformation, Von Misses stress and critical buckling modes of engine package 3.

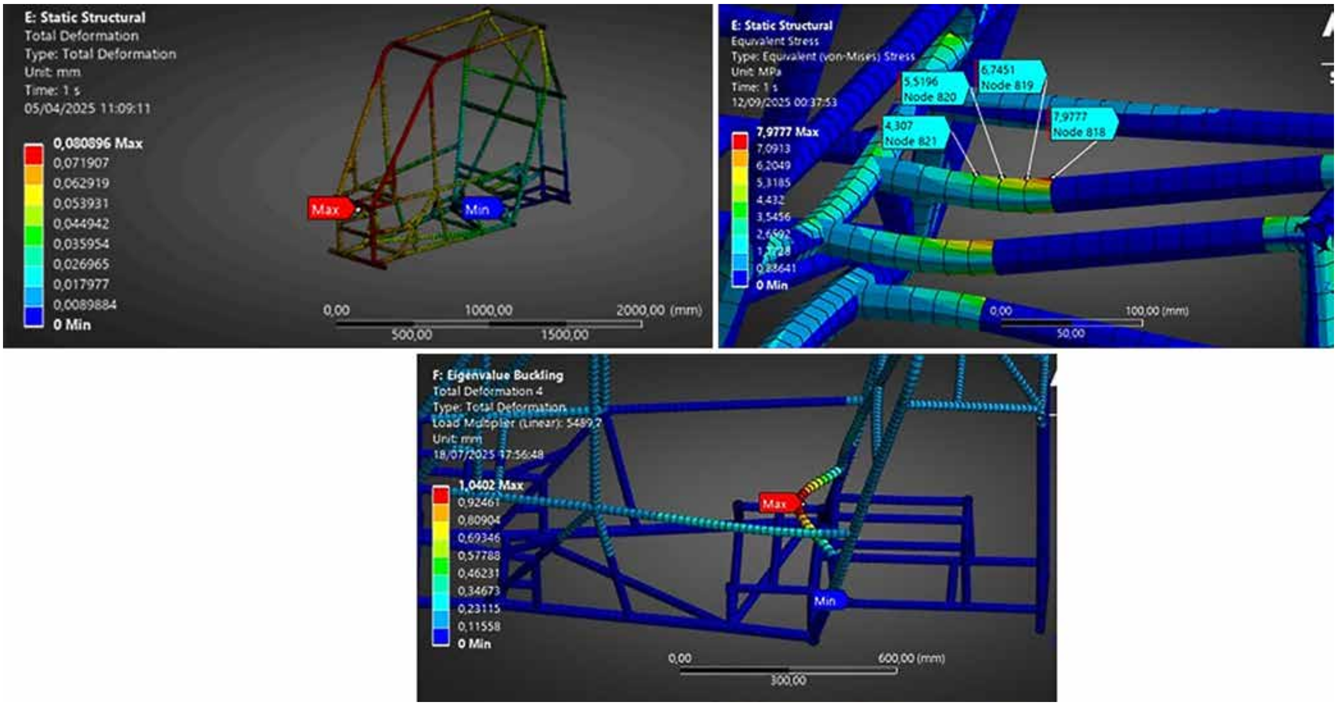


Table 4. Stress engine package 3.

Engine Package	1	2	3
EM def. (mm)	0.00598	0.00521	0.04958
Chassis def. (mm)	0.00687	0.00835	0.08089
Maximum stress (MPa)	7.6	7.1	7.9
Mass (Kg)	41.182	40.755	40.859
Reduction (%)	-	1.04	0.78

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Implementation of an Immersive Environment with 360º Video at SENAI CIMATEC: an Experience Applied to Engineering

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This article presents the experience of conception, development, and implementation of CIMATEC 360º, an immersive environment based on 360º videos conceived to support the teaching of engineering. In this context, the aim was to analyze the development and application of 360º videos as an immersive resource for engineering education, based on practical experience conducted at SENAI CIMATEC. This is a qualitative research study, outlined as a case study, that followed all stages of the process, from the definition of the theme and the preparation of the scripts, through the capture and editing of the material, to the structuring of the interface together with the availability of the solution. In summary, the development integrated, in an articulated manner, pedagogical objectives related to contextualized learning and technological requirements focused on compatibility and usability on multiple devices, including computers, mobile devices, and virtual reality (VR) headsets. The resource allows the student to virtually explore laboratories and institutional facilities, fostering the understanding of processes, the connection between theory and practice, engagement, and autonomy in learning. The results obtained indicate that the use of 360-degree videos represents a viable and scalable strategy to enrich engineering education, although it still faces challenges related to the need for a stable connection, variations in performance depending on the device, and the absence of complementary interactive elements. The evidence gathered points to prospects for improvement, such as the adoption of adaptive streaming techniques, optimization of file compression, and incorporation of interactive resources that expand the possibilities of navigation and conceptual deepening.

Keywords: 360º Video. Immersive Technologies. Engineering Education.

The current educational landscape, marked by the increasing migration of teaching and learning practices to digital spaces, calls for a reevaluation of the principles guiding the organization of informational and pedagogical spaces, as well as the strategies for content creation and curation. From this perspective, adopting immersive technologies is no longer merely following an emerging trend in education but has become an urgent necessity. These technologies enable the design of formative experiences that foster greater student engagement, promote cognitive and emotional immersion in learning processes, and enhance, in an integrated manner, the relevance, dynamism, and effectiveness of proposed activities [1].

Immersive technologies have been occupying an increasingly significant space in the educational field, especially within pedagogical approaches that aim to integrate innovation, engagement, and experiences closer to practical reality, in areas such as engineering that demand an articulation between theory and practice. Rather than assuming a deterministic migration to the digital, these media are understood here as context-dependent options, whose pedagogical value varies according to objectives, learner profiles, and the available infrastructure.

In this context, the use of 360º videos constitutes an accessible and effective strategy to provide more engaging, realistic, and student-centered instructional experiences. By enabling the visual exploration of environments recorded in all directions, these videos foster an intensified sense of presence, promoting both cognitive and

Received on 15 October 2025; revised 20 December 2025.
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J Bioeng. Tech. Health 2026;9(1):38-44

emotional immersion in the presented content [2].

The choice of the engineering field, focusing on 360° videos as an interactive and immersive resource, is supported by the contemporary need to bring future engineers closer to practical and complex contexts, even when access to laboratories and industrial environments is limited [3]. This technology allows immersion in realistic scenarios, fostering interactive and meaningful learning, while enhancing students' understanding of processes, structures, and equipment, and developing technical and cognitive skills [3].

We emphasize that 360° video is not intended to replace the tactile, olfactory, and thermodynamic materiality of laboratory practice; rather, it serves as preparatory visualization and spatial orientation before hands-on sessions, not as a substitute for embodied experimentation.

In engineering education, the incorporation of immersive technologies aligns with pedagogical needs that value active learning and contextualized experiences. As Bolkas and colleagues [4] observe, practical classes often devote significant time to overviews, reducing opportunities for field experimentation, which can leave students underprepared for lab sessions [4].

In this context, the use of 360° videos in engineering education helps align instructional practices with emerging Industry 4.0 trends, which demand professionals skilled in working with advanced technologies and understanding complex systems holistically [5]. By delivering near-professional experiences, even in virtual format, this resource enhances both teaching-learning possibilities and the theory-practice connection, while simultaneously preparing engineers to tackle real-world challenges in their professional field.

Therefore, considering the context of engineering education and the transformations characterizing contemporary educational demands, challenges surrounding teaching and learning processes have been extensively examined in scholarly literature [6-8]. Research demonstrates that the need for professionals equipped to work in dynamic, interdisciplinary environments necessitate restructuring traditional training models historically rooted in one-dimensional and linear approaches.

The lack of immersive experiences may weaken the theory-practice connection, limiting knowledge transfer to professional contexts. Research by Xie and colleagues (2023) [9] demonstrates that virtual reality simulations enhance the practical application of theoretical concepts. Similarly, that immersive technical tours improve interactivity and comprehension in educational projects [1]. However, studies like Nyaaba and colleagues (2024) [10] identify persistent challenges in this interactive process, particularly regarding content development, instructor training, and technological infrastructure requirements.

According to Reyna (2018) [11], the educational use of 360° videos may encompass several applications, including: conducting virtual tours of complex environments that are difficult to fully understand when presented solely through static images, text, or standard audiovisual recordings.

The panoramic perspective offered by 360° video intensifies the user's sense of presence, while encouraging immersion that involves both cognitive processing and emotional engagement. [2]. In their systematic review, Rosendahl (2022) [12] identified three primary pedagogical applications of 360° videos in education: presenting and observing content in authentic environments, mediating interactively between theoretical concepts and practical situations, and stimulating self-reflection through contextualized observation of experiences. The authors further emphasize that 360° video can boost student motivation by promoting autonomous content exploration and learning through multiple visual perspectives, thereby supporting active knowledge construction.

Following the pipeline described by Naef and colleagues (2023) [13], 360° video production requires consideration of successive, complementary stages. The initial stage involves content planning and design, where key variables are established including subject matter, duration, visual elements, and integrated audio components. The subsequent stage focuses on selecting appropriate audiovisual recording equipment and defining capture procedures. The third stage encompasses material creation and processing, involving both the stitching of captured footage into a cohesive 360° video and necessary post-production work. The final stage concerns hardware specifications for content implementation and viewing, covering both technical parameters and experiential requirements.

At SENAI CIMATEC, an institution renowned for its innovative approaches, initiatives have been developed to explore 360° videos' potential as pedagogical mediation tools in engineering education. The experience documented in this study forms part of these efforts, demonstrating the implementation of 360° video immersive environments within a didactic-technological strategy designed to enhance contextualized learning and develop competencies aligned with contemporary engineering challenges.

Within this context, the present study aims to examine the development and implementation of 360° videos as immersive educational resources in engineering education, drawing on practical experience at SENAI CIMATEC. The research proposes to analyze the pedagogical, technical, and institutional dimensions of this technological integration, evaluating its educational potential while addressing the challenges encountered and lessons derived from the implementation process.

Materials and Methods

This study adopts a qualitative research methodology following a case study design. As Silveira (2009) [14] emphasizes, qualitative research focuses on developing an in-depth understanding of social groups rather than statistical representativeness. In our investigation, this approach enabled detailed exploration of participants' perceptions and experiences regarding 360° video implementation, examining both the technical dimensions and pedagogical potential for enhancing engineering education.

Regarding methodological design, this study employs a case study approach, which Yin (2010) defines as an empirical research strategy for developing a comprehensive understanding of contemporary phenomena within their real-world contexts, particularly when boundaries between phenomenon and context remain ambiguous. This method proves especially valuable for investigating educational technology implementation processes, as it facilitates multidimensional analysis (technical, pedagogical, and organizational) of the study object's unique characteristics through evidence gathered in authentic application settings.

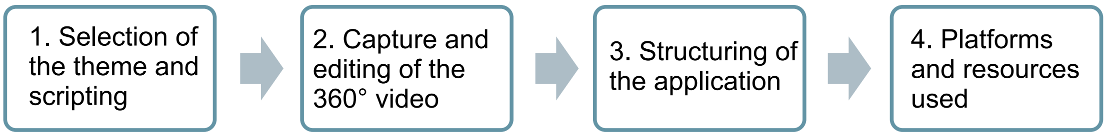
Within this specific context, the case study methodology enabled systematic documentation of all phases in developing and implementing the 360° video immersive environment at SENAI CIMATEC, encompassing the entire process from initial conceptualization to final delivery to end users. This research design facilitated integration of multiple data sources, including direct observations, technical documentation, development team interactions, thereby ensuring a holistic and contextually grounded understanding of the implementation process.

The development of the application - implemented as a didactic resource in an introductory course module of the Engineering program - was structured into four interdependent stages (Figure 1), each with specific objectives and procedures aimed at designing an immersive solution that is both functional and pedagogically aligned.

In the first stage, topic selection and scripting, the institutional environments to be presented in the 360º format were defined, prioritizing strategic spaces for engineering education. Descriptive scripts were prepared to guide the image capture, indicating points of interest as well as narrative sequences aligned with the learning objectives.

The second stage, 360º video capture and editing, involved the use of omnidirectional cameras to record high-resolution images,

Figure 1. Application development stages



ensuring full coverage of the environments, followed by processing and editing in specialized software for distortion correction, stabilization, and adjustments of brightness and color.

In the third stage, application structuring, an interactive interface was developed that brought together the videos in a simple and intuitive navigation library, with support for multiple devices (desktop, mobile, and VR headsets), enabling exploration experiences suited to different access contexts.

In the stage of platforms and resources used, 360º video editing software, responsive web development tools, and hosting servers optimized for high-resolution media were specified and applied, in addition to conducting tests on various devices and browsers to ensure compatibility, responsiveness, and adequate loading times. The process was conducted collaboratively, integrating pedagogical, technical, and instructional design teams, in order to ensure that the decisions made met both the educational demands and the technological requirements for the feasibility and scalability of the solution.

Finally, to support reproducibility, we provide a brief reproducible materials and methods note: a metrics overview comprising average load times under varied network conditions, frame rates across device classes, and post-use usability and presence ratings; and artifacts and documentation including codec and bitrate settings for adaptive streaming, interface screenshots, and the device and browser matrix used in testing.

Results and Discussion

The evidence reported here is descriptive and exploratory. We refrain from causal claims about learning gains. Observed benefits relate to orientation and engagement during pre-lab preparation; they do not generalize to skill acquisition without subsequent guided practice.

