TEchMA 2025

New Frontiers in Mechanical Engineering

Book of Abstracts & Posters

Aveiro, 10th of September 2025

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Opening Remarks

TEMA – Centre for Mechanical Technology and Automation
https://www.ua.pt/pt/tema

The Centre for Mechanical Technology and Automation (TEMA) is a leading research unit at the University of Aveiro, recognised for its scientific excellence and strategic importance, both nationally and internationally. Since its establishment in 1996, TEMA has been the primary research hub for the Department of Mechanical Engineering, promoting innovation in mechanical engineering, materials science, nanotechnology and related interdisciplinary fields.

TEMA is part of the Portuguese Roadmap of Research Infrastructures of Strategic Interest and is aligned with the European Strategy Forum on Research Infrastructures (ESFRI). The Portuguese Foundation for Science and Technology (FCT) recently awarded TEMA the highest rating, in recognition of the quality and impact of its research. TEMA has a multidisciplinary team of 149 members, including 67 PhD holders, and 21 advanced laboratories covering over 2,000 m^2. The centre is deeply committed to producing high-quality, laboratory-based research that addresses societal and industrial challenges.

TEMA is also a founding member of the Laboratory of Intelligent Systems (LASI), the largest associated laboratory in Portugal and a national reference in Artificial Intelligence and Data Science. Within this collaborative framework, TEMA leads the national research line on “Innovative and Sustainable Industries”, reinforcing its commitment to future-oriented, industry-driven, and sustainability-focused technologies.

The centre’s research strategy is structured around three Thematic Mobilising Programmes (MPs), which align its scientific agenda with national and European priorities. These programmes focus on sustainable manufacturing, well-being

technologies, and the strategic use of research infrastructures. Together, they reflect TEMA's mission to generate and disseminate valuable knowledge for industry, society and the scientific community.

TEMA's governance model ensures strategic coherence and responsiveness to emerging challenges. The Management Board includes a Coordinator and four Vice-Coordinators, each responsible for key areas, such as internationalisation, communication, societal engagement and infrastructure management. This structure is supported by a Scientific Council, an External Scientific and Industrial Advisory Board, and a General Assembly. This governance model enables continuous evaluation, strategic alignment and commitment to openness and impact.

Communication, internationalisation and knowledge dissemination are central to TEMA's mission. The centre actively promotes the visibility of its research through strategic partnerships, public engagement and international events. A flagship initiative in this area is the annual TECHMA conference, which provides a platform for scientific exchange and collaboration, promoting cutting-edge research in mechanical engineering and advanced technologies.

The present volume gathers the abstracts and posters presented at **TECHMA25**, reflecting the diversity, quality, and relevance of the research carried out within TEMA and its extended network of collaborators. This edition reinforces the centre's commitment to openness, excellence, and global engagement, in line with its strategic plan to internationalise its activities and amplify its societal impact. We thank all contributors for their valuable participation and invite readers to explore the innovative ideas and scientific advances showcased in these pages.

Aveiro, September 10th, 2025

The Director,

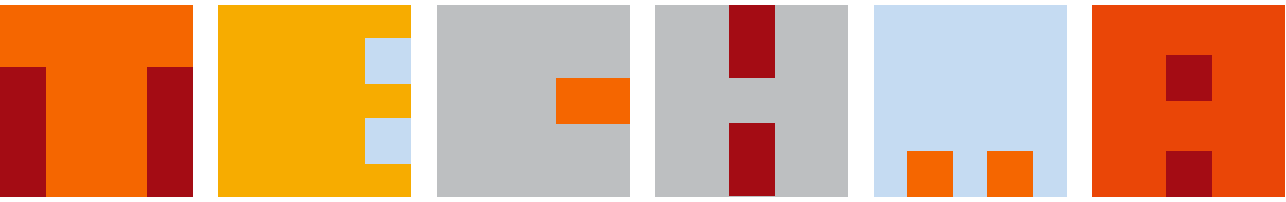
Paula Marques

Program

The following program outlines the sessions, keynote talks, and activities scheduled for TEchMA25.

Time	Session	Description
09:15	Opening Ceremony	**Artur Silva –** Vice-Rector for Research, Innovation and Training **Robertt Valente -** Director of the Department of Mechanical Engineering **Paula Marques –** Coordinator of the Centre for Mechanical Technology and Automation
9:30	Plenary session **«ECIU initiative: interdisciplinarity as a game changer for scientific progress»**	**Pradit Xavier** (Associate Professor, Department of Reactive Flows (CNRS-CORIA), Department of Energy Engineering (INSA), Normandy, France
10:15	Poster session & Coffee Break	Posters discussion & Networking
11:00	Adhesive-Free Joining of Commodity Thermoplastics to Low-Density Foams	António Ferreira
11:15	Simulation and shape prediction strategies in 4D printing	Tiago Andrade
11:30	Gasochromic nanofibrous sensors for visual detection of hydrogen leaks	André Girão
11:45	Structure–property relationships in Yttrium-Doped Barium Zirconate-Stannates: Thermodynamic and electrochemical properties	Laura Holz
12:00	Advances in Nanofluid-Enhanced Cooling for Power Transformers	Alexandre Salgado
12:15	Lunch Break	
14:00	Plenary session **«Artificial Intelligence in Engineering, Industry and Society"**	**Luís Paulo Reis** (Associate Professor, University of Porto and Director of LIACC - Artificial Intelligence and Computer Science Laboratory), Porto, Portugal
14:45	Rule-Based Leak Detection in Industrial Production using Decision Tree Models	José Cação
15:00	Performance Analysis of a Comprehensive IIoT Framework for Smart Manufacturing	Daniel Camarneiro
15:15	Experimental methodology for temperature distribution in domestic gas ovens	Ana Delgado

15:30	Noise Matters: Evaluating How Noise Interference Affects an Acoustic Camera Performance	Samuel Verdasca
15:45	A Stage-Wise Literature Review Toward Smart Digital Twin Developments of Wastewater Treatment Plants	Sara Mota
16:00	Poster session & Coffee Break	Posters discussion & Networking
16:45	Industry challenge 1 **«Mechanical engineering in the industrial age with deadlines: Now!»**	**António Ferreira (Prirev)**
17:00	Industry challenge 2 **«Models of university-industry collaboration: Examples of best practice in German and Austria»**	**Moritz Koppensteiner (Kopptec)**
17:15	Industry challenge 3 **«Decarbonize Fuels and Chemicals – A World of Opportunities»**	**Jorge Matos (Capwatt)**
17:30	Industry challenge 4 **«Foundry of the Future: Industrial Challenges as Academic Opportunities»**	**João Martins (Aluthea)**
18:00	Awards & Closing Ceremony	Best presentation and best poster awards



ABSTRACTS

SUSTAINABLE MANUFACTURING SOLUTIONS

Experimental study on surface grinding of titanium alloys

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Abstract — Titanium alloys are extensively used in a range of industries, such as aeronautics, atuomotive, and medicine, due to their exceptional mechanical and chemical properties. These alloys are renowned for their low density, low Young's Modulus, high resistance to corrosion and high temperatures, among other features, which make them a reliable solution for demanding applications [1,2].

In some applications, attaining precise dimensional accuracy and a smooth surface finish in component manufacturing necessitates the careful selection of appropriate means and equipment [3]. Grinding is a manufacturing process that appears to be a solution capable of meeting these objectives. The process involves removing excess material with an abrasive wheel that has multiple cutting edges. This process is repeated until the desired dimensions or surface roughness are achieved. Grinding is considered a relatively inefficient machining process compared to milling or turning, as it requires a significant amount of energy to remove even a small amount of material [4].

The objective of this study was to compare the surface finish achieved by surface grinding of the aforementioned titanium alloys. For that purpose, test-samples were subjected to grinding tests (Fig. 1) where the differentiating factors were the number of cutting passes, depth of cut and use of lubrication. Surface quality was accessed by roughness measurements in the longitudinal or cutting direction (X-axis) and in the transverse direction (Y-axis).

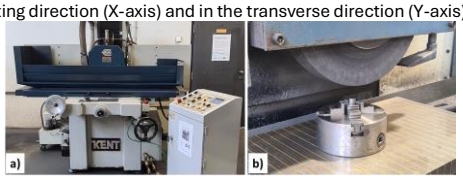

Fig 1 – Experimental setup a) grinding machine, b) test sample support

Findings indicate that the use of lubrication resulted in a 15-20% reduction in roughness compared to dry tests. Also, that with a multi pass strategy roughness decreased 40-50% as opposed to a single pass cutting strategy. As for the roughness in relation to the cutting direction, were measured 20-30% lower values in the longitudinal direction than in the orthogonal direction.

According to the analysis that was carried out, the roughness results indicate that the lowest roughness values were obtained for the Ti-13Zr-13Nb alloy in the longitudinal cutting direction, using a multi-pass deep cutting strategy with values of Ra=0.29µm and Rt=2.73 µm and for abundant cooling with Ra=0.55 µm and Rt=4.81 µm.

Keywords — titanium alloys, surface grinding, roughness, Ti-6Al-4V ELI, Ti-6Al-7Nb, Ti-13Zr-13Nb.

TOPIC

1) Sustainable Manufacturing Solutions. a. Manufacturing Processes & Simulation

ACKNOWLEDGMENTS

This work is supported by the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia. Authors also acknowledge TiFast S.R.L., from Italy, for providing the Ti alloys.

REFERENCES

[1] Festas A, Ramos A, Davim JP. Machining of titanium alloys for medical application - a review. Proc Inst Mech Eng Part B J Eng Manuf 2022;236:309–18. https://doi.org/10.1177/09544054211028531.

[2] Carvalho S, Horovistiz A, Davim JP. Surface topography in machining Ti alloys for biomedical applications: correlative microscopy approach for qualitative and quantitative analysis. Int J Adv Manuf Technol 2021;114:683–94. https://doi.org/10.1007/s00170-021-06824-x.

[3] XIAO G, ZHANG Y, HUANG Y, SONG S, CHEN B. Grinding mechanism of titanium alloy: Research status and prospect. J Adv Manuf Sci Technol 2021;1:2020001–0. https://doi.org/10.51393/j.jamst.2020001.

[4] de Mello AV, de Silva RB, Machado ÁR, Gelamo RV, Diniz AE, de Oliveira RFM. Surface Grinding of Ti-6Al-4V Alloy with SiC Abrasive Wheel at Various Cutting Conditions. Procedia Manuf 2017;10:590–600. https://doi.org/10.1016/j.promfg.2017.07.057.

Towards virtual forming and design: Standardization of material characterization and numerical model calibration through material testing 2.0 (MT 2.0)

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Abstract - Mechanical material characterization is a cornerstone of mechanical design, engineering, and innovation. Although classical mechanical tests remain widely used, they rely on outdated standards and a one-dimensional mindset that fails to capture the complexity of material behaviour, particularly in metal forming processes (Dixit, 2020). This work includes the state-of-the-art review of a PhD that aims to advance the standardization of material characterization and numerical model calibration through the emerging Material Testing 2.0 (MT2.0) (Pierron et.al. 2021) framework. The work will develop both updated and new test standards for homogeneous and heterogeneous tests, exploiting methods like the inverse identification technique e.g., Virtual Field measurement (VFM), full-field measurements and advanced metrology tools such as Digital Image Correlation (DIC) (Grediac, 2004). Emphasis is placed on dual-phase steels (Gonçalves et.al. 2023), validated through combined numerical and experimental campaigns. Expected outcomes of the PhD include improved material behaviour indicators; update 1D mindset to 2D MT2.0 mindset, showing the superiority of MT2.0, standardized MT2.0 test protocols, and robust model calibration methodologies. These advances will promote a faster and more reliable MT2.0 adoption by industry, enhance simulation accuracy, reduce development costs, and contribute to future international standardization efforts in material testing.

Keywords — Material characterization; material testing 2.0; standardization; digital image correlation; virtual field measurement; numerical model calibration; simulation.

TOPIC

1) a: Sustainable Manufacturing Solutions - Manufacturing Processes & Simulation.

REFERENCES

[1] Dixit, U.S. (2020). Modeling of metal forming: a review. Mechanics of materials in modern manufacturing methods and processing techniques, 1-30.

[2] Pierron, F., & Grédiac, M. (2021). Towards Material Testing 2.0. A review of test design for identification of constitutive parameters from full-field measurements. Strain, 57(1),e12370.

[3] Grediac, M. (2004). The use of full-field measurement methods in composite material characterization: interest and limitations. Composites Part A: applied science and manufacturing, 35(7-8), 751-761.

[4] Gonçalves, M., Oliveira, M. G., Thuillier, S., & Andrade-Campos, A. (2023). On the comparison of heterogeneous mechanical tests for sheet metal characterization. Materials Research Proceedings, 28.

Multifunctional Carbon Dots Nanocapsules for Neutron Capture Cancer Therapy

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Abstract — Cancer remains a complex and high-burden disease, ranking among the leading causes of death worldwide. Despite advances in research, current therapies lack effectiveness contributing to persistent disease burden and relapse [1]. Neutron capture therapy (NCT) represents a promising and targeted approach to cancer treatment. In NCT, stable isotopes are delivered to cancer cells and are subsequently irradiated with neutrons, triggering a nuclear reaction that emits high-energy particles, only to the cells where the isotopes are localized. The paradigm shift introduced by NCT lies in its potential to enhance the radiotherapy precision without compromising health tissues. Although several nuclides exhibit high affinity for NCT, the majority of studies have focused on boron-10 (^{10}B). This isotope is particularly effective due to its high neutron capture cross-section and its ability to emit short-range, high-energy particles upon neutron irradiation [2]. Moreover, the lithium-6 (^{6}Li) isotope has recently emerged as a promising candidate for this therapy. When comparing ^{10}B and ^{6}Li, the particles generated by neutron irradiation of ^{6}Li are more energetic than those produced by ^{10}B, which offer additional therapeutic advantages. [3]. Despite NCT potential, its broad implementation has been hindered by low biocompatibility and poor targeting efficiency. To overcome these limitations, carbon dots (CDs) have gained attention as promising nanocarriers for a variety of anticancer agents, offering improved delivery capabilities and biocompatibility. These carbon-based nanomaterials are defined by their small size (<10 nm), spherical morphology, and chemical composition (carbon, nitrogen, and oxygen atoms). Their intrinsic photoluminescence, high biocompatibility, and low toxicity make them highly suitable for biomedical applications, including NCT [4]. This work aims to develop next generation nanodrugs for NCT by engineering CDs. To this end, CDs were optimized to carry high concentrations of the active isotopes ^{6}Li or ^{10}B. Two fabrication methods were investigated to optimize isotope incorporation: a solvent-free hydrothermal method and a microwave-assisted pyrolysis method. In both, citric acid, urea, and the enriched isotope (^{6}Li or ^{10}B) reacted to form CDs. Following synthesis, purification was performed using filtration and dialysis, and isotope content was quantified via inductively coupled plasma analysis. Once CDs synthesis is optimized, the resulting particles will be further characterized. Subsequently, their bioactivity will be evaluated through cellular assays using both 2D and 3D cell models, in collaboration with the Faculty of Medicine of the University of Coimbra. Considering the current limitations in NCT drug delivery, this work represents a significant step toward the development of biocompatible, high-performance nanodrugs with strong translational potential.

Keywords — Carbon Dots, Neutron capture therapy, Nanomedicine

TOPIC

1) b.: Sustainable Manufacturing Solutions – Nanoengineering & Bio-inspired Manufacturing.

ACKNOWLEDGMENTS

This work is supported by the project 2022.03596.PTDC – Multifunctional carbon nanocapsules for highly efficient neutron cancer therapy (CARBONCT) and UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia.

REFERENCES

[1] F. Bray et al., "Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries," CA Cancer J Clin, vol. 74, no. 3, pp. 229–263, May 2024, doi: 10.3322/caac.21834.

[2] C. I. M. Santos et al., "Selective two-photon absorption in carbon dots: a piece of the photoluminescence emission puzzle," Nanoscale, vol. 10, no. 26, pp. 12505–12514, 2018, doi: 10.1039/C8NR03365J.

[3] G. Gonçalves et al., "Lithium halide filled carbon nanocapsules: Paving the way towards lithium neutron capture therapy (LiNCT)," Carbon N Y, vol. 208, pp. 148–159, May 2023, doi: 10.1016/j.carbon.2023.03.034.

[4] A. B. Fithroni et al., "Novel Drug Delivery Particles Can Provide Dual Effects on Cancer 'Theranostics' in Boron Neutron Capture Therapy," Cells, vol. 14, no. 1, p. 60, Jan. 2025, doi: 10.3390/cells14010060.

Optimizing Electron Beam Welding for Circular Copper Pipe Joints

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Abstract — The demand for compact and reliable heat pump and HVAC systems necessitates the development of high integrity joining techniques for copper pipes. *Currently, manual or semi-automated brazing is widely used however, it poses challenges such as inconsistent joint quality, vulnerability to vibration-induced failures, and environmental risks from refrigerant leaks.* Electron Beam Welding (EBW) offers a precise, vacuum-based fusion method capable of delivering deep penetration and minimal defect formation, particularly for copper and dissimilar joints [1]. However, copper's high thermal conductivity (401 W/m·K) and low beam absorptivity result in rapid heat dissipation and keyhole instability, making copper-to-copper welding inherently challenging. These challenges become more pronounced in circular path welding of copper pipes, where perimeter-driven heat flow necessitates dynamic thermal control. As the pipe diameter increases, so does the weld length, necessitating adaptive adjustments of welding parameters to maintain uniform energy delivery and fusion quality. Experimental trials on oxygen-free copper pipes demonstrated that a beam current of 9.5 mA at 55°/s produced complete fusion, while 10 mA at 60°/s resulted in incomplete bonding. These results underscore the narrow process window and the critical need to tailor beam current, and speed based on geometry. Literature confirms that beam current governs 81.13% of bead width variation and 44.56% of penetration depth in Cu-Cr-Zr alloy joints [2]. When properly tuned, this approach avoids defects such as spiking and porosity, which are common in high-conductivity materials but can be mitigated through controlled energy input and oscillation. Moreover, adjusting travel speed in thicker or longer welds helps balance thermal gradients and stabilize fusion. These parameter-property interactions are critical for transferring EBW from flat plate applications to complex tubular geometries. Future work will focus on implementing preheating strategies to manage steep thermal gradients and improve fusion stability in circular welds. Preheating has been shown to minimize porosity and prevent keyhole collapse under high-speed conditions [2]. Additionally, a gradual variation of welding speed from lower at the start to higher toward the end will be explored as a dynamic control method to adapt heat input in real time across the circular path, aiding in thermal balance and consistent joint formation. By stabilizing the melt pool and reducing temperature shocks, such strategies will enable more uniform microstructure evolution, which is particularly valuable in repetitive copper pipe assemblies for thermal applications. This study establishes a practical framework for geometry-dependent process optimization in copper EBW. The findings support the replacement of conventional brazing with high-performance EBW to enhance joint strength, thermal efficiency, and long-term reliability in energy, aerospace, and refrigeration applications. The proposed methodology also facilitates scalable automation and digital control in advanced welding systems.

Keywords — electron beam welding, copper pipes, copper-to-copper welding, process optimization, heat pumps

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation

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REFERENCES

[1] Y. Yin, Y. Tian, J. Ding, T. Mitchell, and J. Qin, "Prediction of Electron Beam Welding Penetration Depth Using Machine Learning-Enhanced Computational Fluid Dynamics Modelling," *Sensors 2023, Vol. 23, Page 8687*, vol. 23, no. 21, p. 8687, Oct. 2023, doi: 10.3390/S23218687.

[2] P. K. C. Kanigalpula, D. K. Pratihar, M. N. Jha, A. V Derose J. and Bapat, and A. R. Pal, "Experimental investigations, input-output modeling and optimization for electron beam welding of Cu-Cr-Zr alloy plates," INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY, vol. 85, no. 1–4, pp. 711–726, Jul. 2016, doi: 10.1007/s00170-015-7964-7.

Adhesive-Free Joining of Commodity Thermoplastics to Low-Density Foams

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Abstract — The increasing demand for lightweight polymeric structures in industries such as automotive, aerospace, and packaging has intensified the search for efficient and sustainable joining technologies. Conventional adhesive bonding methods, while widely used, often rely on toxic chemicals and require long curing times, which can hinder productivity and environmental compliance. Laser transmission welding (LTW) has successfully joined commodity and engineering thermoplastics [1,2]. This study investigates the feasibility of using laser welding as a solvent-free, rapid alternative to bond a commodity thermoplastic to a low-density polymeric foam. Joining these without adhesives poses a challenge due to their dissimilarities. Laser welding experiments were performed with systematic variation of parameters, aiming to optimize the joint strength while preserving the structural integrity of the materials. The resulting joints were characterized using shear lap testing, scanning electron microscopy, x-ray microtomography, infrared spectroscopy and physicochemical polymer analysis to assess mechanical performance, interfacial adhesion, and thermal damage. Preliminary findings demonstrate that adequate bonding between PP and foam is achievable under carefully controlled processing conditions. Process optimization proved essential to enhancing joint strength while minimizing foam collapse and degradation. These results highlight the potential of laser welding as a clean and efficient joining method for morphologically dissimilar polymeric materials, supporting the development of more sustainable manufacturing processes.

Keywords — Laser welding; Dissimilar joining; Adhesive-free bonding; Polymer foam; Commodity thermoplastic;

TOPIC

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REFERENCES

[1] Pereira, A.B., Fernandes, F.A.O., de Morais, A.B., Quintão, J., "Mechanical Strength of Thermoplastic Polyamide Welded by Nd:YAG Laser", *Polymers*, 11, 1381, 2019. https://doi.org/10.3390/polym11091381

[2] Fernandes, F.A.O., Pereira, A.B., Guimarães, B., Almeida, T., "Laser Welding of Transmitting High-Performance Engineering Thermoplastics", *Polymers*, 12, 402, 2020. https://doi.org/10.3390/polym12020402

Experimental Investigation of Filler Metal Delivery Methods in Induction Brazing of Copper Tubes for Heat Pump Manufacturing

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Abstract— Recent advances in manufacturing processes and the growing demand for refrigeration and heat pump systems in residential and industrial applications, driven by global warming and climate change, have increased interest in high-performance joining technologies. Induction brazing has emerged as a promising, rapid, and reliable method for joining copper and dissimilar metals in such systems. Beyond conventional process parameters, the selection and delivery method of the filler metal significantly influence joint quality by affecting thermal distribution, filler spread, defect formation, and local mechanical properties [1]. Existing literature highlights the critical role of parameters such as joint clearance, filler volume, and temperature in achieving consistent metallurgical bonding and reliable mechanical performance [2]. This study presents a comparative analysis of two filler metal feeding techniques, pre-placed filler metal rings and automatic filler wire feeding, in the induction brazing of copper pipe joints. Copper tubes (9.55 mm OD, 0.8 mm wall thickness) were brazed using a BCuP 281a copper–silver–phosphorus alloy at temperatures of 710 °C, 750 °C, and 800 °C, with joint clearances of 9.6 mm and 9.8 mm obtained by controlled expansion. The pre-placed rings were sized to deliver the required filler volume per joint, while in the automatic feeding method, wire was supplied at a constant feed rate of 2 mm/s, with calibrated feed lengths. Brazing was conducted in open atmosphere without the use of flux. Macrographic and microstructural analyses (SEM/EDS) were conducted to assess filler spread, joint geometry, and defect distribution. For defect characterization, an advanced image processing approach using the YOLOv11 algorithm was employed to segment and classify defects over the joint, such as, voids and incomplete penetration zones in both longitudinal and transversal cross-sections. Mechanical performance was evaluated through tensile testing, with failure locations recorded. The results indicate that automatic wire feeding method produced more uniform joints, with enhanced filler penetration and reduced defect area compared to pre-placed rings. Joints fabricated using both methods achieved tensile strengths approaching the base copper (~140 MPa), with failures predominantly occurring in the tube rather than in the joint, indicating sound metallurgical bonding. Process efficiency was high in both cases, with brazing cycles consistently under one minute. SEM/EDS analysis revealed that in both filler delivery conditions, a pronounced reaction layer formed at the filler–base metal interface, likely due to solid-state diffusion caused by excessive heat input, particularly at 800 °C. These irregular and thick interfacial layers may negatively affect joint toughness. The optimal brazing condition was established at 750 °C with a joint clearance of 9.6 mm, yielding minimal defect formation while avoiding the microstructural degradation associated with excessive thermal exposure, thereby preserving joint integrity. The findings suggest that automatic filler feeding enables better adaptability to variable joint geometries, reducing defect occurrence and improving filler distribution, while pre-placed rings offer simplicity and repeatability for standardized joints. These insights provide a practical basis for selecting filler delivery strategies in mass production of brazed components. Further work is recommended to evaluate fatigue performance and to develop adaptive control strategies for real-time optimization of filler metal feeding.

Keywords— Induction brazing; copper tube brazing; pre-placed rings; Automatic filler wire feeder.

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Reference

[1] Zahid, A., & Zahid, U. (2020). Influence of process parameters on the formation and quality of joining zones during induction brazing. *Engineering Research Express*, *2*(2), 025034.

[2] Botstein, O., Schwarzman, A., & Rabinkin, A. (1996). Induction brazing of Ti-6Al-4V alloy with amorphous 25Ti-25Zr-50Cu brazing filler metal. *Materials Science and Engineering: A*, *206*(1), 14-23

Sustainable product engineering through modular architecture:

a framework integrating human centered design and life cycle assessment

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Abstract — The increasing pace of mass production and technological advancements has led to shorter product life cycles. This unsustainable impact leads to increased natural resource exploration and subsequent waste [1]. In an era of growing environmental concerns and shifting consumer demands, modular product development emerges as a crucial strategy to balance product customization and personalization while allowing a sustainable product life cycle. Modularity is achieved by structuring products into smaller, interchangeable modules, allowing for standardization, scalability, adaptability, updateability, swappability, increased product variety, reuse, enhanced maintenance and improved recyclability [2]. It promotes a sustainable consumption pattern and reduces waste by upgrading or replacing individual modules rather than entire products [1,3]. Products are becoming increasingly complex with the integration of sensors, IoT and cyber-physical systems, conventional modularization methods struggle to address these challenges. As modularization approaches focus primarily on technical and strategic principles, they overlook user integration in product development and the environmental impacts of consumption. New modularization methods address this gap by implementing interdisciplinary approaches. Design methodologies can bring several other advantages to modularization methods, such as enabling more concepts and product variants, improving aesthetics for product differentiation, refreshing product designs, and evaluating user needs for product development [4,5]. The Life Cycle Assessment (LCA) tool can also bring advantages by assessing the environmental impact of modules across their different life cycle stages. It can promote corrective measures in products and reduce its environmental impact. This research aims to propose an Integrated modular product development framework that integrates conventional modularization methods with human centered design methodologies and sustainability principles with life cycle assessment. By bridging the disciplines of design and engineering, the study promotes a holistic approach to the development of modular products. The framework is expected to be validated through a case study application focusing on the development of a modular power transformer. By applying this integrated approach, the definition of modular product architectures is expected to not only enable customization and personalization but also reduce environmental impact and support circularity throughout the product's life cycle.

Keywords — Product Architecture; Interdisciplinary; Engineering Design; Human Centered Design; Life Cycle Assessment; Modular Product Development

TOPIC

1) c.: Sustainable Manufacturing Solutions; Manufacturing for Circular Economy

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REFERENCES

[1] M. Sonego, M. E. S. Echeveste, and H. Galvan Debarba, "The role of modularity in sustainable design: A systematic review," J Clean Prod, vol. 176, pp. 196–209, Mar. 2018, doi: 10.1016/j.jclepro.2017.12.106.

[2] K. T. Ulrich and S. D. Eppinger, Product Design and Development; Sixth Edition., Sixth edition. USA: McGraw-Hill Education, 2016. [Online]. Available: www.mhhe.com

[3] N. Machado and S. N. Morioka, "Contributions of modularity to the circular economy: A systematic review of literature," Dec. 01, 2021, Elsevier Ltd. doi: 10.1016/j.jobe.2021.103322.

[4] J. Kuechenhof and D. Krause, "Experimental validation of a method for systemic new development," in Proceedings of the International Conference on Engineering Design (ICED23), Bordeaux, France, 24-28 July 2023, Cambridge University Press, 2023, pp. 1765–1774. doi: 10.1017/pds.2023.177.

[5] M. F. A. Abdullah and R. Marshall, "A research overview of industrial design framework for modular product design," in International Design Conference - Design 2010, 2010, pp. 95–104.

Review of Thermomechanical Effects and Simulation of Residual Stress in SLM

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Abstract — Additive manufacturing technologies have been assuming an increasingly relevant role in the industry, driven by the rapid evolution of equipment, raw materials and the increasing accessibility to technology [1]. Among the different processes, Selective Laser Melting (SLM) stands out in the production of functional metal components, characterized by high geometric complexity and dimensional accuracy [2]. However, this process is marked by steep thermal gradients, due to the high heating and cooling rates, which promote the formation of residual stresses. These stresses negatively affect the structural integrity and mechanical performance of the parts, being responsible for the formation of defects at various scales: interstitials at the nano level, microcracks and porosities at the micro level, and delamination, warps or cracks at the macro scale [3]. The formation of residual stresses is strongly correlated with process variables such as material, parameters and boundary conditions. Understanding these relationships is essential to improve the reliability of manufactured components [4]. The present work consists of a systematic review of the literature focused on the thermomechanical effects associated with the SLM process, with a special focus on the prediction and analysis of residual stresses through numerical simulation tools. This review aims to provide a comprehensive overview of the impact of residual stresses on the functional performance of components, while simultaneously addressing existing computational models and the latest advances in this area. The analysis begins with the description of the SLM process, through the identification of the main defects related to residual stresses, to the survey of the current methodological approaches for its modelling and mitigation. An in-depth understanding of these phenomena is essential for the development of more effective control strategies in metal additive manufacturing.

Keywords — Additive Manufacturing; Selective Laser Melting (SLM); Thermomechanical Effects; Residual Stresses; Numerical Simulation

TOPIC

1) Sustainable Manufacturing Solutions. a. Manufacturing Processes & Simulation

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REFERENCES

[1] A. Vafadar, F. Guzzomi, A. Rassau, and K. Hayward, "Advances in Metal Additive Manufacturing: A Review of Common Processes, Industrial Applications, and Current Challenges," Appl. Sci., vol. 11, no. 3, p. 1213, Jan. 2021

[2] S. Pratheesh Kumar, S. Elangovan, R. Mohanraj, and J. R. Ramakrishna, "Review on the evolution and technology of State-of-the-Art metal additive manufacturing processes," Mater. Today Proc., vol. 46, pp. 7907–7920, Jan. 2021

[3] D. Hu, N. Grilli, L. Wang, M. Yang, and W. Yan, "Microscale residual stresses in additively manufactured stainless steel: Computational simulation," J. Mech. Phys. SOLIDS, vol. 161, pp. 4822–4822, Apr. 2022.

[4] S. Nie, L. Li, Q. Wang, R. Zhao, X. Lin, and F. Liu, "Effects of Thermal Stress on the Formation and Cracking Behavior of Nickel-Based Superalloys by Selective Laser Melting Based on a Coupled Thermo-Mechanical Model," MATERIALS, vol. 15, no. 24, pp. 8968–8968, Dec. 2022.

Composites processing PEEK on a gyroid alumina structure using Polymer-infiltrated ceramic network (PICN) process

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Abstract — This work presents the investigation and development of a hot-pressing system for the manufacturing of high-performance composite materials. The system is designed to optimise the processing of engineering thermoplastics, particularly PEEK (polyether-ether-ketone) infiltrated on digital light processing alumina gyroid structures, using the polymer-infiltrated ceramic network (PICN) process [1, 2], for use in demanding impact applications, as in protective, automotive, and aerospace sectors.

The research involved the design, implementation, and validation of an experimental setup capable of simultaneously applying heat, pressure, and vacuum in a controlled and repeatable manner. A series of parametric tests were carried out to assess the influence of different processing conditions on the final quality of the molded parts, with a particular focus on the density and interfacial adhesion of the final parts [3].

The results show that the correct application of temperature and pressure during hot pressing contributes significantly to reducing internal porosity and improving the structural integrity of the parts. Microstructural and dimensional analyses validated the effectiveness of the proposed system, highlighting its potential for future industrial applications in the production of advanced composite components.