Figure 2. 360º video application.

The developed application (Figure 2), titled "CIMATEC 360°," constitutes an interactive virtual environment incorporating 360° videos for immersive exploration of laboratories and facilities at both SENAI CIMATEC and CIMATEC Park. Designed for cross-platform accessibility, the resource accommodates diverse devices including desktop computers, mobile devices, and VR headsets, ranging from advanced systems to cost-effective solutions like cardboard viewers.

The interactive library of 360° videos provides access to various institutional environments, enabling immersion in spaces that represent distinct academic and technological domains. These include the Brazil Model Factory, specializing in simulating integrated industrial processes; the Creative Resources Laboratory, which facilitates prototyping and experimentation for innovative projects; the Energy Laboratories, dedicated to researching renewable energy sources and energy efficiency systems; the Automotive Engineering sector, focused on developing and testing mobility solutions; the Precision Mechanics sector, specializing in high-accuracy machining processes; and the Networks, Robotics, and Autonomous Systems sector, concentrating on automation and artificial intelligence applications.

This variety of environments enables students to acquaint themselves with the institution's physical infrastructure while comprehending each area's practical context. Consequently, it strengthens the theory-practice connection, enhancing opportunities for contextualized learning and demonstrating real-world knowledge application, particularly for interactive processes like 360° video utilization. This approach proves especially valuable for hybrid and distance learning students, providing immersive exposure to engineering practice environments early in their academic training.

The intuitive, responsive interface was designed for universal accessibility across user profiles, enabling straightforward navigation that includes video selection, full-screen playback, and free environmental exploration. Computer-based navigation utilizes cursor movements to adjust viewing perspectives according to user interest. Mobile device interaction (smartphones and tablets) employs built-in gyroscopic sensors to track physical movements and rotations in real time. When using VR headsets - ranging from advanced systems to cost-effective cardboard solutions - the interface delivers enhanced spatial presence and immersion, closely approximating real-world environmental engagement.

This solution facilitates virtual technical visits, extending access to the institution's physical facilities for students and professionals when on-site presence is unfeasible. By doing so, it enhances knowledge dissemination regarding available infrastructure and resources while reinforcing the theory-practice nexus. Application analysis revealed three key educational benefits: (i) immersion, the panoramic 360° view enables realistic spatial comprehension of environmental layouts, equipment configurations, and operational processes; (ii) engagement, autonomous scenario exploration stimulates learner interest and curiosity, fostering more active participation; and (iii) instructional effectiveness, the integration of high-quality visual media with contextual narratives improves information retention and strengthens conceptual-practical linkages.

During implementation, several limitations were identified: (i) dependence on stable internet connectivity to ensure uninterrupted video streaming, particularly on mobile platforms; (ii) performance variability contingent on device specifications, potentially causing rendering delays on lower-capacity hardware; and (iii) lack of supplementary interactive features, such as informational hotspots, which could otherwise enhance the educational experience.

The application's architecture demonstrated effective multiplatform compatibility across major operating systems (Windows, macOS, Android, iOS) and educational browsers (Google Chrome, Mozilla Firefox, Microsoft Edge, Safari). This cross-platform functionality significantly enhances accessibility, enabling content delivery across diverse devices ranging from high-performance workstations to entry-level smartphones. However, evaluation revealed that 360° video loading times are network-dependent, potentially impairing experience quality in low-bandwidth environments. These findings underscore the necessity for optimization strategies including: (i) efficient video compression, (ii) high-performance codec implementation, and (iii) adaptive streaming technologies that dynamically adjust playback quality based on available bandwidth.

Regarding responsiveness, the application consistently preserved visual and functional integrity across desktop, tablet, and smartphone platforms. However, iOS device limitations preclude cardboard mode compatibility, thereby partially restricting user access to the virtual reality format.

Conclusion

The implementation of the “CIMATEC 360º” application demonstrated the potential of 360º videos as an immersive educational resource for the field of engineering, integrating technical, pedagogical, and technological accessibility aspects. The experience showed that, by enabling the free exploration of real environments, the solution contributes to strengthening contextualized learning, expanding the possibilities for student interaction and engagement.

From a pedagogical perspective, the resource proved effective in bringing theoretical content closer to the practices developed in laboratories, fostering the understanding of processes, equipment, and layouts that, in many cases, would only be experienced through in-person visits. This feature is particularly relevant to the field of engineering, where contact with real environments is necessary for skill development.

From a technological standpoint, the application achieved good compatibility with multiple devices and browsers, maintaining an intuitive and responsive interface. However, the identified limitations, such as the dependence on a stable internet connection and performance variations depending on the device, indicate the need for future improvements, such as the implementation of adaptive streaming, optimized file compression, and the inclusion of additional interactive elements, such as hotspots with information, check questions, or complementary links.

As a proposal for future studies, it is suggested to investigate students' perceptions of the use of the CIMATEC 360º application, analyzing its effects on motivation, engagement, and competence development. Furthermore, it is recommended to integrate the solution with artificial intelligence systems to personalize navigation and suggest pathways aligned with the user's profile and interests, as well as to incorporate augmented reality resources and interactive simulations. Such enhancements could expand opportunities for active learning and guide immersive experience toward specific pedagogical objectives, thereby enhancing the use of immersive technologies in engineering education and other educational contexts.

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Potential Use of Amazon River Sediments in Civil Construction: Environmental and Socioeconomic Perspectives

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It is estimated that the Amazon River transports 1.2 billion tons of sediment annually from the Andes. Research indicates that Amazon sediments can be used in the production of mortars, concrete, and other construction materials, exhibiting favorable physical and mechanical properties. To contribute to this topic, this article explores the potential reuse of Amazon River sediments in civil construction, highlighting their capacity to promote sustainability and reduce environmental impact. Physical, chemical, and mineralogical analyses of the sediments were conducted, confirming their composition rich in quartz and clay minerals. The results of the analyses confirm other studies as an excellent raw material for production in the construction industry.
Keywords: Amazon River Sediment. Civil Construction. Sustainability.

For a sustainable future, it is necessary to change current trends and rethink how to better manage available resources, as well as the development of new materials that do not degrade the environment. Industries, such as the construction industry, require large quantities of raw materials in their manufacturing processes, which negatively impacts the environment [1,2]. One way to minimize this impact is to use waste from other industries, or from within the industry's own supply chain, which, in the construction industry, would reduce the burden on natural resources and carbon emissions [3].

Another possibility is to seek different sources of raw materials, one option for civil construction being sediments from the Amazon River. For many years, the intense accumulation of sediments transported by the river has impacted Amazonian cities located along the Amazon River, which depend on river transportation to ensure the region's supply and economic sustainability [4]. Faced with this impasse, it is necessary to link the demands of industry with socioeconomic activities related to the navigability of the North region. It is noted that this opportunity aligns with the reduction in the extraction of natural resources that are being depleted and opens the possibility of other resources.

Studies indicate that the sediments of the Amazon River (Figure 1) originate from the Andes (the main source of Amazonian rivers) and are transported to the Atlantic Ocean. This phenomenon has been observed in the Amazon lowland region, as have the processes of storage (sedimentation) and resuspension. These phenomena result from changes in the hydraulic gradient over the course of the hydrological cycle [5,6].

Lins [7] reports that the silting of the river and its tributaries significantly impacts navigability, interfering with transport capacity and speed, in addition to the formation of fluid mud [8], which affects the local economy. Therefore, the use of sediments from the Amazon River in civil construction, in addition to meeting industrial demand, would contribute to a local need.

Use of Amazon River sediments in Civil Construction

The geochemistry of the Amazon River

Received on 11 October 2025; revised 15 December 2025.
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J Bioeng. Tech. Health 2026;9(1):45-51

Figure 1. Sediments transported out of the Andes.

Source: Aliança Águas Amazônicas (2023).

is predominantly influenced by inputs from mountainous environments, especially the Andes Mountains in Peru and Bolivia. According to Oliveira [9], approximately 84% of the river's suspended solid sediments originate from these mountainous areas, while about 12% comes from other regions of the Amazon Basin. According to data from the Amazon Water Alliance [10], the Amazon River transports approximately 1.2 billion tons of sediment annually, passing through the Óbidos stretch, considered the narrowest of the river. Of these sediments, approximately 75% reaches the Atlantic, while the remaining 25% is deposited along approximately 800 km downstream.

Slumped land, a phenomenon resulting from climatic events and sediment displacement, is caused by global warming, which intensifies erosion processes on riverbanks. This erosion promotes the formation of ravines, according to Oliveira [9]. The sediments transported by these actions contribute to the formation of river islands, which can partially or completely disappear, giving rise to new sedimentary islands [11,7].

The dynamics of the Amazon River's flow directly influence the formation of these islands. The reduction in current speed favors sediment settling, which can compromise navigability in the region. This variation in flow results in reduced vessel carrying capacity, helping to minimize groundings, especially during the period known as the "Amazonian summer" (October to December), when water volume in the river's headwaters decreases [7].

To mitigate the impact of Amazon River sediments, research is seeking an alternative destination for this material. Studies have been conducted on the use of these sediments in construction, with the goal of reducing the extraction and intensive use of mineral resources through alternative utilization possibilities. For example, Pimental and colleagues [6] investigated the changes in coating mortar when natural aggregate was partially replaced with Amazon River sediment. The presence of clay minerals increased the mortar's tensile strength and led to the formation of stable crystalline products, suggesting greater stability for the coating.

Azevedo and colleagues [4] state that Amazon River sediment has immense potential for use as a supplementary cementitious material due to its chemical composition ($SiO_2 + Al_2O_3 + Fe_2O_3 = 91.49\%$) and mineralogical characteristics, which allow it to be incorporated into cement without compromising its essential properties. The study demonstrated that Amazon River sediment improves the workability of the cement paste. Rozière and colleagues [12] verified the use of treated sediments in self-compacting concrete as a substitute for aggregates and limestone fillers (mineral additives). As a result, they obtained a dense cement paste with compressive strength equivalent to that of conventional materials.

Ennahal and colleagues [13] used marine and river sediments from northern France in their studies, which were recovered as mineral aggregates for the composition of polymeric mortars for floor coverings. The mortars showed low void content and good chemical resistance, indicating the potential for using these sediments in polymeric matrix materials as well.

Given the relevance of the studies presented and the limited amount of available data, a gap remains to be explored: the use of Amazon River sediments in civil construction as a partial replacement for traditional inputs. This approach can add value by fostering more sustainable performance for the industry and the local population. In this context, this article aims to present the characteristics of Amazon River sediments with a focus on their potential use in the production of materials in civil construction.

Materials nd Methods

To utilize Amazon River sediment in civil construction, its characteristics must be understood. Therefore, physical, chemical, and mineralogical characterizations were performed using analytical techniques and instruments. For this study, 200 kg of sediment was collected from the riverbed in a silted area on the dryland banks, at a distance of 200 m, called the sediment strip. This strip forms a "beach" where, starting 100 m away, the sediment is collected using wooden boxes measuring 170 cm x 30 cm x 30 cm, allowing for storage during tides. The sediments were then removed from the river, bagged, and transported to an open area, where moisture was removed and sieved. The collection criterion considers not interfering with the local ecosystem surrounding the riverbanks (organic matter - humus); therefore, this distance is important. For a new collection, try to maintain a distance from the initial collection site, covering an area of 1 hectare. The material's particle size distribution curve was obtained by diffraction with previously measured particle size standards. A PSA 1190L (Anton Paar) laser particle sizer with a reading range of 40 nm to 2.5 mm was used. The mineralogical composition was determined by X-ray diffraction (XRD) using a Bruker D2 Phaser model, with a 30 kV, 10 mA copper target tube, wavelength (λ) of 0.15406 nm, and no secondary monochromator filtering system. The diffraction spectra were in the 2θ range from 5° to 90°, continuous mode at 0.04°/s. The micromorphology of the sample was analyzed by scanning electron microscopy (SEM) with DENTON VACUUM (model JEOL-JSM-6510LV) and Thermo Scientific equipment. The XRF Axios Max equipment from Panalytical was used to study the chemical composition of the sediment.

Results and Discussion

Granulometry

The particle size range of the Amazon River sediment was 1 and 100 µm, and the equivalent diameters (D10, D50, and D90) were 2.24 µm, 12.24 µm, and 46.35 µm, respectively. Most of the grains were between 0.002 mm and 0.05 mm, classifying the material as silty. This classification suggests a potential use in civil construction, as fine particles, such as silt, act to fill the voids between larger aggregates, promoting better packing for the mixture [14]. For example, in the study by Hussain and colleagues [3], sediments dredged from the Usumacinta River, France, were reused for adobe bricks. The laser granulometric test yielded percentages of clay (5.9%), silt (41.3%), and sand (52.8%) with an average D50 diameter of 51.85 µm. In the adobe bricks, the percentages of silt (41.3%) and clay (5.9%) promoted cohesion and minimized shrinkage.

In both cases, the sediments extracted from rivers presented fine grain sizes, which can contribute to good workability and adhesion. However, it is essential to perform appropriate analyses regarding the amount of water and additives to ensure good product performance.

Chemical Characterization

Chemical analyses were performed by X-ray fluorescence for the following oxides, yielding the following results (Table 1).

The sediment exhibits a high SiO_2 content, possibly in the form of quartz, in addition to clay minerals. Regarding loss on ignition, the sediment presented a percentage of 2.48%, indicating high purity and thermal stability under high temperature conditions. The results obtained are similar to those of Azevedo and colleagues [4];Pimentel and Paes [6], who also observed a high SiO_2 value

(78.87%) in the form of quartz, an inert material when in a cementitious matrix.

Unlike the applications discussed in previous studies, Laoufi and colleagues [15] used sediment to partially replace cement through the calcination process. For this purpose, the sum of the oxides (SiO_2 + Al_2O_3 + Fe_2O_3) presented values close to the 70% limit, as established by the ASTM C618-3 [16] standard, which corroborates the feasibility of its application. Therefore, the relevance of using river sediments both in the production of aggregates and in the partial replacement of cement as a pozzolanic material is highlighted, especially due to the presence of hydrated clay minerals, such as kaolinite, contributing to the reduction of costs and CO_2 emissions.

Mineralogical Characterization

The result of the diffractogram of the Amazon River sediment (Figure 2) indicates the presence of two crystalline phases: quartz (SiO_2) and kaolinite [$Al_2Si_2O_5(OH)_4$]. This result corroborates that obtained through XRF, since the identified oxides compose the minerals.

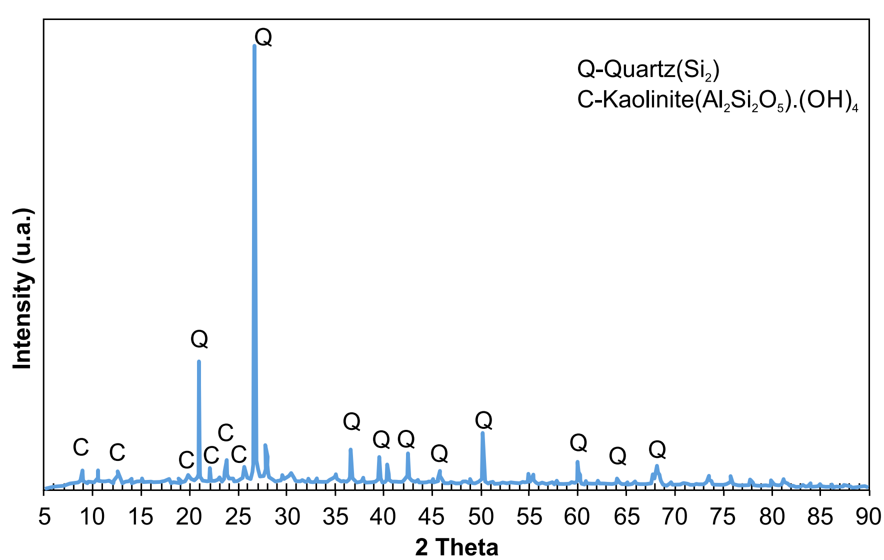
The presence of quartz and kaolinite in the Amazon River sediment is closely linked to the natural erosion process that occurs along its banks. Kaolinite is formed by the weathering of feldspar and other aluminosilicates under acidic conditions [17]. Quartz, on the other hand, is found in sedimentary deposits. These minerals have been widely used in processes related to

Table 1. Chemical composition obtained for the mineral fillers evaluated.

Material	Oxides (%)									
	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	CaO	TiO_2	Others	PF*
A-Sediment	78.55	9.87	3.36	1.77	0.84	1.09	0.99	0.68	0.37	2.48
B-Sediment	78.87	9.48	3.14	1.57	0.67	1.44	0.89	0.71	0.12	3.04
C-Sediment	78.87	9.48	3.14	1.57	0.35	1.44	0.89	0.71	0.12	3.04

Source: Authors (2025). B [6]. C[4].

Figure 2. Diffractogram of the Amazon River sediment.



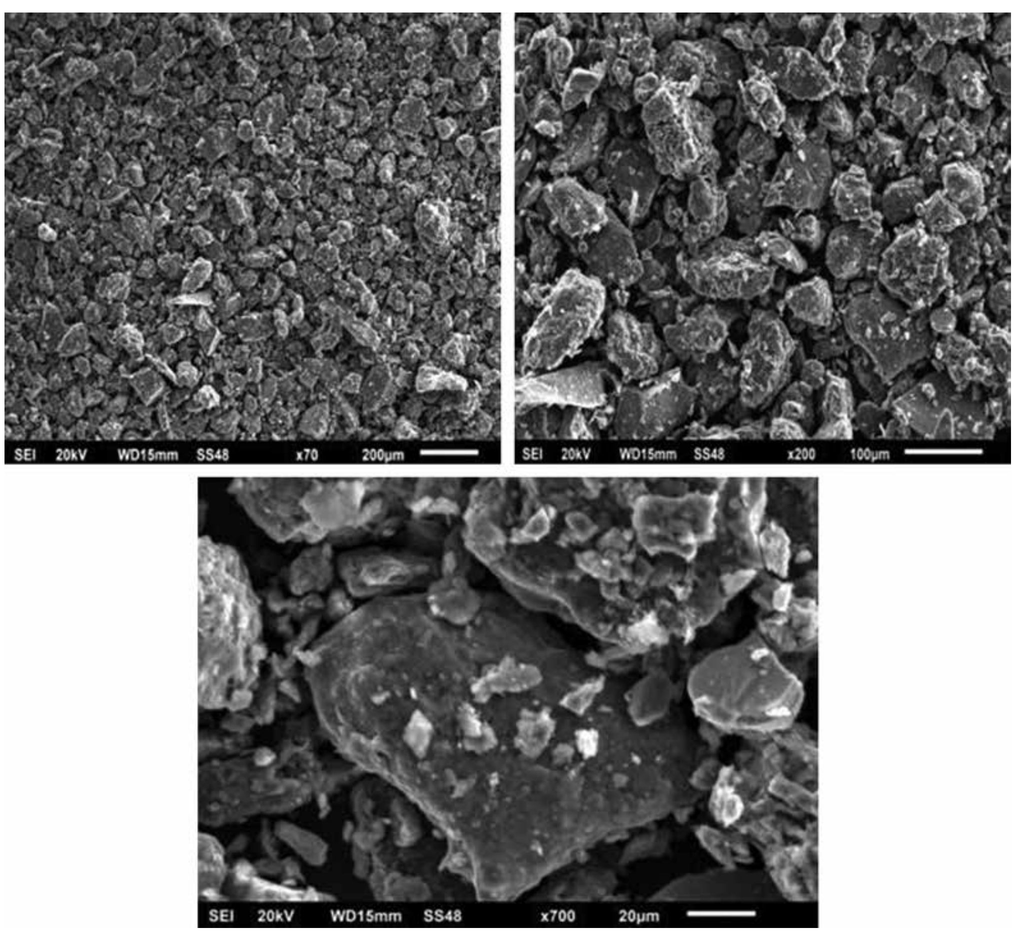
sustainability and materials innovation due to their physicochemical properties [6,18-22].

Micromorphology

Figure 3 shows the image obtained from the scanning electron microscopy (SEM) test performed on the Amazon River sediment. The images show that the particles are smaller than 100 μm, corroborating the data obtained from the laser particle size analysis. The particle size distribution is somewhat heterogeneous, with diameters ranging from less than 1 micrometer to 90 micrometers. Furthermore, the presence of smoother particles with low roughness, typical characteristics of the mineral quartz, is observed [6,23]. In Figure 3, it is also possible to note that the smaller particles, below 1 micrometer, exhibit characteristics of the mineral kaolinite, presenting tabular, pseudo-hexagonal, euhedral and subhedral crystals, the latter resulting from particles with irregular shapes, which reflect different orientations and crystalline arrangements of the mineral [24]. In general, fluvial sediments exhibit irregular contours and sharp edges, resulting from mechanical fragmentation and turbulent transport [25].

As in the study by Rozière [13], developed for self- compacting concrete, the presence of randomly distributed mineral crystalline phases in the sediment particles was identified, including large crystals (> 50 μm) of quartz, hematite, albite, and orthoclase, which corroborates the results obtained in this study regarding chemical characterization. The presence of these minerals contributes to increased mechanical strength in mortars and concretes due to their highly hard

Figure 3. SEM micrographs obtained for the Amazon River sediment sample.



structure. Rozière [12] reported that the mix for self-compacting concrete requires a significant amount of sediment. Although the initial average particle size was relatively large, microstructural analyses demonstrated that the largest particles were fragmented during concrete mixing, favoring particle packing and, consequently, improving the material's workability.

The characterization performed in this study on Amazon River sediment presented results that are consistent with those already demonstrated in the literature, reinforcing the viability of its use for industrial purposes. Therefore, it contributes to sustainable processes and, mainly, to reducing the consumption of conventional mineral resources in civil construction.

Conclusion

This study demonstrated river sediment as a viable alternative for the construction industry, potentially used as an aggregate or as a partial replacement for cement through the calcination process. Furthermore, its potential for producing adobe bricks, coating mortars, and self- compacting concrete stands out. The use of Amazon River sediments offers potential for reducing the consumption of conventional raw materials, which are becoming depleted, and opens opportunities for new resources. Furthermore, this practice can play a strategic role in improving navigability and mitigating the impacts of climate phenomena affecting the North region. To this end, it is essential to strengthen research and formulate public policies that promote the responsible reuse of these sediments, ensuring lasting benefits for the region's sustainable socioeconomic development.

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Territory Mapping as a Citizen Education Tool: A Community Extension Approach from SENAI CIMATEC University

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In 2018, the Ministry of Education implemented Resolution No. 7, which establishes guidelines for extension in Higher Education and makes it a part of the curriculum. This new model seeks to strengthen the social commitment of Higher Education Institutions by promoting social participation. At SENAI CIMATEC University, university extension was restructured with the creation of the Community Extension Center (NEC) in 2024. The NEC works to develop extension programs that incorporate the principles of Popular Education and Citizen Education, promoting social development and integrating teaching and research. To identify community needs, the NEC adopted the Territory Mapping tool, in which students conduct a sociocultural assessment of the location, understanding its physical, political, and cultural dimensions. The territory mapping was conducted by Mechanical Engineering and Data Science and Artificial Intelligence students between March and July 2025. This work aimed to report on the experience of the NEC team and the students, addressing the main stages of the mapping, student feedback, and the identification of potential projects. The first part of the mapping investigated basic infrastructure and environmental and cultural aspects. The second part addressed community participation, economic issues, security, and cultural manifestations. The most frequently identified cultural manifestations were music, dance, sports, graffiti, and crafts. Through their experience reports, the students demonstrated their involvement and knowledge of local realities. Territory mapping proved to be an effective tool for civic education, allowing students to connect with the realities of their communities and awakening the desire to develop relevant extension projects. The mapping results, including the identification of infrastructure, environmental risks, and cultural manifestations, will serve as a basis for future extension projects, strengthening the relationship between teaching, research, and extension, in line with the objectives of SENAI CIMATEC University.
Keywords: Territorial Mapping. Citizen Education. Extension. Engineering. Data Science.

In 2018, the Ministry of Education implemented Resolution No. 7, which establishes guidelines for extension in Higher Education and makes extension curricular [1]. This new model reinforces the social commitment of Higher Education Institutions through actions that foster Social Participation. Thus, university extension at SENAI CIMATEC University was restructured in 2024 with the implementation of a community- focused extension program through the creation of the Community Extension Center (NEC), located within the Office of the Provost for Extension and Community Affairs. To gain a broader understanding of the problem, provide more effective responses, and strengthen citizenship and sustainability initiatives, the NEC established a multidisciplinary structure composed of professionals from the fields of engineering, pedagogy, anthropology, psychology, and social work. Biweekly meetings are held to discuss key cases and tools for analysis, feedback, and integration of different perspectives based on the PBL methodology. The new community outreach culture was implemented systematically, articulating with teaching and research and involving the University's and the SENAI CIMATEC ecosystem's key areas: education, science, technology, innovation, and business for industry and society, such as the Institutional

Received on 26 October 2025; revised 28 December 2025.
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J Bioeng. Tech. Health 2026;9(1):52-57

Relations and Technology areas. This proposal is based on the development of an outreach program guided by the principles of Popular Education and Citizen Education, focused on promoting social development, overcoming merely welfare-based practices. Community outreach is structured and curricular based on the premises of the document "Extension in Social Participation – Reference Document" [2]. With this premise, extension practices are articulated at NEC through two extension programs: the Girls 4.0 Program: Connection to Change the World, which began as a teaching initiative, was added to the core due to the experience and alignment of its mission with that of NEC. It is composed of extension workers, members of the Women in Engineering (WIE) student branch, and partner schools. The objective is to guide, connect, and inspire girls from elementary and high school onwards to greater participation in the STEM (Science, Technology, Engineering, and Mathematics) field through workshops and guided tours at various companies in the industrial sector; and the Public Office of Engineering and Architecture (EPAE), whose main objective is to provide architecture and engineering services to the communities and partner institutions served, focused on the development of supervised projects that enable students to develop and improve technical skills in their respective areas of training, in addition to strengthening transversal skills related to extension practices.

To identify the demands and needs of the communities, the Territory Mapping tool was adopted. This tool allows students to conduct a sociocultural assessment of the territory chosen for extension work. This allows them to understand its physical, political, and cultural dimensions, enabling them to identify actions and projects to be developed. The tool brings students closer to the communities.

Territory mapping involves conducting research on the community's socioeconomic data on official websites such as the Brazilian Institute of Geography and Statistics (IBGE), researching the map of streets and public spaces in the area in digital and georeferenced format using aerial photogrammetry and satellite imagery, available on Google Earth, for example. In addition, technical field visits and dialogue with community members are conducted.