This work represents a valuable contribution to the advancement of composite forming technologies, via the polymer-infiltrated ceramic network (PICN) process, offering practical solutions to improve product quality and feasible process.

Keywords — PEEK, Alumina gyroid structures, Polymer-infiltrated ceramic network (PICN), Composites

TOPIC

1) Sustainable Manufacturing Solutions. a. Manufacturing Processes & Simulation

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REFERENCES

[1] Zhang, J.; Pou, P.; Hodásová, L.; Yarahmadi, M.; Elizalde, S.; Cabrera, J.-M.; Llanes, L.; Armelin, E.; Fargas, G. Polymer-Infiltrated ceramic network produced by direct ink writing: the effects of manufacturing design on mechanical properties. Ceramics 2024, 7, 436–451. https://doi.org/10.3390/ceramics7020028

[2] Douglas Fabris, Joana Mesquita-Guimarães, Paulo Pinto, Júlio C.M. Souza, Márcio C. Fredel, Filipe S. Silva, Bruno Henriques, Mechanical properties of zirconia periodic open cellular structures, Ceramics International, Volume 45, Issue 13, 2019, Pages 15799-15806, ISSN 0272-8842. https://doi.org/10.1016/j.ceramint.2019.05.010

[3] Benjamin Pomès, Pascal Behin, Laurence Jordan, Stéphane Legoff, Gregory Stoclet, Emmanuel Richaud, Jean-François Nguyen, Influence of polymerization pressure and post-cure treatment on conversion degree and viscoelastic properties of polymer infiltrated ceramic network, Journal of the Mechanical Behavior of Biomedical Materials, Volume 115, 2021, 104286, ISSN 1751-6161. https://doi.org/10.1016/j.jmbbm.2020.104286

ISO 9001 Certification

Ensuring Quality Excellence at the Mechanical Testing Laboratory

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Abstract — ISO 9001 is an international standard that establishes guidelines for implementing a Quality Management System (QMS) aimed at enhancing an organization's effectiveness and customer satisfaction. Beyond providing a recognized quality seal, this standard serves as a strategic framework that transforms organizational operations, providing greater credibility, efficiency, and long-term sustainability [1] [2].

The objective of this work is to provide an overview of the implementation of a Quality Management System (QMS) within a laboratory at a Higher Education Institution, emphasizing its benefits and its role in enhancing operational efficiency, service quality, and risk mitigation, ultimately leading to increased customer satisfaction. To this end, the Mechanical Testing Laboratory (LEM) will be presented as a case study. Located within the Department of Mechanical Engineering (DEM) at the University of Aveiro and integrated into the Centre for Mechanical Technology and Automation (TEMA), LEM's mission is to perform mechanical tests - tensile, compression and bending - for students, researchers, and external clients.

In 2019, LEM achieved certification in accordance with the normative requirements of NP EN ISO 9001:2015. Six key processes have been identified within its activities, including: Management, Employee Management, Infrastructure & Operation, Purchases, Commercial and Quality. The effectiveness of these processes has been continuously monitored over time using the following tools: 1) definition of specific targets and corresponding key performance indicators, including the number of essays performed, the service request volume and the overall client count; 2) satisfaction surveys (targeting both personnel and clients).

The results presented in Figure 1 demonstrate consistent growth in the key performance indicators, except for 2020 and 2021, when restrictions imposed at the University of Aveiro due to the SARS-CoV-2 pandemic affected performance.

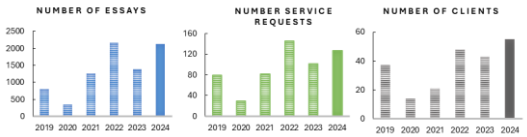

Figure 1. LEM performance overview: 2019–2024.

Since its certification, LEM has received no grievances concerning the services provided. This, together with average satisfaction scores of 3.98 and 3.64 (on a 4.00 scale) from client and employee surveys respectively, demonstrates a strong commitment to quality and customer satisfaction. The implementation of a Quality Management System (QMS), combined with the establishment of clear quality policies and continuous monitoring of performance against defined objectives and indicators, has driven ongoing improvements in the efficiency and effectiveness of its services. Furthermore, these measures have enabled the optimization of available resources and a reduction in operational costs.

The ISO 9001 certification, combined with LEM's dedication to excellence, has ensured the delivery of robust and reliable results to its users. This sustained commitment has been instrumental for TEMA and DEM in aligning their policies and objectives, as well as allocating the necessary resources to maintain the laboratory's ISO 9001 certification.

Keywords — Mechanical Testing; Quality; Certification; ISO 9001.

TOPIC

This work can be included in: Topic 1a, 1b and 1c and Topic 2a.

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REFERENCES

[1] Manders B., De Vries H.J. and Blind K., "ISO 9001 and product innovation: A literature review and research framework", *Technovation*, vol. 48-49, pp. 41-55, 2016. https://doi.org/10.1016/j.technovation.2015.11.004
[2] Susanto, D.A., Suef, M., Karningsih, P.D., Prasetya, B., "ISO 9001 implementation model: a review and future research agenda", *The TQM Journal*, vol. 37|5, pp. 1342-1363, 2025. https://doi.org/10.1108/TQM-10-2023-0343.

Multiscale analysis of fused filament fabrication 3D printed CNT/PLA nanocomposites

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Abstract —Additive Manufacturing (AM), also known as 3D printing, have been showing significant advantages on raw materials saving, fast operation, and customized geometries for complex structure components [1]. Adding nanomaterials such as carbon nanotubes to host matrices via AM technologies has the potential to enable greater capabilities in 3D printed parts production. The design and analysis of 3D printed parts is a key challenge in the field of AM. The final properties of 3D printed parts differ from those of the materials fabricated by traditional manufacturing methods, due to their anisotropy, internal void array and infill design. Anisotropy and internal voids are mainly due to variation in the mesostructure, which is produced while the part is fabricated by deposition of material layer upon layer. In the present work, a multiscale analysis of fused filament fabrication 3D printed CNT/PLA nanocomposites was developed. In macroscale, homogeneous FEM model and model considering internal void array were built. It is expected that with more accurate modeling, the later model showed closer numerical results to experimental results than the homogeneous one. However, the accurate modeling also takes more consumption, which could not be extended to complex and large-scale engineering cases. In mesoscale, the mesostructure of layers of the printed parts was considered for finite element modeling of the representative volume element (RVE), and to determine their elastic moduli. The mechanical behaviors of the printed parts are governed by the constitutive behavior of the material. The constitutive material modeling of the printed parts using numerical homogenization procedure is emphasized in this work. The elastic moduli of the present method accurately characterized the mechanical behavior of printed parts using laminate theory. Since the filler chosen in the present work is CNT, which cannot be characterized in mesoscale model, therefore, nanoscale modeling considering geometry and distribution of CNT was also carried out. The effect of CNT walls, CNT numbers, curvature, wave numbers, wave direction of CNT on elastic moduli of nanocomposites. In summary, the multiscale computational models provided more insights on the final properties of 3D printed parts for different materials, representing an important step towards enabling the effective design and analysis of 3D printed structures using both experimental investigation and computational methodology.

Keywords —Additive manufacturing; Mechanical properties; Carbon nanotube; Mesostructure; Nanostructure, Computational modeling

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation ".

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REFERENCES

[1] S. Yuan, S. Li, J.Zhu, Y. Tang, "Additive manufacturing of polymeric composites from material processing to structural design," *Compos B Eng*, 219, 108903, 2021. https://doi.org/10.1016/j.compositesb.2021.108903

SMART Mould@Footwear

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Abstract — The consumer market has seen a growing demand for personalised footwear products, with an increasing appreciation for differentiated items [1]. However, the production of differentiated products, often also referred to as "pair-by-pair" production, presents challenges in terms of production management. These include logistical issues (production flow control), construction complexities (personalised products involve more production stages), and time constraints (personalised products generally have longer delivery times). One of the biggest challenges derives from the current need for a large quantity of moulds for producing shoe soles across different sizes, a requirement reinforced by the constant evolution of footwear designs with each fashion season. The advancement of additive manufacturing is transforming moulds manufacturing, particularly in injection moulding, by enabling direct fabrication from digital models, which reduces design and planning time, as well as manufacturing costs. Innovative strategies include the creation of hybrid moulds, combining additive manufacturing with traditional techniques or interchangeable elements, and the development of soft tooling for pre-production [2]. Furthermore, additive manufacturing facilitates the creation of lightweight moulds with lattice structures, significantly reducing both weight and raw material consumption [3]. Automated real-time quality monitoring, utilising computer vision and deep learning, complements these innovations, allowing for simultaneous defect detection and dimensional measurement for optimised process control [4]. Robotic advancements are reshaping footwear manufacturing, with automated work cells handling tasks like sole scanning and manipulation. In this context, the project SMARTMould@Footwear – Sustainable Modular Advanced Reusable Tooling for footwear, aims to study, develop, and optimise new moulds for footwear production in a sustainable and flexible manner. The main objective is the development of a hybrid mould with evolutive cavities for the footwear sector, supported by additive manufacturing and process automation, enabling the production of different sole sizes and models, thereby promoting sustainability by reducing the quantity of moulds required.

Keywords — industry 4.0; footwear; injection moulding; additive manufacturing.

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1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation.

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REFERENCES

[1] Firtikiadis, L., Manavis, A., Kyratsis, P., & Efkolidis, N., "Product Design Trends within the Footwear Industry: A Review", Designs, 8(3), 49, 2024. https://doi.org/10.3390/designs8030049

[2] Martinho, P. G., & Pouzada, A. S., "Alternative materials in moulding elements of hybrid moulds: structural integrity and tribological aspects", The International Journal of Advanced Manufacturing Technology, 113(1–2), 351–363, 2021. https://doi.org/10.1007/s00170-021-06630-5

[3] Park, S. J., Lee, J. H., Yang, J., Heogh, W., Kang, D., Yeon, et al, "Lightweight injection mold using additively manufactured Ti-6Al-4V lattice structures", Journal of Manufacturing Processes, 79, 759–766, 2022. https://doi.org/10.1016/j.jmapro.2022.05.022

[4] Zhang, Y., Shan, S., Frumosu, F. D., Calaon, M., Yang, W., Liu, Y. et al "Automated vision-based inspection of mould and part quality in soft tooling injection moulding using imaging and deep learning", CIRP Annals, 71(1), 429–432, 2022. https://doi.org/10.1016/j.cirp.2022.04.022

Piezoelectric PLLA-based fibrous scaffolds for myocardial regeneration

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Abstract — Within cardiovascular disease mortality, four out of five fatalities occur due to heart attacks and strokes [1]. After a myocardial infarction, cardiac tissue undergoes physiological and molecular changes in response to injury leading to a gradual loss of function. Due to their capacity of converting mechanical forces into electrical energy, and vice versa, piezoelectric materials have been garnering more attention as components of self-powered biomedical solutions. However, most current implantable smart piezoelectric devices are made of non-degradable materials like PZT or PVDF, often requiring post-surgery removal. The utilization of synthetic biomaterials like poly-L-lactic acid (PLLA) represents an excellent biodegradable and safe alternative. Recently, PLLA fibers coupled with an ultrasound-driven wireless system promoted myocardial repair and recovery through activation of mitochondrial function and VEGF signalling pathways [2]. Herein, the potential of different e-field assisted techniques, like electrospinning (ES), electrohydrodynamic printing (EHD), and near-field electrospinning (NFES) techniques to produce piezoelectric PLLA-based nano and micro fibrous patches was explored.

Although electrospinning is regarded as the gold standard to produce fibrous platforms, it lacks the capacity to create controlled architectures. EHD and NFES, on the other hand, allowed for precise positioning of micro and nanofibers in a predefined path, hence allowing for tuning the architecture mechanics towards more compliant and mechanically relevant cardiac platforms. To evaluate the mechano-electrical conversion of these new structures, impact testing was used. Aligned electrospun samples showcased the highest mechano-electro conversion (2.75 V at 100 MΩ) attributed to the combination of high electric field and fast collector rotation, which induced dipole alignment on PLLA chains, contrasting with the lower output performance of random fibers (1.8 V at 100 MΩ). In contrast, the principles of EHD and NFES to design complex geometries, relying on smaller electric fields and low printing speed, do not yield a similar mechanical stretching of the PLLA chains, therefore leading to smaller outputs (~0.5 V at 100 MΩ) under impact test.

To conclude, although EHD and NFES present lower mechano-electrical output, their ability to design complex structures makes them highly promising for tailoring a next generation of piezoelectric cardiac platforms where structural control and mechanical compatibility are essential.

Keywords — Electric-field assisted manufacturing; Mechano-electric conversion; HL-1 cardiomyocytes

TOPIC

1) b.: Sustainable Manufacturing Solutions - Nanoengineering & Bio-inspired Manufacturing"

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REFERENCES

[1] A. Silvestri, M. Boffito, S. Sartori, and G. Ciardelli, "Biomimetic Materials and Scaffolds for Myocardial Tissue Regeneration," Macromol. Biosci., vol. 13, no. 8, pp. 984–1019, Aug. 2013, doi: 10.1002/mabi.201200483.

[2] X. Zhao et al., "Biodegradable Piezoelectric Implant for Wirelessly Delivering Electrical Stimulation to the Heart under Ultrasound Stress," Adv Funct Mater, p. 2418708, 2025, doi: 10.1002/ADFM.202418708.

In situ plasticization for continuous extrusion of starch-based foams: toward scalable production of biodegradable materials

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Abstract — Plastic pollution and stricter environmental regulations are fostering a transition toward innovative materials and scalable technologies aligned with circular economy principles. Among these, thermoplastic starch (TPS) has been highlighted due to its renewable origin and inherent biodegradability. In foam processing, TPS has been used in niche applications such as loose-fill packaging solutions, although its broader adoption remains limited by processing and performance-related challenges. Recent efforts have focused on improving TPS foam properties through chemical modification, polymer blending, and plasticization. However, further research is required to establish a robust and scalable manufacturing solution that combines material properties with processability. This work investigates an *in-situ* plasticization strategy for continuous extrusion foaming of native starch. A laboratory-scale twin screw extruder (Process 11, ThermoFisher Scientific) was adapted for that purpose, featuring a custom screw configuration for thermoplasticization and pressure build-up, and a slit die for producing TPS foam sheets. Water-glycerol mixtures were used as plasticizers at varying ratios and introduced into the processing equipment through a peristaltic pump (Dose it P910, Integra Biosciences AG), while sodium bicarbonate was premixed with dry starch as a chemical blowing agent. A systematic design of experiments was conducted, varying key parameters such as barrel temperatures, screw speed, plasticizer composition, and blowing agent content to evaluate their impact on melt behaviour, expansion performance, and foam morphology. Preliminary results revealed that a narrow processing window in terms of temperature profile and plasticizer content constrains simultaneous starch thermoplasticization and expansion. Higher water content (*i.e.,* >50%) in the plasticizer mixture increased expansion potential but reduced melt strength, leading to cell collapse at the die exit. In contrast, glycerol-rich formulations improved melt stability but suppressed foaming. Ongoing work focuses on identifying optimal formulation–process combinations that ensure sufficient melt strength, stable foam structure, and reproducible processing behaviour. These findings highlight both the challenges and opportunities of TPS foam processing and suggest viable conditions for the continuous production of lightweight, bio-based, and biodegradable foams. In a broader sense, this work emphasizes the role of a multidisciplinary approach to material development and process engineering, leveraging small-scale experimental platforms as testbeds for scalable, sustainable manufacturing solutions.

Keywords — twin-screw processing; biodegradable packaging; renewable polymers; foam morphology; sustainable manufacturing

TOPIC

Sustainable Manufacturing Solutions - Manufacturing for Circular Economy

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Effect of Polymer Reprocessing on the Bending Behaviour of Thermoresponsive multi-material 4D Printed Structures

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Abstract — 4D printing combines additive manufacturing with stimuli-responsive materials to create structures that evolve over time in response to external stimuli. When combined with thermoplastics such as PLA and TPU, this technology enables the fabrication of lightweight, low-cost, and programmable mechanisms capable of shape transformation without external actuators. It holds strong potential in areas such as soft robotics, biomedical devices, deployable structures, and smart textiles [1]. The intelligent behaviour of these systems is typically encoded during printing through geometric design, material choice, distribution, and printing parameters, and activated post-fabrication by stimuli such as heat. While functional development in 4D printing has progressed significantly, the use of reprocessed polymers remains largely unexplored. Most current studies rely on virgin materials, limiting investigation into how material history could influence actuation behaviour. Reprocessed polymers may show altered mechanical, thermal, and viscoelastic properties [2], [3], potentially affecting the time-dependent performance of shape-morphing structures. Understanding these changes could offer new strategies for tuning functional responses. This work investigates how reprocessing affects the curvature behaviour of PLA/TPU bilayer structures produced via Fused Deposition Modelling (FDM). Virgin and reprocessed filaments will be used to fabricate bilayer strips, with reprocessed material obtained by grinding and re-extruding printed parts. Samples will be subjected to a constant thermal stimulus, and curvature evolution over time will be tracked via image analysis. Mechanical testing will provide tensile properties, while thermal analysis will detect changes in thermal transitions. Viscoelastic performance will be assessed through dynamic mechanical analysis (DMA), and melt-state rheology will be used to characterise flow properties. It is expected that reprocessed materials will exhibit reduced curvature and slower actuation due to degradation-related changes. However, this study also explores whether such changes can be exploited to develop alternative actuation profiles. This study aims to determine if these altered properties can be used constructively to design alternative actuation responses or functional delays. Ultimately, this work contributes to a broader understanding of how material history affects 4D printing performance, opening the door to new material-driven strategies in the design of shape-morphing systems.

Keywords — multi-material 4D printing; PLA; TPU; reprocessed polymers

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation

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REFERENCES

[1] F. K. Aldawood, "A Comprehensive Review of 4D Printing: State of the Arts, Opportunities, and Challenges," *Actuators*, vol. 12, no. 3, p. 101, Feb. 2023, doi: 10.3390/act12030101.

[2] J. Smorawska, M. Włoch, and E. Głowińska, "Structure–Property Relationship and Multiple Processing Studies of Novel Bio-Based Thermoplastic Polyurethane Elastomers," *Materials (Basel).*, vol. 16, no. 18, Sep. 2023, doi: 10.3390/ma16186246.

[3] A. Romani, L. Perusin, M. Ciurnelli, and M. Levi, "Characterization of PLA feedstock after multiple recycling processes for large-format material extrusion additive manufacturing," *Mater. Today Sustain.*, vol. 25, Mar. 2024, doi: 10.1016/j.mtsust.2023.100636.

Tensile and flexural characterizations of biaxial non-crimp fabric composites for sustainable, two-wheeled electric vehicle chassis

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Abstract — The rising demand for sustainable automotive materials has driven research into renewable composite solutions. This study investigates the tensile and flexural behaviour of biaxial non-crimp-fabric (NCF) laminates—carbon fibre (post-cured for 4 h and 10 h), glass fibre and flax (linen)—intended for lightweight two-wheeled electric-vehicle chassis applications [1]. Mechanical testing followed ISO 527-4 for tension and ISO 14125 for three-point bending, while 3-D Digital Image Correlation (ARAMIS) captured full-field strains during the tensile trials. Carbon-fibre laminates delivered the highest performance: the 10 h post-cured panels attained a tensile strength of about 1.13 GPa, a Young's modulus of 60 GPa and an exceptionally low Poisson's ratio of 0.038; their flexural strength and modulus reached roughly 696 MPa and 43 GPa, respectively. Shortening the cure to 4 h lowered the tensile strength to 0.85 GPa and the flexural strength to 633 MPa, confirming cure duration as a key lever for stiffness and strength. Glass-fibre laminates offered a balanced, cost-effective alternative, combining a tensile strength near 351 MPa and a modulus of 17 GPa with flexural strength of about 350 MPa and a mid-span deflection of 16.7 mm. Flax-reinforced laminates, although limited to around 102 MPa tensile strength, exhibited the greatest ductility, with rupture strains of roughly 2 % and flexural deflections exceeding 11 mm, traits that recommend them for energy-absorbing, non-critical zones. These results affirm that both synthetic and natural fibre NCF composites can replace conventional metallic structures, delivering substantial weight savings and clear sustainability benefits [2]. Future work will extend to fatigue, environmental ageing and full life-cycle assessment to underpin their adoption in durable, circular mobility solutions.

Keywords — Non-crimp fabrics, Polymer-based composites, Tensile & flexural properties, Lightweight electric vehicle.

TOPIC

1) c.: Sustainable Manufacturing Solutions – Manufacturing for a Circular Economy

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REFERENCES

[1] S. H. Kamarudin et al., "A review on natural fiber reinforced polymer composites (NFRPC) for sustainable industrial applications" Polym., vol. 14(17), no. 3698, pp. 1-36, 2022. https://doi.org/10.3390/polym14173698
[2] R. Gonçalves et al., "Biobased polymers for advanced applications: towards a sustainable future," Prog. Polym. Sci., vol. 162, no. 101934, pp. 1-35, 2025. https://doi.org/10.1016/j.progpolymsci.2025.101934

Compressive and shear behaviour of novel non-crimp fabric composites for sustainable and lightweight electrical mobility

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Abstract — The transition to lightweight electric-vehicle (EV) chassis demands composites whose compressive and in-plane shear responses are as well understood as their tensile behaviour. Accordingly, we characterised biaxial non-crimp-fabric (NCF) laminates reinforced with carbon fibre (post-cured for 4 h and 10 h), glass fibre and flax (linen) in accordance with ISO 14126 and ISO 14129, respectively [1]. Compressive testing showed that carbon laminates dominate: the 10 h cure delivered a modulus of 49 GPa and a strength of 367 MPa, while the shorter 4 h schedule unexpectedly raised the modulus to 54 GPa and the strength to 377 MPa, indicating that moderate post-curing can sharpen matrix–fibre bonding without embrittlement. Glass laminates offered a mid-range solution, combining a 25 GPa modulus with 263 MPa strength, whereas flax laminates, though limited to a 6 GPa modulus and 74 MPa strength, withstood four to five times more compressive strain (≈ 4.6 %) before failure, underscoring their potential for energy-absorbing zones. Shear characterisation reinforced these trends. Carbon laminates resisted up to 70–78 MPa in-plane shear while maintaining moduli near 3.7–3.8 GPa and sustaining large shear strains at break (24–29 %), attributes well suited to complex load paths in monocoque frames. Glass laminates matched the carbon systems in stiffness (3.8 GPa) and reached 73.5 MPa shear strength, validating them as lower-cost structural alternatives. Flax laminates, by contrast, recorded a shear modulus of 1.6 GPa and 29.8 MPa strength, restricting them to non-critical or deformation-tolerant areas, yet contributing valuable compliance and sustainability. Taken together, the data confirm that carbon- and glass-fibre NCF composites satisfy the stringent compressive and shear requirements of next-generation EV chassis, while flax-fibre composites add ductility and ecological merit wherever peak strength is unnecessary [2].

Keywords — Non-crimp fabrics, Mechanical characterizations, Compressive & shear properties, Novel polymer-based composite materials

TOPIC

1) c.: Sustainable Manufacturing Solutions – Manufacturing for a Circular Economy

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REFERENCES

[1] S. H. Kamarudin et al., "A review on natural fiber reinforced polymer composites (NFRPC) for sustainable industrial applications" Polym., vol. 14(17), no. 3698, pp. 1-36, 2022. https://doi.org/10.3390/polym14173698
[2] R. Gonçalves et al., "Biobased polymers for advanced applications: towards a sustainable future," Prog. Polym. Sci., vol. 162, no. 101934, pp. 1-35, 2025. https://doi.org/10.1016/j.progpolymsci.2025.101934

From ride data to carbon credits: a LCA-based mobile solution for sustainable EV usage

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Abstract — Electrified micro-mobility offers a practical pathway toward multiple Sustainable Development Goals (SDGs), yet credible, user-level evidence of its impact remains scarce. This study introduces a SimaPro-based life cycle analysis/assessment (LCA) workflow embedded in a cross-platform mobile application that quantifies real-time carbon savings for rides made with a prototype 2-wheeled electric vehicle (EV) and converts them into traceable and manageable carbon credits. Telemetry captured through IoT sensors, GPS and MQTT messaging is fused with ISO 14040/44–compliant inventory data covering manufacture, energy use and end-of-life stages. The MariaBike App displays avoided emissions relative to internal-combustion travel, enabling transparent carbon-credit issuance and behavioural feedback. The solution advances SDG 3 by encouraging active travel and improving urban air quality; SDG 7 through promotion of low-carbon electricity usage; and SDG 8 by opening new revenue streams in the voluntary carbon market. Its modular, open architecture contributes to SDG 9 by leveraging digital innovation and interoperable infrastructure, while location-based ride tracking—validated against the Atlas ITDP city-scale carbon-monitoring framework [1]—supports equitable access to sustainable transport (SDG 10) and enhances planning for resilient, low-emission cities (SDG 11). Finally, integrating LCA findings directly into daily decision-making fosters responsible consumption patterns consistent with SDG 12. Comparative results confirm that e-bikes emit up to 88 % less CO_2-e per kilometre than the European car fleet average [2], translating to 0.001–0.002 carbon credits per typical urban trip [3]. By uniting rigorous LCA methodology with mobile digitalisation, the MariaBike Flutter platform/app provides a scalable blueprint for data-driven sustainability in the growing EV micro-mobility sector.

Keywords — LCA, 2-wheeled EV, Carbon footprint, Mobile IoT telemetry, Sustainable mobility, Flutter application integration

TOPIC

1) c.: Sustainable Manufacturing Solutions – Manufacturing for a Circular Economy

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REFERENCES

[1] "The atlas of sustainable city transport," Institute for Transportation and Development Policy, 2023. https://itdp.org/publication/the-atlas-of-sustainable-city-transport/ and https://atlas.itdp.org/
[2] E. Fishman and C. Cherry, "E-bikes in the mainstream: Reviewing a decade of research," *Transp. Rev.*, vol. 36, no. 1, pp. 72–91, 2016. https://doi.org/10.1080/01441647.2015.1069907
[3] E. Pipitone, S. Caltabellotta, and L. Occhipinti, "A life cycle environmental impact comparison between traditional, hybrid, and electric vehicles in the European context," *Sustainability*, vol. 13(19), no. 10992, pp. 1-32, 2021. https://doi.org/10.3390/su131910992

Simulation and shape prediction strategies in 4D printing

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Abstract — In today's competitive manufacturing landscape, balancing cost and performance is crucial. Additive Manufacturing (AM) offers a path to efficient, functional designs, with four-dimensional (4D) printing emerging as a key innovation [1]. By using materials responsive to external stimuli, 4D printing enables objects to change shape over time, opening new possibilities in adaptive design [2]. Building on this, research into the shape morphing behaviour of 4D-printed objects was conducted through simulation. Based on a literature review, this process can be effectively approached as a thermomechanical problem [3]. Bearing this in mind, this work first simulated the shape morphing of two-layer structures. Multiple parameters were varied through Finite Element Analysis (FEA) to assess both their independent influence and this method's feasibility. The study then analysed the use of orthotropic properties to evaluate control over deformation direction. Finally, insights from these phases were applied to more complex geometries. It is concluded that the printing process can be planned computationally with a thermomechanical approximation, paving the way for the incorporation of the influence of parameters such as printing speed, pattern design and strategic division into active/passive regions. Notably, this approach represents a simplified and first approximation with inherent limitations in simulation fidelity regarding physical behaviour, requiring further future experimental validation and an introduction of numeric models that better reflect the 4D morphing's physics. Nevertheless, this study provides a foundation for future work in 4D printing, especially regarding shape prediction of printed objects.

Keywords — Numerical Modelling; Fused Deposition Modelling; Finite Element Analysis, Shape Morphing; 4D Printing; Shape Prediction

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation

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REFERENCES

[1] B. Redwood, F. Schöffer, and B. Garret, *The 3D printing handbook: Technologies, design and applications*, 1st ed. 3D Hubs B.V., 2017.

[2] S. C. Ligon, R. Liska, J. Stampfl, M. Gurr, and R. Mühlhaupt, "Polymers for 3D printing and customized additive manufacturing," *Chem. Rev.*, vol. 117, no. 15, pp. 10212–10290, 2017. doi: 10.1021/acs.chemrev.7b00074

[3] S. Zeng, Y. Gao, Y. Feng, H. Zheng, H. Qiu, and J. Tan, "Programming the deformation of a temperature-driven bilayer structure in 4D printing," *Smart Mater. Struct.*, vol. 28, no. 10, p. 105031, 2019. doi: 10.1088/1361-665X/ab39c9

Enhancing Cooling Efficiency of Power Transformers: A CFD Approach

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Abstract — Power transformers are essential elements in electrical infrastructure, facilitating reliable power transmission across networks. While these systems are designed for high efficiency, they encounter critical thermal regulation issues that can compromise performance and durability [1]. Elevated operating temperatures degrade insulation materials and diminish the effectiveness of dielectric fluids, heightening the risk of system malfunctions. Therefore, robust cooling mechanisms are vital to preserve operational integrity and prolong service life [2]. Radiator-based oil-directed air-natural (ODAN) systems, which rely exclusively on buoyancy-driven airflow, impose no parasitic energy cost but lose efficiency as ambient temperature increases. Literature-validated computational-fluid-dynamics (CFD) studies indicate that elevating ambient temperature from 20 °C to 35 °C can reduce ODAN heat-dissipation capacity by up to 60 % [3] [4]. These findings underscore the need for low-cost upgrades that restore cooling capacity without introducing fans.

Therefore, a high-fidelity CFD model of a two-radiator assembly has been developed in **ANSYS Fluent**, comprising approximately 11 million poly-hexcore cells. This study involves a coupled simulation of two fluids, air and oil, where their thermal and physical behaviors are interdependent, thereby accurately modelling the interactions typical of natural convection. The oil flow within the radiator channels is modelled as laminar, with shell conduction employed to represent the 1.2 mm-thick steel panels. The air side is resolved with a *k–ω* SST turbulence model, while a **COUPLED** pressure–velocity scheme with **PRESTO!** pressure interpolation ensures convergence under strong buoyancy forces. Validation against full-scale laboratory measurements reveals a deviation of only **1.9 %** in heat dissipation rate, confirming the model's predictive accuracy.

To recover cooling capacity under warmer climates, the study evaluates the implementation of a **chimney structure** [5] that intensify the chimney effect above the radiator banks. A systematic parametric campaign varies chimney height (0.5 – 1.5 m), number of channels (1-5) and chimney geometry quantified by their effect on velocity fields, heat flux and oil temperatures. The optimum configuration raises the cooling capacity by **15%.**

These results demonstrate that targeted geometric refinements can restore ODAN effectiveness under higher ambient temperatures, stabilize winding temperatures, retard insulation ageing, and extend transformer service life. The proposed chimney retrofit thus provides a practical, low-cost strategy for utilities aiming to future-proof existing transformer fleets against escalating thermal loads in a climate change scenario.

Keywords — Radiator Enhancements, Climate Change, Cooling Systems, Thermal Modelling.

TOPIC

1) Sustainable Manufacturing Solutions. a. Manufacturing Processes & Simulation

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REFERENCES

[1] Nogueira, G. C.; Medeiros, L. H.; Oliveira, M. M.; Barth, N. D.; Bender, V. C.; Marchesan, T. B.; Falcão, C. E. G. Thermal Analysis of Power Transformers with Different Cooling Systems Using Computational Fluid Dynamics. *Journal of Control, Automation and Electrical Systems* 2022, *33* (1), 359–368. https://doi.org/10.1007/s40313-021-00848-0.

[2] Sorte, S.; Monteiro, A. F.; Ventura, D.; Salgado, A.; Oliveira, M. S. A.; Martins, N. Power Transformers Cooling Design: A Comprehensive Review. *Energies 2025, Vol. 18, Page 1051* 2025, *18* (5), 1051. https://doi.org/10.3390/EN18051051.

[3] Koca, A.; Senturk, O.; Akbal, Ö.; Özcan, H. A-Techno-Economic Optimization of Radiator Configurations in Power Transformer Cooling. *Designs (Basel)* 2024, *8* (1). https://doi.org/10.3390/designs8010015.