Within this context, this work aimed to report the experience of the NEC team and first-semester extension students in the Mechanical Engineering and Data Science and Artificial Intelligence programs during the territory mapping activity. The main stages of this activity, including student insights and feedback, and the identification of potential projects and actions based on the mapping results, were discussed here. In other words, it's important to emphasize that this was the first step in the ongoing initiative, which will continue in subsequent semesters, as the extension program runs from the first to the fourth semester.

Territory from the Perspective of Extension Practice

It is necessary, first, to conceptualize territory and then to understand its dimension for extension practice. The term territory comes from the Latin "territorium," an expression referring to a delimited space. However, the "physical" dimension alone does not encompass all the issues involved in extension work. Other dimensions, such as political, cultural, economic, and regional, must be considered [3]. Thus, the NEC operates based on Corrêa's understanding, which considers that territory is, in reality, a concept subordinate to a more comprehensive one: space—that is, spatial organization. Territory is space endowed with political, affective, or both dimensions [4]. In addition, it is based on Santos' understanding that it is within the territory, as it currently exists, that citizenship is learned and must be claimed, as it occurs within the political, social, and legal context through institutional mechanisms that guarantee the exercise of agreed-upon rights and, in the event of denial, ensure the right to file a complaint and be duly heard. This is one of the areas in which extension practices operate: contributing to the awareness of citizenship through Social Participation [5]. Since the beginning of globalization, the concept of territory has expanded, no longer tied to a single physical space, changing the way individuals relate spatially, breaking down borders, and building a new order—an open, global space.

In extension, territory presents itself as a space for the development of citizenship education, the consolidation of teaching and research, and the dissemination of knowledge. This interrelationship between territory and education is addressed in various fields of knowledge and represents important milestones in the history of Brazilian education. Table 1 shows the evolution of the concept of territory over the decades, its origins, and its foundations, as they relate to education.

It can be seen that the set of values that guided figures in the history of Brazilian education, such as Paulo Freire and Anísio Teixeira, or important movements such as Educating Cities, remain relevant and fundamental in building a more just and equal society. After almost a century, Brazilian education is experiencing a moment of profound transformation with the emergence of curricular extension. The territory is, so to speak, a space for the dissemination of knowledge based on the relationships between extension workers and communities. It is worth emphasizing that the use of territory mapping is precisely an affirmation of this bias, as this tool invites extension workers to step outside their supposedly knowledgeable position and listen to those in the territory, thus enabling a joint diagnosis and paving the way for joint planning and action. In this way, the civic experience is encouraged in all involved in the process.

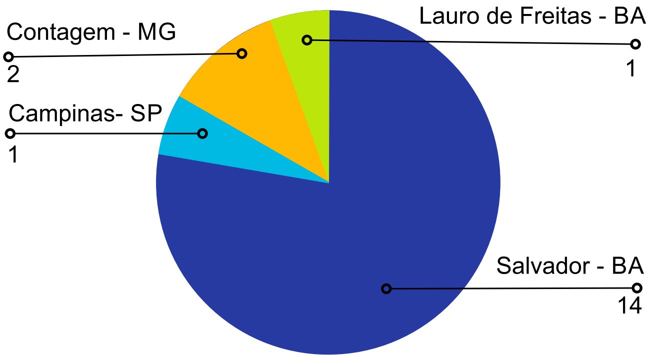
Results of the Territory Mapping

The territory mapping was conducted by first-semester students of the Mechanical Engineering and Data Science and Artificial Intelligence (CDIA) programs, offered through distance learning (EAD) by SENAI CIMATEC University, with different campuses. The activity was conducted between March and July 2025. Figure 1 shows the number of students involved in this activity, distributed by city/hub.

Table 1. Important milestones in the history of Brazilian education. Adapted from [6].

Author	Educational Territory	Principles
Mário de Andrade, 1935 (Architect)	Playgrounds	Learning environment through experience and play.
Anísio Teixeira, 1950, (Jurist and professor)	Public School (Park School)	Comprehensive education, democratic and inclusive principles, openness to the community, socially engaged education.
Paulo Freire, 1960 (Pedagogue)	Schools and Universities	Citizen Education.
Charter of Educating Cities, Bologna, 1994	Educating Cities (Cities that are part of the International Association of Educating Cities)	Participation in urban planning.
Ladislau Dawbor, 2000, (Economist)	Neighborhood/Community	Student protagonism, knowledge of reality, connection,empowerment and citizenship.
Multi-authored, 2025	Academic Territory (Symbolic Space)	Education takes place inside and outside the University walls.

Figure 1. Number of students by city.



To prepare students for the practical work, they had the opportunity to experience synchronous meetings with their faculty advisors and participate in thematic workshops (Community Outreach and Anti-Racist Practices), which are part of the set of outreach strategies for developing social technology.

The goal of territory mapping was to identify the initial information important for developing outreach projects, such as needs, resources, and social factors.

This tool allowed students to delimit the area of attention (the area where outreach projects will be developed) and define the micro-areas based on the identified indicators, social risks, and territorial barriers [7,8].

In the synchronous monitoring, guidance, and project dedication classes, the tasks to be submitted by students were presented: the territory mapping, divided into two parts, and the experience report, which is the student's perception of what they learned using the tool. At this stage, students were able to define which territory to map based on their teaching center. Table 2 shows the number of students and the territories/communities chosen for mapping.

The first part of the mapping investigated aspects of basic infrastructure, such as access to water and sewage services, housing typology, public facilities, as well as environmental and cultural aspects.

After defining the territory/community, the students identified areas with potential for developing outreach projects, described as follows: Buraquinho, Bairro da Paz, Trobogy, and Calabetão (Bahia); Vila Barraginha (MG) were defined as peripheral areas; Aristides Maltez Hospital (HAM) as a philanthropic (public) hospital; Day Center as a foundation specializing in elderly care; and the Case Foundation, identified as a center for the detention and education of young people deprived of liberty.

Table 2. Number of students per team and territories chosen.

City/State	District / Community	Students per Team
Salvador-BA	Bairro da Paz	7
Lauro de Freitas-BA	Vila Praiana Community	1
Salvador-BA	Community of Trobogy	1
Salvador-BA	Aristides Maltez Hospital	3
Contagem-MG	Vila Barraginha	2
Salvador-BA	Calabetão	2
Campinas-SP	Centro Dia	1
Salvador-BA	CASE Foundation	1

After the geographic characterization of the territories, other aspects related to infrastructure were analyzed, such as the quality and availability of public transportation and housing types.

Most students identified public transportation as efficient, and regarding the type of occupancy, only 27.8% considered it regularized. This data highlights the need to examine the status of these properties and consider possible actions in this regard. On the other hand, this percentage reveals the difficulty of EPAE's actions, since property documentation is a prerequisite for project development.

Regarding public facilities, 90% of students identified the presence of public facilities in the areas investigated, with schools being the most cited type, reaffirming that this is the most strategic space for the development of extension activities. Since 2024, NEC has been carrying out activities at Colégio Mestre Paulo dos Anjos (CEMPA), located in the Bairro da Paz Community, where several extension projects have already been developed and others are underway or in the implementation, deployment, and monitoring phases.

The most frequently cited environmental risks were floods, landslides, erosion, and pollution. This data also reveals a significant field of action. The second part of the instrument addressed aspects of community participation and development, economic and security issues, and local cultural manifestations. The results revealed limited or no community participation in collective decision-making processes, highlighting the need to develop strategies to increase community political engagement, especially when striving for equity, social justice, and sustainable development. When the community participates in decision-making, these decisions better reflect the real needs and desires of the area, ensuring that public policies and government actions are more effective and legitimate. Furthermore, historically marginalized groups can have an active voice in decision-making, strengthening the fight against inequalities, and securing rights.

Regarding safety, almost half considered the area safe. It is important to emphasize that this is an external perception, a perspective from someone "outside" the community. Identifying cultural manifestations opens a space for recognizing and strengthening local culture. The most frequently identified manifestations were music, dance, sports, graffiti, and crafts. The presence of leisure and cultural spaces points to potential development initiatives.

After completing the second part of the mapping, experience reports were compiled, in which the teams evaluated what was learned in the previous phases. The experiences were recorded through videos and podcasts.

Two notable reports were presented in podcast format. A team from Minas Gerais reported on a landslide that occurred in 1993 in Vila Barraginha, killing 36 people, leaving nearly 70 injured and hundreds homeless [9]. When the students described the Vila Barraginha area, they realized the scale of the tragedy for that community, the state of Minas Gerais, and Brazil. They reported, in their orientation, that in 1993, a year after the landslide, the National Conference of Bishops (CNBB) presented decent housing as the theme of its fraternity campaign, given the scale of the tragedy. The theme was "Fraternity and Housing" and the motto "Where Do You Live?" [10].

According to the students, more than twenty years after the tragedy, the local community still faces difficulties resulting from the tragedy, sparking a desire to develop something relevant, through outreach, to improve that community. It is noteworthy that the perspective of the students and the Center itself refers to a contribution, with an awareness of the limits and responsibilities that fall to the Academy in its relationship with the social context.

A second account came from a group that described the Brotas neighborhood, where the Aristides Maltez Hospital is located. The team's goal is to develop an application to reduce the waiting time for treatment in patients with BI-RADS 4 results (indicative of cancer) [11]. The Aristides Maltez Hospital is a reference in cancer treatment, classified as the largest 100% cancer center within the Unified Health System (SUS) in Brazil [12]. In both reports, it was concluded that the teams were engaged with the spaces delimited in their respective mappings. The instrument proved effective in enabling connection between them and the communities, as a first step toward understanding and building bonds. By the end of the semester, they demonstrated engagement and a greater understanding of local realities.

Conclusion

Territorial mapping proved to be an effective tool for civic education, allowing students to connect with the realities of their communities.

Initially, students had more general information about the realities they studied, but by the end of the semester, they demonstrated engagement and a greater level of knowledge about local contexts. This connection sparked a desire to develop relevant outreach projects, such as the Minas Gerais team, which, after studying the history of Vila Barraginha, expressed interest in working to improve the community. Another example is the group that mapped Aristides Maltez Hospital and proposed creating an app to reduce waiting times for patients diagnosed with cancer.

The results of the territorial mapping, which included the identification of infrastructure, environmental risks, and cultural manifestations, will serve as a basis for the development of outreach projects in subsequent semesters. Schools, for example, were the most frequently identified public facilities, indicating potential for outreach activities. The presence of environmental risks such as floods and landslides also revealed significant scope for action. Thus, mapping strengthens the inseparability of teaching, research, and outreach by enabling the structuring of diagnostic research, discussions mediated by the teaching field, and projects for community feedback. Furthermore, the foundation of secondary education is the construction of a critical analysis regarding the value and relevance of local knowledge contributed by social actors, forming a cycle of knowledge based on experience and social relationships: students are protagonists of outreach activities, which, in turn, foster the appreciation and protagonism of the community, in accordance with the objectives of SENAI CIMATEC University.

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Comparison of the Value Chain of Steel Inserts for Multi-Cavity Tools Manufactured Additively and Conventionally Using Flexsim

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The tooling sector is essential for industrial development, providing tools and molds that directly influence the efficiency and competitiveness of industries. In Brazil, low productivity meets only 50% of domestic demand, requiring imports. The main obstacles include lack of modernization, shortage of professionals, inadequate management, and inefficient use of resources. The development of injection molding tools is expensive, time-consuming, and resource-intensive; additive manufacturing emerges as an alternative for faster production. However, there is a lack of effective methods for choosing the ideal technology for each project. Computer simulation allows the emulation of production chains with additive and conventional technologies, enabling economic analysis and the identification of bottlenecks. In this article, FlexSim was used to model a 32-cavity mold and compare the results with those obtained in Tecnomatix Plant Simulation. The systematic review supported the simulation methodology, and the results indicated that conventional manufacturing had higher productivity and lower manufacturing costs.

Keywords: Simulation with FlexSim. Decision Support Tool. Metal Plastic Injection Molds. Additive Manufacturing. Conventional Manufacturing.

Abbreviations: AM, Additive Manufacturing. CM, Conventional Manufacturing.

In the tooling sector, the use of technologies such as artificial intelligence, interconnectivity, machine learning, and, above all, customization in production is growing. With a focus on productivity, flexibility, and rapid tool development, the expansion of additive manufacturing (AM) stands out.

This process forms the final product by depositing successive layers, allowing for rapid prototyping and customized parts with minimal waste. Despite its advantages, conventional manufacturing (CM) still predominates due to its stability, consolidated processes, and high production capacity.

The evolution of AM equipment suggests a possible replacement of conventional methods, requiring careful analysis to identify the most advantageous approach, considering the pros and cons and their implications for the transformation of raw materials [16].

In Brazil, about 90% of tool shops have fewer than 20 employees, which makes it difficult to adopt complex and expensive technologies such as AM. In addition, strong competition from Asian tool shops requires innovation and greater efficiency [15]. This study aims to compare AM and CM to assist managers in making the most appropriate choice, using computer simulation as a decision support tool, evaluating time, process optimization, bottlenecks, automation, and digital twins, contributing to operational, administrative, and financial management [3]. With FlexSim, technical parameters, limitations, and impacts on reliability will be simulated, providing input for strategic decisions and strengthening the competitiveness and sustainability of the sector.

Theoretical Foundations

The manufacturing process in tool shops began during the Industrial Revolution, with the aim

Received on 15 October 2025; revised 17 December 2025.
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J Bioeng. Tech. Health 2026;9(1):58-64

of producing standardized parts and molds that would optimize craftsmanship or enable large-scale production. Milling, turning, and grinding became commonplace with the advancement of automation in the 19th century, increasing precision [2]. In the following century, CNC machines made it possible to manufacture complex geometries with high quality, establishing themselves as essential technology for molds and dies [6].

Additive manufacturing brought greater flexibility, reduced waste, and made complex parts feasible [9]. Conventional manufacturing, on the other hand, removes material by machining and grinding until the desired geometry is achieved [23].

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology was applied to the literature review to enhance understanding of the problem addressed in this study and provides a structured framework that ensures transparency and reproducibility in systematic reviews. In this research, it guided the identification of relevant databases, the definition of inclusion and exclusion criteria, and the screening and selection of sources, guaranteeing that only high-quality and contextually appropriate references were considered. For comparison purposes, the data used in the FlexSim simulation model were the same as those adopted in the TecnoMatix Plant Simulation case study [17], which was identified through the PRISMA-based review. Sixty-three studies were initially retrieved from SCOPUS, but [17] was selected for its direct comparison of AM and CM in an industrial multi-cavity molding case. Reference [17] used Tecnomatix, a Siemens software based on digital twins, to optimize manufacturing and identify bottlenecks [22], presenting an annual economic comparison to support decision-making. To complement these findings, this study applies FlexSim—an OpenGL-based simulation platform capable of real-time scenario analysis and bottleneck identification—to evaluate time, inventory, and cost variables.

Materials and Methods

Following the literature review, the research progressed through several stages: defining the problem situation and objectives for process improvement; establishing the study scope to compare AM and CM; and collecting and processing data, including selecting tools and detailing the procedures for using FlexSim. The production processes for both CM and AM were thoroughly mapped, identifying setup times, operation durations, post-processing requirements, resource use, and potential bottlenecks. Based on this mapping, a conceptual model representing the logic and flow of operations was developed and implemented in FlexSim for computational simulation. The model was validated and calibrated to ensure the simulated behavior accurately reflected industrial performance. Sensitivity analyses and parameter variations were conducted to evaluate the impact of machine configurations, labor allocation, and production volumes. Finally, performance indicators such as productivity, cycle time, resource utilization, and operational costs were monitored to systematically compare CM and AM.

Problem Situation

Toolmakers need to optimize production efficiency, costs, and quality. This study compares additive and conventional manufacturing, evaluating production time, cost, raw material consumption, customization, geometric complexity, post-processing, and skilled labor, considering a company that manufactures a specific type of tooling on a large scale.

Scope Definition

Through a production analysis, this article seeks to identify which manufacturing method is most efficient and viable for industries and toolmakers, with a view to improving the production process. Comparing the total manufacturing time for inserts using both techniques allows for an assessment of productivity and costs related to raw materials, machinery, and operation, determining the economic impact of each approach.

In addition, it considers how each method influences the accuracy of the inserts in terms of tolerances and surface quality, an essential factor in industrial applications, especially on a large scale. The need for skilled labor is also evaluated, analyzing both the cost of hiring specialized professionals and the availability of this profile in the market.

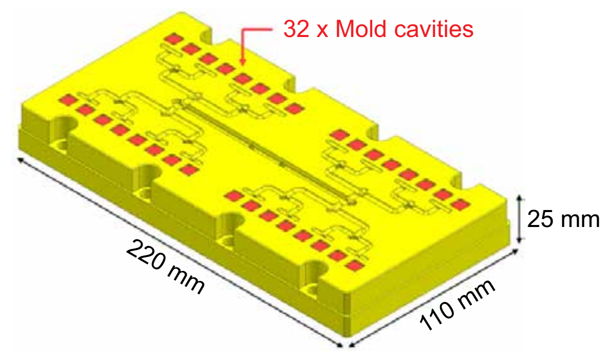


Figure 1. 32-cavity mold for plastic injection molding [17].

Data Collection

Considering the variables influencing technological choice and based on Moshiri and colleagues [17], the FlexSim software was used for simulation, applied to an industrial case study of a 32-cavity plastic injection mold (Figure 1).

According to Babulak and Wang [1], discrete-event simulation was employed to compare CM and AM process chains, analyzing delivery deadlines, bottlenecks, and critical points. For comparison purposes, the same data from the case study with TecnoMatix Plant Simulation [17] were used, allowing the acquisition of real machine data.

In the CM chain, the process includes drilling, milling (rough, semi-finish, and finish), EDM or manual polishing, laser engraving, ultrasonic cleaning (UC), and quality control (QC), with times presented in Table 1 [17].

In the AM chain, the process starts with metal additive manufacturing (LPBF), followed by

Table 1. Time data for CM manufacturing flow obtained from the base article [17].

Step	Machines	Process Time	Setup Time
DC drilling/ejectors	CC (Cooling Channels)	180 min	60 min
Plugging	CC (Cooling Channels)	60 min	N/A
RMB (Rough Milling Back)	3-axis milling machine	180 min	30 min
RMF (Rough Milling Front)	3-axis milling machine	180 min	90 min
Grinding	AM grinding machine	30 min	30 min
FMB (Finish Mill backside)	5-axis milling machine	105 min	75 min
SFF (Semi-finish front)	5-axis milling machine	540 min	60 min
FF (Finish front)	5-axis milling machine	540 min	60 min
EDM	EDM + Wire cutter	480 min	60 min
Laser engraving	Laser cutter	60 min	15 min
Ultrasonic cleaning	UC	40 min	N/A
Quality control	QC	22 min	5 min

N/A – not applicable.

post-processing, heat treatment, and steps similar to those in CM, with adjustments for the specific characteristics of printed parts, as shown in Table 2 [17].

The analysis with FlexSim incorporated cycle times, production capacity, and rejection rates into the model, accurately representing the behavior of the physical system. Statistical tools enabled the monitoring of metrics such as waiting times, utilization rates, OEE, and productivity, facilitating the identification of bottlenecks and a detailed comparison between AM and CM. FlexSim also enabled the creation of realistic scenarios, layout analysis, and proposals for changes in process flows, operators, and machinery, considering cost, production time, and material consumption, thus supporting decision-making on the most suitable technology for the project.

Simulation Model

Based on the machine data and their distribution in the respective analysis sections, it was possible to map and simulate the process flows, resulting in the sequence for conventional manufacturing: CC, followed by 3-axis milling, grinding, 5-axis milling, EDM, laser, UC, and finally QC; and for additive manufacturing: LPBF, followed by furnace, grinding, 5-axis milling, EDM, laser, UC, and finally QC.

The simulation shown in Figure 2, based on the data presented, enabled the optimization of machine placement and operation, taking into account the performance of both conventional and additive manufacturing processes.

Results and Discussions

Simulation Scenario Analysis

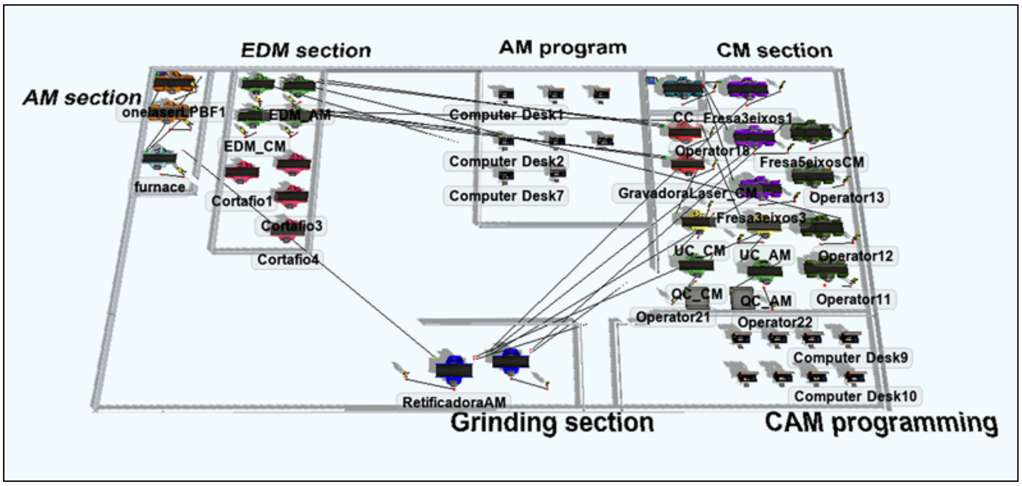
Based on the Gantt charts generated by the FlexSim simulation — which analyzes the idle, processing, blocked, waiting for transport, and setup times of each machine — it can be observed that the scenario considered the operation of all machines, for both additive manufacturing and conventional manufacturing processes, at maximum capacity.

Table 2. Time data for AM manufacturing flow obtained from the base article [17].

Step	Machines	Process Time	Setup Time
MAM (LPBF) process	LPBF laser	3240 min	120 min
AM post-processing	LPBF laser	130 min	N/A
Heat treatment	Furnace	2880 min	N/A
Grinding	AM grinding machine	180 min	180 min
FMB (Finish Mill Backside)	5-axis milling machine	180 min	120 min
SFF (Semi-finish Front)	5-axis milling machine	540 min	60 min
FF (Finish Front)	5-axis milling machine	540 min	60 min
EDM	EDM + Wire cutter	480 min	60 min
Laser engraving	Laser cutter	60 min	15 min
Ultrasonic cleaning	UC	40 min	N/A
Quality control	QC	22 min	5 min

N/A – not applicable.

Figure 2. Simulation model in FlexSim.



A period of one year was simulated, corresponding to 250 working days, with continuous operation 24 hours a day. During this period, 203 units of the mold were produced by AM and 518 units by CM (Table 3).

The simulation analysis showed that, in additive manufacturing, the main bottleneck is in the printing stage, where the LPBF laser machine has the highest processing occupancy rate, blocking subsequent stages. A second potential bottleneck is heat treatment, due to the long processing time and the availability of only one furnace. In conventional manufacturing, the most relevant bottleneck occurs in the 5-axis milling machine.

Different operating states were identified in both processes: idle, active processing, blocked due to unavailability of the next stage, waiting for material transport, and machine setup. In AM, there is longer continuous processing time on the initial machines, especially on the 3D printer, which causes upstream blockages and impacts the workflow. In CM, on the other hand, blocked states are predominant on several machines, which interrupts the flow even when there is available capacity, especially at the machining stations. Despite this, the final productivity of CM (518 parts) was significantly higher than that of AM (203 parts), indicating greater efficiency of the conventional process in the analyzed scenario.

Table 3. Production per year by CM and AM.

	CM	AM
Number of parts per year, 250 days of active work	518	203

<u>Economic and Variable Analysis</u>

The comparison between additive manufacturing and conventional manufacturing showed that CM has a lower initial cost, due to the use of widely available equipment, lower technological investment, and reduced raw material costs. The analysis also revealed significant differences in direct and indirect costs throughout the production chain.

In terms of productivity, CM manufactured 518 molds compared to 203 for AM, demonstrating greater efficiency even with bottlenecks. For industrial-scale operation, the estimated total cost of acquiring the factory is $4,240,000.00, with annual operating expenses of approximately $380,500.00 (Table 4).

Although additive manufacturing requires a higher initial investment in specific machines and uses metal powders that are more expensive than conventional manufacturing steel, it reduces operating costs and material waste, offering advantages in sustainability

Table 4. Estimated machine acquisition, maintenance costs, and quantities.

Machine	Estimated Acquisition Cost (USD)	Annual Maintenance Cost (%)	Number of Machines
Three-axis milling machine	$80.000 – $120.000	8%	3
Five-axis milling machine	$250.000 – $600.000	10%	4
UC and QC laser engraver	$10.000 – $50.000	5%	1
LPBF machine	$300.000 – $800.000	12%	2
Industrial furnace	$20.000 – $100.000	6%	1
Wire cutting machine	$50.000 – $150.000	7%	4
EDM machine	$60.000 – $200.000	8%	4
AM grinding machine	$30.000 – $100.000	6%	2

and economy. CM, on the other hand, is more affordable in the short term, especially for simple parts, and generally requires less post-processing time.

AM excels in the manufacture of parts with complex geometries and high customization, allowing digital modifications without the need for physical adjustments to tools, unlike CM. However, AM requires skilled labor in 3D software and printer adjustments, while CM relies on more readily available professionals.

Conclusion

This study compared the value chain of steel inserts for injection molding manufactured by AM and CM, based on FlexSim simulation and literature data. CM showed higher productivity in continuous and large-scale production, with shorter post-processing time, lower demand for skilled labor, and lower initial costs, making it more suitable for simple parts and traditional geometries. AM stood out for its sustainability, with less waste generation, and its ability to produce complex and customized parts without physical changes to the tools.

Despite the higher cost of raw materials and lower productivity over a one-year period, AM offers benefits in terms of flexibility, product innovation, and potential long-term reduction in operating costs, and should not be seen as a direct replacement for CM, but as a strategic and complementary technology depending on production volume, geometric complexity, required precision, and long-term objectives.

While the findings provide strong evidence of CM's higher productivity and lower cost under the simulated conditions, they should not be generalized without caution. Variations in production scale, regional labor or energy costs, technological advancements in AM equipment, the specific feedstock materials used in additive manufacturing, or different product geometries could shift the balance of advantages. Additionally, the simulation relied on parameters from a specific industrial case study ([17]) and may not fully represent all operational environments. Future studies incorporating diverse case studies, updated cost data, and alternative manufacturing technologies would refine and expand the applicability of these results.