[4] Anishek, S.; Sony, R.; Jayadeep Kumar, J.; Kamath, P. M. Performance Analysis and Optimisation of an Oil Natural Air Natural Power Transformer Radiator. *Procedia Technology* 2016, *24*, 428–435. https://doi.org/10.1016/J.PROTCY.2016.05.059.

[5] Si, W.; Jin, S.; Shou, Y.; Yuan, P.; Tian, Y.; Yang, J. Numerical study of cooling performance augmentation for panel-type radiator under the chimney effect. *thermal science* 2024, *28* (4), 3013–3028. https://doi.org/10.2298/tsci230926076s.

Design and Performance Trade-offs in ODAF Transformer Cooling Systems: A Numerical Investigation

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Abstract — Power transformers are indispensable elements of electrical distribution networks, underpinning efficient energy transmission and ensuring the stability of power grids. In the face of rising global energy demand and the integration of renewable sources, safeguarding the operational integrity of these devices is more critical than ever. Thermal stress from prolonged overheating irreversibly degrades Kraft-paper insulation, undermining transformer reliability, driving up maintenance costs, and shortening service life [1]. Consequently, designing and optimising of effective cooling systems are vital to preserving insulation performance and achieving long-term operational robustness. Oil Directed/Air-Forced (ODAF) cooling systems represent the prevailing technology for transformer thermal management. In these, transformer oil absorbs heat from windings before conveying it to exterior radiators, where forced convection with ambient air dissipates thermal energy. Radiator geometry—particularly fin spacing, fin count and fin length—strongly influences heat transfer. Additionally, fan arrangement and operating speed govern external convection performance. This study develops a comprehensive computational methodology grounded in Computational Fluid Dynamics and Ansys Fluent to address these interdependent factors. The proposed model employs a porous-media approximation allowing a decoupled approach. This approach substantially reduces computational overhead without sacrificing physical fidelity - validation of the numerical model against experimental measurements from a commercial transformer radiator with high predictive accuracy. Parametric studies examined four key variables: (i) fin spacing from 32.58 mm to 67.50 mm, (ii) fin count at constant radiator volume, (iii) fan configuration, and (iv) fan rotational speed. Focusing on fin spacing, the wider 67.50 mm gap yielded an 11.94 % increase in the cost-effectiveness index—defined here as euros per kilowatt of heat dissipated—relative to the denser 32.58 mm arrangement. This trend mirrors results previously reported for natural convection [2]. This trend mirrors results previously reported for natural convection [2]. Nevertheless, when radiator volume is fixed, compact arrangements can accommodate additional fins, augmenting total heat-transfer surface area. Fan configuration analyses compared three equivalent setups: two large, six medium, and ten small fans. Although smaller, more numerous fans exhibited superior resilience to individual unit failure and promoted more uniform thermal distribution, they incurred higher electrical consumption and bypass-flow losses. Conversely, the dual-large-fan arrangement yielded the poorest cost-benefit ratio in cooling power dissipation and operational expenses. Increasing fan rotational speed uniformly enhanced heat-removal rates but introduced significant trade-offs in energy consumption and acoustic emissions, highlighting the necessity of optimising operational thresholds. Together, these findings furnish actionable design guidelines that balance thermal efficiency, capital cost and acoustic impact. Furthermore, they motivate adopting of dynamic control strategies capable of modulating fan RPM and oil flow rate in response to fluctuating transformer loading and ambient conditions.

Keywords — Computational Fluid Dynamics; Porous media approximation; Radiator design; Forced convection.

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Processes & Simulation

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REFERENCES

[1] R. Medya and N. Haque, "Effect of Organic Acids and Thermal Ageing in Oil-Impregnated Kraft paper used in Power Transformers," 2022 2nd International Conference on Intelligent Technologies (CONIT), Hubli, India, 2022, pp. 1-4, doi: https://doi.org/10.1109/CONIT55038.2022.9847831
[2] Koca, A.; Senturk, O.; Akbal, Ö.; Özcan, H. Techno-Economic Optimization of Radiator Configurations in Power Transformer Cooling. *Designs* **2024**, *8*, 15. https://doi.org/10.3390/designs8010015

Stress distribution analytical analysis in the vicinity of cooling channels during injection moulding

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Abstract — The use of tailored Temperature Control Systems (TCS) in injection moulding (IM) is increasing due to their ability to meet stricter part requirements with increase process productivity [1], [2]. Nevertheless, designing these TCS is challenging, and requires guidelines with a compromise between thermal and structural constraints. This work was designed to tackle these issues, aiming to develop a tool to assist the design of tailored TCS. Previous work has shown that a comprehensive understanding of the thermal, fluid dynamics and mechanical processes intrinsic to the IM process can lead to the development of new guidelines for optimal channel design. The thermal analysis of TCS was previously studied and the analysis depicts that the cooling process is governed by two heat transfer mechanisms — convection and conduction, with convection being the predominant heat transfer mode. Furthermore, channel position has proven to significantly impact cooling time and part quality. Having identified the key parameters and their interdependencies for the thermal analysis, the structural analysis was investigated to determine the stress distributions around the cooling channels (CC) during an IM cycle. The latter is modelled considering CC enclosed in a mould and subjected to the process representative distributed load. To ensure proper coupling between the thermal and structural models, the same assumptions and simplifications were considered. Steady-state conditions were assumed, and the mould was treated as a homogeneous, isotropic, linear elastic semi-infinite solid. Moreover, the analysis was undertaken, considering the combination of two problems using the principle of superposition: Problem 1 – the mould was taken as a semi-infinite solid without CC, but subjected to a uniformly distributed load (solved using the Flamant solution), and Problem 2 – the CC were considered enclosed in the mould, a semi-infinite solid, loaded by prescribed displacements along its boundary (solved through the Complex Variable method) [3], [4], [5]. Subsequent steps will involve the structure model validation and its integration with the thermal model via optimisation algorithms. The resulting coupled thermo-mechanical model is expected to enable the design and evaluation of TCS solutions across a range of component geometries.

Keywords — Injection Moulding; Temperature Control Systems; Stress distribution analysis.

TOPIC

1) a.: Sustainable Manufacturing Solutions – Manufacturing Process & Simulation

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REFERENCES

[1] P. Paraye and R. M. Sarviya, “Heat transfer analysis of conventional and conformal cooling channel in injection mold,” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 47, no. 1, pp. 1244–1268, Dec. 2025, doi: 10.1080/15567036.2024.2443947.

[2] J. Li, Y. C. Ong, and W. M. Wan Muhamad, “Optimization Design of Injection Mold Conformal Cooling Channel for Improving Cooling Rate,” Processes 2024, Vol. 12, Page 1232, vol. 12, no. 6, p. 1232, Jun. 2024, doi: 10.3390/PR12061232.

[3] A. H. . England, Complex Variable Methods in Elasticity. Dover Publications, 2003.

[4] N. I. Muskhelishvili, Some Basic Problems of the Mathematical Theory of Elasticity, 1st ed. Springer Dordrecht, 1977. doi: 10.1007/978-94-017-3034-1.

[5] X. Gao, H. N. Wang, and M. J. Jiang, “Analytical solutions for the displacement and stress of lined circular tunnel subjected to surcharge loadings in semi-infinite ground,” Appl Math Model, vol. 89, pp. 771–791, Jan. 2021, doi: 10.1016/J.APM.2020.07.061.

Advances in Nanofluid-Enhanced Cooling for Power Transformers

Integrating Flow Modelling and Design Strategies for Next-Generation Thermal Management

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Abstract — This paper presents the development of a comprehensive computational framework designed to systematically evaluate and optimise novel insulating fluids, namely nanofluids, for power transformers, with a primary focus on enhancing thermal performance while maintaining dielectric integrity. The framework integrates thermo-economic and dielectric analyses through virtual fluids characterised by fundamental thermophysical properties, thereby remaining independent of specific nanoparticle types. Effective Medium Theory (EMT) supplies the correlations used to predict effective conductivity, viscosity, density and specific heat across a range of nanoparticle concentrations and configurations, [1]. The computational platform couples a numerical model implemented in Computational Fluid Dynamics (CFD) with a simplified analytical heat-transfer model that serves as benchmark. Thermo-hydraulic analysis reveals a monotonic dependence of thermal performance on nanoparticle concentration: heat-transfer improvements up to 0.89 % are achieved through increased thermal conductivity, while the associated rise in dynamic viscosity produces operational pressure-loss penalties that can reach 12 %. Density and specific heat capacity appear only in higher-order terms and thus have negligible influence on either metric. Dielectric investigations confirm that the proposed nanofluids not only preserve dielectric properties within safe operating thresholds but in several cases improve breakdown voltage and permittivity. These results demonstrate that thermal performance gains can coexist with electrical reliability. Long-term colloidal stability, especially agglomeration control under electric stress, remains the critical issue to be addressed before large-scale deployment. An economic assessment, kept agnostic by excluding particle-specific production costs that vary widely with material choice and manufacturing scale, compares the cost of a nanofluid retrofit with that of installing auxiliary cooling fans, the conventional forced-ventilation solution for transformer uprating, [2]. Even after accounting for the extra pumping power demanded by the more viscous fluids, the nanofluid option shows favourable economic margins. The framework is also applied to sustainable base fluids by extrapolating the property space to natural ester oils. Results suggest that comparable conductivity gains are achievable while retaining the biodegradability and high flash point advantages of ester oils, broadening the applicability of the approach. Practical guidelines derived from the study recommend particle volume fractions near 1%, which balance measurable temperature reduction against acceptable pressure-loss growth. By combining multiphysics simulation and cost analysis, the framework delivers a quantitative decision-making tool for advancing transformer-cooling technology.

Keywords — Power Transformer, Cooling Systems, Thermal Performance, Dielectric Performance, Nanofluids, Economical Analysis, CFD

TOPIC

1) b.: Sustainable Manufacturing Solutions – Nanoengineering & Bio-inspired Manufacturing ".

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REFERENCES

[1] M. D. Alsulami, A. Abdulrahman, R. N. Kumar, R. J. Punith Gowda, and B. C. Prasannakumara, “Three-dimensional swirling flow of nanofluid with nanoparticle aggregation kinematics using modified Krieger–Dougherty and Maxwell–Bruggeman models: A finite element solution,” Mathematics, 11 (9), 2023.

[2] S. Sorte, A. F. Monteiro, D. Ventura, A. Salgado, M. S. A. Oliveira, and N. Martins, “Power transformers cooling design: A comprehensive review,” *Energies*, 18 (1051), 2025.

PLA-LnMOFs nanocomposites:

A study of polymeric nanotags for anticounterfeiting applications

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Abstract — The counterfeiting of polymer-based products and packaging presents a serious global challenge across commercial, industrial, and everyday contexts. The growing demand for secure information handling and counterfeit prevention has driven the rapid advancement of anti-counterfeiting technologies, from traditional methods like watermarks and holograms to sophisticated multi-level luminescent labelling systems. More recently, optically responsive markers, such as luminescent polymer composites that react to external stimuli, have garnered significant attention [1]. Their ability to modulate optical output under selective excitation conditions makes them especially promising for security-related applications [2].

Luminescent materials are available in large varieties and are relatively straightforward to manipulate, further enhancing their appeal in anti-counterfeiting strategies [3]. In this study, we investigated the optical properties of lanthanide-based metal-organic frameworks (LnMOFs), specifically those incorporating europium (EuMOF), terbium (TbMOF), dysprosium (DyMOF), and praseodymium (PrMOF), embedded within a biodegradable matrix (polylactic acid (PLA)). The hybrid composites were synthesized using a solvent casting method at ambient temperature, using chloroform ($CHCl_3$) as the solvent. This approach produced a series of PLA-based nanocomposites containing individual LnMOFs as well as various combinations of the LnMOFs under study.

Steady-state photoluminescence (PL) analysis of these nanocomposites revealed strong and distinct luminescent emissions upon targeted excitation. Notable intraionic emission lines were observed for: the EuMOF at 615 nm ($^5D_0 \rightarrow {}^7F_2$), TbMOF at 542 nm ($^5D_4 \rightarrow {}^7F_5$), and DyMOF at 570 nm ($^4F_{9/2} \rightarrow {}^6H_{13/2}$). In the case of PrMOF, characteristic intraionic absorption bands corresponding to transitions from the $^3H_4$ to ^3P_J levels were observed in the 445–485 nm range.

To support the feasibility of multi-tiered security tagging, we further examined the nanocomposites' luminescent behaviour under varying excitation wavelengths and temperatures. A selected hybrid nanocomposite was tested with the aim of obtaining color-tunable emissions, reinforcing the potential of these PLA-LnMOF nanocomposites as advanced, trackable optical markers suitable for high-level anti-counterfeiting applications.

Keywords — Polymeric nanocomposites; Lanthanide MOFs; Photoluminescence; Anti-counterfeiting.

TOPIC

1) Sustainable Manufacturing Solutions. b. Nanoengineering & Bio-inspired Manufacturing

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REFERENCES

[1] H.-M. Yang, G.-P. Yang, Y.-Y. Wang, Robust lanthanide MOFs as multifunctional luminescent sensors for intelligent visualization monitoring of MEAA and texture code anti-counterfeiting applications, J. Mater. Chem. C. 12 (2024) 6831–6840. https://doi.org/10.1039/D4TC00658E.
[2] X. Yu, A.A. Ryadun, D.I. Pavlov, T.Y. Guselnikova, A.S. Potapov, V.P. Fedin, Ln-MOF-Based Hydrogel Films with Tunable Luminescence and Afterglow Behavior for Visual Detection of Ofloxacin and Anti-Counterfeiting Applications (Adv. Mater. 19/2024), Adv. Mater. 36 (2024) 2470150. https://doi.org/https://doi.org/10.1002/adma.202470150.
[3] R. Simões, J. Rodrigues, C.M. Granadeiro, L. Rino, V. Neto, T. Monteiro, G. Gonçalves, Boosting the optical properties of polylactic acid/ lanthanide-based metal-organic framework composites, Mater. Today Chem. 29 (2023) 101436. https://doi.org/10.1016/J.MTCHEM.2023.101436.

Design Tool for Optimizing PCM-Based Energy Storage in Refrigeration Systems

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Abstract — By 2019, an estimated two billion domestic refrigeration systems (DRSs) were running worldwide, accounting for 4% of the global electricity demand [1]. Cold chain-related markets are projected to grow at a compound annual rate of 8.60% until 2030 [2]. This is while the cooling provision for perishable food remains under 35% of the demand in developing nations, and the yearly production of refrigerators and freezers exceeds 80 million. Thus, actions are required to ensure sustainable growth [3]. New technologies for storing surplus energy from RES are thus required to face supply-demand balance, intermittency, and volatility challenges associated with the expansion of RES power plants [4]. In this context, Thermal Energy Storage (TES), specifically by using Phase Change Materials (PCMs) in refrigeration systems, is a promising solution to enhance energy efficiency and store renewable energy. This study introduces a custom TRNSYS module for PCM-based thermal energy storage (TES) to improve energy efficiency in domestic refrigeration. It employs a one-dimensional heat transfer model with an implicit time-stepping scheme, achieving an average temperature and energy error of below 5% when validated against ANSYS-Fluent CFD simulations. The module was further tested by simulating refrigeration systems, demonstrating its real-world applicability with experimental results from chest freezers and PCM-modified prototypes. Numerical data showed strong alignment with experimental findings, effectively capturing thermal effects and extending autonomy during power outages, with relative errors under 0.5% and 1%. Simulations of 100-hour outages were completed in under 2 minutes, highlighting the model's computational efficiency. This validation positions the module as a valuable tool for design-stage studies and optimisation in PCM-enhanced refrigeration, with future work focusing on energy reduction strategies and the role of refrigeration as thermal energy storage in renewable energy systems.

Keywords — Phase change materials; energy storage; Dynamic simulation; Parametric study; Refrigeration systems.

TOPIC

1) Sustainable Manufacturing Solutions. a. Manufacturing Processes & Simulation. 2) Technologies for the Wellbeing. b. Innovative Technologies for Smart Cities.

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REFERENCES

[1] Dupont J-L. The Role of Refrigeration in the Global Economy (2019), 38th Note on Refrigeration Technologies. 2019. https://doi.org/10.18462/iif.NItec38.06.2019.

[2] InsightAce Analytic. Vaccine Cold Chain Logistics Market Expected to Reach US$ 4.90 Billion by 2030 - Growing Beyond COVID-19 Application 2022. https://www.prnewswire.com/news-releases/vaccine-cold-chain-logistics-market-expected-to-reach-us-4-90-billion-by-2030---growing-beyond-covid-19-application-301686152.html (accessed December 13, 2022).

[3] James C, Onarinde BA, James SJ. The Use and Performance of Household Refrigerators: A Review. Compr Rev Food Sci Food Saf 2017;16:160–79. https://doi.org/10.1111/1541-4337.12242.

[4] Schleicher-Tappeser R. How renewables will change electricity markets in the next five years. Energy Policy 2012;48:64–75. https://doi.org/10.1016/j.enpol.2012.04.042.

TECHNOLOGIES FOR THE WELLBEING

Development of an Instrumented Implant Comprising Capacitive Sensing to Monitor the Fracture Bone Healing

New era of bone fracture monitoring

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Abstract — Bone fractures represent a major public health issue, with rising incidence among active-age individuals, particularly due to conditions like osteoporosis [1]. Current monitoring methods rely mostly on imaging analysis, which are sporadic, subjective, and expose patients to radiation. Furthermore, they fail to provide real-time information on the biomechanical state of the healing bone [2]. To address these limitations, new approaches capable of delivering continuous and quantitative assessments of the fracture healing process are required. Such innovations can reduce recovery time, avoid unnecessary surgical interventions, and improve overall healthcare efficiency and patient outcomes [3].

This work introduces a novel bioelectronic osteosynthesis plate incorporating capacitive sensing technology to monitor bone healing progression. The concept is based on the variation of dielectric properties in different tissue types across the healing stages. A multi-phase methodology was used, which included designing a sensor-integrated implant, developing computational models to mimic the healing process, and conducting *in vitro* testing with biological samples that replicated different fracture stages.

The device is intended to be mechanically compatible with existing clinical implants and features an enclosed network of capacitive sensors for targeted monitoring. Complementary computational models were used to anticipate sensor behavior during healing, providing a foundation for future integration with intelligent data interpretation platforms. *In vitro* validation was performed mimicking each stage: hematoma with clotted blood; soft callus with crushed cartilage; hard callus with crushed trabecular bone; remodeling with intact bone. The system was placed over the bone, measurements were taken, and data were transmitted via Bluetooth to a mobile phone, then processed on a computer. Results showed a progressive decrease in capacitive variations across stages, demonstrating the system's ability to distinguish healing phases through measurable electrical signals.

The results suggest that this technology can provide clinicians with reliable, real-time feedback on fracture progression. By enabling early detection of complications and supporting personalized treatment strategies, the proposed system represents a significant advancement in orthopedic care. Overall, this work paves the way for the next generation of intelligent medical implants improving the field of personalized orthopaedic care.

Keywords — Instrumented Implant, Bone Fracture Healing, Bioelectronic Implants, Capacitive Sensing, Healing monitoring

TOPIC

2) Technologies for the Wellbeing: a. Multiscale Technologies and Devices for Medicine,

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REFERENCES

[1] *D. Pires, N. Silva, B. Sousa, J. Marques, A. Ramos, J. A. F. Ferreira, R. Morais, S. Vieira and M. P. Soares dos Santos, "A millimetre-scale capacitive biosensing and biophysical stimulation system for emerging bioelectronic bone implants", Journal of the Royal Society Interface, vol.21. no. 218, 2024, DOI: https://doi.org/10.1098/rsif.2024.0279*

[2] *C. Conceição, A. Completo, and M. P. Soares dos Santos, "Ultrasensitive capacitive sensing system for smart medical devices with ability to monitor fracture healing stages," Journal of The Royal Society Interface, vol. 20, no. 199, 2023, DOI: https://doi.org/10.1098/rsif.2022.0818*

[3] *D. Pires, N. Silva, A. Completo, and M. P. Soares dos Santos, "Bioelectronic osteosynthesis plate to monitor the fracture bone healing using electric capacitive variations" Journal of Orthopaedic Surgery and Research 20, 105, 2025, DOI: https://doi.org/10.1186/s13018-025-05534-4*

Anomaly Detection using Machine Learning Models in Water Supply Systems

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Abstract — Water loss remains a critical global concern, particularly within the present-day scarcity of water resources. This problem constitutes a significant challenge faced by water supply systems (WSS) utilities, as these deal with water leakage, which can persist undetected for extended periods of time and have a significant impact on the system efficiency. The occurrence of water leakage in these systems can range from 3% to over 50% depending on the level of system network maintenance performed, since it happens in pipe and/or junctions by uncontrolled actions [1]. Moreover, and according to the Portuguese regulator ERSAR in the RASARP 2024 [2], actual water leakage in Portugal in 2023 was 5.5 m^3/(km day) for the bulk side, which corresponds to a loss of more than 21 billion m^3/year. On the other hand, on the distribution side the value was 2.4 m^3/(km day) representing 4.6 billion m^3/year. To address this problem, several leakage management measures can be implemented, including preventive measures, detection and localization techniques, and repair initiatives. The detection and localization techniques comprise hardware- and software-based methods, which can integrate Machine Learning (ML) models and digital twins technologies. This data analytics integration can become a powerful tool in automated data analysis and hydraulic simulation, leading to significant advancements to a faster and more accurate leakage detection and localization.

This work aims to present a novel sub-framework employing ML techniques to detect anomalies in pressure time series, as small discrepancies in the values may represent potential water leakage scenarios in the water system. This approach is implemented on a benchmark dataset, the BattLeDIM network [3], in which different ML-based models were evaluated and then compared with prior baseline results.

Keywords — Water Leakage, Water Supply System, Machine Learning, Anomaly Detection, BattLeDIM Benchmark

TOPIC

2) b.: Technologies for the Wellbeing - Innovative Technologies for Smart Cities".

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REFERENCES

[1] R. Puust, Z. Kapelan, D. A. Savic, and T. Koppel. A review of methods for leakage management in pipe networks. Urban Water Journal, 7(1): 25–45, February 2010. Doi: 10.1080/15730621003610878

[2] ERSAR. Edições anuais do RASARP – Vol 1, 2024. https://www.ersar.pt/informacao-relevante-setor/

[3] Vrachimis, S. G., Eliades, D. G., Taormina, R., Kapelan, Z., Ostfeld, A., Liu, S., Kyriakou, M., Pavlou, P., Qiu, M., and Polycarpou, M. M. (2022). "Battle of the leakage detection and isolation methods." Journal of Water Resources Planning and Management, 148(12), 04022068. Doi: 10.1061/(ASCE)WR.1943-5452.0001601

Structure–property relationships in Yttrium-Doped Barium Zirconate-Stannates: Thermodynamic and electrochemical properties

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Abstract — Barium stannates are notable for their unique structural and chemical characteristics, positioning them as highly promising ceramic electrolytes for proton conducting fuel cells [1-2].

The current research investigates the $BaZr_{0.8-x}Sn_xY_{0.2}O_{3-\delta}$ (x = 0.2, 0.4, 0.6, 0.8) perovskites, focusing on the influence of Sn substitution on structural properties, microstructure and high-temperature electrochemical and thermodynamic properties. The samples were synthesized through a conventional solid-state reaction method. Powder X-ray diffraction with Rietveld refinement confirmed that all the compositions resulted in a single-phase cubic perovskite structure. As the Sn content increases, there is a decrease in the lattice parameter—a phenomenon predicted because of the replacement of the larger Zr^{4+} ions by the smaller Sn^{4+} ions.

Microstructural examination reveals enhanced densification with higher Sn incorporation. Electrochemical impedance spectroscopy (EIS) was conducted under controlled oxygen and water vapor partial pressures across a temperature range of 550–700 °C. This enabled the extraction of key thermodynamic and transport parameters based on defect chemical modelling. *Van't Hoff* analysis indicates that higher Zr concentrations lead to more exothermic hydration enthalpies and elevated proton defect concentrations. Proton mobility also improves with increased Zr content, demonstrated by reduced migration enthalpies. These observations are interpreted through the lens of structural tolerance factors, differences in B-site and A-site electronegativities, and the evolution of lattice parameters—all factors that modulate the formation and transport of protonic defects. Overall, this work provides a framework for rational design of Ba-based perovskite materials optimized for solid-state proton conduction applications.

Keywords — fuel cells, solid-state, proton conductor, ceramics

TOPIC

2) Technologies for the Wellbeing a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] Y. Wang, A. Chesnaud, E. Bevillon, and G. Dezanneau, Properties of Y-doped $BaSnO_3$ proton conductor, *Solid State Ionics*, 2012, 214, 45–55.

[2] I.A. Zvonareva, G.N. Starostin, M.T. Akopian, G.K. Vdovin, X.Z. Fu, D.A. Medvedev, Ionic and electronic transport of dense Y-doped barium stannate ceramics for high-temperature applications, *J. Power Sources*, 565 (2023) 232883.

Comparison of palladium-modified WO3 sensors for hydrogen detection:

synthesized vs. commercial WO3

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Abstract — The transition to a hydrogen-based economy demands reliable and accessible gas detection technologies to ensure safety and efficiency. Tungsten trioxide-based sensors are gaining attention for their potential in monitoring hydrogen across various applications [1]. However, conventional fabrication methods often rely on energy-intensive processes or complex equipment, leading to elevated costs and limited scalability. This study compares palladium-modified tungsten trioxide (Pd-WO_3) gasochromic particles for H_2 detection, using synthesized and commercial materials. Commercial WO_3 (cWO_3) was functionalized with several amounts of Pd (2 wt%, 5 wt%, 10 wt% and 20 wt%) to select the optimal composite for gasochromic H_2 detection. These compositions were tested under 10 % H_2/N_2 and Air atmospheres, 10%Pd-cWO_3 and 20%Pd-cWO_3 achieving maximum color changes (ΔE) of 21.87 (T_{90} = 203.21 s) and 20.15 (T_{90} = 187.21 s) (Figure 1- B and C & Table1). The synthesized WO_3 (sWO_3) was prepared via a simple protocol, where tungsten hexachloride was mixed with ethanol (72 h), centrifuged, washed, and dried at ambient conditions. sWO_3 was modified with 20wt% Pd, presenting a maximum ΔE of 18.83 and T_{90} of 190.64 s. For the sensor made with sWO_3, a noticeable color change is observed from approximately 50 to 100 seconds after air injection, aligning with the steep slope of the response curve in this region. Following 300 seconds of air injection, the sensor made with sWO_3 fully returned to its original color within an additional 200 seconds (Figure 1-A), indicating complete reversibility in a relatively short total time. However, the two sensors made with cWO_3, 10%Pd-cWO_3 and 20%Pd-cWO_3, did not return to their original color within the human visual range even after 5 minutes (Figure 1-B, C), suggesting partial irreversibility (possibly requiring over 48 hours for reversibility). As noted in previous studies, this lack of reversibility may be attributed to the relatively dense morphology of the cWO_3 coating layer [2]. These findings highlight the potential of sWO_3 for cost-effective, flexible, and reversible hydrogen sensors, advancing environmental and energy applications [1].

Keywords — hydrogen sensor; tungsten trioxide; palladium; gas detection; reversibility

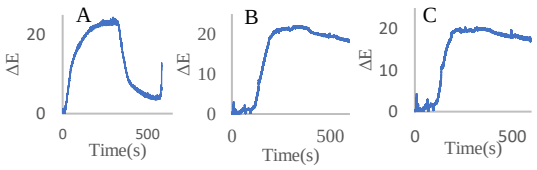

Figure 1 Hydrogen response over time for palladium-modified WO3 sensors: A) sWO_3 (17 wt% palladium) with full reversibility and response of 18.83; B) cWO_3(10 wt% palladium) and C) cWO_3(20 wt% palladium) with faster responses (21.87 and 20.15) but no reversibility.

	A	B	C
ΔE_{max}	18.83	21.87	20.15
T_{90}(S)	190.64	203.21	187.21

Table1, Summray of ΔE_{max} and T_{90} A)17%Pd-sWO_3, B)10%Pd-cWO_3, C)20%Pd-cWO_3

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] A. F. Girão and A. Completo, "Eye-readable sensors for intuitive hydrogen monitoring," Int. J. Hydrogen Energy, vol. 65, pp. 593–605, 2024.

[2] Ambardekar, V., Bhowmick, T., & Bandyopadhyay, P. P. (2022). Understanding on the H_2 detection of plasma sprayed tin oxide/tungsten oxide (SnO2/WO3) sensor. Int. J. *Hydrogen Energy*, *47*(33), 15120-15131.

Recapitulating the Mechanical Anisotropy of the Spinal Cord via 3D Printing

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Abstract — Demographic data related to spinal cord injuries (SCI) indicate that traumatic ones are the most common type, typically resulting in contusions that primarily affect the superficial white matter of the spinal cord [1], for which effective treatments are absent. Regarding its physiology, the spinal cord presents anisotropy in terms of architecture and mechanical properties.

This work aims to replicate the anisotropic behaviour of the spinal cord by designing scaffolds with sinusoidal characteristics. Incorporating sinusoidal geometry into the scaffold design enables precise control over its rigidity. This approach is crucial because: i) neuronal cells are highly sensitive to their mechanical environment; ii) mechanical mismatch can lead to inadequate neuronal support or exert excessive pressure on surrounding tissue, thereby increasing damage. Respecting these requirements is key for developing effective strategies for spinal cord repair [2].

Here, by using the finite element method (FEM), a design of experiments (DOE) was conducted to identify the optimal sinusoidal parameters, specifically amplitude and wavelength, while accounting for both printing constraints and the biomechanical requirements of spinal cord tissue. The final design was conceptualized based on these findings and simulated again using FEM. Fabrication was achieved via 3D printing more specifically by melt-electrowriting (MEW), and the resulting structures underwent tensile testing to validate their mechanical performance. Simulations revealed longitudinal and transverse elastic moduli of 64 kPa and 24 kPa, respectively, matching the target values for spinal cord white matter. Experimentally, the longitudinal modulus ranged from 113 to 245 kPa, and the transverse modulus from 18 to 69 kPa. Furthermore, the scaffold design was refined to improve its Poisson's ratio, ensuring closer mechanical similarity to native spinal cord tissue in the way it deforms.

This study demonstrates the potential of sinusoidal MEW fabricated scaffolds to replicate the mechanical anisotropy of spinal cord white matter, thereby contributing to the advancement of spinal cord tissue engineering.

Keywords — Spinal Cord, Melt-Electrowriting, Finite Element Method.

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] Young, Wise. "Spinal cord contusion models." *Progress in brain research* vol. 137 (2002): 231-55. DOI: 10.1016/s0079-6123(02)37019-5.

[2] M. P. Lutolf and J. A. Hubbell, "Synthetic biomaterials as instructive extracellular microenvironments for morphogenesis in tissue engineering", 2005. DOI: 10.1038/nbt1055.

Multidimensional vibrationally driven energy generation: literature review

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Abstract — Most real-world mechanical energy sources present significant dynamics in multiple degrees of freedom (DOF). As the performance of vibration-driven energy generators is highly anisotropic, and thus dependent not only on the time variation of the input mechanical excitation but also on its spatial orientation, a new era of multi-DOF generators has recently emerged to harvest energy from 6 DOF excitations. Up to date, literature reviews analysing the conversion of mechanical energy from vibrational sources into electrical energy using electromagnetic, triboelectric and piezoelectric generators, have not addressed multi-DOF generators and their intrinsic characteristics. Instead, they have been focused on linear and/or rotational architectures, optimized only for unidirectional vibrations. Besides, a generalized modelling approach to effectively deal with the dynamic complexity of multi-DOF generators is still lacking. This study provides a multifaceted investigation that includes a review of the major breakthroughs carried out in the scope of multi-DOF generators. Thorough analyses were performed encompassing several design configurations, modeling approaches, electric outcomes, and real-world applications of 35 designs of multi-DOF generators incorporating electromagnetic and triboelectric and/or piezoelectric transduction mechanisms. Both electromagnetic and hybrid generators were already engineered comprising up to fourteen rigid free bodies and twenty-four DOFs. Three modeling approaches were used to predict the electromechanical dynamics of generators: analytical, finite element, and related hybridizations.

Power densities up to 5.44 mW/cm3 (5.44 kW/m^3) and efficiencies up to 48.5% [1] were experimentally found in the literature. Nevertheless, no relationship has been widely explored yet between the increasing power density and the increasing sensitivity of the generators to mechanical excitations with a wide range of DOFs. Even though significant advances have already achieved in this field, our findings highlight that future research must focus on developing sophisticated generators with the ability to effectively couple all translational and rotational DOFs from both kinetic and potential energy, ensuring the minimization of coil Ohmic losses and maximization of the electromechanical coupling coefficient, and thus energy conversion efficiency, for multi-DOF excitations and loads.

Keywords — Multidimensional energy generation; omnidirectional energy generation; Three-Dimensional vibrational energy harvesting; Six-degree of freedom energy converter; electromagnetic generator; piezoelectric and triboelectric generators.

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy.

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REFERENCES

[1] Lu, ZQ., Zhao, L., Fu, HL. et al. Ocean wave energy harvesting with high energy density and self-powered monitoring system. Nat Commun 15, 6513 (2024). https://doi.org/10.1038/s41467-024-50926-5

A magnesium hydride-added titania anode for Li-ion batteries

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Abstract - Lithium-ion batteries (LIBs) are essential for powering portable electronics and electric vehicles due to their high energy density and long cycle life. However, their conventional graphite anodes face challenges such as low operating voltage and safety risks from lithium dendrite formation [1]. Titanium dioxide (TiO2) offers a safer alternative with greater cycling stability, but its limited capacity and lithium-ion diffusion hinder broader application [2].

This study explores the performance of a TiO2 anode modified with 10 wt% magnesium hydride (MgH2), which acts as a chemical reducing agent during high-energy ball milling, partially converting TiO2 to oxygen-deficient TiO2−δ. Advanced microscopy, including scanning electron and atomic force microscopy, reveals that during repeated charging/discharging cycles, the modified TiO2−δ anode develops nanodomains with varying conductivity. Some of these become non-conductive, which could negatively affect electron transport and charge-discharge efficiency, as determined by electrochemical impedance spectroscopy. However, this drawback is counteracted by the markedly improved lithium-ion diffusion facilitated by the TiO2−δ structure, as denoted in charge-discharge testing.

This modification improves lithium-ion diffusion, resulting in a significantly higher diffusion coefficient, which is almost an order of magnitude greater than that of unmodified TiO2, and a reversible capacity reaching ~300 mAh g-1 during 50 tested cycles @0.1 C. The study demonstrates that MgH2-modified TiO2 anodes offer a promising balance of structural stability, lithium mobility, and capacity retention for next-generation LIB applications.

Keywords — Lithium-ion battery (LIB), Titanium dioxide (TiO2), Magnesium hydride (MgH2), Electrochemical Impedance spectroscopy (EIS), Cyclic voltammetry (CV).

TOPIC

2) Technologies for the Wellbeing a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] S. Goriparti, E. Miele, F. De Angelis, E. Di Fabrizio, R. Proietti Zaccaria, C. Capiglia, Review on recent progress of nanostructured anode materials for Li-ion batteries, *J. Power Sources*, 257 (2014), 421-443.

[2] F.J.A. Loureiro, D. Pukazhselvan, Igor Bdikin, Aliaksandr L. Shaula, Sergey M. Mikhalev, Duncan P. Fagg, Electrochemical behaviour of magnesium hydride-added titania anode for Li-ion battery, *Electrochimica Acta*, 394, (2021), 139142.

Optimisation of electrodes for fuel cells using the electrospinning technique

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Abstract — Solid oxide fuel cells (SOFCs) are valued for their efficiency in generating electrical energy, as well as for significantly reducing the emission of pollutants such as CO_2, sulphur and nitrogen oxides [1]. The cathode plays a crucial role in this process, as the oxygen reduction reaction occurs at a slower rate, requiring materials that can improve the kinetics of this reaction [2]. Perovskite-structured oxides are a promising material for SOFCs due to their mixed ionic-electronic conductivity. However, their high thermal expansion coefficient (TEC), compared to common electrolytes, presents challenges during both fabrication and operation. Calcium cobaltite with the composition $[Ca_2CoO_{3-\delta}]_{0.62}[CoO_2]$ (CCO) has a more compatible TEC and excellent electrical properties; however, its low oxygen-ion diffusion coefficient restricts its electrochemical performance [3,4]. Electrospinning (ES) is a promising technique for producing high-performance electrodes. In this study, CCO electrodes were synthesised using ES for SOFC cathodes and compared with samples obtained *via* the solid-state reaction (SSR) method [5]. Microscopic characterisation was carried out to investigate the influence of the microstructure on the electrochemical responses. CCO produced by the SSR method exhibits a platelet-like morphology with particle sizes ranging from 0.4 µm to 2.5 µm. In contrast, CCO synthesised by the ES method consists of various nanofibres made up of multiple platelets sized <300 nm. Impedance spectra reveal a substantial reduction in total polarisation resistance (approximately 62 %) for the ES-CCO electrode. The maximum power density increased from 13.21 mW cm^{-2} at 0.51 V for the SSR-CCO sample to 111.57 mW cm^{-2} at 0.58 V for the ES-CCO sample at 700 °C. This superior performance is due to fibre breakage during electrode preparation and the higher aspect ratio of the synthesised particles, both of which contribute to enhanced grain-to-grain connectivity in the final electrode microstructure [5].

Keywords — Fuel cell; SOFC; Electrodes; Electrospinning.

TOPIC

2) a.: Technologies for the Wellbeing - Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] R. M. Ormerod, “Solid oxide fuel cells”, Chem. Soc. Rev., vol. 32, pp. 17–28, 2003. DOI: 10.1039/b105764m

[2] G. C. Mather, D. Muñoz-Gil, J. Zamudio-García, J. M. Porras-Vázquez, D. Marrero-López, and D. Pérez-Coll, “Perspectives on cathodes for protonic ceramic fuel cells”, Appl. Sci., vol. 11, no. 12, p. 5363, 2021. DOI: 10.3390/app11125363

[3] K. Nagasawa, S. Daviero-Minaud, N. Preux, A. Rolle, P. Roussel, H. Nakatsugawa, and O. Mentré, “$Ca_3Co_4O_{9-\delta}$: A thermoelectric material for SOFC cathode”, Chem. Mater., vol. 21, no. 19, pp. 4738–4745, 2009. DOI: 10.1021/cm902040v

[4] V. Thoréton, Y. Hu, C. Pirovano, E. Capoen, N. Nuns, A. S. Mamede, G. Dezanneau, C. Y. Yoo, H. J. M. Bouwmeester, and R. N. Vannier, “Oxygen transport kinetics of the misfit layered oxide $Ca_3Co_4O_{9+\delta}$”, J. Mater. Chem. A, vol. 2, pp. 19717–19725, 2014. DOI: 10.1039/C4TA02198C

[5] A. J. M. Araújo, I. I. Maor, L. I. V. Holz, M. Mann-Lahav, V. Beilin, A. Feldhoff, G. S. Grader, and F. J. A. Loureiro, “Optimization of misfit calcium cobaltite oxygen electrodes for solid oxide fuel cells through electrospinning processing”, J. Mater. Chem. A, vol. 12, pp. 26266–26279, 2024. DOI: 10.1039/D4TA04085F

Synergistic Impacts of CAVs on Traffic Flow and Emissions

Design of an intelligent traffic management system

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Abstract — Advances in technology have allowed transport systems to be improved both in terms of digitalisation, which allows for a better travel experience, and with the emerging technologies in the automotive sector. Although all its benefits, the road sector still presents challenges in terms of harmful effects, such as congestion, inappropriate driving performance, and degradation of air quality and the environment. Thus, it seems important to understand ahead the impacts of a coexistence scenario with the integration of connected and autonomous vehicles (CAV) into current traffic conditions and to investigate. Effects of CAVs vary based on traffic composition, penetration rates, and operational behaviours [1]. This study seeks to investigate evidence of the impact of CAV operational behaviour on traffic dynamics and environmental impacts in a mixed traffic scenario and begins by exploring a real urban case study around the University of Aveiro, Portugal - an area characterised by moderate congestion and sensitive land uses such as a kindergarten and health services. The research simulates traffic with different levels of CAV integration using PTV VISSIM and is divided into two phases. First, three scenarios are modelled: a baseline scenario with only conventional vehicles (CV), another with 30% cautious CAVs and another with 30% all-knowing CAVs with optimised behaviour [2]. The simulation employs vehicle-specific power (VSP) methodology to estimate CO_2 and NOx emissions, alongside operational performance metrics such as speed and acceleration. Cautious CAVs show a significant reduction in aggressive driving behaviours, leading to smoother traffic flows and improved safety margins. Meanwhile, the all-knowing CAVs optimise acceleration and deceleration patterns, resulting in more stable and energy-efficient driving conditions, which influence even CVs positively by harmonising their driving patterns. Results indicate that the integration of CAVs, especially those with optimised driving strategies, can lead to substantial environmental benefits [3]. The second phase (ongoing) seeks to focus on fine-grained spatial analysis and behavioural propagation models to optimise CAV deployment for more optimised operational and environmental performance and environmental sustainability, involving different market penetration rates and volumes, and including speed restrictions for CAVs in specific segments. One of the main results of this research is the demonstration of how CAVs can induce synergistic behaviour in the rest of the conventional vehicle fleet, improving not only their own performance and impact, but also that of the surrounding vehicles. To support policy and planning, a graphical concept interface is being developed, allowing users to manage traffic scenarios and evaluate environmental and operational compromises. This work contributes to the design of smarter and more sustainable urban mobility systems, emphasising the importance of aligning technological implementation with real-world dynamics and strategic environmental objectives.

Keywords — Traffic Simulation; Optimisation of operational behaviour; Data-driven models.

TOPIC

2) b.: Technologies for the Wellbeing – Innovative Technologies for Smart Cities.

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REFERENCES

[1] Abdelghaffar H, Menendez M "Influential Control Parameters for Autonomous Vehicles in a Mixed Environment", IEEE Open Journal of Vehicular Technology (2024) 5 927 – 939

[2] Bandeira J, Macedo E, Fernandes P, Rodrigues M, Andrade A, Coelho M "Potential pollutant emission effects of connected and automated vehicles in a mixed traffic flow context for different road types", IEEE Open Journal of Intelligent Transportation Systems (2021) 2 364-383

[3] G.Chaves, J.M.Bandeira, E.Macedo "A step-forward to understand connected and automated vehicle impacts: a synergistic behaviour assessment", EWGT2025, accepted for presentation

Eco-Routing in Practice:

Evaluation of Google Maps Eco-Routing Performance in Portugal

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Abstract — In the context of advancing sustainable mobility and mitigating transport-related emissions, building upon existing research into eco-routing guidance strategies and navigation systems [1-4], the study seeks to understand how effective Google Maps eco-routing is in practice, considering real-world performance specifically within the Portuguese setting. This is particularly relevant to the development of Innovative Technologies for Smart Cities that aim to enhance urban efficiency and Technologies for the Wellbeing of their inhabitants. The research is conducted focusing on various case studies and by quantifying the environmental impacts (energy and fuel consumption reductions), assessing practical usability, and examining potential unintended consequences for drivers and urban environments. The used approach and potential results yield insights that can be valuable to initiatives like the SPOTLOG project focused on sustainable last-mile logistics. Field tests were performed using gasoline, diesel, and electric vehicles across a variety of route types - urban, suburban, and intercity. The evaluation incorporated real-time vehicle telemetry and physiological data from drivers, with environmental performance compared against estimates from the Vehicle Specific Power (VSP) model, this methodology can be applied to both vans and light vehicles. Initial findings highlight potential energy savings of up to 39% for electric vehicles and fuel reductions reaching 16% for internal combustion vehicles when using eco-routes, aligned with previous research [3,4]. We found that, despite these benefits, eco-routing choices offered by Google Maps often prioritise routes through dense urban areas, raising significant concerns over pedestrian safety, increased localised emissions, and heightened driver stress. These insights underscore the potential of eco-routing as a tool for sustainable mobility, while also pointing to the critical need for further research and development. In practice, it is important that routing solutions not only optimise for fuel/energy consumption but also consider delivery time windows, potential driver stress, and ensure minimal disruption to urban life, thereby enhancing overall wellbeing. Future development must aim for a more holistic optimisation, balancing energy efficiency with factors such as community impact, equitable air quality distribution, pedestrian safety, and driver acceptance to truly align with smart city goals and contribute positively to urban ecosystems.

Keywords — Eco-routing; Google Maps; Sustainable Mobility; Fuel Consumption; Greenhouse Gas Emissions.

TOPIC

2) b.: Technologies for the Wellbeing – Innovative Technologies for Smart Cities.

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REFERENCES

[1] Bandeira, Jorge M., Claudio Guarnaccia, Paulo Fernandes, and Margarida C Coelho. 2018. “Advanced Impact Integration Platform for Cooperative Road Use.” International Journal of Intelligent Transportation Systems Research 16(1): 1–15. http://link.springer.com/10.1007/s13177-016-0133-z.
[2] Bandeira, Jorge M et al. 2018. “Exploring Multiple Eco-Routing Guidance Strategies in a Commuting Corridor.” International Journal of Sustainable Transportation 12(1): 53–65. https://www.tandfonline.com/doi/full/10.1080/15568318.2017.1328545.
[3] Gao, K., Jia, R., Liao, Y., Liu, Y., Najafi, A., & Attard, M. (2024). Big-data-driven approach and scalable analysis on environmental sustainability of shared micromobility from trip to city level analysis. *Sustainable Cities and Society*, *115*, 105803. https://doi.org/10.1016/j.scs.2024.105803
[4] Jovanovic, A., Gavric, S., & Stevanovic, A. (2024). Evaluating Google Maps’ Eco-Routes: A Metaheuristic-Driven Microsimulation Approach. *Geographies*, *4*(4), 732–752. https://doi.org/10.3390/geographies4040040.

Demand-Responsive Transport for Sustainable Mobility

A case Study of SIT-Flexi in the Coimbra Region

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Abstract — The increasing complexity of urban and rural mobility has fostered the emergence of innovative transport models, such as Mobility on Demand (MoD) and Mobility as a Service (MaaS). These concepts prioritize user-centric, flexible, and multimodal systems that integrate digital platforms with various transport modes. Literature highlights how MoD and MaaS address critical challenges in accessibility, social equity, and energy efficiency, particularly in regions underserved by conventional public transport. Sustainable mobility, when supported by responsive and adaptable services, enables not only environmental benefits but also fosters inclusion and resilience in spatially disadvantaged communities [1][2].

This study analyses the SIT-Flexi service implemented in the Coimbra Region, Portugal, covering 18 municipalities. Using data from a 407-user survey and official records, the results reveal significant variation in service adoption, with higher usage in low-density municipalities such as Penacova and Pampilhosa da Serra. The user base is mainly composed of elderly women, highlighting the system's contribution to mitigating social and geographic disparities. A moderate negative correlation (r = -0.62) was identified between population density and SIT-Flexi usage, with a threshold of 80 inhabitants per square kilometer marking the transition from high to low adoption rates. This suggests that demand responsive transport plays a strategic role in peripheral areas. The findings highlight the importance of developing transport policies that consider local demographic, geographic, and infrastructural characteristics to promote sustainable and equitable mobility.

Deepening the understanding of user behavior and service effectiveness, future work will involve conducting a new survey targeting current SIT-Flexi users. This will allow for a comparative analysis with the existing dataset provided by CIM-RC, enabling the identification of evolving mobility needs, satisfaction levels, and potential service gaps. The results are expected to inform recommendations for optimizing the SIT-Flexi system, particularly in terms of accessibility, environmental impact, and integration with sustainability. This next phase will also explore the feasibility of implementing sustainable business models and public policies that enhance social inclusion and territorial cohesion in low-density regions.

Keywords — Sustainable Mobility; Demand-responsive Transport; Low-density Regions; Social Inclusion; SIT-Flexi

TOPIC

2) Technologies for the Wellbeing. b. Innovative Technologies for Smart Cities.

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REFERENCES

[1] Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-González, M. J., & Narayan, J. (2017). *Mobility as a Service: A critical review of definitions, assessments of schemes, and key challenges*. Urban Planning, 2(2), 13–25. https://doi.org/10.17645/up.v2i2.931

[2] Buics, L., Suta, M., & Szalay, Z. (2025). *Sustainability dimensions of Mobility on Demand in smart cities*. Journal of Urban Mobility Studies, 12(1), 10–18.

[3] Comunidade Intermunicipal da Região de Coimbra. (2024). *Serviço de Transporte a Pedido SIT-Flexi: Relatório operacional e análise estatística*. Coimbra: CIM-RC.

A Stage-Wise Literature Review Toward Smart Digital Twin Developments of Wastewater Treatment Plants

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Abstract — Wastewater treatment plants (WWTPs) are essential for safeguarding public and environmental health. However, they are among the most energy-intensive infrastructures in urban systems, consuming over 1–3% of global electricity and more than 233 GWh annually in Europe [1]. These challenges are compounded by increased inflow variability due to climate change and more restrictive environmental regulations. To address these issues, data-driven modelling and smart digital tools have become pivotal in enhancing WWTP operational efficiency and sustainability.

This systematic review explores recent advances in Machine Learning (ML), the Internet of Things (IoT), and Digital Twin (DT) technologies as applied to WWTPs. Using a stage-wise approach covering preliminary, primary, secondary, tertiary, and sludge treatment stages, this review maps out how data-driven techniques are being used to optimise specific processes. While predictive maintenance dominates applications in the preliminary phase, primary and secondary treatments, especially aeration as the most energy-intensive stage, have seen the extensive deployment of ML algorithms for real-time flow prediction, effluent quality modelling, and energy optimisation. Similarly, tertiary treatment and sludge processing increasingly use AI for fault detection, disinfection control, and biogas yield forecasting [2]. Recent studies have revealed two primary modelling categories: (1) system simulation and (2) energy optimisation. Hybrid models that combine physics-based simulations with ML techniques, such as neural networks, reinforcement learning, and AI-CFD, show improved prediction accuracy and generalisability. Several studies have reported significant gains, including up to 60% energy savings, improved effluent compliance, and enhanced fault detection through soft sensing and online learning [3].

Notably, the integration of IoT technologies supports the real-time monitoring of influent characteristics and operational states, thereby enabling adaptive process control. While these technological advances show promising results, the practical, widespread implementation of full-scale digital twins encounters significant obstacles. Most implementations focus on academic simulations, with limited real-world deployment or scalability owing to challenges such as poor data quality, limited data science expertise in utilities, and high computational costs.

Furthermore, commercial tools provide robust platforms for simulation and control strategy development but are often underutilised in dynamic, real-time contexts. This review also identifies a significant research gap: the lack of integrated, cross-stage optimisation strategies that bridge localised model insights and global plant performance.

The novelty of this work lies in its stage-wise analysis of the literature, providing a structured perspective that helps identify specific WWTP stages where optimisation is most effective. It also serves as a foundational assessment for the design of Smart Predictive Digital Twins (SPDTs) that combine real-time data, ML-driven modelling, and modular architectures to enable adaptive, efficient, and resilient WWTP operations.

Keywords — Water Systems; Wastewater Operation; Machine Learning; Digital Twin; Cost and Energy Reduction; Climate Change Impact;

TOPIC

2) b.: Technologies for the Wellbeing – Innovative Technologies for Smart Cities.

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REFERENCES

[1] I. C. for Resource Recovery from Water, “Circular economy: Tapping the power of wastewater.”

[2] G. Sabia et al., “Energy saving in wastewater treatment plants: A methodology based on common key performance indicators for the evaluation of plant energy performance, classification and benchmarking”, *Energy Conversion and Management*, vol. 220, 2020

[3] J. F. de Canete et al., “Control and soft sensing strategies for a wastewater treatment plant using a neuro-genetic approach”, *Computers & Chemical Engineering*, vol. 144, 2021.

Real-World Assessment of Integrated Driving Performance in Urban Traffic Singularities: A Multi-Parameter Approach to Safety, Emissions, and Volatility

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Abstract — Urban transport must balance safety and environmental concerns. This research examines real-world driving behaviour, vehicle performance, and emissions on different urban road types, comparing shared spaces with conventional infrastructure.

This work uses an integrated Driving Indicator (iDI) that combines safety measures (headway and stopping distance), driving behaviour (acceleration and vehicular jerk), and emissions (carbon dioxide and nitrogen oxides) [1]. The innovative nature of the study relies on the fact that it is the first to test an integrated indicator on real-world data from the above parameters. This empirical methodology quantifies how road designs affect driver behaviour and environmental impact.

Data were collected along a 1,100m corridor in Aveiro, Portugal, including a roundabout, a shared road section, two mini-roundabouts, and urban road sections. Three diesel vehicles equipped with one emission measurement monitoring system (PEMS), on-board diagnostic (OBD) readers, GPS device, and cameras collected information during different traffic periods, collecting almost 3,400 seconds of valid PEMS data and 6,800 seconds of valid OBD and GPS data over were collected over 26 trips to evaluate driving behaviour according to the iDI metric.

The results show clear differences among traffic singularities. Roundabout influence areas produced the highest emissions and driving irregularities, exceeding manufacturer and regulatory standards. On the other hand, shared road sections yielded the lowest emissions per unit distance and smoothest driving patterns. Overall, emissions issues dominated all road types (>60%), followed by safety concerns (~30%).

The study suggests that shared spaces perform better than conventional roads from both an environmental and safety perspective. These areas encourage more careful driving and produce fewer emissions than roundabouts. The results support urban planning strategies that include the design of shared spaces [2]. The iDI methodology provides a practical tool for transport professionals to assess how different road designs affect driver behaviour, emissions, and safety.

Keywords — Driving behaviour; Volatility; Emissions; Shared space; Sustainable mobility.

TOPIC

"2) b.: Technologies for the Wellbeing – Innovative Technologies for Smart Cities"

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REFERENCES

[1] E. Ferreira, P. Fernandes, E. Macedo, and M.C. Coelho. "Driving Safety-Volatility-Emissions integrated indicator application to urban road environment." Transp. Res. Procedia., vol. 86, pp. 572-579, 2025. 10.1016/j.trpro.2025.04.072

[2] A. Karndacharuk, D.J. Wilson, and R.C.M. Dunn. "Qualitative evaluation study of urban shared spaces in New Zealand." Transp. Res. Part D Transp. Environ, vol. 42, pp. 119–134, 2016. 10.1016/j.trd.2015.10.020

Real-Time Monitoring of Porto's Urban Tunnels for Enhanced Incident Response

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Abstract — In an urban context, road infrastructures, particularly tunnels, present unique challenges not only in terms of public safety but also in terms of operational efficiency. Road tunnels are characterised by limited natural light, complex visibility conditions and restricted access for emergency interventions [1]. These features can significantly compromise real-time incident detections, such as stationary vehicles or accidents, and response, making intelligent surveillance solutions a critical necessity. Although video surveillance is a common tool in traffic monitoring, the large volume of data and dynamic nature of tunnel environments require automated, robust and resource-efficient systems for detecting, tracking and alerting moving objects, even anomalous movement. This study aims to deliver an efficient and intelligent monitoring tool, adapted to the specific needs of Porto City Council's tunnels, to significantly contribute to improving operational efficiency in traffic management (e.g., queue detection), in response to accidents, vandalism, and other risks. The research is currently under development in collaboration with the Porto City Council, emerging from the pressing demand for smarter tunnel surveillance systems capable of proactive incident management, and focuses on developing a real-time data-driven platform that addresses the critical need for enhancements in real-time video surveillance systems in urban road tunnels. The solution adopted to develop the monitoring tool explores the use of the You Only Look Once (YOLO) architecture, specifically using the YOLOv8n model [2]. This choice was motivated by its excellent balance of speed, accuracy, and resource efficiency, relevant for the real-time processing required by the application. The system is being developed to integrate YOLOv8n for the precise detection of objects, namely, vulnerable road users and vehicles, complemented by an identity-based tracking system, which focuses on identifying and tracking moving objects through different frames. Key functionalities under development for tunnel safety include the detection of stationary vehicles beyond a defined threshold, triggering immediate alerts. Additionally, the system provides warning messages for the detection of vulnerable road users within the monitored area, with potential future expansion to include the detection of animals and other undesirable objects in tunnels. The platform yields a dashboard for easy use. The PyQt6 library is being used to make dynamic pop-up alerts that are strategically placed on the screen to make them more visible and easier for users to interact with. These alerts will provide clear visual notifications without getting in the way of the primary video display. The developed system designs a Region of Interest (ROI) so that the focus is not diverted, and this helps data processing and cuts down on false positives. A multi-threaded architecture for reading video streams and automatically reconnecting the camera makes the system more stable. To reduce system crashes, performance improvements such as YOLO input frame resizing and processing frequency management have proven essential. It was decided not to employ background subtraction (MOG2) for the model's input because preliminary investigations into this preprocessing method revealed that it reduced YOLO's detection accuracy.

Keywords — Object detection and tracking; Intelligent monitoring system; Warning messages.

TOPIC

2) b.: Technologies for the Wellbeing – Innovative Technologies for Smart Cities.

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REFERENCES

[1] Borghetti F, et al. Road Tunnels Operation: Effectiveness of Emergency Teams as a Risk Mitigation Measure. *Sustainability*. 2022; 14(23):15491.

[2] Li Y, et al. Lightweight Tunnel Obstacle Detection Based on Improved YOLOv5. *Sensors*. 2024; 24(2):395.

[3] Wei Y, et al. An Adaptive Vehicle Detection Model for Traffic Surveillance of Highway Tunnels Considering Luminance Intensity. *Sensors*. 2024; 24(18):5912.

Development of a 3D-Printed PEGDA Microneedles Patch for Gingival Application: Design and Fabrication Approach

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Abstract — Maintaining good oral health is vital for overall well-being but is often neglected in healthcare systems. Periodontal diseases like gingivitis and periodontitis, caused by bacterial infections and inflammation, affect nearly half the global population. According to the World Health Organization, approximately 19% of adults worldwide suffer from severe periodontitis [1]. In Portugal, the prevalence of periodontitis mirrors the global trend, affecting 50% of adults [2].

Current treatments rely on invasive surgical procedures to manage biofilm accumulation, periodontal disease, and gingival recession. Antibiotics are commonly used as adjuncts, with systemic oral administration preferred for ease. However, high doses are needed to reach effective levels, increasing risks of antimicrobial resistance, dysbiosis, and systemic side effects [3,4].

Localised drug delivery offers a targeted approach to improve gingival healing while reducing systemic risks - especially relevant for immunocompromised patients. In this context, microneedles (MNs) have emerged as a promising method for localised and transdermal delivery [3].

This work presents a hydrogel microneedles patch using PEGDA and 3D vat photopolymerisation. PEGDA was chosen for its biocompatibility and compatibility with light curing. The patch features an anchor-shaped design for better gingival fixation and includes an internal reservoir for precise drug loading. This allows the delivery of tailored doses of therapeutic agents, released gradually into the tissue.

Three 3D printers - FormLabs and Prusa (SLA) and Anycubic (DLP) - were tested. After optimisation and morphological analysis via SEM, the Prusa printer was selected. Dimensional control was assessed using SEM and Micro-CT, swelling tests simulated oral conditions, and insertion/pull-out tests evaluated mechanical performance. A colourimetric assay confirmed sustained drug release over time.

Keywords — Vat-Photopolymerization; Microneedles Patch; Polyethylene glycol diacrylate (PEGDA); Gingival application

TOPIC

2) Technologies for the Wellbeing: a.Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] "Global oral health status report: towards universal health coverage for oral health by 2030." [Online] Available: https://www.who.int/publications/i/item/9789240061484

[2] M. Relvas, P. López-Jarana, L. Monteiro, J. J. Pacheco, A. C. Braga, and F. Salazar, "Study of Prevalence, Severity and Risk Factors of Periodontal Disease in a Portuguese Population," J. Clin. Med., vol. 11, no. 13, 2022, doi: 10.3390/jcm11133728.

[3] X. Zhang et al., "Immunomodulatory microneedle patch for periodontal tissue regeneration," Matter, vol. 5, no. 2, pp. 666–682, Feb. 2022, doi: 10.1016/j.matt.2021.11.017.

[4] M. Dubar et al., "In-situ forming drug-delivery systems for periodontal treatment: Current knowledge and perspectives," Nov. 01, 2021, IOP Publishing Ltd. doi: 10.1088/1748-605X/ac254c.

Stannate-based proton-conducting materials for proton ceramic electrochemical applications

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ABSTRACT — As the response to the global energy landscape must also confront urgent climate challenges, the European Union aims to achieve carbon neutrality by 2050 through the promotion of renewable energy alternatives, such as hydrogen. In this context, this study investigates a new Ni-Ba2SnO4 anode composition in symmetrical cells built on BaSn0.8Y0.2O3-δ electrolyte substrates, for application in proton ceramic electrochemical cells [1].

Ba2SnO4 (Ruddlesden-Popper structure [2]) was synthesized via solid-state reaction and confirmed by X-ray diffraction (XRD) to be in a pure tetragonal phase. The BaSn0.8Y0.2O3-δ electrolyte material was synthesized using mechanochemical activation, followed by calcination, and exhibited a cubic perovskite structure confirmed by XRD.

Symmetrical cells were fabricated through a stepwise process commencing with the uniaxial pressing of the BaSn0.8Y0.2O3-δ electrolyte substrate and its sintering at 1600 °C. Ni-Ba2SnO4 electrodes, formed by mixing the two component powders (40 vol%Ni), were then applied to both faces of the electrolyte via screen printing, followed by calcination and reduction in H2, 800 °C, overnight.

Scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) analyses confirmed a homogeneous distribution of Ni and ceramic phases in the electrodes. Electrochemical Impedance Spectroscopy (EIS) in wet H2(pH2O = 0.033 atm) revealed thermally activated behavior below 500 °C, with the lowest total polarization resistance (Rp = 20.78 Ω cm2) observed at 500 °C.

These findings suggest strong potential for Ni-Ba2SnO4 anodes in ceramic-based electrochemical devices for green syngas production, supporting a sustainable and carbon-neutral energy future.

Keywords — Ceramic electrolyzer; hydrogen; barium stannate, electrochemical impedance spectroscopy (EIS).

TOPIC

2) Technologies for the Wellbeing a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] D. Kim, T.K.Lee, S. Han, Y. Jung , D.G. Lee, M. Choi, W. Lee, “Advances and challenges in developing protonic ceramic cells”, *Materials Today Energy*, 36 (2023), 101365.

[2] N. Tarasova, I. Animitsa, “Materials $A^{II}LnInO_4$ with Ruddlesden-Popper Structure for Electrochemical Applications: Relationship between Ion (Oxygen-Ion, Proton) Conductivity, Water Uptake, and Structural Changes“, *Materials*, 15 (2022), 114.

Gasochromic nanofibrous sensors for visual detection of hydrogen leaks

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Abstract — Eye-readable sensors are promising tools to accelerate the arrival of the hydrogen economy fostered by the European Commission [1]. Advantages include (1) intuitive readouts like discernible colour changes to enable safe and universal access to equipment/infrastructure; (2) absence of electronic components to avoid accidental sparks and energy consumption; and (3) high compatibility with sustainable, automated microfabrication techniques to mitigate environmental and economic impacts. The design of gasochromic nanofibrous sensors is particularly interesting since their inherent high surface-to-volume ratio boosts stimuli-responsivity [2]. Additionally, fabrication via electrospinning further encourages versatility, scalability, reproducibility and cost-efficiency.

Herein, the polymer backbone of inexpensive polyvinyl alcohol (PVA) was functionalized with Platinum-Prussian blue nanoparticles (Pt-PB) able to reversibly change their colour (ΔE) from blue to white when exposed to hydrogen. Electrospinning of PVA/Pt-PB composites resulted in nanofibres with customizable gasochromic performances. On the one hand, H_2/air cycles triggered sequential bleaching (ΔE_{max} of 21 at a rate of 4.2 min^{-1} in H_2) and colouring (ΔE from 21 to 15 after 10 minutes in air) of PB-rich nanofibers. On the other hand, PB-poor nanofibers presented longer colouring periods, only recovering their pristine blue colour after 24 h in air. Although these performances are still far from alternative gasochromic nanomaterials like tungsten oxide and palladium oxide, both prototypes were engineered according to green manufacturing principles and without post-fabrication treatments (*e.g.*, annealing, addition of coatings, *etc.*).