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Textile Waste in Civil Construction: A Systematic Review of Applications and Benefits

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This work is a systematic review based on the PRISMA protocol, used to evaluate the use of polymeric materials with textile waste in civil construction. The research was conducted using a search strategy across three databases (Web of Science, Scopus, and ScienceDirect), with a focus on studies published within the last 5 years. The keywords used in these searches were: "Composites AND Architecture AND textile waste." Subsequently, screening and exclusion criteria were established and applied to the group of articles to organize and select the most relevant ones according to the theme. At the end of the analysis of the selected articles, a comparison was made regarding the uses and trends of recycled textile material as a basis for new technologies aimed at greater sustainability in civil construction.
Keywords: Sustainability. Civil Construction. Polymers. Textile Waste. Architecture.

Tons of polymeric material waste are produced daily worldwide [1]. The production, consumption, and disposal cycle of these materials occurs at a pace that is significantly exceeding current management capacity, often surpassing the recycling limits of conventional methods, both in technological terms and within the scope of environmental and economic policies.

This situation highlights the need for alternative approaches to enable their reuse, given that certain polymers are predominantly intended for single-use applications [1].

In addition to this issue, the textile industry contributes substantially to environmental problems through waste generations. It produces, on average, 5.8 million tons of waste annually, of which approximately 75% is sent to landfills or incinerated [2].

The main textile waste streams originate from wool, cotton, and synthetic fibers, with polymer-derived materials such as acrylic fabrics often present in their composition, even though garments, fabrics, and yarns are among the most common types of waste [1,2].

The reuse of discarded polymeric and textile materials has already been incorporated into the civil construction sector [1, 2], with sustainability increasingly becoming a prevailing trend in the field of architecture [3]. For instance, during important and influential architectural events such as CASACOR Bahia Edition [4] in 2024, the architectural firm Andrade & Schimmelpfeng Arquitetos, in partnership with the store Plasticaria, presented a decorative wall panel produced using recycled plastic materials, designed as a high-value aesthetic product. These materials were arranged in colorful blocks, creating a textured surface, alongside numerous other examples of sustainable material applications [4].

In this context, the present review article, based on a systematic literature analysis using the PRISMA methodology, aims to investigate the applications of polymer composites formulated with textile waste, with an emphasis on the integration between technological innovation and sustainability.

The objective is to understand how such materials have been utilized in innovations in recent years within the architectural and civil construction field, particularly in sectors requiring functional and safe solutions.

Received on 17 October 2025; revised 22 December 2025.
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J Bioeng. Tech. Health 2026;9(1):65-69

Materials and Methods

The systematic review methodology is essential for gathering and organizing previous studies in a targeted manner, aiming to address relevant questions for a specific research focus, ensuring that the selected works are genuinely useful to the final understanding of the subject. Based on these procedures, inclusion and exclusion criteria are established to guide future research on the topic.

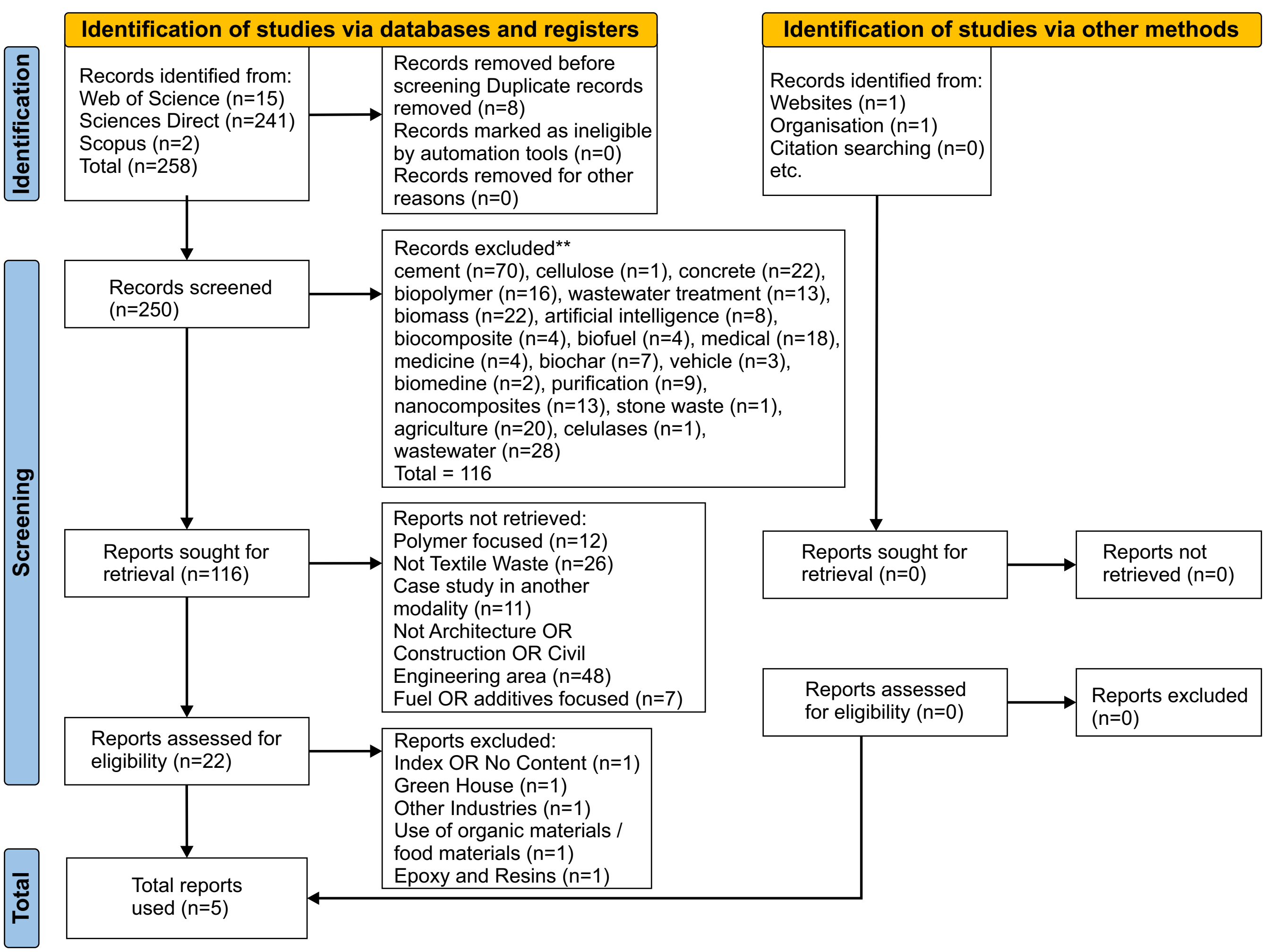
In this article, a systematic review was conducted following the guidelines of the PRISMA protocol (Preferred Reporting Items for Systematic Meta-Analyses), focusing on identifying publications that address the sustainable use of textile waste in composites applied to architecture.

To this end, the Scopus, ScienceDirect, and Web of Science databases were consulted, applying the pre-defined inclusion and exclusion criteria, such as a maximum publication date of five years. The primary search expression used was: (Composites AND Architecture AND "Textile Waste") (Figure 1).

Results and Discussion

Among the studies collected and analyzed, the majority identified applications in the civil construction sector, primarily directed toward the use of discarded textile and polymer waste for thermal insulation purposes, as well as for sound absorption purposes. Publications in journals such as the Journal of Cleaner Production and Waste

Figure 1. PRISMA protocol.



Management demonstrate that, due to their thermal insulation capacity, such waste can be revalorized for this purpose, thereby contributing to the energy efficiency of buildings while mitigating environmental impacts.

The use of textile waste in insulating panels [2] exhibited satisfactory thermal performance as well as technical feasibility when compared to conventional materials. In an experiment, Briga-Sá and colleagues [2] constructed two types of wall systems: one composed of two ceramic masonry walls and the other of concrete masonry, both finished with cement mortar.

An open cavity was left between the walls and subsequently filled with two types of completely dry waste: WFW (woven fabric waste) and WFS (woven fabric subwaste), followed by sealing with polyurethane foam and extruded polystyrene (XPS). A double-wall configuration without any filling was also considered.

Three systems were thus analyzed: a double wall with WFW, a double wall with WFS, and a double wall with an empty air gap. During monitoring, data were collected on heat flux, surface temperature, and ambient temperature, using a domestic heater to maintain a controlled average indoor temperature condition to ensure the reliability of the analyzed results.

The results showed that the thermal resistance of the double-wall system increased substantially, though the degree of improvement differed between WFW and WFS. Compared to the unfilled wall, the WFW system demonstrated a 56% increase in thermal resistance, while the WFS system showed a 30% increase.

The higher efficiency of WFW is attributed to its thermal conductivity being comparable to that of traditional insulation materials, such as EPS and XPS, whereas WFS exhibits a performance more similar to materials like expanded clay and perlite.

In a similar vein, the reuse of disposable face masks [5] made of polypropylene (PP) was investigated by Dehdashti et al. [5] as a sustainable alternative. The process involved manual removal of metallic and elastic components, followed by separation of the melt-blown (MB) and spunbond (SB) PP layers.

These were then fragmented and aligned using a Garnet machine, with precise adjustments to achieve a specific degree of fiber opening for the intended outcome. This process produced new polymeric fibers that were subsequently bonded with a natural adhesive.

Fabrics produced from MB microfibers—discontinuous and randomly oriented—resulted in irregular porous structures, whereas SB fabrics consisted of continuous, thicker filaments, more regularly and compactly arranged, producing a smoother and less porous surface.

Dehdashti and colleagues [5] considered thickness, density, and mixing ratios of SB (thicker fibers) and MB (finer fibers) fabrics as independent variables, given their influence on the sound absorption properties of fibrous panels. The results confirmed that fabrics combining SB and MB fibers possess favorable characteristics for both thermal insulation and sound absorption, partly due to the adhesive not occluding the pores of the textile material.

Similarly, another study by Dongchan Jin and colleagues [6] evaluated the application of post- consumer textile waste for pipe insulation, deliberately avoiding any pre-sorting process to reflect realistic usage conditions in which natural and synthetic fibers are mixed. This approach also accounted for the cost implications of separation. Only decontamination and shredding were performed, producing fibrous strands for thermal insulation.

The fibers were then molded via thermal pressing, using the partial melting of polyester for adhesion, into two types of specimens: flat panels and cylindrical sleeves for pipe insulation. The sleeves were internally coated with aluminum to prevent moisture ingress. These cylindrical specimens were referred to as recycled insulation (RI), general insulation (GI, a commercially available generic thermal insulation material), and Ref (reference, i.e., pipe without insulation). RI panels were also produced for mechanical testing.

Tests revealed that RI outperformed conventional insulation materials such as glass, wool, and mineral wool in thermal performance, even with increased density. Due to its mixed porosity, higher air permeability, and reduced heat transfer, the material also exhibited superior resistance to water vapor penetration—a property that makes it suitable for environments subjected to condensation, thus extending its application potential beyond pipe insulation.

Additional experiments included moisture absorption and desorption tests as well as thermal conductivity analysis. The findings indicated that RI exhibited greater resistance to water vapor transmission than traditional fibrous materials. This characteristic is critical as a moisture barrier, particularly in applications where significant temperature differences between indoor and outdoor environments may lead to condensation.

Consequently, the material also proves suitable for alternative uses beyond problematic pipe insulation where moisture accumulation occurs [6].

Therefore, considering its thermal insulation and waterproofing properties, the application proposed by Dongchan Jin et al. [6] for thermal pipe insulation also demonstrates exceptional potential as a sustainable construction material.

Conclusion

The excessive consumption of single-use polymeric materials, such as expanded polystyrene (EPS), occurs at a rate far exceeding the capacity for their degradation in the natural environment [1]. Such waste causes severe environmental problems, with increasingly catastrophic consequences for life on Earth.

Similarly, the excessive use of materials with limited reuse potential in the textile industry generates another type of waste, discarded in quantities and at a frequency that surpasses the natural degradation capacity of the environment [7].

Given this environmental challenge, there is a constant need for the development of new alternative methods to minimize, replace, or dilute the use of such materials. The pursuit of sustainability has become increasingly important over the years, leading to the creation of these new construction methods, alternative materials, and emerging trends that are significant for the progress of the academic community.

In this article, research in the fields of sustainability and civil construction was reviewed, focusing on the use of repurposed polymeric materials and textile waste. The findings from these studies indicate that this is a rapidly evolving area, often centered on addressing challenges related to thermal and acoustic comfort and their various applications. The analyzed studies demonstrate that post- consumer textile waste and polymeric materials can offer technical performance comparable to, and in some cases superior to, conventional thermal insulators such as EPS, XPS, glass wool, and mineral wool. Additionally, they contribute to energy efficiency and the improvement of thermal and acoustic comfort in buildings.

The proven technical feasibility in multiple studies, combined with the potential for reducing environmental impacts, shows that the reuse of such waste not only fosters a circular economy but also expands opportunities for innovation in sustainable building systems.

However, large-scale adoption still depends on advances in process standardization, optimization of mechanical and thermal properties, and overcoming economic and regulatory barriers.