All things considered, electrospinning of PVA/Pt-PB composites can anticipate important targets of the hydrogen economy related to safe use of new technology. Soon, PB-rich and PB-poor nanofibrous platforms would be optimized toward efficient monitorization and long-term recording of hydrogen leaks, respectively.

Keywords — Hydrogen; Eye-readable sensors; Electrospinning; Gasochromic nanofibers

TOPIC

2) a. : Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] A. F. Girão, A. Completo, "Eye-readable sensors for intuitive hydrogen monitoring", Int. J. Hydrogen Energy, vol. 64, pp. 593-605, 2024. DOI: 10.1016/j.ijhydene.2024.04.014
[2] D. Razzaghi, M. Babazadeh-Mamaqani, A. Babaie, F. Esmati, H. Roghani-Mamaqani, M. Rezaei, K. Clerck, R. Hoogenboom, "Chromic Electrospun Polymer Nanofibers: Preparation, Applications, and the Future", ACS Appl. Mater. Interfaces, vol. 17, pp. 4247–4289, 2025. DOI: 10.1021/acsami.4c17105

Optimization of the operation of Flexible Transport in the Region of Coimbra

Towards Integrated Passenger and Parcel Mobility

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Abstract — Demand-responsive transport (DRT) systems for passenger mobility are growing in Europe, especially in low-density areas with limited public transport and an ageing population [1]. These areas struggle to provide affordable, accessible transport. In these regions, ageing populations with changing e-commerce habits and needs for essential goods have increased demand for efficient and reliable parcel delivery and collection, straining logistical frameworks. Thus, innovative and sustainable operational conditions are needed to make these vital services economically viable and socially inclusive [2]. As part of Interreg Europe projects SPOTLOG and EMBRACER, the University of Aveiro and Internuncial Community of Coimbra Region collaborated on this research. This study examines the synergies of First-Last Mile (FLM) Logistics and Passenger Transportation with a technologically-enabled Flexible Transport System in light of the above challenges. In this larger study, SIT Flexi, the Coimbra Region's Demand-Responsive Transport (DRT) system, is optimised to improve its KPIs. This optimisation will refine routes using GIS tools and transport data analysis and promote intermodality by integrating DRT with CPT. The goal is to maximise service efficiency, minimise resource consumption, reduce environmental impact, and sustain the regional transport network. One of the most promising ways to integrate diverse demands is to use existing taxi fleets, which are already used in some DRT systems due to their flexibility and geographical coverage, for passenger transport and dynamically integrating parcel delivery and collection into their optimised routes [3]. This integration could increase vehicle usage and revenue. Different government policies and regulatory frameworks that treat freight and passenger transport as separate, non-interacting domains hinder integrated transport solution adoption and scaling [1,4]. Integrating passenger and freight transport with sophisticated scheduling and routing algorithms can boost trip efficiency, reduce vehicle empty-runs, and lower DRT operational costs. Based on preliminary analysis, a light taxi (e.g., emitting 70 gCO2/passenger-km) could save more CO2 than a standard bus operating below capacity for two passengers (which could exceed 500 gCO2/passenger-km). A non-door-to-door DRT system that feeds CPT whenever possible could improve regional transport by right-sizing vehicles and rotes to demand. Importantly, the study aims to reduce logistical isolation in remote and peripheral areas that were previously unprofitable or underserved by conventional parcel delivery services [3], promoting regional equity, improving vulnerable populations' access to goods and services, and improving their well-being.

Keywords —Demand Responsive Transport (DRT); Passenger and Freight Transport; Shared Mobility; Sustainable Peri-Urban Logistics.

TOPIC

2) b.: Technologies for the Wellbeing - Innovative Technologies for Smart Cities.

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REFERENCES

[1] KOSTOVASILI M, KANELLOPOULOS J, AMDITIS A. INTEGRATED PASSENGER AND FREIGHT TRANSPORT: SEAMLESS DOOR-TO-DOOR MOBILITY AND OPTIMAL USE OF RESOURCES. IN 2025. P. 569–75.

[2] MO P, YAO Y, LI P, WANG Y, LIU Z, D'ARIANO A. SYNERGISING URBAN FREIGHT TRANSPORTATION IN PASSENGER-ORIENTED TRANSIT CORRIDORS: AN EFFICIENT MIXED-INTEGER LINEAR PROGRAMMING APPROACH. TRANSP RES PART C EMERG TECHNOL [INTERNET]. 2024 JUN 1;163:104644.

[3] XUE S, ZHANG Q, SHIWAKOTI N. SHARING A RIDE: A DUAL-SERVICE MODEL OF PEOPLE AND PARCELS SHARING TAXIS WITH LOOSE TIME WINDOWS OF PARCELS. SYSTEMS [INTERNET]. 2024 AUG 14;12(8):302.

[4] CAVALLARO F, EBOLI L, MAZZULLA G, NOCERA S. DESIGN OF INTEGRATED PASSENGER-FREIGHT TRANSPORT: A MULTI-STAKEHOLDER PERSPECTIVE. J PUBLIC TRANS [INTERNET]. 2023 JAN 1;25:100069.

Design and fabrication of microchip able to really emulate tumour microenvironment and metastasis

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Abstract — Cancer remains one of the leading causes of death worldwide, yet traditional research models, such as 2D cell cultures and animal xenografts, fall short in replicating the complexity of tumor microenvironments (TMEs). These limitations hinder the development of effective therapies and the advancement of personalized medicine. In response, tumor-on-chip (ToC) technology has emerged as a promising solution, combining microfluidics, 3D cell culture, and patient-derived tissues to model cancer biology with greater physiological relevance [1]. ToC platforms closely mimic key aspects of TME. Through microfluidic perfusion, they recreate dynamic biochemical gradients of oxygen, nutrients, and signalling molecules, allowing detailed studies of tumor heterogeneity and drug diffusion [2]. Functional vasculature can be achieved via endothelial-lined channels or bioprinted networks, enabling realistic modelling of nutrient transport, tumor cell intravasation, and anti-angiogenic therapies [2]. The inclusion of multiple cell types, such as cancer-associated fibroblast and immune cells, allows investigation of tumor-stroma interactions and immune suppression [4]. Importantly, the use of biopsy-derived spheroids or organoids ensures patient specificity, capturing genetic diversity and enabling personalized drug screening [5]. Innovations in ToC design further enhance its potential. Advanced biomaterials like collagen, decellularized extracellular matrix (ECM), and hydrogels replicate the physical and biochemical properties of the ECM, influencing cell invasion, drug resistance, and mechanotransduction [6]. Integrated biosensors allow real-time monitoring of critical parameters such as pH, oxygen levels, and metabolites, shedding light on metabolic shifts under hypoxia [2]. Additionally, 3D bioprinting techniques help recreate organized tumor-vascular interfaces and metastatic niches formation [2]. The applications of ToC systems are broad and impactful. In drug development, they simulate pharmacokinetics and resistance mechanisms more accurately than 2D static cultures. In immunotherapy, cocultures with T cells or tumor-associated macrophages allow assessment of checkpoint inhibitors and immune evasion [4]. For metastasis research, multi-organ chips enable the study of tissue-specific colonization and the influence of mechanical forces like shear stress [4]. Despite these advancements, challenges remain, particularly in sustaining vascular networks, scaling for high-throughput screening, and standardizing patient-derived models [1]. Looking forward, integrating ToC systems with AI-driven analysis and multi-organ platforms will be key to improving clinical relevance and supporting precision oncology.

Keywords — Tumor-on-chip, microfluidics, vascularization, biomimetic ECM, sensing.

TOPIC

"2) a.: Multiscale Technologies and Devices for Medicine, Environment & Energy ".

REFERENCES

[1] C. Bouquerel, et al. "Bridging the gap between tumor-on-chip and clinics: A systematic review of 15 years of studies," *Lab Chip*, 23, 3906, 2023. DOI: 10.1039/D3LC00531C.

[2] D. Gaebler, et al. "Improving tumor microenvironment assessment in chip systems through next-generation technology integration," *Front. Bioeng. Biotechnol.*, 12, 2024 DOI: 10.3389/fbioe.2024.1462293.

[3] R. Wang, et al. "Tumor-on-a-chip: Perfusable vascular incorporation brings new approach to tumor metastasis research and drug development," *Front. Bioeng. Biotechnol.*, 10, 2022. DOI: 10.3389/fbioe.2022.1057913.

[4] L. R. Avula, et al. "How organ-on-a-chip is advancing cancer research and oncology – a cancer hallmarks' perspective," *Front. Lab Chip Technol.*, 3, 2024 DOI: 10.3389/frlct.2024.1487377.

[5] E. Steinberg, et al. "A fully 3D-printed versatile tumor-on-a-chip allows multi-drug screening and correlation with clinical outcomes for personalized medicine," *Commun. Biol.*, 6, 1157, 2023. DOI: 10.1038/s42003-023-05531-5.

[6] C. Liu, et al. "Heterogeneous microenvironmental stiffness regulates pro-metastatic functions of breast cancer cells," *Acta Biomater.*, 131, 326, 2021. DOI: 10.1016/j.actbio.2021.07.009.

Noise Matters: Evaluating How Noise Interference Affects an Acoustic Camera Performance

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Abstract — Nowadays, ensuring product quality and safety in globally competitive markets requires a rigorous leak assessment after the manufacturing process. Indeed, undetected leaks, in particular in pressurized systems, not only can compromise their performance, but also introduce significant safety, environmental and health risks [1]. In this context, robust and efficient technologies for leak detection and localization are highly sought out for implementation in industrial quality control stations.

Acoustic-based technologies have emerged as effective and non-invasive tools for leak detection and localization, capable of identifying high-frequency soundwaves generated by the turbulent escape of pressurized fluids through small defects [2]. Their advantages over traditional methods include: (1) their high sensitivity; (2) their fast response; (3) their high localization accuracy; and (3) their ability to perform remote and continuous monitoring [3]. Among the available acoustic tools, acoustic cameras stand out as particularly promising, by using microphone arrays to generate acoustic maps overlaid on visual images for intuitive and accurate leak localization [4]. However, a major limitation of these devices is their susceptibility to environmental noise, which can mask leak-induced acoustic signals and compromise their detection accuracy. In this instance, it is crucial to assess the extent to which environmental noise interferes with the performance of acoustic cameras.

In this regard, experiments were conducted under controlled conditions both with and without interfering noise. The experimental setup used included a SOUNDCAM 2.0 acoustic camera, an ATEQ leak tester, a boiler with an embedded leak system designed to provide different leak apertures (0.1, 0.2, 0.4 and 0.8 mm), and a high-frequency generator (5, 10, 15 and 20 kHz). Interfering signals were introduced either in the line-of-sight or out-of-sight of the camera (approximately 1 m from the leak source). Additionally, a preliminary field test was conducted in a simulated industrial environment with intermittent environmental noise levels exceeding 30 dB, generated by operating equipment placed more than 1 m away.

While the leak-induced signals were clearly visible for all leak apertures tested in a low-noise conditions, the introduction of interfering high-frequency signals affected the camera's performance. If the interfering signal was in the line-of-sight of the camera, it was not possible to detect any leaks. However, if the interfering signal was out-of-sight there were instances where the leak was visible, particularly for larger leak apertures. Interestingly, in the simulated industrial scenario, all leaks were visible at some point during the experiment, despite the intermittent interferences of the surrounding equipments. All in all, these results highlight the potential of acoustic cameras for reliable leak localization in industrial settings, particularly when environmental noise sources are spatially placed.

Keywords — Leak; Acoustic Camera; Noise; Boiler.

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] Biezma, M.V., Andrés, M.A., Agudo, D. and Briz, E., "Most fatal oil & gas pipeline accidents through history: A lessons learned approach," *Engineering Failure Analysis*, vol. 110, pp. 104446, 2020. DOI: 10.1016/j.engfailanal.2020.104446
[2] Huang, Y., Liu, Z., and Li, S., "Leak detection and localization of fluid-filled pipeline using accelerometer pairs and mode separation method," *Measurement*, vol. 239, pp.115491, 2025. DOI: 10.1016/j.measurement.2024.115491.
[3] Fan H., Tariq S. and Zayed T., "Acoustic leak detection approaches for water pipelines ," *Automation in Construction*, vol. 138, pp.104226, 2022. DOI: 10.1016/j.autcon.2022.104226.
[4] Eret P. and Meskell C., "Microphone Arrays as a Leakage Detection Tool in Industrial Com-pressed Air Systems. Advances in Acoustics and Vibration," vol. 2012, pp. 689379, 2012. DOI: 10.1155/2012/689379

MnO_2 as a potential sintering additive for the development of Metal-Supported Proton-Conducting Electrochemical Cells

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Abstract — An emerging structural class of ceramic electrochemical devices, known as metal-supported protonic ceramic electrochemical cells (MS-PCECs), is gaining interest due to offering combination of the excellent mechanical properties of metal supports and the high efficiency and low-temperature operation of proton-conducting ceramics that can permit them to work in challenging environments, especially those where they are exposed to pressurisation gradients or rapid temperature fluctuations [1].

However, several critical challenges have been identified for the processing of these structures, including chemical compatibility issues, incomplete electrolyte sintering, and evaporation of barium-based compositions upon electrolyte densification. To address these issues, decreasing the sintering temperature can be beneficial by using sintering additives [1,2]. Nonetheless, limited information on potential additives is currently available because these devices must be prepared in complex reducing conditions to avoid the oxidation of the metal support. Hence, in this study, we assess the impact of adding minor amounts of MnO_2 on the sintering behaviour of the electrolyte material BaCe0.4Zr0.4Y0.2O3 (BCZY44), performed under reducing conditions.

A range of characterisation techniques, including XRD, SEM/EDS, dilatometry, and impedance spectroscopy (IES), are used to characterize the processed materials.

Our findings indicate that the addition of MnO_2 successfully improves the sinterability of BCZY44 electrolyte under reducing conditions, resulting in both an increase in grain growth and a reduction in the densification temperature, as assessed by dilatometry and microstructural observations. Furthermore, the impact of addition of MnO_2 on the resultant conductivity of the electrolyte was studied as a function of its amount, by IES performed under controlled conditions of temperature and humidity, to evaluate if the presence of this sintering additive compromised levels of protonic conductivity.

In conclusion, the current works sets out the groundwork necessary to assess the use of MnO_2 as a possible sintering aid for the development of low-temperature MS-PCEC cells; studies that can open their potential use as robust electrochemical devices that can function in complex application environments.

Keywords — Protonic ceramic fuel cells; Metal supported; Doped barium zirconate

TOPIC

2) Technologies for the Wellbeing. a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] R. Wang et al. Int. J. Hydrogen Energy, vol. 44, nº 26, pp. 13768–13776, 2019 . https://doi.org/10.1016/j.ijhydene.2019.03.181

[2] G. Y. Lau, M. C. Tucker, ECS Meeting Abstracts, vol. MA2021-03, p. 83, 2021. https://doi.org/10.1149/MA2021-03183mtgabs

Localization and quantification of air leaks for product testing

Performance evaluation of infrared thermography and acoustic technologies

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Abstract — Compressed air leaks are a serious problem nowadays. Studies conducted through various industrial sectors have concluded that a single compressed air leak is likely to cost an average of around 1200 euros a year, considering the significant loss of efficiency that results from it [1]. Its repair can also be expensive and require the conditioning or total shutdown of the equipment, further increasing the costs. In addition to the economic repercussions, air leaks can pose a safety risk to workers, users of the equipment and infrastructure. For this reason, it is imperative to find solutions that can effectively and quickly detect leaks. This is possible by implementing technologies directly on the production line at the end-of-line (EOL) stations. Infrared (IR) thermography [2] and acoustic methods [3] are highly relevant technologies in this area, given that they are suitable for use with dry tests (with compressed air), keeping components dry and free of contaminants and eliminating the need to use hazardous fluids [4]. Other advantages include high sensitivity, capacity for continuous monitoring, localization and quantification of leaks and ease of transportation, use and implementation.

To compare these technologies, a series of tests were carried out using an ATEQ leak tester and the hydraulic circuit of a boiler with an embedded leakage system. This system generated leaks at three different flow rates (0.98, 2.76 and 6.05 $Pa.m^3/s$). The distance between the cameras and the leakage system (1 and 0.5 m) and the inclination of the cameras (-30º, -20º, -10º, 0º, 10º, 20º and 30º) were the other variables considered.

The analysis of the acoustic images obtained revealed that all the leaks could be detected and located quickly at all circumstances, while the IR camera showed a better performance in scenarios where the flow rate was 6.05 $Pa.m^3/s$, the angle was in the range -10º to 20º and the distance was 1 m. Using the parameters associated with the temperature curves provided by the IR camera, it was found that at 1 m some leaks could be clearly identified, in contrast to 0.5 m, in particular the 6.05 $Pa.m^3/s$ flow leak. Despite the evident influence of the camera inclination on the curves, it was not possible to infer any clear relationship. On the other hand, the parameters inferred from the acoustic camera clearly enabled, not only the detection, but also the quantification of leaks for most scenarios, without being affected by the camera inclination. In light of this, this study demonstrated the superior performance of the acoustic method for locating and quantifying air leaks, opening the way for its implementation at EOL stations.

Keywords — air leaks; infrared thermography camera; acoustic camera; localization; quantification

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] Peter Boon, “How much air leaks really cost – Leak Survey Examples”, Maintworld, vol. 3, pp. 36-37, 2023. ISSN 1799-8670
[2] D. Zimmerle *et al.*, “Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions”, Environ Sci Technol, vol. 54, no. 18, pp. 11506–11514, 2020. DOI: 10.1021/acs.est.0c01285
[3] J. L. Loth *et al.*, “Technology Assessment of On-Line Acoustic Monitoring for Leaks/Infringements in Underground Natural Gas Transmission Lines,”, 2003.
[4] Semitela, Â. *et al.*, “Combining Infrared Thermography with Computer Vision Towards Automatic Detection and Localization of Air Leaks”, Sensors, vol. 25, no. 11, pp. 3272, 2025. Doi: 10.3390/s25113272

LCA of Fischer-Tropsch fuel production:

comparing different gasification routes

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Abstract — Combustion of liquid-based fossil fuels contributes approximately 33% of the world's greenhouse gas (GHG) emissions [1]. The urgent nature of climate change dictates that we transition to low-carbon alternatives. One promising pathway is the production and use of drop-in alternatives like Fischer-Tropsch fuels (FT) derived from non-fossil sources such as Municipal Solid Waste (MSW) [2].

This work analyzes the environmental impact associated with the production of FT-fuel from MSW through gasification, using a cradle-to-gate Life Cycle Assessment (LCA). Four different process configurations are compared to identify the most effective solution for emission reductions. The configurations are a combination of direct or indirect gasification with either a Solid Oxide Electrolyzer (SOEC) or the Water-Gas Shift (WGS) reaction for H_2/CO ratio correction. The syngas composition from gasification is calculated using the Gibbs free energy minimization method and the SOEC is assumed to operate at the thermoneutral potential.

The main hotspot in all four process configurations is shown to be the MSW drying sub-process due to the energy required for reducing the moisture content of the MSW to the 10-20% range necessary for gasification. Other significant contributions come from the H_2/CO ratio correction sub-process and the chemical scrubbing of syngas with diethanolamine (DEA). The FT synthesis sub-process acts as a net carbon sink due to its highly exothermic nature. The waste heat produced is recirculated within the system to replace heat from natural gas combustion, leading to a negative value of Global Warming Potential (GWP).

Direct gasification combined with an SOEC has the lowest total normalized impact and lowest cumulative rank-based index score. Its GWP is 23% lower than Direct gasification combined with WGS, highlighting the environmental advantage of using an SOEC instead of WGS for H_2/CO ratio correction. This configuration leads to lower impacts in five out of six impact categories considered. This can be attributed to the higher overall carbon conversion efficiency of this route [3]. Comparison of direct and indirect gasification shows only minor differences, with the excess energy requirements of the indirect gasification process being offset by the significantly higher H_2/CO ratio of the product syngas (1.5 as compared to 1.2 for direct gasification) [4], and greater volume of syngas produced [5].

In conclusion, the current study shows that utilization of MSW to produce FT-fuels can help waste management as well as contribute toward combating the effects of climate change and, among the process configurations assessed, direct gasification combined with SOEC based H_2/CO ratio correction leads to the lowest environmental impact.

Keywords — Life cycle assessment, Solid Oxide Electrolyzer Gasification, Fischer-Tropsch synthesis, Drop-in fuels.

TOPIC

2) a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] U. Energy Information Administration, Monthly Energy Review – published: February 2025. www.eia.gov/mer.
[2] I.J. Okeke, S. Mani, Techno-economic assessment of biogas to liquid fuels conversion technology via Fischer-Tropsch synthesis, Biofuels, Bioproducts and Biorefining 11 (2017) 472–487. https://doi.org/10.1002/bbb.1758.
[3] E. Baraj, K. Ciahotný, T. Hlinčík, Advanced Catalysts for the Water Gas Shift Reaction, Crystals (Basel) 12 (2022). https://doi.org/10.3390/cryst12040509.
[4] D. Venugopal, L. Thangavelu, A. Natarajan, Investigation of gasification reactions and h2/co ratio analysis for rice husk air gasification simulation, Thermal Science 27 (2023) 881–890. https://doi.org/10.2298/TSCI220119087V.
[5] S. Khalilarya, A. Chitsaz, P. Mojaver, Optimization of a combined heat and power system based gasification of municipal solid waste of Urmia University student dormitories via ANOVA and taguchi approaches, Int J Hydrogen Energy 46 (2021) 1815–1827. https://doi.org/10.1016/j.ijhydene.2020.10.020.

New metal phosphate electrolytes for proton ceramic electrochemical devices

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Abstract — Recent advancements in metal phosphate proton conductors highlighted the promise of trivalent metal phosphates due to their structural versatility and tunable conductivity [1], though further research is needed to assess their suitability as electrolyte membranes for low- and intermediate-temperature fuel cells. In this context, two novel trivalent metal phosphates, $Er_3H_5P_6O_{22}$ (EHPO) and $Y_3H_5P_6O_{22}$ (YHPO), were studied in this work to assess their potential as solid-state proton-conducting electrolytes.

Both compounds were synthesized using the thin layer technique (TLT) [2], and characterized using powder X-ray diffraction (PXRD), which confirmed that both EHPO and YHPO crystallize in the same tetragonal system. Subsequently, mid-infrared spectroscopy (400–4000 cm^{-1}) *via* ATR-FTIR was used to identify phosphate anions, underscoring the presence of different key vibrational features associated with phosphate (PO_4^{3-}) and pyrophosphate ($P_2O_7^{4-}$) groups that are relevant to proton transport. Meanwhile, simultaneous thermal analysis (STA) was conducted from 20 °C to 1000 °C under nitrogen, revealing that both EHPO and YHPO compounds are stable up to ~400 °C, where the onset for dehydration occurs.

After performing the structural characterization, both powders were densified into pellets *via* the cold sintering process (CSP) [3]. Surface microstructures were examined by scanning electron microscopy (SEM), revealing distinct bimodal grain size distributions: YHPO has larger grains (4-35 µm) while EHPO features smaller grains overall (0.8–5 µm). Their electrical behaviour was further evaluated through electrochemical impedance spectroscopy (EIS) under nitrogen atmospheres at varying humidity levels (p_{H2O} = 0.033 atm and ~10^{-5} atm).

EIS revealed that the total conductivity of both compounds were nearly one order of magnitude higher in wet conditions (p_{H2O} = 0.033 atm) at around 140 °C, reflecting the strong dependence of their protonic transport on environmental water content. However, EHPO consistently showed higher conductivity, especially at ~140 °C in wet conditions, likely due to its optimal O–O distances, particularly between hydrogen-bonded phosphate units, promoting stronger hydrogen-bond networks for faster proton transport.

Overall, both the novel EHPO and YHPO are shown to be promising solid-state proton conductors, with potential applications in proton-conducting ceramic devices for clean and efficient energy conversion.

Keywords — fuel cells, solid-state, proton conductor, electrolytes, metal phosphates.

TOPIC

2) Technologies for the Wellbeing a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] R.M.P. Colodrero, P. Olivera-Pastor, A. Cabeza, M. Bazaga-García, “Properties and Applications of Metal Phosphates and Pyrophosphates as Proton Conductors”, *Materials,* vol.15(4), p. 1292, 2022. https://doi.org/10.3390/ma15041292

[2] A.F. Selevich, A.I. Lesnikovich, “Interactions in the Mn_2O_3-P_2O_5-H_2O System by the Thin-Layer Technique”. *Russ J Inorg Chem*, Vol. 39, pp. 1322–6, 1994.

[3] B.M.G. Melo, F.J.A. Loureiro, S.M. Mikhalev, D.P. Fagg, L.C. Costa, M.P.F. Graça, “Alternative processing routes on CsH2PO4 proton conductors: Cold sintering and ball-milling routes”, *Int J Hydrogen Energy*, Vol. 73, pp. 736–48, 2024, https://doi.org/10.1016/j.ijhydene.2024.06.077.

Impact of Decellularized Extracellular Matrix Dissolution Medium on Properties of Ice-Templated Scaffolds: A Cautionary Tale

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Abstract — Researchers intuitively explore decellularized extracellular matrices (dECM) for tissue engineering purposes owing to their native tissue-like biochemistry. Nonetheless, one of the first steps into shaping dECM into scaffolds involves their dissolution. Collagen, the primary structural protein of these matrices, requires an acidic environment for solubilization. However, biomedical engineers often use acids with varying molarity without considering the potential downstream effect on the final properties of the scaffold, such as morphology, functional properties, collagen organization and self-assembly. Therefore, in this work we aim to understand the effect of the solubilization conditions on the properties and *in vitro* performance of dECM-based scaffolds prepared by ice templating, a technique well-established in tissue engineering strategies and biomedical companies [1].

Thus, an adipose-derived decellularized extracellular matrix (adECM) was dissolved in acetic acid (AA) varying the molarity, i.e. either 0.1M or 1M and shaped into 3D scaffolds by ice templating. Both the adECM-based solutions and the scaffolds were analysed regarding their viscosity, morphology, mechanical properties, water absorption, electromechanical response and cytocompatibility towards neural stem cells. On a macroscopic scale, the scaffolds present similar denaturation profiles, viscoelastic properties and compressive Young's moduli. Regarding the morphology, scaffolds based on adECM dissolved in AA 1M presented a narrow range of pore size, with most pores below 100 µm. Decreasing the molarity by ten-fold caused the pore size distribution to shift to a larger range including about half the pores larger than 100 µm. Interestingly at the nanoscale, piezoresponse force microscopy (PFM) revealed that the electromechanical response of the matrix dissolved in AA 0.1M is larger than the one dissolved in AA 1M, thereby translating that the collagen molecular assembly exhibits a higher degree of organization. When collagen is more structured, the tighter packing of fibrils minimizes available space for water molecules, thereby potentially limiting hydration. This was corroborated by the 0.1M scaffolds exhibiting a slightly lower swelling capacity (15.19 ± 0.89) comparing to the 1M-based scaffolds (19.00 ± 1.59). Moreover, when investigating the performance of these scaffolds to induce neuronal differentiation in neural stem cells, the ones prepared in AA 0.1M leads to a microenvironment more prone for neuronal network formation.

In summary, this study underscores the need for biomedical engineers to carefully consider the molarity of acetic acid upon dissolution of decellularized extracellular matrices. Variations in molarity not only may influence scaffold morphology in ice-templated scaffolds but also substantially affect collagen organization, with potential implications for biological functionality and regenerative outcomes.

Keywords — ice templating scaffolds; decellularized extracellular matrix, neural tissue.

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] H. Joukhdar, A. Seifert, T. Jüngst, J. Groll, M.S. Lord, J. Rnjak-kovacina, "Ice Templating Soft Matter: Fundamental Principles and Fabrication Approaches to Tailor Pore Structure and Morphology and Their Biomedical Applications", *Adv. Mater.* Vol. 33 (34) 2100091 2021. DOI: 10.1002/adma.202100091

Experimental methodology for temperature distribution in domestic gas ovens

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Abstract — The decarbonization of domestic energy systems is a key pillar of global climate strategies, particularly in the context of the European Union's target to achieve 75% renewable energy use by 2050 [1]. To reduce carbon emissions without requiring full infrastructure replacement, blending natural gas with hydrogen has emerged as a viable solution [2]. However, the inclusion of hydrogen introduces challenges related to thermal performance and safety in gas-fired appliances.

Several studies have investigated temperature distribution in domestic gas ovens using conventional natural gas. Mistry et al. employed J-type thermocouples and infrared thermography to assess cavity symmetry. Park et al. implemented 100 thermocouples distributed across four vertical layers and CFD simulations were validated using their measurements. Hincapié et al. focused on the false bottom plate, using 18 high-precision type-K thermocouples. While these studies offer important benchmarks, they do not account for the effects of hydrogen-enriched fuel. Additionally, they often lack information on standardized definitions for critical test parameters such as measurement timesteps, temperature setpoints, and test durations - all of which affect thermal stability assessments. Hydrogen blending can significantly modify flame characteristics and heat transfer behaviour. Zhao et al. reported improved flame stability, increased burner surface temperatures, and reduced CO emissions with up to 25% hydrogen by volume. These changes demand revised methodologies for assessing temperature distribution under modified combustion conditions. To address these gaps, this work proposes a methodology for experimentally evaluating thermal behaviour in domestic gas ovens operating with hydrogen–natural gas mixtures. The approach standardizes thermocouple placement, defines data sampling intervals, establishes precise setpoints, and determines the duration required to reach thermal steady state. This framework enables accurate identification of thermal asymmetries that may affect cooking performance or appliance safety.

In conclusion, establishing robust, reproducible testing protocols is essential for integrating hydrogen into domestic ovens. This work contributes a foundational methodology for thermal assessment tailored to hydrogen-enriched fuels, supporting safer and more consistent appliance design in the transition to low-carbon energy.

Keywords — Domestic gas ovens; Hydrogen-natural gas blends; Thermal performance evaluation; Experimental methodologies.

TOPIC

2) b. Innovative Technologies for Smart Cities.

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REFERENCES

[1] European Commission, "Energy roadmap 2050," https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0885, accessed March 13, 2025 (2011).

[2] H. Yang, X. Lin, H. Pan, S. Geng, Z. Chen, and Y. Liu, "Energy saving analysis and thermal performance evaluation of a hydrogen-enriched natural gas-fired condensing boiler," Int. J. Hydrogen Energy, Jun. 2023.doi:10.1016/j.ijhydene.2023.02.027.

[3] H. Mistry, S. Ganapathisubbu, S. Dey, P. Bishnoi, and J. L. Castillo, "A methodology to model flow-thermals inside a domestic gas oven," Appl. Therm. Eng., vol. 31, no. 1, pp. 103–111, 2011. doi:10.1016/j.applthermaleng.2010.08.022

[4] S. P. Park, Y. H. Kim, Y. S. Kim, Y. G. Park, and M. Y. Ha, "Numerical study on the effect of different hole locations in the fan case on the thermal performance inside a gas oven range," Appl. Therm. Eng., vol. 137, pp. 123–133, 2018. doi:10.1016/j.applthermaleng.2018.03.087.

[5] F. F. Hincapié and M. J. García, "A surrogate model of heat transfer mechanism in a domestic gas oven: A numerical simulation approach for premixed flames," Appl. Mech., vol. 5, no. 2, pp. 391–404, 2024.

[6] Y. Zhao, V. McDonell, and S. Samuelsen, "Experimental assessment of the combustion performance of an oven burner operated on pipeline natural gas mixed with hydrogen," Int. J. Hydrogen Energy, vol. 44, no. 47, pp. 26049–26062, 2019. doi:10.1016/j.ijhydene.2019.08.011. 2024.