Acknowledgements

The authors would like to thank the National Council for Scientific and Technological Development (CNPQ) for supporting the research. We also express our gratitude to our advisor, Pollyana da Silva Melo, for her valuable guidance. Finally, we thank SENAI CIMATEC University for providing the infrastructure and a conducive environment for conducting this research.

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Artificial Intelligence Applied to Last-Mile Logistics: A Systematic Review

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Last-mile logistics is one of the biggest challenges in the modern supply chain, especially due to the rise in e-commerce and the high demand for fast and efficient deliveries. In this context, it is observed that Artificial Intelligence (AI) has stood out as a promising solution to optimize routing in this delivery process, improving the distribution of resources and dynamically adjusting routes. With the aim of analyzing and mapping AI techniques applied to last-mile logistics, this study developed a systematic review combined with a bibliometric and qualitative analysis. This methodology uses the strategy of searching and collecting works on a specific topic, evaluating their scientific relevance through the PRISM 2020 flowchart. Based on the results, it is concluded that AI applied to the last mile has the potential to reduce costs and increase operational efficiency and customer satisfaction.
Keywords: Artificial Intelligence. Logistics 4.0. Last Mile Logistics. Innovation for Logistics.

Logistics, as a strategic field of management, has evolved significantly over the years. The process consists of managing the supply chain, planning, executing and controlling the flow and storage of goods, services and related information, from the point of origin to the point of consumption, to meet customer requirements [1]. The development of transport networks and the creation of sophisticated storage systems are milestones in this evolution, which has transformed logistics into a strategic function within companies and a central element in global trade. Especially with the growth of e- commerce, where the demand for fast and efficient deliveries has required a new look at the distribution process, in particular, for last- mile logistics. The last mile refers to the final phase of the logistics process, which involves transporting the product to the final consumer, whether for B2B (CNPJ), B2G (Government) or B2C (CPF) customers. Thus, this phase represents one of the biggest challenges of the modern supply chain, given that it involves operational complexity, high costs, and the need for satisfactory customer experience [2].

With technological advancement, Logistics 4.0 emerges, a new paradigm that integrates technologies such as automation, internet of things (IoT), big data, and, especially, Artificial Intelligence (AI). The concept of Logistics 4.0 can be summarized by the improvement of ancestral (traditional) logistics, which has as its basic proposal more need for technological investments [3]. In this way, it represents a revolution in the sector, allowing the digitalization of logistics operations and the optimization of processes through intelligent solutions.

Among these technologies, Artificial Intelligence (AI) stands out, considered one of the central pillars of Logistics 4.0 for its ability to analyze, learn, and make decisions in real time. AI encompasses a set of techniques applicable through computer systems that are related to the intelligent behaviors of human beings. And when applied to logistics, it has the potential to bring innovative solutions to optimize routing in the last mile [4]. Through intelligent algorithms, it is possible to predict demands, analyze traffic in real time, and adjust routes dynamically. In addition, AI contributes to a more efficient management of fleets and resources, with warehouse automation, the use of drones and autonomous vehicles such as RPAs and mobile robots, and the integration of automated systems.

Received on 20 October 2025; revised 18 December 2025.
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J Bioeng. Tech. Health 2026;9(1):70-77

These advancements offer a unique opportunity for companies not only to improve their processes, but also to adapt to new market demands, ensuring greater agility, sustainability, and competitiveness. But this requires planning for the incorporation of these emerging technologies.Given this scenario, this study explores the following guiding question:

What is published in the state of the art about Artificial Intelligence solutions applied to last-mile logistics?

This article aims to present the impacts, analyze and map the AI tools strategically applied in last mile logistics. For this, a systematic review combined with a bibliometric and qualitative analysis will be presented through the PRISMA 2020 flowchart.

This study is relevant for the improvement of knowledge about Artificial Intelligence and Logistics, areas in constant evolution. In the social sphere, the improvement of routing in last-mile logistics brings direct benefits to society, making deliveries more accessible, efficient, and sustainable. The relevance of this research is also due to the academic and scientific contribution in gathering and analyzing the main studies on the application of AI in logistics routing and its impacts, to assist in studies to identify strategies and technological tools for optimizing transport and distribution and as a reference for academics and professionals.

Materials and Methods

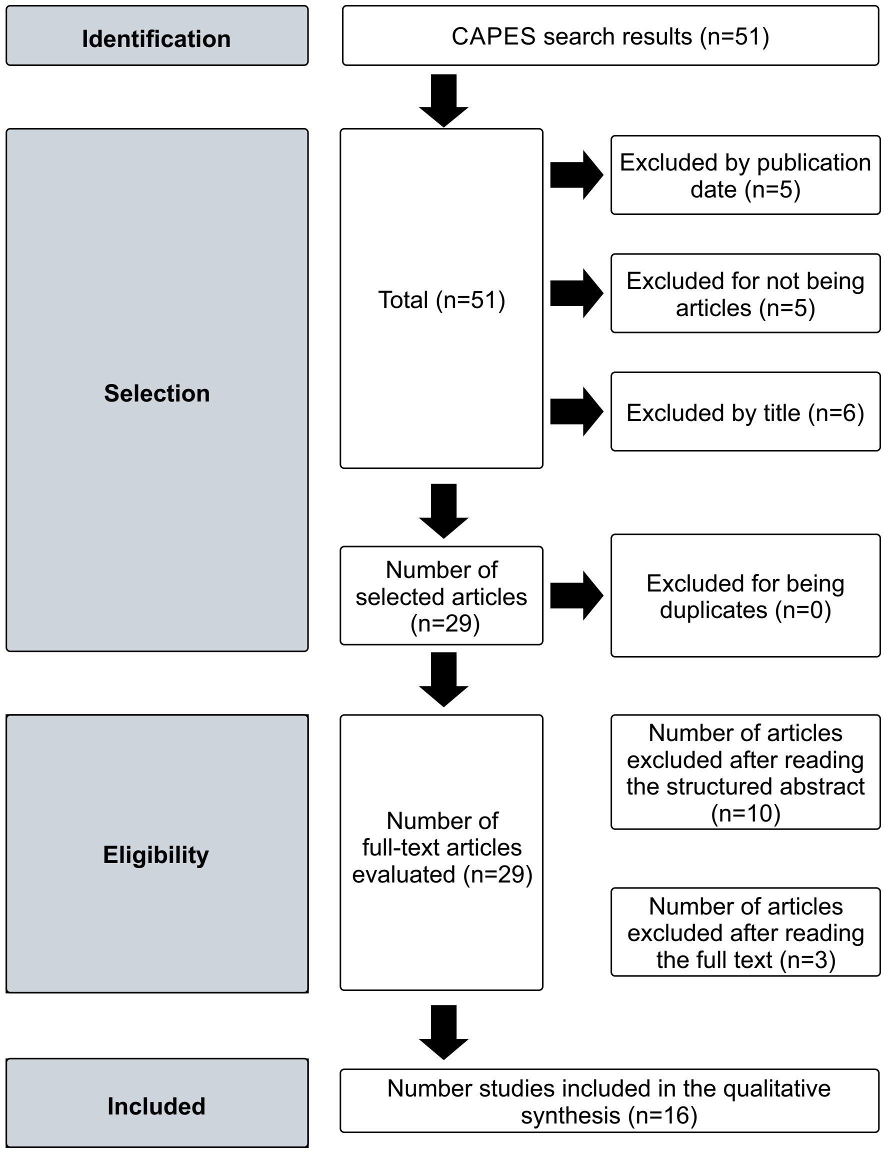
The method of the present study is a systematic review of the literature combined with a bibliometric and qualitative analysis, using the PRISMA 2020 flowchart. Thus, it is characterized as a bibliographic survey that integrates qualitative and quantitative aspects.

PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a protocol used in conducting and reporting systematic reviews. It provides guidelines to ensure transparency, reproducibility, and methodological quality. The updated model includes a checklist with 27 items and a standardized flowchart, which organizes the selection of studies into four main steps: a) identification, b) screening, c) eligibility, and d) inclusion. This structure allows us to clearly understand how the studies were filtered and to justify any exclusions based on objective criteria [5]. Remembering that PRISMA 2020 is a reporting tool, with the objective of assisting authors in the transparent reporting of the methods and results of systematic reviews and should not be used as a guideline for conducting systematic reviews, evaluating methodological quality or as a study protocol [6]. Thus, this study, despite having used the checklist to verify the method, was limited to a clear and succinct description of the methodological steps developed (Figure 1).

In the identification phase, the keywords addressed were delimited: "last mile logistic" and "artificial intelligence", using the results of the research carried out in several relevant sources such as Science Direct and IEEE, and through the CAPES journal portal, obtaining 51 articles. For selection and screening, the search was refined in peer-reviewed scientific articles (disregarding books, book chapters, conference papers, and others) in the last five years, comprising publications between 2020 and 2025, resulting in 35 articles (excluding 11 non- articles and 5 outside the publication period), no duplicates were detected. After analyzing the titles, 6 divergent articles on the topic were excluded, studies that addressed last-mile logistics without the use of Artificial Intelligence or AI applications in different sectors, as well as research on logistics or urban transport without a direct link to the last mile, leaving 29 articles.

In the next phase (eligibility), the abstracts were read and 10 articles were eliminated, studies that mentioned AI or logistics without direct application to the last mile, studies that dealt with AI in a conceptual way, without practical application, and research focused on different technologies (for example, IoT or Blockchain without integration with AI) were excluded. Posteriorly 19 articles were read in full, resulting in the exclusion of 3

Figure 1. Flowchart of the selection process based on the PRISMA 2020 method.



Source: Adapted from PRISMA (2020), 2025.

more articles that did not present a description of AI methods, models, or tools applied to last-mile logistics, used AI in different stages of the logistics chain or had only theoretical discussions without results or practical cases. Finally, the 16 articles that addressed AI tools applicable to last mile logistics were validated and included in the qualitative analysis of the present study. Although the selected studies present different approaches and scopes, all met the established eligibility criteria and demonstrate alignment with the objectives of the review.

Results and Discussion

Table 1 below lists the 16 articles selected through the funnel of criteria presented in Materals and Methods with the information of the authors, year of publication, as well as the sources, in which ScienceDirect stands out with 9 articles.

Regarding publication by authors, three participated in more than one publication within the ranking obtained, namely: Zhe Yuan (China and France), Dragan Pamučar (Serbia, India and Turkey) and Vladimir Šimić (India and Turkey).

Table 1. List of selected articles.

Title	Authors	Years	Sources
Use of artificial intelligence in last mile delivery	Peter Jucha	2021	Management Sciences
Sustainable last mile parcel delivery and return service using drones	Nawin Yanpirat, Daniel F. Silva, Alice E. Smith.	2023	SHS Web of Conferences
Delivery network design of a locker-drone delivery system	Bipan Zou, Siqing Wu, Yeming Gong, Zhe Yuan, Yuqian Shi.	2023	ScienceDirect
Artificial intelligence for last- mile logistics - Procedures and architecture	André Rosendorff, Alexander Hodes, Benjamin Fabian.	2021	ScienceDirect
Smart home devices and B2C e- commerce: a way to reduce failed deliveries	Arianna Seghezzi, Riccardo Mangiaracina.	2023	ScienceDirect
Learning for multiple purposes: A Q-learning enhanced hybrid metaheuristic for parallel drone scheduling traveling salesman problem	Ping Chen, Qianlong Wang.	2023	ScienceDirect
A novel Aczel-Alsina triangular norm-based group decision- making approach under dual hesitant q-rung orthopair fuzzy context for parcel lockers' location selection	Souvik Gayen, Animesh Biswas, Arun Sarkar, Tapan Senapati, Sarbast Moslem.	2023	International Journal for Research in Applied Science and Engineering Technology
Prioritization of crowdsourcing models for last-mile delivery using fuzzy Sugeno–Weber framework	Dragan Pamucar, Dragan Lazarević, Momčilo Đobrodolac, Vladimir Šimić, Ömer Faruk Görçün.	2023	IEEE Transactions on Evolutionary Computation
Optimal models for autonomous trucks and drones resupply for last-mile delivery in urban areas	Zhe Yuan, Simon, HERVE	2022	ScienceDirect
A two-stage data-driven metaheuristic to predict last- mile delivery route sequences	Juan Pablo Mesa, Alejandro Montoya, Raúl Ramos-Pollán, Mauricio Toro.	2023	Industrial Management & Data Systems
Multiple attribute decision- making model for artificially intelligent last-mile delivery robots selection in neutrosophic square root environment	M. Palanikumar, Chiranjibe Jana, Ibrahim M. Hezam, Abdelaziz Foul, Vladimir Šimić, Dragan Pamučar.	2024	ScienceDirect
Vehicle routing software selection for last mile delivery companies using Fermatean fuzzy-based model	Karahan Kara, Galip Cihan Yalçın, Vladimir Šimić, Pınar Gürol, Dragan Pamučar.	2024	International Journal of Production Research
Dynamic dispatch algorithm proposal for last-mile delivery vehicle	Daniel de Oliveira Mota.	2021	ScienceDirect
A novel mathematical model and a hybrid grouping evolution strategy algorithm for an automated last mile delivery system considering wind effect	M.T. Ahmadi, Seyed Hessameddin Zegordi.	2023	ScienceDirect
Review Paper on Anti-Theft Autonomous Delivery Robot for Food and E-Commerce	Shivansh Choudhary, Mansi Tiwari.	2023	IEEE Latin America Transactions
Enhancing Genetic Algorithm with Explainable Artificial Intelligence for Last-Mile Routing	Yonggab Kim Reem Khir, Seokcheon Lee.	2025	ScienceDirect Source: own elaboration, 2025

The surveys were carried out in several countries around the world, as illustrated in Figure 2. On the Asian continent, seven institutions are included, making this the continent with the largest number of institutions that produced the research. In second place, with six institutions, is Europe and, finally, America, containing three intuitions, two from South America and one from North America. Among the countries, India stands out as the leader in the number of publications, with three educational institutions.

It is also observed that a large part of the studies focuses on technologically advanced regions, such as Asia, Europe and North America, where investments in autonomous vehicles and AI are already more consolidated.

Temporal Distribution of Publications

The temporal analysis of the selected publications shows a growing trend in academic interest in the theme of AI applied to last-mile logistics. A significant peak was observed in 2023, which concentrated most of the studies included in the review. This increase may reflect the maturation of research in the area, as well as the intensification of debates and recent technological advances. Although the number of publications was lower in years such as 2021, 2024 and 2025, the fact that there are studies published already in the current year (2025) reinforces the timeliness and continuity of discussions in literature (Figure 3). This distribution confirms that the theme remains relevant and evolving, justifying the relevance of its investigation.

Keyword Analysis

Fifty seven keywords were identified in the publications. Figure 4 highlights the most recurrent ones, including: Last mile delivery (10 times), Fuzzy sets (7 times), Logistics (6 times), Drone (5 times), Artificial intelligence (4 times), Decision-making (4 times), Machine learning (3 times) and Traveling salesman problem (3 times). They also appeared with two occurrences: Vehicle routing problem and Genetic algorithm. The other words occurred only once each.

Figure 2. Map of searches by country.

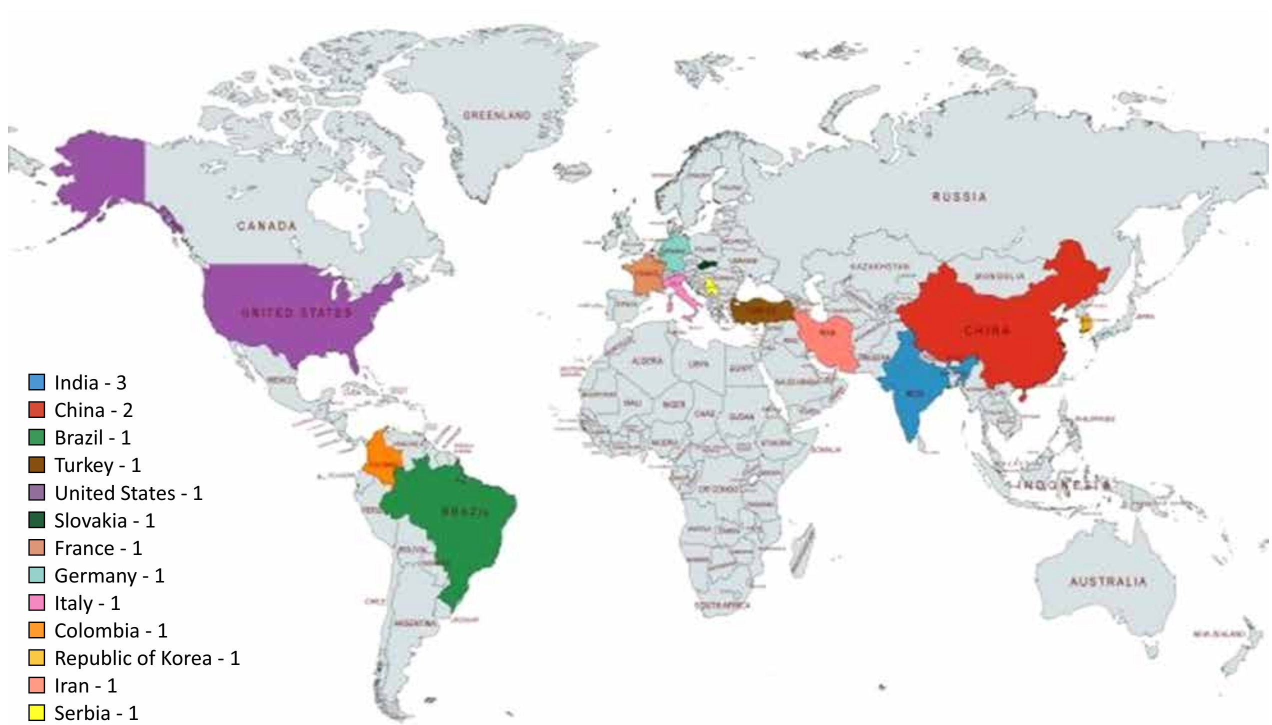
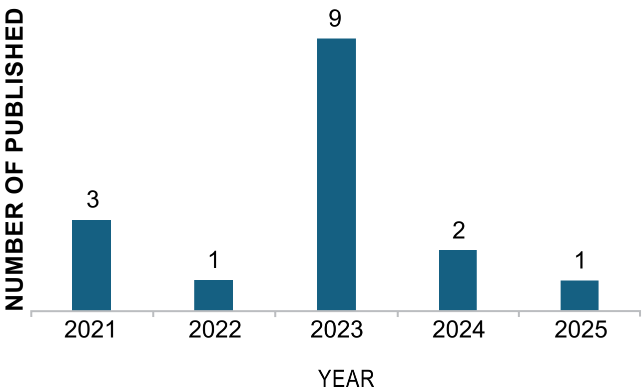


Figure 3. Temporal distribution of the selected publications.



Critical Analysis of Articles

In the analysis of the 16 selected publications, different lines of investigation are identified on how AI was applied: five studies present mathematical and metaheuristic models for routing and dispatching vehicles [7-11], two articles deal with the use of drones and autonomous vehicles for sustainable deliveries [12, -13], three studies apply multicriteria decision models with fuzzy logic for robot selection, software and locker locations [14-16], and others address autonomous robots, anti- theft security, and smart home devices to reduce delivery failures.

The analysis showed that the research focuses mostly on routing and route optimization, followed by the selection of technologies such as routing software and autonomous robots, the use of drones and autonomous vehicles and, to a lesser extent, solutions aimed at reducing delivery failures and safety in autonomous robots (Figure 5).

These percentages show that the application of AI is more strongly directed to operational efficiency and intelligent resource management, indicating a global concern to reduce costs and delivery times.

The adherence classification of the studies revealed that 56.25% (9 articles) have high adherence, that is, they apply AI in a robust and central way in the development of new logistics solutions. Among these approaches, advanced techniques such as machine learning, intelligent metaheuristics, Q-learning, and fuzzy logic stand out, which are key elements for complex decision and routing problems in the last mile. Another 31.25% (5 articles) were classified as

Figure 5. Distribution of research topics.

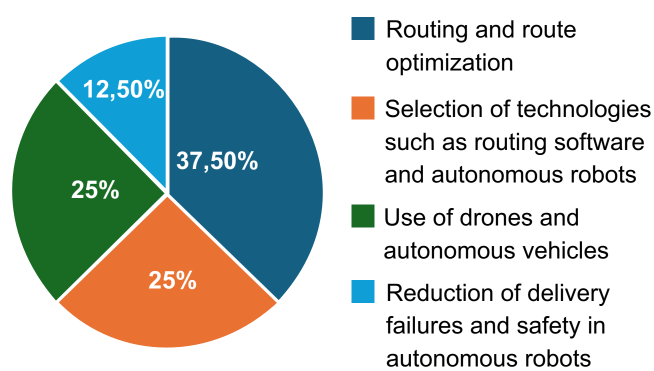


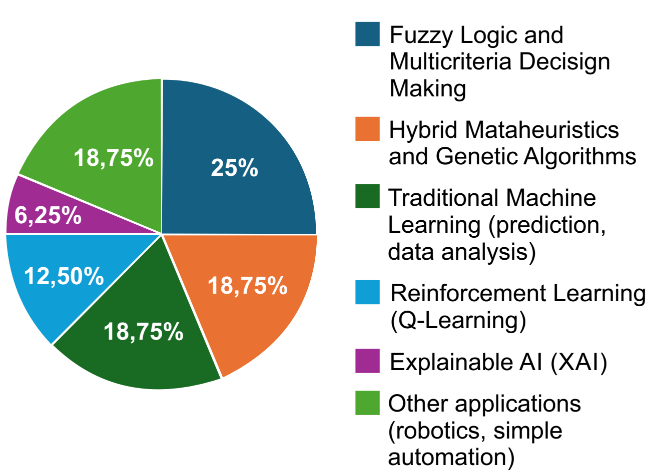
Figure 4. Keyword frequency.

medium adherence, as they partially apply AI or use automated technologies without fully exploring intelligent methods. Finally, 12.5% (2 articles) have low adherence, treating AI only as a theoretical mention or applying traditional methods without intelligent integration.

Regarding the AI techniques used, it was observed that 25% of the articles employ fuzzy logic and multicriteria methods, mainly for the selection of software, robots, and definition of locations for smart lockers. Hybrid metaheuristics and genetic algorithms were applied in 18.75% of the studies, while traditional machine learning (for prediction and analysis of historical data) also accounted for 18.75%. More advanced methods, such as Q- learning, appeared in 12.5% of the surveys, and only 6.25% explored explainable AI (XAI) through techniques for assigning importance to variables such as SHAP (SHAP) [22]. Simple robotics and automation technologies, without extensive use of AI, appeared in 18.75% of the articles, aimed at anti-theft security and reduction of delivery failures. This implies that last-mile AI is applied primarily for operational efficiency, while explainability (XAI) is still underexplored, indicating a gap for future research (Figure 6).

Another relevant fact is that 75% of the articles are based on computer simulations, while only 25% have validation in real cases or empirical data collected in logistics operations. This predominance of theoretical studies and modeling demonstrates that, although AI has great potential and is advanced in scientific and academic research, its practical implementation in large-scale global solutions is still limited. The reasons include the difficulty of integrating with existing logistics systems, high costs of adopting emerging technologies (such as drones and robots), and the lack of standardization in metrics to evaluate the gains obtained with AI [12-14].

Figure 6. Distribution of AI techniques used.



Conclusion

In this study, emerging trends in the area were identified: a) hybrid solutions that combine AI with traditional optimization methods to deal with complex scenarios; b) intelligent automation of deliveries, including the use of drones, autonomous trucks and robots for urban operations; c) sustainability, as an additional factor [12], although little explored, aiming at reducing emissions and energy efficiency; and d) explainable systems (XAI), which are beginning to emerge to provide greater transparency in automated decisions. Techniques such as fuzzy logic, intelligent metaheuristics, and machine learning are already consolidated, while more advanced approaches (XAI, deep reinforcement learning) are still incipient.

Despite the advances, important limitations were identified in the studies that form real barriers to implementation, such as: lack of integration between operational efficiency [7,8], social and environmental aspects [12,19], little attention to the scalability of solutions in complex urban environments [13,18,17], and the lack of research on the impact of AI on the consumer experience and social acceptance of autonomous technologies [19,21]. As one of the limitations of the research (gap between theory and practice), it is noteworthy that the absence of standardized benchmarks makes it difficult to compare studies.

It is concluded that, although AI represents an inevitable path for the evolution of last-mile logistics, its full and sustainable use still depends on significant advances. Future research should prioritize robust, interpretable, empirically validated, replicable, and aligned solutions with the principles of sustainability and social responsibility, ensuring that technology not only optimizes processes but also contributes to more resilient, ethical, and environmentally responsible supply chains.

Acknowledgement

We thank SENAI CIMATEC and CAPES/ CNPq, because this work was carried out with the support of CNPq - National Council for Scientific and Technological Development - Brazil.

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Instructions for Authors

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Manuscript	Original	Review	Birief Comunication	Case Report	Editorial ; Letter to the Editor; Editor' s Corner	Innovative Medical Products	State-of-the-Art	Health Innovation Initiatives
Font Type	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial
Number of Words – Title	120	90	95	85	70	60	120	90
Font Size/Space-Title	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space
Font Size/Space-Abstracts/Key Words and Abbreviations	10; single space	10; single space	10; single space	10; single space	-	-	10; single space	10; single space
Number of Words – Abstracts/Key Words	300/5	300/5	200/5	250/5	-	-	300/5	300/5
Font Size/Space-Text	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space
Number of Words – Text	5,000 including spaces	5,500 including spaces	2,500 including spaces	1,000 including spaces	1,000 including spaces	550 including spaces	5,000 including spaces	5,500 including spaces
Number of Figures	8 (title font size 12, double space)	3 (title font size 12, double space)	2 (title font size 12, double space)	2 (title font size 12, double space)	-	2 (title font size 12, double space)	8 (title font size 12, double space)	8 (title font size 12, double space)
Number of Tables/Graphic	7 title font size 12, double space	2 title font size 12, double space	2(title font size 12, double space)	1(title font size 12, double space)	-	-	7 title font size 12, double space	4 title font size 12, double space
Number of Authors and Co-authors*	15	10	5	10	3	3	15	10
References	20 (font size 10,single space	30(font size 10,single space	15 (font size 10,single space)	10 (font size 10,single space)	10 (font size 10,single space	5(font size 10,single space	20 (font size 10,single space	20

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❑3. The entire manuscript (including tables and references) must be typed according to the guidelines instructions.

❑4. The order of appearance of material in all manuscripts should be as follows: title page, abstract, text, acknowledgements, references, tables, figures/graphics/diagrams with the respective legends.

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