Polyvinylpyrrolidone-Prussian blue electrospun sensor for visual detection of hydrogen

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Abstract — Hydrogen has emerged as a key element in the global transition towards cleaner and more sustainable energy systems. However, its safe application depends on the availability of effective detection systems that are not only sensitive and reliable but also simple and accessible. Among the available solutions, visual sensors that change colour upon exposure to hydrogen offer a promising alternative for low-cost, power-free detection in domestic and industrial settings [1]. This work presents the development of a gasochromic hydrogen sensor based on nanostructured polymer fibres incorporating Prussian blue (PB) nanoparticles. The gasochromic particles were prepared by dispersing PB in a poly(vinyl alcohol) solution using ultrasonic energy. The sonication process was explored at different durations (5, 30, 60 and 90 minutes) to study its influence on particle morphology, dispersion stability and final performance. The goal was to identify the optimal conditions for producing a stable and functional sensing material. The resulting suspensions were characterised by Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), Energy-Dispersive X-ray Spectroscopy (EDX), and X-ray Diffraction (XRD). These analyses confirmed the effective incorporation of PB into the polymer matrix and showed that shorter sonication times (especially 5 minutes) provided better particle dispersion, with less aggregation and more homogeneous structures. Excessive sonication appeared to damage the particle network and reduce functional efficiency. The most promising formulations were then mixed with polyvinylpyrrolidone to fabricate nanofibrous membranes via electrospinning. The porosity of the electrospun mesh facilitated gas diffusion and interaction with the embedded PB particles. Mechanical testing showed limited tensile strength across all samples, which remains a challenge for practical application. Functional performance was evaluated by exposing the membranes to cycles of 100% hydrogen and synthetic air, and the colour change was quantified using the CIELAB model and the ΔE parameter. The formulation sonicated for 5 minutes showed the highest and most reversible response, with ΔE values exceeding 45 and a response time (t_{90}), defined as the time required for the chromatic variation to reach 90% of its total amplitude after hydrogen exposure began, of 300 seconds. However, colour recovery was incomplete in all samples, and prolonged exposure reduced the intensity of the signal, indicating some degree of degradation in the gasochromic response over repeated exposures. Overall, the electrospun system shows potential to integrate safe, low-cost applications. Further studies should improve mechanical robustness and long-term stability.

Keywords — Eye-readable hydrogen sensors; electrospinning; gasochromic nanofibers; Prussian Blue.

TOPIC

2) a. Technologies for the Wellbeing - Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] A. F. Girão and A. Completo, “Eye-readable sensors for intuitive hydrogen monitoring,” *Int. J. Hydrogen Energy*, in press. DOI: 10.1016/j.ijhydene.2024.04.014.

Finite-Element Modeling of Electroporation Dynamics in Tumor-on-a-Chip

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Abstract — Tumor-on-a-Chip (ToC) platforms are microfluidic devices engineered to recapitulate essential features of the tumor microenvironment (TME), as three-dimensional extracellular matrix scaffolding, multicellular architectures, and dynamic fluid perfusion, enabling fundamental studies of tumor physiology and high-throughput drug screening.

Electroporation uses short, high electrical field pulses to transiently permeabilize cell membranes, enhancing intracellular delivery of therapeutic agents. Thus, having great potential for use in drug delivery, gene therapy, and cancer treatment [1]. However, protocol definition and optimization remain challenging. To address this, robust, multicellular and cell-specific models linking electrical parameters to pore formation kinetics are in need.

We performed finite element method (FEM) simulations in COMSOL Multiphysics to solve the coupled charge-conservation equation and transient pore-formation equations, using the TOC's geometry and incorporating biophysical properties as the membrane, cytoplasmatic and extracellular medium conductivity and permittivity. The pore formation dynamics were modelled using asymptotically reduced Smoluchowski equations, yielding ordinary differential equations for pore density and radius evolution in response to a electrical field pulse [2,3]. The microfluidic device was fabricated with two electrode configurations (a set of needles and a set of concave sheets), to create an electric field exposure across a cancer spheroid suspended in a collagen matrix.

Using a simple exponential decay pulse (0.71 kV/cm at the centre of the spheroid; τ = 0.1 ms), the simulation results reveal that transmembrane voltage (TMV) rapidly reaches around the 1V threshold levels at cell poles within 1–2 µs of pulse onset, triggering pore nucleation peaking at densities of ~10^{11} pores/m^2 before equilibrating through membrane resealing currents. Pore radius increases rapidly to a maximum of 270 nm within 75 µs, then reseals completely by 290 µs. In the spheroid model, results revealed some spatial heterogeneity in pore formation, where cells immediately adjacent to the electrodes undergo a high pore nucleation reaching high peak densities whereas those farther from the field source exhibit lower pore densities. The pore density decaying with distance from the electrodes, highlighting the critical role of tissue-level interactions in shaping electroporation outcomes. Under the same conditions, the needle-electrode configuration produced more focused fields that originated peak pore densities greater than the concave-sheet electrodes that resulted in a more uniform but less intense electroporation profile.

Overall, this integrated design and computational framework offers a robust platform for preclinical optimization of electroporation conditions within ToC devices, reducing reliance on live-cell experimentation and enabling high-throughput screening of electrical parameters. Future efforts will extend the model to include multicellular co-cultures, extracellular matrix heterogeneity, and on-chip sensor integration for real-time monitoring of membrane integrity and drug uptake, advancing toward precision, automated ToC-based therapies.

Keywords — electroporation; tumor-on-a-chip; finite-element modeling; pore dynamics; microfluidics.

TOPIC

2) Technologies for the Wellbeing. a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] S. Sherif, Y. H. Ghallab, and Y. Ismail, "Computational analysis of electric stimulus protocols on breast cancer cells," Biomed. Mater. Devices, in press, 2024.
[2] W. Krassowska and P. D. Filev, "Modeling electroporation in a single cell," Biophys. J., vol. 92, pp. 404–417, 2007.
[3] K. A. DeBruin and W. Krassowska, "Modeling electroporation: effects of field strength and rest potential," Biophys. J., vol. 77, pp. 1213–1224, 1999.

Embracing Autonomous Mobility? Survey Evidence from the Portuguese Context

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Abstract — Automated vehicles (AVs) are increasingly regarded as a transformative solution for emerging mobility challenges, offering potential benefits in terms of road safety, energy efficiency, and transport accessibility [1]. Despite significant technological progress, public acceptance remains one of the most persistent barriers to implementation [1, 2]. In Portugal, where AV development is still in its infancy, there is an urgent need to understand how public perception, knowledge, and context influence the willingness to adopt this emerging mobility technology [3]. This study examines the willingness of the Portuguese population to use AVs, both for private and public transport. A structured survey was conducted to 425 participants, exploring themes such as technological trust, safety perception, environmental awareness, and AV knowledge, and data analysis was conducted using correlation tests and robust linear regression modelling with MM estimators.

The results revealed that technological optimism and positive environmental perceptions are the most significant predictors of willingness to adopt AVs. Yet, rural living experience negatively influences acceptance, with concerns about infrastructure availability and trust in automated systems. Although the effect was marginal, age was positively associated with willingness to adopt AVs, indicating that older respondents expressed slightly higher acceptance. Other sociodemographic factors, such as gender and income, had limited influence. Whilst safety and reliability remain primary concerns, especially regarding emergency scenarios and the ethical decision-making capabilities of AVs, participants expressed higher openness to using AVs in specific contexts such as emergency transport, healthcare, and commuting. Comprehensively, there was a clear preference for partially automated vehicles that allow user override, while exclusive private ownership showed less appealing than shared or public use models. Additionally, there was a strong correlation between willingness to adopt AVs and environmental motivations, particularly when associating AVs with clean energy, low emissions, and sustainable mobility.

This study provides valuable insights into the sociotechnical factors that shape AV acceptance in Portugal. The findings highlight the importance of promoting public trust, addressing safety concerns, and tailoring strategies to urban and rural contexts. Policymakers and industry stakeholders may use these results to support the design of inclusive and effective transport systems that integrate AVs in a sustainable and equitable manner.

Keywords — automated vehicles; regression modelling; adoption decision; survey; Portuguese context.

TOPIC

2) Technologies for the Wellbeing. b. Innovative Technologies for Smart Cities.

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REFERENCES

[1] C. Lee, C. Ward, M. Raue, L. D'Ambrosio, and J. F. Coughlin, "Age differences in acceptance of self-driving cars: A survey of perceptions and attitudes," in Human Aspects of IT for the Aged Population. Aging, Design and User Experience, Cham: Springer, 2017, pp. 3–13. https://doi.org/10.1007/978-3-319-58536-9_1

[2] F. Rebelo, A. Faria, J. Costa, R. Dias, E. Vilar, and P. Noriega, "Acceptance of automated electric vehicles as a collective passenger transport: The case of Portugal," in Int. Conf. Human-Computer Interaction, 2023, pp. 304–316. https://doi.org/10.1007/978-3-031-35169-2_23

[3] R. Rodrigues, F. Moura, A. B. Silva, and Á. Seco, "The determinants of Portuguese preference for vehicle automation: A descriptive and explanatory study," Transp. Res. Part F: Traffic Psychol. Behav., vol. 76, pp. 121–138, 2021. https://doi.org/10.1016/j.trf.2020.12.015

Microfluidic fabrication of protein-based nanoparticles for cancer

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Abstract — Cancer continues to be one of the most pressing global health challenges, with rising incidence rates and current treatment options often limited by significant side effects and lack of specificity [1]. Conventional therapies such as chemotherapy and radiotherapy remain the standard in clinical practice, but their non-selective nature can harm healthy tissues and reduce patients' quality of life. In recent years, novel approaches like photothermal therapy (PTT) and photodynamic therapy (PDT) have gained attention for their ability to selectively target tumor cells using heat or reactive oxygen species [2]. These methods are particularly promising when combined with nanotechnology, which allows for more precise drug delivery and enhanced imaging. Nanoparticles (NPs), due to their small size and high surface area, can be tailored to carry therapeutic agents directly to tumor sites while minimizing systemic toxicity [3]. Biomimetic nanoparticles made from proteins naturally found in the human body offer enhanced biocompatibility, reduced immunogenicity, and the possibility for targeted drug delivery. Their ability to circulate longer in the bloodstream and accumulate preferentially in tumors makes them especially relevant for cancer treatment [4]. However, traditional methods for producing these particles often face challenges such as high production costs, variability in size and shape, and difficulty in scaling up. Microfluidic systems have emerged as a compelling solution to these issues.

By enabling the manipulation of fluids in microscale channels, these systems provide tight control over reaction conditions such as flow rate, temperature, and mixing efficiency, allowing for the reproducible synthesis of nanoparticles with desired properties. Compared to conventional methods, microfluidic fabrication is more efficient, uses less reagent, and can be scaled for continuous production [5]. This work explores how microfluidic technologies are being used to fabricate protein-based NPs for cancer-related applications. It reviews various microfluidic designs and features in shaping the properties and performance of the resulting NPs. Overall, this study highlights the potential of combining microfluidic engineering with protein-based NPs design to develop more effective, targeted, and safer cancer therapies. Several in vitro and in vivo studies showed the high potential of protein-based NPs application cancer diagnosis and therapy.

Keywords — Drug Delivery; Microfluidics; Protein-based nanoparticles; Theranostics.

TOPIC

2) a.: Technologies for the Wellbeing – Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] D. Fan, Y. Cao, M. Cao, Y. Wang, Y. Cao, and T. Gong, "Nanomedicine in cancer therapy," *Signal Transduction and Targeted Therapy 2023 8:1*, vol. 8, no. 1, pp. 1–34, Aug. 2023, doi: 10.1038/s41392-023-01536-y.

[2] Z. Cheng, M. Li, R. Dey, and Y. Chen, "Nanomaterials for cancer therapy: current progress and perspectives," *Journal of Hematology & Oncology 2021 14:1*, vol. 14, no. 1, pp. 1–27, May 2021, doi: 10.1186/S13045-021-01096-0.

[3] A. Aghebati-Maleki *et al.*, "Nanoparticles and cancer therapy: Perspectives for application of nanoparticles in the treatment of cancers," *J Cell Physiol*, vol. 235, no. 3, pp. 1962–1972, Mar. 2020, doi: 10.1002/JCP.29126.

[4] M. Motallebi and F. Heidarizadeh, "Introduction to Biomimetic Nanoparticles for Biomedical Applications," *ACS Symposium Series*, vol. 1464, pp. 1–7, Mar. 2024, doi: 10.1021/BK-2024-1464.CH001/ASSET/IMAGES/LARGE/BK-2023-00315M_G001.JPEG.

[5] A. Agha *et al.*, "A review on microfluidic-assisted nanoparticle synthesis, and their applications using multiscale simulation methods," 2023. doi: 10.1186/s11671-023-03792-x.

Optimizing the operational efficiency of the municipal waste collection transport system

Case study in Aveiro

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Abstract — This project aims to analyse the feasibility of replacing a part of or a total fleet of urban solid waste collection vehicles currently powered by diesel with alternative propulsion sources, such as biodiesel and electric vehicles, listing their advantages and disadvantages.

The evaluation considers technical, economic, energy and environmental aspects. The methodology employed resulted from data collection and treatment from the following sources: operational vehicle data from vehicle operators (distances, loads, fuel consumption, etc.); commercial data supplied by vehicle manufacturers; data available in the literature. Also considered was commercial data from manufacturers, both for diesel and electric vehicles. There were three distinct fleet evolution scenarios investigated. The initial scenario maintained the current fleet, assessing its performance with three fuel options: B7 diesel, 100% hydrotreated vegetable oil (HVO), and a 54% blend (B54). The second scenario considered upgrading to new diesel vehicles and then evaluating them with the same fuel blends. The final scenario represented a complete shift, replacing the entire fleet with battery electric vehicles (BEVs).

Overall, the BEV option has a specific consumption (kWh/km), significantly lower than the ICE one. Considering the technical and functional aspects, both the ICE and BEV commercially available options are adequate for the current operational characteristics. The current infrastructure is prepared only for the ICE vehicles. It would be necessary to increase installed electric capacity and to purchase fast-charging chargers for the vehicles. Since the HVO is a drop-in fuel [1], no alterations would be needed for the implementation of the biofuel, neither in the vehicle itself, nor in the fuel tanks at the Aveiro operational centre. The economic study was based on a few key cost categories for both internal combustion engine (ICE) and battery electric vehicles (BEV). For ICE vehicles, we looked at the costs of: acquisition (buying the vehicle), maintenance, and fuel. For BEVs, we considered the same categories, with a few differences: Fuel costs were replaced with electricity costs, adding the costs of charging infrastructure and its upkeep. It was also factored in revenue from avoided costs, such as waived acquisition taxes and annual ownership taxes, which can make BEVs more financially attractive. Environmental impacts, such as pollutants are significantly decreased with the HVO, such as CO, NOx, PM, and especially, CO_2, with a reduction of up to 89% [2].

The results present that the BEV is slightly cheaper than a new diesel fleet on B100, though the current fleet is the cheapest option. BEV is the least pollutant one and the most efficient energy-wise. This shows that the decarbonisation of this sector is possible without compromising technical, economic and environmental principles. The objective of delivering strategic guidelines promoting environmental sustainability and economic and energy efficiency in the waste management collection was achieved [3]. Conclusions aim for the optimization of this sector and contribute to smart and sustainable cities.

Keywords - Waste Collection, Refuse Truck, Electric Vehicle, HVO

TOPIC

2) b.: Technologies for the Wellbeing - Innovative Technologies for Smart Cities

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REFERENCES

[1] Aatola H, Larmi M, Sarjovaara T, “Hydrotreated vegetable oil (HVO) as a renewable diesel fuel: trade-off between NOx, particulate emission, and fuel consumption of a heavy duty engine,” *SAE International Journal of Engines*, 2008. 10.4271/2008-01-2500

[2] Entidade Nacional para o Setor Energético, “HVO100 – um combustível 100% renovável”, 2023

[3] European Council, “Fit for 55: towards more sustainable transport”, 2023

Magnesium for Rechargeable Battery Applications

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Abstract — Magnesium (Mg) is emerging as a promising, strategically important material in the field of rechargeable batteries, owing to its intrinsic qualities such as ore abundance, cost efficiency, and multifunctionality across diverse electrochemical systems [1]. Recent research works suggest that it is possible to deploy Mg for electrochemical energy storage either through Mg ion secondary battery systems or through Mg based electrodes assisted Li/Na ion battery systems [2]. While Mg-ion batteries are still in their infancy due to the intrinsic difficulty of intercalating divalent Mg^{2+} ions into the host materials, our research suggest that, by using right combination of materials it is possible to overcome such limitations. In this context, we report the synthesis of a MgO-pillared reduced graphene oxide (rGO) composite via a solid-state reaction between magnesium hydride (MgH_2) and graphene oxide (GO) and apply this material as anode for Li/Na/Mg ion batteries. This nanostructured material, when employed as an anode, delivers specific capacities of ~445 mAh g^{-1} in Li ion coin cells and ~225 mAh g^{-1} in Na ion coin cell systems. We have observed only ~40 $mAhg^{-1}$ in Mg-ion coin cell batteries, however, this value is higher than that observed with pure rGO anode (10 $mAhg^{-1}$), underscoring the potential of MgO pillared rGO nanostructure for electrochemical energy storage.

Another alternate aspect of this study is the investigation of MgH_2 as a high-capacity anode material. MgH_2 theoretically undergoes a two-electron conversion reaction with lithium as follows, $MgH_2 + 2Li^+ + 2e^- \rightarrow Mg + 2LiH$ (1). This electrochemical reaction theoretically provides a capacity of 2038 $mAhg^{-1}$. Despite this promise, pure MgH_2 exhibits limited reversibility and poor electrochemical activity under practical conditions due to sluggish kinetics and low electronic conductivity. We explore that incorporating just a 5 wt.% of MgO-pillared rGO as an additive for MgH_2 significantly promotes the reaction (1). For instance, the forward conversion can be fully realized and also a 50% of reversible conversion can be achieved.

All electrochemical measurements in this study were conducted using CR2032-type coin cells in half-cell configuration. The electrolytes employed were 1 M $LiPF_6$ in EC/DMC (1:1 v/v) for Li-ion batteries, 1 M $NaPF_6$ in EC/PC (1:1 v/v) for Na-ion batteries, and 0.25 M $Mg(ClO_4)_2$ in acetonitrile for Mg-ion systems. Cycling was performed over a wide current density range from 100 mA g^{-1} to 2 A g^{-1} using NEWARE battery testing system.

In conclusion, our findings highlight the potential of magnesium-based materials for energy storage applications, not only as redox-active species but also as structure-directing components. This underscores the importance of interfacial engineering in advancing both conventional and emerging battery chemistries. Our results further establish a viable pathway for leveraging Mg in the design of next-generation energy storage systems.

Keywords: Sustainable Energy; Rechargeable Batteries; Pillared Nanostructures; Battery Anodes.

TOPIC

2) Technologies for the Wellbeing. a. Multiscale Technologies and Devices for Medicine, Environment & Energy

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REFERENCES

[1] D. Pukazhselvan, I. Çaha, C. Lemos, S.M. Mikhalev, F.L. Deepak, D.P. Fagg, "Understanding the catalysis of chromium trioxide added magnesium hydride for hydrogen storage and Li ion battery applications" J. Magnes. Alloy, 12(3), 1117-1130, 2024, https://doi.org/10.1016/j.jma.2024.03.007.

[2] A.G. Olabi, Q. Abbas, P.A. Shinde, M.A. Abdelkareem, "Rechargeable batteries: Technological advancement, challenges, current and emerging applications", Energy, 266, 126408, 2023, https://doi.org/10.1016/j.energy.2022.126408.

INTELLIGENT SYSTEMS

Performance Analysis of a Comprehensive IIoT Framework for Smart Manufacturing

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Abstract — The current Industry 4.0 revolution is redefining the traditional paradigms employed in industrial companies [1]. The Internet of Things (IoT) represents the Industry 4.0 field responsible for interconnecting various diverse intelligent devices onto a common unified platform [2].

In our previous work [3], we presented a conceptual solution for an easy-to-use, open-source medium-size Industrial IoT (IIoT) platform. Our main objective is to provide an entry point for small to medium industries to explore and develop new solutions for each specific use cases, aiding with the digitalization of production lines and processes. In contrast to solutions proposed by other authors [4], which mainly focus on supervision and monitoring services, this solution aims to provide a complete package of IoT services capable of satisfying the minimum requirements of a IIoT platform, such as data acquisition, industrial supervision and dynamic remote control of equipment, while allowing users to easily develop their own applications, such as machine learning algorithms for predictive maintenance and production management.

The platform must be capable of integrating custom data acquisition and control with a wide range of industrial communication protocols for shopfloor implementation, devices and user management, a customizable monitorization interface, and options for long-term data storage and memory management, functionalities essential for smart manufacturing development. Due to its open-source nature, the platforms offer a set of features for the development of new functionalities, varying between easily integrating custom applications for predictive and energy management, to adding new communication protocol with equipment or connection with new databases, allowing the user to customize the platform to his needs.

In this paper we present the development of the conceptual solution, describing the modifications conducted and their respective impact on the platform's performance via a set of analyses carried out locally, thus providing the best possible outcomes regarding latency, jitter and package loss between different intra-platform microservices, specially for most basic interactions, e.g. data acquisition sequence, command messages sequence and permanent data storage, concluding with a brief description on the development of the remaining functionalities.

Keywords — Industry 4.0, Industrial Internet of Things, Digitalization, Industrial Connectivity

TOPIC

3) c.: Intelligent Systems – Digital transformation

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REFERENCES

[1] Kaur, K., Garg, S., Aujla, G. S., Kumar, N., Rodrigues, J. J., & Guizani, M. (February de 2018). Edge Computing in the Industrial Internet of Things Environment: Software-Defined-Networks-Based Edge-Cloud Interplay. *IEEE Communications Magazine, 56*, 44–51. doi:10.1109/mcom.2018.1700622

[2] Mumtaz, S., Alsohaily, A., Pang, Z., Rayes, A., Tsang, K. F., & Rodriguez, J. (March de 2017). Massive Internet of Things for Industrial Applications: Addressing Wireless IIoT Connectivity Challenges and Ecosystem Fragmentation. *IEEE Industrial Electronics Magazine, 11*, 28–33. doi:10.1109/mie.2016.2618724

[3] Camarneiro, D., Cação, J., Nunes, P., Santos, J. P. Comprehensive IIoT Framework for Enhanced Data Collection and Analysis in Manufacturing. Presented at the *IEEE International Conference of Mechatronics (ICM 2025), Wollongong, Australia, Feb 28 – Mar 2, 2025 (to be published)*

[4] Christos, S. C., Nektarios, G., Fotios, G., Nikolaos, D., Panagiotis, P., & Areti, P. (July de 2021). Development of an IoT Early Warning Platform for Augmented Decision Support in Oil & Gas. *2021 10th International Conference on Modern Circuits and Systems Technologies (MOCAST)* (pp. 1–4). IEEE. doi:10.1109/mocast52088.2021.9493348

Rule-Based Leak Detection in Industrial Production using Decision Tree Models

Application to a real-world industrial use case

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Abstract — In recent years, the manufacturing sector has undergone a rapid transformation. Emerging technologies, such as Digital Twins and Machine Learning (ML) are being increasingly adopted within industrial data workflows, from data acquisition and storage to real-time processing and analysis [1, 2]. ML techniques, and particularly Deep Learning (DL) methods, have demonstrated great promise for tasks such as predictive maintenance, process monitoring, and product defect detection, owing to their ability to process large volumes of data and extract highly complex features [3]. However, DL architectures are often seen as "black-boxes": their complex internal structures make it difficult for end-users to understand their outputs [4]. This limits their practical deployment in industrial settings, where transparency and trust are essential [5].

This work explores the development of a "white-box", highly interpretable Decision Tree (DT) model for leak prediction and detection, applied to a real-world use case in collaboration with Bosch Termotecnologia S.A. The case study consists of a leak detection test, conducted during the final functional test phases of production. It leverages an ATC equipment, which attached to the target product, initially fills its circuits with compressed air and then monitors the flow needed to maintain a constant operational pressure. The entire process is controlled by a PLC, constraining the complexity of the solution to be developed. The current leak detection approach relies on a human-defined rule: *"if the flow at timestep X is above Y, the output is a leak"*. Such method, while easily implementable, is strict, potentially biased, and not optimal particularly for noisy test samples. The proposed ML-based approach eliminates the need for manual threshold definition. Using a DT model, the system learns a set of *"if-else"* rules directly from the labelled train data. Such solution, while fully compatible with PLC deployment (just requiring rule extraction and writing in the PLC), also offers transparency through extracted rules, class probability outputs, confidence levels, and identification of influential time points.

Results indicate that the proposed model has high performance, with accuracy, F1, and MCC scores all above 0.95 for a manually labelled, controlled set of tests. Moreover, leveraging the rule-extraction capabilities of the ML model, a reduction in 20 seconds (40%) of the test time is possible to be achieved. Overall, this approach demonstrates how interpretable ML can replace traditional logic in constrained industrial environments, by improving performance while maintaining trust.

Keywords — Industrial Automation; Decision Trees; Leak Detection; Interpretable Machine Learning.

TOPIC

3) b.: Intelligent Systems - Digital Transformation

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REFERENCES

[1] R. Rai, M. K. Tiwari, D. Ivanov, and A. Dolgui, 'Machine learning in manufacturing and industry 4.0 applications', International Journal of Production Research, vol. 59, no. 16, pp. 4773–4778, Aug. 2021, doi: 10.1080/00207543.2021.1956675.
[2] A. Dogan and D. Birant, 'Machine learning and data mining in manufacturing', Expert Systems with Applications, vol. 166, p. 114060, Mar. 2021, doi: 10.1016/j.eswa.2020.114060.
[3] G. Pang, C. Shen, L. Cao, and A. V. D. Hengel, 'Deep Learning for Anomaly Detection: A Review', ACM Comput. Surv., vol. 54, no. 2, pp. 1–38, Mar. 2022, doi: 10.1145/3439950.
[4] R. Machlev et al., 'Explainable Artificial Intelligence (XAI) techniques for energy and power systems: Review, challenges and opportunities', Energy and AI, vol. 9, p. 100169, Aug. 2022, doi: 10.1016/j.egyai.2022.100169.
[5] A. Barredo Arrieta et al., 'Explainable Artificial Intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI', Information Fusion, vol. 58, pp. 82–115, Jun. 2020, doi: 10.1016/j.inffus.2019.12.012.

Performance and Robustness in Smart Predictive Digital Twins: A Review with Emphasis on Water Supply Systems

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Abstract — Water Supply Systems (WSS) play a critical role in ensuring a reliable and sufficient water supply to residential, agricultural and industrial sectors. In Europe, WSS consumes 1,13% of all energy, of which at least 60% is used by pumping stations [1]. For this reason, efficient management of WSS is imperative, however it is a complex challenge. Firstly, due to the high number of variables that need to be considered, such as the pump's variable speed drivers, dynamic energy tariffs and local production of energy. Secondly, the shortage of personnel has become a concern, since a considerable number of them are approaching the retirement age, leading to the loss of valuable management knowledge [2]. In this context, Digital Twins (DT) present an effective tool to support the decision-making process and help to manage WSS in a more efficient way by helping to minimize operational costs. DT replicate real-world systems, with the incorporation of three core components: the physical asset, the digital asset and the connection between the two [3]. More mature DTs integrate new components, such as cloud computing, a predictive engine and optimisation modules, allowing them to work as a decision support system [3]. This form of more mature and advanced DT is designated as Smart Predictive Digital Twin (SPDT). Despite the evident potential, there are only few applications reported in real-time, reflecting its immaturity and a general lack of trust in these systems, not only in WSS, but in other sectors.

This review examines how the performance and robustness of SPDT are currently addressed, especially in their application in critical systems such as WSS. A targeted literature search was conducted to select relevant studies, with a focus on DT maturity levels, performance assessment methods and techniques for enhancing robustness. Although there is a growing awareness of the need to assess DT performance, current evaluation practices remain uncoordinated, with varied approaches across studies and domains. Robustness strategies are frequently implemented reactively as workarounds instead of being integrated systematically. This review identifies a lack of comprehensive evaluation framework and synthesises promising approaches to improving the robustness of SPDT in WSS applications.

The present review contributes to the development of structured approaches for implementing trustworthy SPDTs. It is important that performance and robustness are strengthened in order to increase operators' confidence, enable wider adoption and contribute to more efficient and sustainable operations for WSS and beyond.

Keywords — Performance Evaluation; Robustness Enhancement; Smart Predictive Digital Twins; Water Supply Systems.

TOPIC

3) c.: Intelligent Systems - Artificial Intelligence

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REFERENCES

[1] - International Energy Agency, *Energy, water and the Sustainable Development Goals: Excerpt from World Energy Outlook 2018*, IEA, Paris, France, 2018. [Online]. Available: https://www.iea.org/reports/energy-water-and-the-sustainable-development-goals. [Accessed: 28 May, 2025].

[2] - C. Kalyani, K. Pradnya, C. Samkit, and V. Patil, 'Regular and Equal Water Supply System', SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, vol. 15, no. 01, pp. 34–37, Jan. 2023, doi: 10.18090/samriddhi.v15i01.05.

[3] – M. Segovia and J. Garcia-Alfaro, "Design, modeling and implementation of digital twins," Sensors, vol. 22, no. 14, p. 5396, 2022. doi: 10.3390/s22145396

Artificial Intelligence in Product Development

Transforming the Innovation Process

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Abstract — Artificial Intelligence (AI) is increasingly influencing New Product Development (NPD), offering new possibilities for designers and engineers to create more innovative and efficient solutions [1]. It provides tools that support creativity, optimize decision-making, and reduce development times, reshaping how products are conceived, developed, and refined. This study presents a structured literature review on the integration of AI into product design and development processes. The review followed a systematic approach based on thematic analysis of academic and industry sources retrieved from Scopus, Web of Science, IEEE Xplore, ACM Digital Library, and Google Scholar, covering the period from 2015 to 2025.

The results highlight three key domains where AI offers significant value: (i) **creative support**, through generative models that enable divergent thinking, analogical reasoning, and ideation support [2]; (ii) **technical optimisation**, including AI-driven simulations, performance prediction, structural optimisation, material selection, and digital prototyping; and (iii) **data-informed decision-making**, by creating enhanced data-driven knowledge to predict market behaviours and user needs [3]. While the benefits are promising, including reduced development and testing times [2], improved product quality [3], cost efficiency [1], and the contribution to the development of more sustainable outcomes [5], the review also identifies persistent challenges: usability barriers, algorithmic opacity and ethical concerns [6].

This review consolidates current knowledge on how AI is reshaping product development. It highlights the transformative potential of intelligent systems and the limitations that require critical attention. Among the most pressing research challenges is understanding how to combine computational capabilities with human expertise in a meaningful way, a synergy often referred to as *hybrid intelligence*. AI is increasingly seen as a complement to human creativity and judgment, enhancing problem-solving while maintaining the need for human validation and oversight. As the field evolves, exploring how this collaborative model can be structured, evaluated and applied at scale will be essential for a responsible and impactful integration of AI in future product development practices.

Keywords — Artificial Intelligence; New Product Development; Innovation; AI-Driven Innovation.

TOPIC

3) e.: Intelligent Systems – Artificial Intelligence

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REFERENCES

[1] R. G. Cooper, "The AI transformation of product innovation", *Industrial Marketing Management*, vol. 119, pp. 62–74, 2024. 10.1016/j.Indmarmn.2024.03.008

[2] J. I. Saadi and M. C. Yang, "Generative design: reframing the role of the designer in early-stage design process," *Journal of Mechanical Design*, vol. 145, no. 4, 041411, 2023. 10.1115/1.4056799

[3] J. Joosten, V. Bilgram, A. Hahn, and D. Totzek, "Comparing the ideation quality of humans with generative artificial intelligence," *IEEE Engineering Management Review*, vol. 52, no. 2, pp. 153–164, 2024. 10.1109/EMR.2024.3353338

[4] F. Tao, F. Sui, A. Liu, M. Zhang, B. Song, ... A. Y. Nee, "Digital twin-driven product design framework," *International Journal of Production Research*, vol. 57, no. 12, pp. 3935–3953, 2018. 10.1080/00207543.2018.1443229

[5] C. K. M. Lee, J. Liang, K. L. Yung, and K. L. Keung, "Generating TRIZ-inspired guidelines for eco-design using Generative Artificial Intelligence," *Advanced Engineering Informatics*, vol. 62, 102846, 2024. 10.1016/j.aei.2024.102846

[6] O. Plätke and R. C. Geibel, "The Use of Artificial Intelligence for Idea Generation in the Innovation Process," in *International Scientific-Practical Conference*, pp. 181–198, Cham: Springer Nature Switzerland, Nov. 2023. 10.1007/978-3-031-66517-2_14

Patient-Specific Gyroid Scaffold Design via Machine Learning-Driven Optimization of DEXA T-score Data

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Abstract — This study presents an advanced computational framework for designing gyroid scaffolds tailored to individual bone mineral density (BMD) profiles derived from DEXA data and T-score value.

Leveraging machine learning (ML) models trained on an open-access clinical dataset from Harvard University [1,2], the methodology predicts femoral neck BMD using relevant patient variables such as age, height, weight, blood biomarkers, cardiovascular health, and lifestyle factors. These predictions inform a parametric optimization algorithm that generates gyroid scaffold geometries aligned with clinically defined bone health categories: healthy, osteopenic, and osteoporotic.

The gyroid geometry was selected for its unique triply periodic minimal surface (TPMS) architecture, offering an optimal balance of high porosity, interconnected networks for biological activity, and superior mechanical properties crucial for bone regeneration.

The optimization process uses voxel-based modeling accelerated by GPU computing via OpenCL, enabling rapid and efficient exploration of geometric parameters to achieve target areal densities. Results demonstrate the feasibility of integrating patient-specific clinical data with ML and high-performance computing to inform scaffold design for additive manufacturing.

Future work involves fabricating the optimized scaffolds through 3D printing and validating density distribution using micro-CT imaging, aiming to calibrate and enhance the predictive model. This approach builds upon recent advances in ML-based BMD estimation and scaffold optimization techniques [3].

Keywords — Bone mineral density (BMD), T-score, ML optimisation, Gyroid structures

TOPIC

3) Intelligent Systems. d. Machine learning

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REFERENCES

[1]: G. M. Bezerra, E. F. Ohata, L. L. Loureiro, V. Z. Bittencourt, V. L. M. C. Junior, A. R. da Rocha, e P. P. R. Filho, "Estimation of Bone Mineral Density using Machine Learning and SHapley Additive exPlanations," Harvard Dataverse, V1, 29 de maio de 2024. doi: 10.7910/DVN/UDZIJS.
[2] G. M. Bezerra, E. F. Ohata, L. L. Loureiro, V. Z. Bittencourt, V. L. M. C. Junior, A. R. da Rocha, e P. P. Rebouças Filho, "Estimation of Bone Mineral Density using Machine Learning and SHapley Additive exPlanations," in 2024 IEEE 37th International Symposium on Computer-Based Medical Systems (CBMS), Fortaleza, Brazil, 2024, pp. 446-451. doi: 10.1109/CBMS61543.2024.00076.
[3] C. Qiu, K. Su, Z. Luo, Q. Tian, L. Zhao, L. Wu, H. Deng, e H. Shen, "Developing and comparing deep learning and machine learning algorithms for osteoporosis risk prediction," Front. Artif. Intell., vol. 7, Art. no. 1355287, 11 de junho de 2024. doi: 10.3389/frai.2024.1355287. [2] Author 1, Author 2, and Author 3, "Title of the article," *J. Name Stand. Abbrev.*, in press. DOI [3] Author 1, Author 2, and Author 3, "Title of the article," *IEEE Transl. J. Magn. Japan*, vol. X, pp. yyy–zzz, Year [*Digests 9th Annual Conf. Magnetics Japan*, p. xxx, Year] DOI.

Mesh Influence Reduction in Dataset Generation for ML-Based Prediction of Constitutive Parameters in Sheet Metal Forming

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Abstract — Sheet metal-forming processes play a critical role in the automotive, aerospace and metalworking industries, where low production costs and high product quality are essential. To reduce costly trial-and-error approaches, the Finite Element Method (FEM) is used to simulate forming operations and reduce time-to-market. However, simulation accuracy depends on the precise identification of constitutive parameters that characterize the material's behaviour [1,2]. Traditional identification techniques, based on standardized mechanical tests, are limited to simple strain paths and fail to capture heterogeneous deformation patterns. Additionally, the emergence of new materials leads to more complex constitutive models with an increased number of parameters, requiring extensive mechanical testing [3]. To address these limitations, inverse identification methods, such as the Finite Element Model Updating (FEMU) and the Virtual Fields Method (VFM), have been proposed, though they often involve high computational cost [4]. Conversely, machine learning (ML) techniques offer a promising, data-driven alternative for predicting parameters directly from simulated or experimental data. Recent works using ML algorithms have shown encouraging results, particularly when applied to full-field data from biaxial cruciform tests [2,5]. However, trained ML models are often constrained by the limited dataset coverage from simulations, restricting their predictive capability and ability to adapt to experimental Digital Image Correlation (DIC) data, leading to a dependency on the mesh discretisation scheme [2,5].

This work proposes an interpolation-based dataset generation strategy enabling mesh-independent ML model training. FEM simulations of a biaxial tensile test on a cruciform-shaped sample generate full-field strain data, which is interpolated onto regular grids using various interpolation methods. These datasets train XGBoost models to predict Hill'48 material parameters with Swift hardening. Evaluation through simple and cross-validation tests shows that cubic and multiquadric interpolations, especially with grid sizes matching or exceeding the original mesh, provide highly accurate reconstruction and predictive robustness. A synthetic DIC case study confirms the model's generalization to non-matching spatial resolutions.

Keywords — machine learning; parameter identification; sheet metal forming; numerical simulation

TOPIC

3) d.: Intelligent Systems – Machine learning

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REFERENCES

[1] Parreira, T.G.; Marques, A.E.; Sakharova, N.A.; Prates, P.A.; Pereira, A.F.G. Identification of Sheet Metal Constitutive Parameters Using Metamodeling of the Biaxial Tensile Test on a Cruciform Specimen. Metals, 14(2), 212, 2024, doi:10.3390/met14020212

[2] Bastos, N.; Prates, P.A.; Andrade-Campos, A. Material Parameter Identification of Elastoplastic Constitutive Models Using Machine Learning Approaches. Key Eng. Mater., 926, 2193–2200, 2022, doi:10.4028/p-zr575d

[3] Rabahallah, M. *et al.* Parameter identification of advanced plastic strain rate potentials and impact on plastic anisotropy prediction. Int. J. Plast, 25, 491–512, 2009, doi:10.1016/j.ijplas.2008.03.006

[4] Kim, J.; Ebrahim, A.S.; Kinsey, B.L.; Ha, J. Identification of Yld2000–2d anisotropic yield function parameters from single hole expansion test using machine learning. CIRP Ann., 73, 233–236, 2024, doi:10.1016/j.cirp.2024.04.026

[5] Prates, P. *et al.* Influence of data filtering and noise on the calibration of constitutive models using machine learning techniques. Mater. Form., 41, 1807–1816, 2024, doi:10.21741/9781644903131-200

Visually Right, Structurally Wrong: The Risk of Machine Learning Predictors in Topology Optimization

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Abstract — Topology optimization is a powerful technique that allows the creation of highly efficient designs by distributing material within a given domain according to specific performance criteria. However, conventional approaches typically require numerous iterations, each involving the Finite Element Method (FEM), resulting in high computational costs, especially for large-scale and complex problems. To address this challenge, recent research has explored the integration of machine learning into topology optimization. Metamodeling [1] or surrogate modelling stands out for its potential to replace the computationally expensive FEM steps with rapid predictions.

In this work, a metamodel was developed to predict displacement fields in both directions for a cantilever beam topology optimization problem. Multiple machine learning architectures were evaluated, including Convolutional Neural Networks (CNNs) with and without residual connections. U-Nets, originally designed for medical image segmentation [2], achieved the best performance in terms of Mean Squared Error (MSE) relative to training time. For a domain of size 180 by 60, the metamodel enabled a 6.5 times speedup compared to traditional methods, using a parameterized version of the Solid Isotropic Material with Penalization (SIMP) method to generate the dataset for 35 hours, and training the metamodel offline for approximately 20 hours. While the predicted displacement fields exhibited strong visual similarity to ground truth results, pixel-wise discrepancies led to significant divergence in the final topology optimization outcome. Sensitivity map analysis revealed that the machine learning framework exhibited amplified responses compared to the classical SIMP method. These discrepancies are attributed to localized displacement gradients, which led to deviations from the optimal solution. Several strategies were explored to improve the results, though sensitivity discrepancies persisted. These findings highlight the inherent difficulty of accurately predicting displacement fields using a purely data-driven approach, especially for configurations governed by complex physical laws.

Nonetheless, the results demonstrate the potential of such metamodels to accelerate topology optimization, particularly for non-gradient-based methods (e.g., genetic algorithms or particle swarm optimization). Furthermore, the proposed metamodel may offer significant time savings when applied to standalone FEM simulations across a range of engineering problems.

Keywords — Topology Optimization; Metamodeling; Finite Element Method; Machine Learning.

TOPIC

3) Intelligent Systems. d. Machine learning

ACKNOWLEDGMENTS

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REFERENCES

[1] S. Shin, D. Shin, and N. Kang, "Topology optimization via machine learning and deep learning: a review," *Journal of Computational Design and Engineering*, vol. 10, pp. 1736–1766, 2023. https://doi.org/10.1093/jcde/qwad072

[2] O. Ronneberger, P. Fischer, and T. Brox, "U-Net: convolutional networks for biomedical image segmentation," *CoRR*, 2015. https://doi.org/10.48550/arXiv.1505.04597

Uncertainty Quantification in hydraulic prediction

Reframing Noise-Contrastive Estimation for Regression in Water Supply Systems

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Abstract — Water Supply Systems (WSS) are fundamental infrastructures for the general well-being of society, responsible for providing safe drinking water. These systems are faced with numerous challenges, such as aging components, climate change, and volatility in energy costs. Among many of its management facets, its primary task is to produce pump schedules that minimize costs, while respecting hydraulic constraints. This is often achieved with a pump scheduling optimization algorithm, which requires an accurate predictive component. In practice, a WSS is a critical system, hence its decision-making should be robust to avoid any malfunction. Subsequently, the prediction component of the pump scheduling algorithm should reflect this by being both accurate and robust.

In the context of regression tasks, Machine Learning (ML) techniques are widely used in numerous domains. However, conventional ML models provide only point estimates, which contain no information regarding the confidence of its prediction. Uncertainty Quantification (UQ) methodologies have emerged as approaches that enhance ML predictions by providing additional information regarding the certainty of the prediction. For instance, Bayesian Neural Networks (BNN) (e.g., [1]) are popular UQ methodologies with state-of-the-art results. Beyond BNN models, there is also a body of research in Density Regression that focuses on directly estimating the Probability Density Function (PDF) of target variables. Although Density Regression are often applied to unsupervised learning or generative tasks, this work showcases the effectiveness of one such technique in a supervised learning regression task.

This work proposes the use of a Density Regression technique, specifically Noise-Contrastive Estimation (NCE) [2], to quantify uncertainty in a water hydraulic prediction task. To the authors' knowledge the NCE technique has not been applied to a regression task, making the proposed work novel. Preliminary results both on synthetic and real-world hydraulic prediction datasets demonstrate that the developed methodology is promising. These results also suggest that Density Regression techniques, such as NCE, are viable alternatives to other UQ methodologies, with evidence of competitive performance.

Keywords — Water Supply Systems; Uncertainty Quantification; Machine Learning, Noise-Contrastive Estimation.

TOPIC

3) d.: Intelligent Systems- Machine learning

ACKNOWLEDGMENTS

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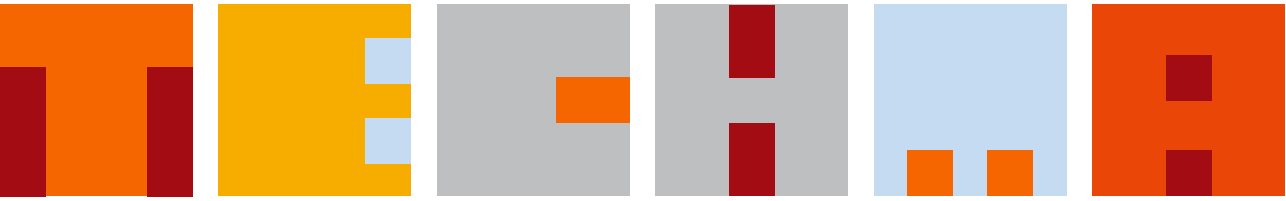
REFERENCES

[1] C. Blundell, J. Cornebise, K. Kavukcuoglu, and D. Wierstra, "Weight uncertainty in neural networks," International Conference on Machine Learning, pp. 1613–1622, 2015.

[2] M. Gutmann and A. Hyvärinen, "Noise-contrastive estimation: A new estimation principle for unnormalized statistical models," Journal of Machine Learning Research, vol. 9, pp. 297–304, 2010. [Online].



POSTERS

SUSTAINABLE MANUFACTURING SOLUTIONS

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New Frontiers in Mechanical Engineering

Experimental study on surface quality in titanium alloys grinding

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Abstract

Titanium alloys are extensively used in a range of industries, such as aeronautics, automobiles, and medicine, due to their exceptional mechanical and chemical properties. These alloys are renowned for their low density, low Young's Modulus, high resistance to corrosion and high temperatures, among other features, which make them a reliable solution for demanding applications [1,2].

In some applications, attaining precise dimensional accuracy and a smooth surface finish in component manufacturing necessitates the careful selection of appropriate means and equipment [3]. Grinding is a manufacturing process that appears to be a solution capable of meeting these objectives. The process involves removing excess material with an abrasive wheel that has multiple cutting edges. This process is repeated until the desired dimensions or surface roughness are achieved. Grinding is considered a relatively inefficient machining process compared to milling or turning, as it requires a significant amount of energy to remove even a small amount of material [4].

The objective of this study was to compare the surface finish achieved by surface grinding of the aforementioned titanium alloys. For that purpose, test-samples were subjected to grinding tests where the differentiating factors were the number of cutting passes, depth of cut and use of lubrication. Surface quality was accessed by roughness measurements in the longitudinal or cutting direction (X-axis) and in the transverse direction (Y-axis).

Findings indicate that the use of lubrication resulted in a 15-20% reduction in roughness compared to dry tests. Also, that with a multi pass strategy roughness decreased 40-50% as opposed to a single pass cutting strategy. As for the roughness in relation to the cutting direction, were measured 20-30% lower values in the longitudinal direction than in the orthogonal direction.

According to the analysis that was carried out, the roughness results indicate that the lowest roughness values were obtained for the Ti-13Zr-13Nb alloy in the longitudinal cutting direction, using a multi-pass deep cutting strategy with values of Ra=0.29µm and Rt=2.73 µm and for abundant cooling with Ra=0.55 µm and Rt=4.81 µm.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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Objective

- Compare **surface roughness** in surface grinding in titanium alloys;
- **Titanium alloys**: Ti-6Al-4V, Ti-6Al-7N and Ti-13Zr-13Nb;
- Evaluate the influence of cut of depth, use of lubrification, anisotropy regarding cutting direction and material.

Fig 1 / Experimental setup

Experimental method

•Test conditions

- n=1450rpm → ω ≈ 24m/s
- ap = 2 (x10) µmm , 20 (x1) µmm
- Flood cooling (3% emulsion) / Dry

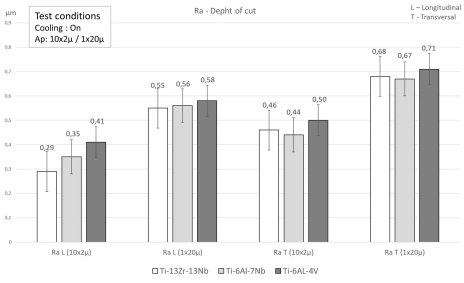
•Grinding wheel

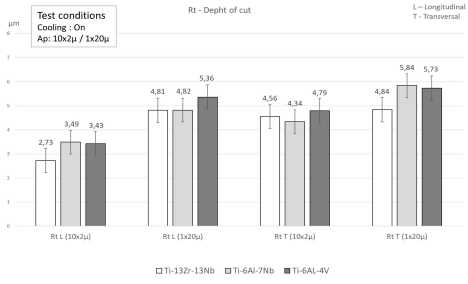
- Al2O3, Ø 310mm

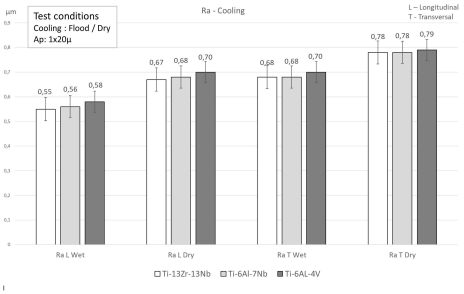
•Equipment

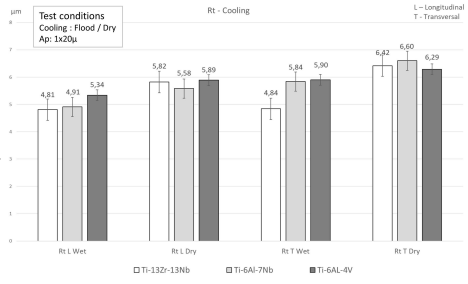
- Kent KGS-64SD
- Hommel tester 1000

Results









Conclusions

- Ra between 0.29µm and 0.79µm ← within grinding range [0.1 – 1.6µm];
- Lower Ra (0.29µm) with **multi-pass** cutting strategy versus single-pass;
- Lower Ra (0.55µm) with **flood cooling** versus dry**;**
- Lower roughness in **cutting direction (longitudinal)**;
- **Ti-13Zr-13Nb** presented lower roughness, therefore better machinability;
- **Lowest roughness** is attainable with a multi-pass cutting strategy and use of flood cooling.

References

[1] Festas A, Ramos A, Davim JP. Machining of titanium alloys for medical application - a review. Proc Inst Mech Eng Part B J Eng Manuf 2022;236:309–18. https://doi.org/10.1177/09544054211028531.

[2] Carvalho S, Horovistiz A, Davim JP. Surface topography in machining Ti alloys for biomedical applications: correlative microscopy approach for qualitative and quantitative analysis. Int J Adv Manuf Technol 2021;114:683–94. https://doi.org/10.1007/s00170-021-06824-x.

[3] XIAO G, ZHANG Y, HUANG Y, SONG S, CHEN B. Grinding mechanism of titanium alloy: Research status and prospect. J Adv Manuf Sci Technol 2021;1:2020001–0. https://doi.org/10.51393/j.jamst.2020001.

[4] de Mello AV, de Silva RB, Machado ÁR, Gelamo RV, Diniz AE, de Oliveira RFM. Surface Grinding of Ti-6Al-4V Alloy with SiC Abrasive Wheel at Various Cutting Conditions. Procedia Manuf 2017;10:590–600. https://doi.org/10.1016/j.promfg.2017.07.057.

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New Frontiers in Mechanical Engineering

Towards virtual forming and design: Standardization of material characterization and numerical model calibration through material testing 2.0

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Abstract

Mechanical material characterization is a cornerstone of mechanical design, engineering, and innovation. Although classical mechanical tests remain widely used, they rely on outdated standards and a one-dimensional mindset that fails to capture the complexity of material behaviour, particularly in metal forming processes (Dixit, 2020).

This work includes the state-of-the-art review of a PhD that aims to advance the standardization of material characterization and numerical model calibration through the emerging Material Testing 2.0 (MT2.0) (Pierron et.al. 2021) framework. The work will develop both updated and new test standards for homogeneous and heterogeneous tests, exploiting methods like the inverse identification technique e.g., Virtual Field measurement (VFM), full-field measurements and advanced metrology tools such as Digital Image Correlation (DIC) (Grediac, 2004). Emphasis is placed on dual-phase steels (Gonçalves et.al. 2023), validated through combined numerical and experimental campaigns.

Expected outcomes of the PhD include improved material behaviour indicators; update 1D mindset to 2D MT2.0 mindset, showing the superiority of MT2.0, standardized MT2.0 test protocols, and robust model calibration methodologies. These advances will promote a faster and more reliable MT2.0 adoption by industry, enhance simulation accuracy, reduce development costs, and contribute to future international standardization efforts in material testing.

Keywords: Material characterization; material testing 2.0; simulation; digital image correlation, virtual field measurement; standardization,; numerical model calibration.

Problems & Methodology

The intent of this work is to contribute to the standardization of material characterization and numerical model calibration through MT2.0, so that MT2.0 can be more rapidly adopted into the industry. Therefore, finding ways to; update classical tests standards for MT2.0, update 1D mindset to MT2.0 2D mindset, show MT2.0 framework superiority to 1D analyses, develop standard framework to birth mechanical test in MT2.0 and direct methods to calibrate material constitutive models using classical and MT2.0 tests.

Methods adopted involve a deep critical literature review to update knowledge on the existing standards for material testing and characterization. Enhance and adapt existing standards for classical mechanical tests in MT2.0 technology through experimental and numerical campaigns. Designing of a standard for heterogeneous tests and MT2.0, using validated but not standardized heterogeneous specimens. Application of the standardization on the calibration of elastoplastic constitutive models, using dual-phase steel (DP600) sheet metal. Dissemination of the obtained results and developed tools to both the scientific and industrial communities.

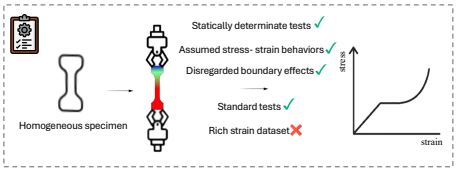

Fig 1. Classical standard test in 1D mindset.

Impact of the PhD

Development of models that will improve development time, minimize material and energy waste and cut associated costs in product development processes. MT2.0 presents a paradigm shift in how materials are tested and understood, thereby offering a higher resolution and rich-strain data and improved predictive capabilities. The results from this work will contribute to the universally accepted testing protocols through collaborations with bodies like VAMAS and create a synergy in practice across research institute and industries.

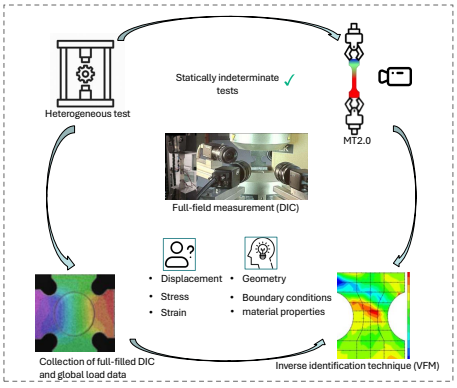

Fig 2. Material testing 2.0 (MT2.0).

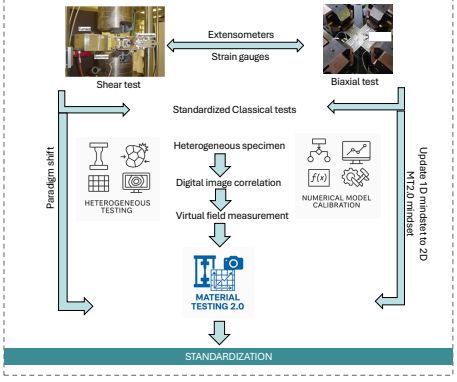

Fig 3. Proposed methodology.

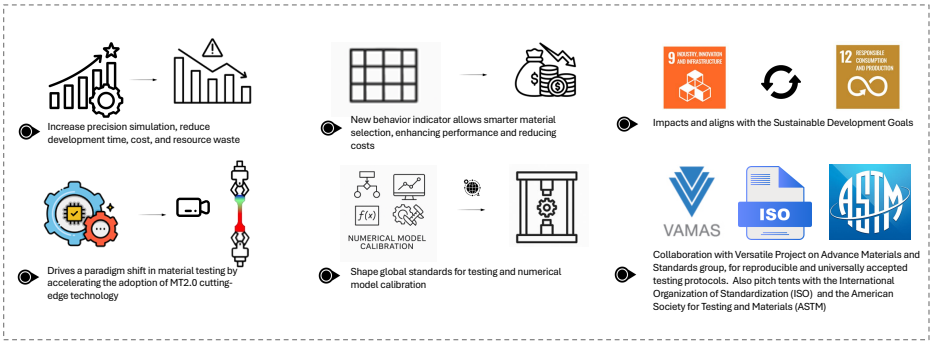

Fig 4. Impact of this PhD.

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New Frontiers in Mechanical Engineering

Multifunctional Carbon Dots Nanocapsules for Neutron Capture Cancer Therapy

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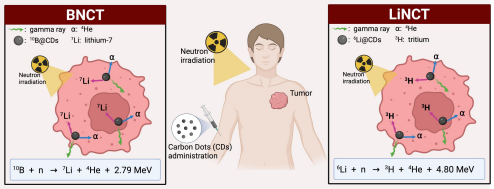
Abstract

Cancer remains one of the leading causes of death worldwide, with current therapies often lacking effectiveness [1]. Neutron capture therapy (NCT) offers a targeted alternative by delivering stable isotopes to tumor cells, where neutron irradiation triggers a localized nuclear reaction that selectively damages malignant cells [2]. While ^{10}B has been extensively studied, ^{6}Li is emerging as a promising candidate due to the higher energy of its emitted particles [3]. Despite its potential, NCT faces challenges such as poor drug biocompatibility and limited targeting efficiency [2]. This work explores carbon dots (CDs) as nanocarriers for ^{6}Li and ^{10}B in NCT, aiming to improve these limitations. CDs were synthesized via hydrothermal and microwave-assisted methods, purified and briefly characterized. Future steps include physicochemical characterization and in vitro evaluation to develop biocompatible nanodrugs for effective NCT.

INTRODUCTION

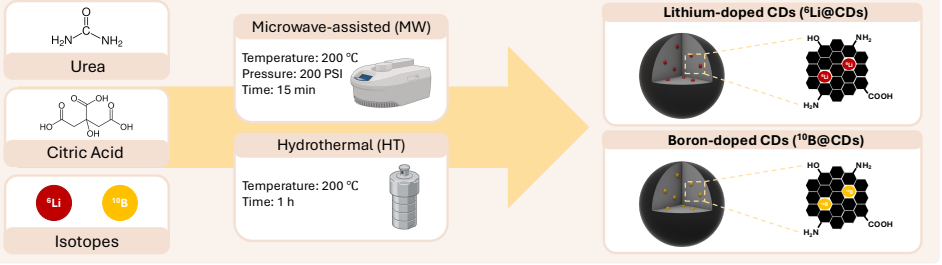
Cancer remains a leading cause of death, with current therapies being inefficient and failing to prevent relapse [1].
Neutron Capture Therapy (NCT) offers a targeted alternative, using neutron-activated isotopes to selectively destroy tumor cells while sparing healthy tissue [2]. While most studies focus on boron (^{10}B), this work stands out by also exploring lithium (^{6}Li) as an alternative isotope for NCT [3]. Carbon dots (CDs) are promising nanocarriers for NCT and adjuvant diagnostics.



AIMS

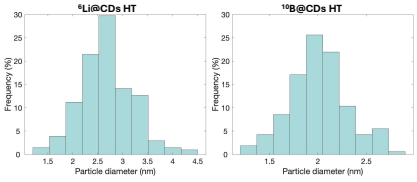
→ Develop boron- and lithium-doped CDs as potential agents for NCT.
→ Optimize isotope incorporation into carbon dots using distinct synthesis parameters and methods: microwave-assisted and hydrothermal.
→ Investigate the cytotoxicity of the engineered carbon dots.

METHODS



RESULTS

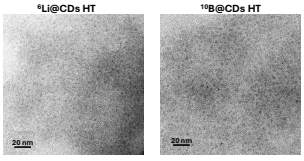
Particle Size Distribution



⁶Li@CDs HT	¹⁰B@CDs HT
MPS = 2.70 nm	MPS = 2.01 nm

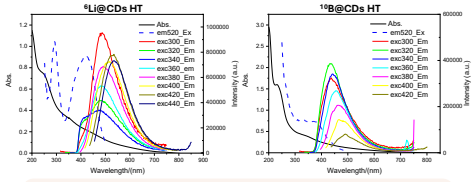
Mean particle size (MPS)

TEM



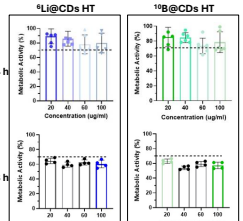
→TEM images revealed spherical CDs with uniform morphology and well-defined edges.
→CDs exhibited a narrow size distribution.

Fluorescence analysis



→Emission peaks at 475 and 550 nm suggest the presence of C-N and N-H covalent bonds, likely associated with surface functional groups contributing to the CDs photoluminescence behavior.

Cytotoxicity studies



Human fibroblast cell line (MRC-5)

After 24 h, metabolic activity remained **above 70%** for both ^{6}Li and ^{10}B@CDs.

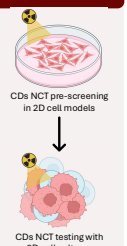
Increasing concentrations (20–100 µg/mL) **did not induce a dose-dependent cytotoxic effect.**

CONCLUSIONS & FUTURE DIRECTIONS

CDs SYNTHESIS
- High photoluminescence quantum yield (PLQY)
- High concentration of ^{6}Li or ^{10}B isotopes

BIOCOMPATIBILITY
- High metabolic activity after 24 h
- Unchanged metabolic activity with increasing CDs concentration

WHAT IS NEXT?
- Neutron irradiation testing of CDs
- Assessment of cytotoxicity following neutron irradiation



References:

[1] F. Bray et al., "Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries," CA Cancer J Clin, vol. 74, no. 3, pp. 229–263, May 2024, doi: 10.3322/caac.21834.
[2] F. Wu et al., 2Nanocarrier-driven neutron capture therapy: Strategies and perspectives", Acta Biomater, Jul. 2025, doi: 10.1016/j.actbio.2025.07.009.
[3] G. Gonçalves et al., "Lithium halide filled carbon nanocapsules: Paving the way towards lithium neutron capture therapy (LiNCT)," Carbon N Y, vol. 208, pp. 148–159, May 2023, doi: 10.1016/j.carbon.2023.03.034.

Aknowlegements:

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New Frontiers in Mechanical Engineering

Optimizing Electron Beam Welding for Circular Copper Pipe Joints

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Abstract

Next-generation heat pump and HVAC systems require compact, leak-proof copper joints produced using low-carbon, automation-ready methods. Vacuum Electron Beam Welding (EBW) meets these criteria; however, copper's exceptional thermal conductivity (401 W/m-K) limits the process window when welding circular copper pipes. This research presents a significant breakthrough: by introducing circumferential preheating and continuously adjusting the beam current and travel speed during rotation, the process window is expanded, resulting in fully fused, leak-tight joints. Experimental results confirm that optimized parameters (9.5 mA at 55 °/s) consistently produce leak-tight welds. This advancement broadens the applicability of EBW for copper pipe welding in heat pumps, advancing the development of more reliable, energy-efficient HVAC manufacturing that meets next-generation sustainability and performance standards.

Acknowledgments

The present study was developed in the scope of the Project "Agenda ILLIANCE" [C644919832-00000035 | Project nº 46], financed by PRR – Plano de Recuperação e Resiliência under the Next Generation EU from the European Union, and had laboratory support from the Centre for Mechanical Technology and Automation (TEMA), project UID/00481.

Introduction

Copper's exceptional thermal conductivity (401 W/m-K) nearly ten times that of stainless steel creates a paradox: the very property that makes it ideal for energy systems also renders it extraordinarily difficult to join. Traditional welding methods struggle with copper: arc welding causes excessive heat distortion; resistance welding yields unpredictable results; and laser welding is hindered by copper's high reflectivity. These limitations lead to leak-prone joints, which are unacceptable for critical applications. EBW offers a compelling solution by delivering concentrated energy that penetrates copper's high thermal conductivity. Additionally, its vacuum environment prevents oxidation, producing precise, narrow welds with minimal heat-affected zones. This research addresses the final challenge in copper EBW the dynamic thermal evolution during circumferential welding by developing adaptive strategies that transform static parameters into responsive solutions for high-performance thermal management systems.

Result and Discussion

Initial electron beam welding (Fig. 1 & Fig. 2) trials were conducted by varying only the welding current and speed while keeping all other EBW parameters constant. Tests were performed at 9 mA and 55 °/s, and at 10 mA and 60 °/s. The samples welded at 9 mA and 55°/s (Fig. 3) showed promising visual fusion in scanning electron microscopy (SEM) analysis. EDS analysis confirmed predominant copper composition (97.85% mass, 91.98% atomic) with minimal oxygen presence (2.15% mass, 8.02% atomic), attributed to surface oxidation (Fig. 4).

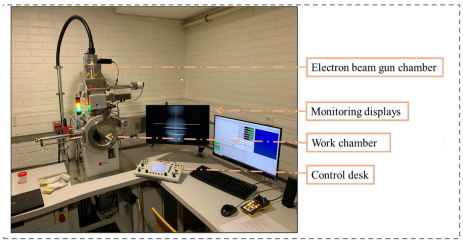


Fig 1 Electron beam welding set-up

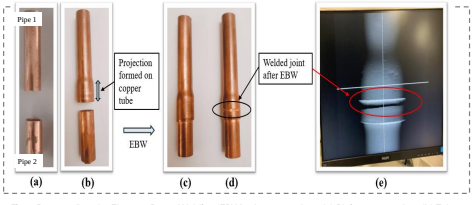
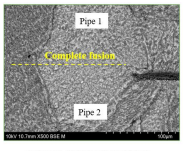
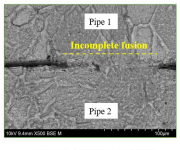


Fig 2. Process flow for Electron Beam Welding (EBW) of copper tubes; (a) Plain copper tubes (b) Tubes after projection forming for alignment (c) Assembled samples prior to welding (d) Copper tubes after EBW showing the welded region (e) Radiographic image showing the weld profile after EBW.



a) Sample 1, welded at 9.5mA and 55°/s



b) Sample 2, welded at 10mA and 60°/s

Fig 3. SEM Images of welding zone for sample 1 and sample 2.

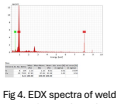


Fig 4. EDX spectra of weld zones (9.5 mA and 55 degree per second)

However, all samples failed subsequent leak testing. Metallographic examination of the 9 mA and 55 °/s samples (Fig. 5) revealed the underlying cause: analysis of four circumferential zones showed incomplete fusion in zones 1 and 2, while zones 3 and 4 exhibited complete fusion, indicating inconsistent heat distribution during the welding process. Implementing circumferential preheating with the same 9 mA and 55° /s parameters successfully produced fully fused (Fig. 6) , leak-tight joints by establishing more uniform thermal gradients throughout the welding zone. Additionally, a dynamic current control approach was developed by maintaining all parameters, including welding speed, constant but systematically varying the beam current starting at 13 mA and progressively decreasing to 11 mA, 8 mA, and finally 7 mA for each 90 ° segment, which effectively compensated for the increasing material temperature during rotation (Fig. 7). Both approaches successfully produced leak-tight joints by precisely managing heat input throughout the process, overcoming copper's challenging thermal conductivity. Current research continues to refine these promising techniques for industrial implementation in next-generation HVAC systems.

Conclusion

This research presents a practical framework for geometry-dependent process optimization in copper EBW by implementing adaptive thermal management strategies. By employing circumferential preheating and zone-specific dynamic current control, the study effectively addresses uneven heat distribution in circular joints, overcoming the challenging thermal properties of copper. The methodology facilitates scalable automation through digital control integration, supporting the transition to high-efficiency HVAC manufacturing essential for achieving building sustainability targets.

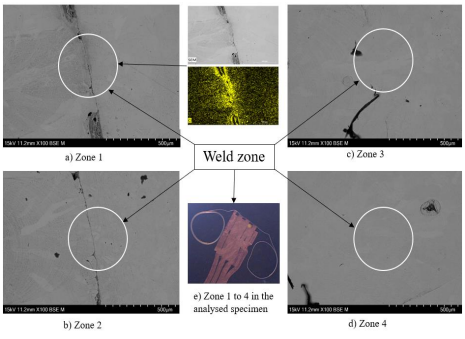


Fig 5. Analysis of 9.5 mA and 55 °/s welding zones of a circular copper pipe divided into four uniform zones (Zone 1 to Zone 4).

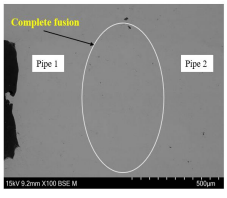


Fig 6. Samples welded by EBW with chamber preheating (9 mA and 55 °/s.)

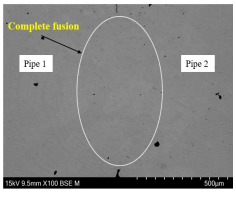


Fig 7. Samples welded by EBW with varying beam current, where the beam current ranges from 13 mA to 7 mA.

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New Frontiers in Mechanical Engineering

Adhesive-Free Joining of Commodity Thermoplastics to Low-Density Foams

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Abstract

The increasing demand for lightweight polymeric structures in industries such as automotive, aerospace, and packaging has intensified the search for efficient and sustainable joining technologies. Conventional adhesive bonding methods, while widely used, often rely on toxic chemicals and require long curing times, which can hinder productivity and environmental compliance. Laser transmission welding (LTW) has successfully joined commodity and engineering thermoplastics [1,2]. This study investigates the feasibility of using laser welding as a solvent-free, rapid alternative to bond a commodity thermoplastic to a low-density polymeric foam. Joining these without adhesives poses a challenge due to their dissimilarities. Laser welding experiments were performed with systematic variation of parameters, aiming to optimize the joint strength while preserving the structural integrity of the materials. The resulting joints were characterized using shear lap testing, scanning electron microscopy, x-ray microtomography, infrared spectroscopy and physicochemical polymer analysis to assess mechanical performance, interfacial adhesion, and thermal damage. Preliminary findings demonstrate that adequate bonding between PP and foam is achievable under carefully controlled processing conditions. Process optimization proved essential to enhancing joint strength while minimizing foam collapse and degradation. These results highlight the potential of laser welding as a clean and efficient joining method for morphologically dissimilar polymeric materials, supporting the development of more sustainable manufacturing processes.

Acknowledgements

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Materials & Methods

LTW is achieved using an overlap joint, where a near-infrared beam passes through the laser transmissive part (polypropylene - PP) and is absorbed by the absorbent component (polyethylene foam – PE), and heat is conducted to the transmissive component, melting at the interface, which then cools and bonds the materials.

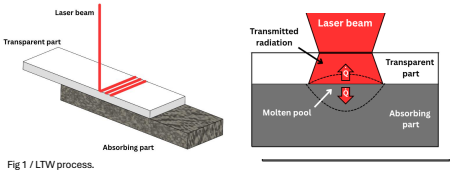

Fig 1 / LTW process.

A 200 W ytterbium-doped fiber laser with a 1070 nm wavelength was used, and pressure was applied between the materials to guarantee the heat conduction between them. The design of experiments covered a power range of 40-100 W and a scanning velocity between 400-2400 mm/s.

The samples were joint with a 15 x 5 (mm^2) weld interface, the same dimensions as the foam section to simplify data treatment of the mechanical results. The results are in N/mm, as the interface thickness varies as the power input changes.

To characterize the materials and the joints, the following analyses were performed:

- Shear lap tests at 10 mm/min.
- Differential Calorimetry Scanning (DSC) and Thermogravimetric analysis (TGA) at 30-200ºC and 30-600ºC, respectively, at a heating rate of 10ºC/min under a N_2 atmosphere.
- Raman spectroscopy using a green, 532 nm wavelength laser with 2 mW power was used, focusing on PE foam interface degradation and PP surface defects.
- Optical, scanning electron microscopy (SEM – 10kV) and X-ray microtomography (MicroCT).

Results

Three types of failure were noticed (Fig 2):

1. Complete interfacial detachment (at 23.75% of occurrence): there is no joining;
2. Failure at the joint (at 16.875% of occurrence): local defects caused by excessive energy input compromised the bond, failing at the interface but leaving some residue.
3. Foam failure far from the joint (at 58.75% of occurrence): excellent joint strength was achieved.

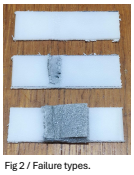

Fig 2 / Failure types.

Fig 4 presents the strength of the welded samples, per power level. The foam base material strength (0.890±0.031 N/mm) was achieved for a wide range of process conditions.

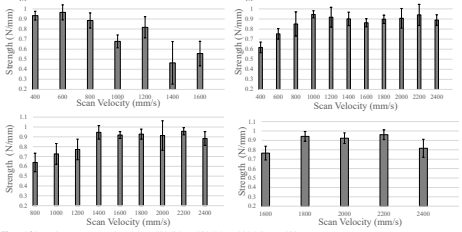

Fig 3 / Shear lap tests results. (a) 40 W; (b) 60 W; (c) 80 W; (d) 100 W.

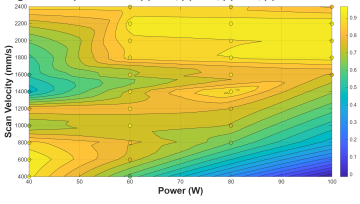

Fig 4 / Strength (N/mm) contour map.

The DCS and TGA results (Table 3) gives a better an understanding on the range of temperatures (169 – 428 ºC) capable of melting both materials before decomposition. This data is also used to better understand the morphological changes shown in SEM and Micro-CT analysis.

Table 5 / DSC and TGA results

	T_{cc} (ºC)	H_{cc} (J/g)	X_{cc} (%)	T_m (ºC)	H_m (J/g)	T_d (ºC)
PP	131.3	79.5	34.9	168.8	72.3	428.3
PE	96.4	61.4	23.2	108.8	68.2	456.5
	Crystallinity			Melting		Decomposition

Raman spectroscopy results (Fig 6) show how degradation, represented as the baseline increase, is associated with using high energy inputs. For other welded samples and regions, the curves approach the base material level.

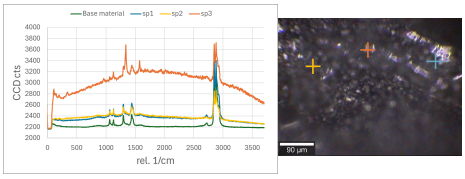

Fig 6 /Raman results for the PE Foam in the interface region (80 W- 1000 mm/s).

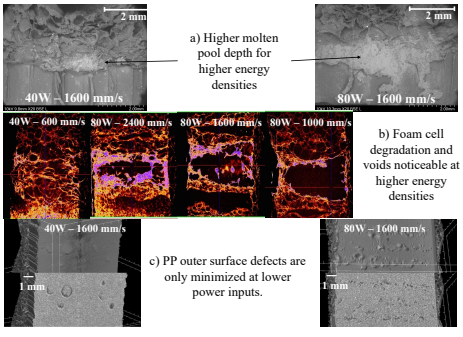

Fig 7 / a) SEM micrographs; Micro-CT images - b) PE Foam; c) PP surface layer on top, and internal cross section below.

Conclusions

Process parameters optimisation made it possible to obtain excellent joints between morphologically dissimilar thermoplastics. An innovative joining solution is presented for a clean and efficient joining method for morphologically dissimilar polymeric materials, supporting the development of sustainable manufacturing processes. Overall:

- Optimal conditions were found across various parameter combinations, demonstrating the flexibility and industrial potential.
- PP surface defects were found across the parametric window, being less noticeable in low power input.
- The cell foam degradation increases at high power, decomposing the material structure.
- Low power favours surface and foam structural quality, while higher powers allow higher scanning velocities and faster processing.

References

[1] Pereira, A.B., Fernandes, F.A.O., Morais, A.B., Quintão, J., "Mechanical Strength of Thermoplastic Polyamide Welded by Nd:YAG Laser", Polymers, 11, 1381, 2019.

[2] Fernandes, F.A.O., Pereira, A.B., Guimarães, B., Almeida, T., "Laser Welding of Transmitting High-Performance Engineering Thermoplastics", Polymers, 12, 402, 2020.

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New Frontiers in Mechanical Engineering

Experimental Investigation of Filler Metal Delivery Methods in Induction Brazing of Copper Tubes for Heat Pump Manufacturing

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Abstract
Induction brazing is a key joining method in HVAC and heat-pump manufacturing, offering localized heating and reduced distortion compared with traditional torch brazing. This study investigates the influence of filler metal delivery methods by comparing conventional pre-placed rings with a novel automatic wire-feeding technique. Experiments were performed on copper pipes at 710 °C, 750 °C, and 800 °C with varied gap sizes. Joint quality was evaluated using macrographic analysis, defect segmentation with a YOLOv11 algorithm, tensile tests, and SEM/EDS characterization. Results show automatic feeding reduced defect area and improved filler spread, while optimal mechanical performance was achieved at 750 °C.

Introduction
Induction brazing is an advanced joining process widely applied in HVAC and heat-pump manufacturing due to its ability to deliver localized heating, minimize thermal distortion, and improve energy efficiency compared with conventional torch brazing. Despite significant research on filler alloy composition and process parameters, limited attention has been given to the influence of filler delivery methods on joint quality. In industrial practice, filler rings are commonly used but are often associated with incomplete penetration and localized porosity. This study explores an alternative approach using automatic wire feeding, aiming to reduce defects and enhance process reliability. A comparative investigation highlights how feeding methods affect defect formation, filler distribution, and overall joint performance.

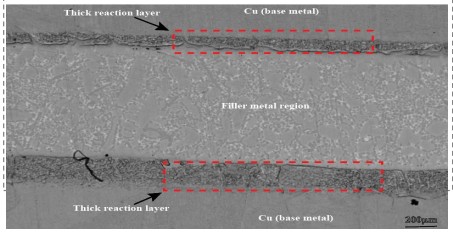
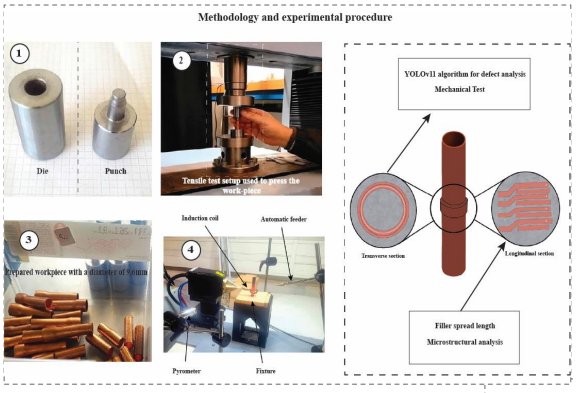


Fig 1. SEM image of a copper joint brazed at 800 °C, showing thick reaction layers at the filler–base metal interfaces.

Result and discussion
Microstructural analysis (Figure 1) revealed that brazing at excessive temperature of 800 °C promoted the formation of thick reaction layers at the filler–copper interfaces, indicating intermetallic growth and potential microstructural degradation. Tensile testing (Figure 2) confirmed the mechanical integrity of both feeding methods, with maximum strengths of 140 MPa for the ring method and 125 MPa for automatic feeding, all failing in the base metal. The effect of brazing temperature on defect area (Figure 3) showed a clear reduction with increasing temperature, with automatic feeding consistently producing fewer defects across all conditions. Similarly, the effect of gap size (Figure 4) highlighted that ring-fed samples were more sensitive to wider gaps, whereas automatic feeding maintained lower defect areas, confirming its advantage for robust and repeatable joint quality.

Conclusion
This study demonstrated that filler metal delivery method plays a critical role in determining the quality of induction-brazed copper joints. The automatic wire-feeding technique consistently reduced defect areas, particularly at wider gap sizes, while the pre-placed ring method achieved slightly higher tensile strength but was more prone to porosity and incomplete penetration. Optimal results were obtained at 750 °C, which provided a balance between defect minimization, filler spread, and joint integrity. Overall, automatic wire feeding offers greater process flexibility and reliability, making it a promising alternative for high-quality, repeatable brazed joints in HVAC and heat-pump manufacturing.



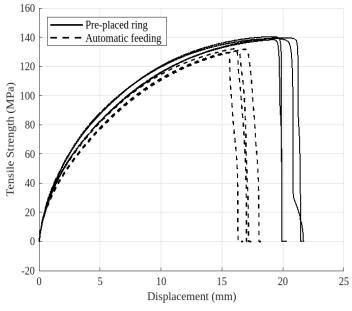


Fig 2. Tensile strength of brazed joints with different filler feeding methods.

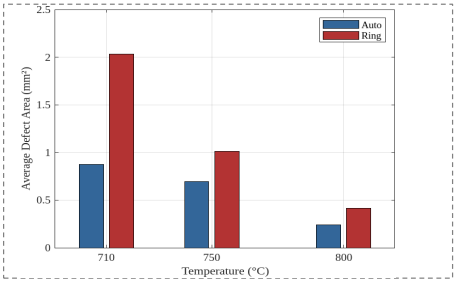


Fig 3. Effect of brazing temperature on average defect area.

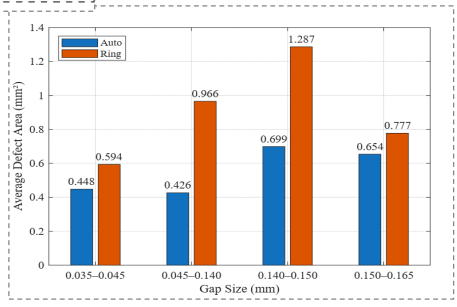


Fig 4. Distribution of defects across various gap sizes.

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New Frontiers in Mechanical Engineering

Sustainable product engineering through modular architecture:

a framework integrating human centered design and life cycle assessment

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Abstract

The increasing pace of mass production and technological advancements has led to shorter product life cycles, increasing resource use and waste [1]. Modular product development offers a sustainable solution by dividing products into interchangeable modules, enabling customization, scalability, maintenance, and reduced waste [2,3]. However, traditional modularization methods often overlook user needs and environmental impacts [4,5]. This research proposes an integrated modular product development framework combining conventional approaches with human-centered design and life cycle assessment (LCA). By bridging design and engineering, and validating through a modular power transformer case study, the framework aims to enhance sustainability, circularity, and user-focused product customization.

Keywords

Product Architecture; Interdisciplinary; Engineering Design; Human Centered Design; Life Cycle Assessment; Modular Product Development

Acknowledgments

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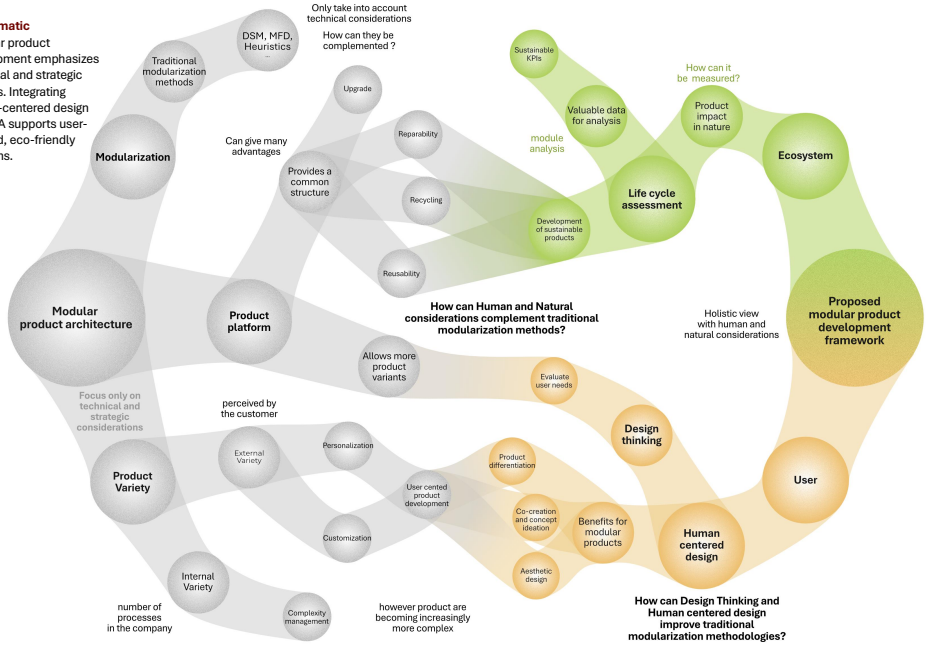
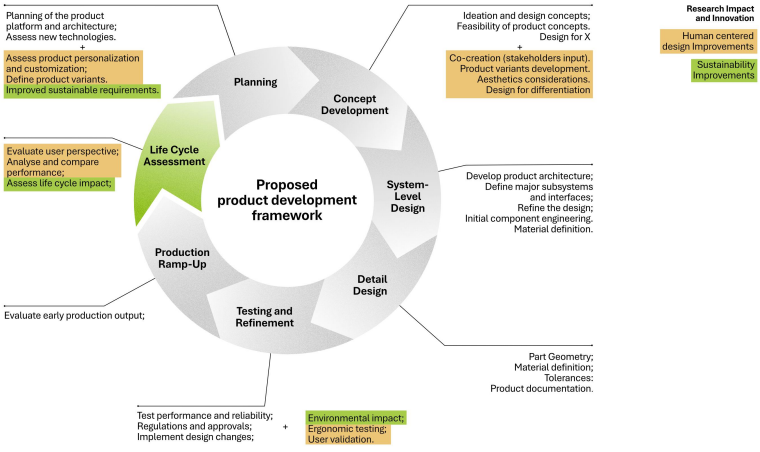
Problematic

Modular product development emphasizes technical and strategic aspects. Integrating human-centered design and LCA supports user-focused, eco-friendly solutions.



Work in development

This research aims to enhance the conventional modular product development process by integrating methodologies such as Design Structure Matrix and Design for Variety with user-centered approaches to identify user needs and requirements. It also incorporates Life Cycle Assessment during the development phase to better identify environmentally harmful modules and propose corrective measures.



References

[1] M. Sonego, M. E. S. Echeveste, and H. Galvan Debarba, "The role of modularity in sustainable design: A systematic review," J Clean Prod, vol. 176, pp. 196–209, Mar. 2018, doi: 10.1016/j.jclepro.2017.12.106.
[2] K. T. Ulrich and S. D. Eppinger, Product Design and Development; Sixth Edition., Sixth edition. USA: McGraw-Hill Education, 2016. [Online]. Available: www.mhhe.com
[3] N. Machado and S. N. Morioka, "Contributions of modularity to the circular economy: A systematic review of literature," Dec. 01, 2021, Elsevier Ltd. doi: 10.1016/j.jobe.2021.103322.
[4] J. Kuechenhof and D. Krause, "Experimental validation of a method for systemic new development," in Proceedings of the International Conference on Engineering Design (ICED23), Bordeaux, France, 24-28 July 2023, Cambridge University Press, 2023, pp. 1765–1774. doi: 10.1017/pds.2023.177.
[5] M. F. A. Abdullah and R. Marshall, "A research overview of industrial design framework for modular product design," in International Design Conference - Design 2010, 2010, pp. 95–104.

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New Frontiers in Mechanical Engineering

Review of Thermomechanical Effects and Simulation of Residual Stress in SLM

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Abstract

Additive manufacturing technologies have been assuming an increasingly relevant role in the industry, driven by the rapid evolution of equipment, raw materials and the increasing accessibility to technology. Among the different processes, Selective Laser Melting (SLM) stands out in the production of functional metal components, characterized by high geometric complexity and dimensional accuracy. However, this process is marked by steep thermal gradients, due to the high heating and cooling rates, which promote the formation of residual stresses. These stresses negatively affect the structural integrity and mechanical performance of the parts, being responsible for the formation of defects at various scales: interstitials at the nano level, microcracks and porosities at the micro level, and delamination, warps or cracks at the macro scale. The formation of residual stresses is strongly correlated with the material, process parameters and boundary conditions. Understanding these relationships is essential to improve the reliability of manufactured components. The present work consists of a systematic review of the literature focused on the thermomechanical effects associated with the SLM process, with a special focus on the prediction and analysis of residual stresses through numerical simulation tools. This review aims to provide a comprehensive overview of the impact of residual stresses on the functional performance of components, while simultaneously addressing existing computational models and the latest advances in this area. The analysis begins with the description of the SLM process, through the identification of the main defects related to residual stresses, to the survey of the current methodological approaches for its modelling and mitigation. An in-depth understanding of these phenomena is essential for the development of more effective control strategies in metal additive manufacturing.

Introduction

The SLM process, characterized by layer-by-layer construction, uses a laser source that melts the metal powder. This process allows to produce highly complex parts in a wide range of materials. Being a process that uses a heat source to melt metal particles into thin layer thicknesses, it gives rise to thermomechanical effects. These thermomechanical effects, mainly caused by high thermal gradients, develop at the macro, micro and sub-micro level successive deformations leading to a final part with high residual stresses. Figure 1 shows the melting of a layer and its deformations and stresses.

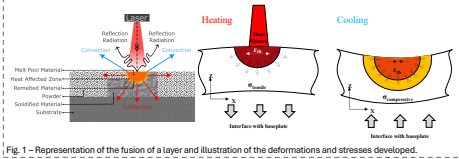
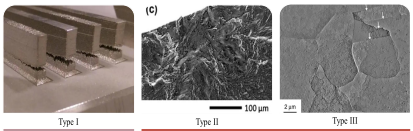


Fig. 1 – Representation of the fusion of a layer and illustration of the deformations and stresses developed.

Residual stresses are classified into three types, type I are macro-scale stresses, type II are micro-scale stresses and type III are sub-micro scale stresses, as represented in figure 2.

Simulation Model

Given the high complexity of the process, there are several research works focus on isolated physical phenomena to better understand the underlying physics involved. Other studies perform macro analysis to obtain a simulation model that returns results that balance the calculation time with the accuracy of the results. Figure 3 shows two flowcharts where variables related to residual stresses are identified, as well as the boundary conditions involved in the thermal problem. Another challenge lies in the validation and calibration of numerical models. Being an expanding area both in the field of research and in the field of application, it is often difficult to obtain data to calibrate the numerical models. For this reason, it is often necessary to add specific experimental activity to the research work to obtain valid data for the calibration and validation of the model. The table 1 describes the studies conducted in the field of residual stresses found in the literature. These studies are stratified by groups of phenomena most studied in this field.



Non-uniform residual stresses accumulated in successive layers result in cracks and/or delamination's, which occur in the part or in the part-base and part-support interface. Excessive deformation often occurs on surfaces with low heat flow and thin walls. These defects are caused by high thermal gradients that cause excessive contractions and expansions, thus deforming the piece.

Type II and Type III are the result of parts with residual self-balancing stresses, i.e. they were formed during manufacturing but did not trigger visible defects. This aspect, however, has a high potential to affect the mechanical properties of materials. During the work cycles of the parts, the residual stresses will be released or distributed, thus leading to micro-cracks that can easily evolve into macro-cracks and even total rupture. Studies show that in parts from the SLM manufacturing process, the main cause of the development of cracks and ruptures during the life cycle of the component is due to the presence of residual stresses. It is also scientifically supported that in some cases, even when post-processing processes are used to reduce residual stresses, fatigue failure exists.

Fig. 2 – Classification of the types of residual stresses existing in metallic materials.

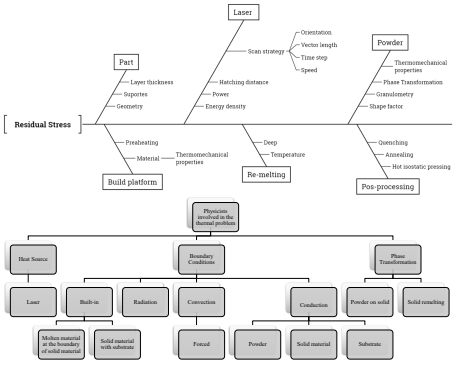


Fig. 3 – Flowcharts of the process variables and boundary conditions of the thermal problem

Tab. 1 – Types of Residual Stress Modelling Studies in SLM.

Analysis	Objective	Outcomes
Thermal Evolution	Study of the thermal gradient in the layer.	Cooling rates influence microstructural formation and in turn affect residual stress formation.
Melting Pool	Study of the size and shape of the molten zone.	It increases with power and decreases with scanning speed.
Process Parameters	Evaluation of power, speed, distance and scanning strategy.	High energy densities – high tensions. Base preheating reduces thermal gradient and residual stresses.
Thermal Boundary Conditions	Analysis of powder, solid and substrate conductivity, convection and radiation, as well as the embedding of the part in the substrate.	Thermal dissipation on the substrate and powder-solid interface conditions are critical for reliable results.
Model Scale	Comparison between micro (melting pool) and macro (complete part with global distortion analysis)	Micro-scale models are detailed and applied in the analysis of isolated physics. Macro-scale models use simplifications to predict global distortions and stress trends.

Conclusion

Residual stresses in the additive process is a topic of high interest for the scientific community. This is proven by the high amount of research work carried out in this area. It should be noted that the SLM additive process, in addition to being a manufacturing process, is also a metallurgical process, thereby enhancing the physical phenomena occurring in the process.This makes it difficult to design robust and effective simulation models in predicting mechanical properties and residual stresses. However, as soon as the research around this topic can respond and allows for simulation models capable of predicting these properties, it will be possible to produce parts with homogeneous or heterogeneous properties controlled, based on the application needs of the component. The doctoral research aims to investigate the phenomena described and develop a simulation model capable of predicting residual stresses based on process, material and part geometry parameters.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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TEchMA 2025

New Frontiers in Mechanical Engineering

Composites processing PEEK on a gyroid alumina structure using Polymer-infiltrated ceramic network (PICN) process

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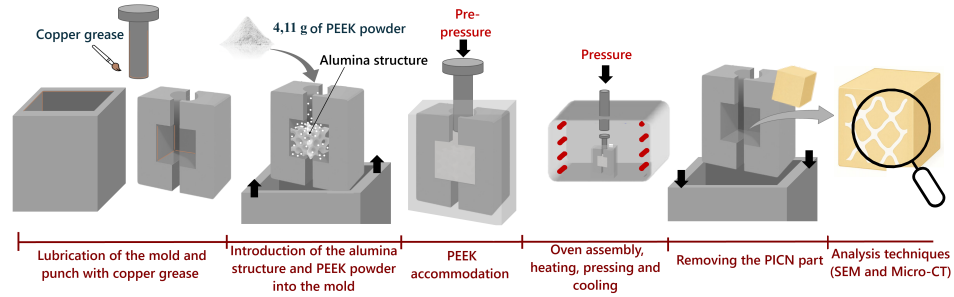
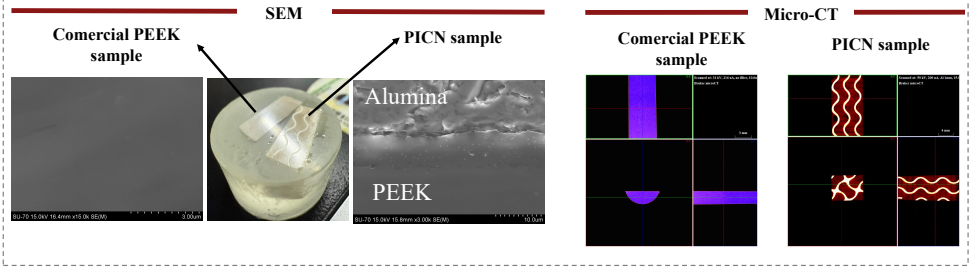
Abstract

This work presents the investigation and development of a hot-pressing system for the manufacturing of high-performance composite materials. The system is designed to optimise the processing of engineering thermoplastics, particularly PEEK (polyether-ether-ketone) infiltrated on digital light processing alumina gyroid structures, using the polymer-infiltrated ceramic network (PICN) process [1, 2], for use in demanding impact applications, as in protective, automotive, and aerospace sectors. The research involved the design, implementation, and validation of an experimental setup capable of simultaneously applying heat, pressure, and vacuum in a controlled and repeatable manner. A series of parametric tests were carried out to assess the influence of different processing conditions on the final quality of the molded parts, with a particular focus on the density and interfacial adhesion of the final parts [3]. The results show that the correct application of temperature and pressure during hot pressing contributes significantly to reducing internal porosity and improving the structural integrity of the parts. Microstructural and dimensional analyses validated the effectiveness of the proposed system, highlighting its potential for future industrial applications in the production of advanced composite components. This work represents a valuable contribution to the advancement of composite forming technologies, via the polymer-infiltrated ceramic network (PICN) process, offering practical solutions to improve product quality and feasible process.

Methodology



Results



Conclusions

- Optimised temperature, pressure and cycle time allowed deeper and more homogeneous PEEK penetration into the gyroid ceramic framework;
- SEM observations confirmed a good level of adhesion at the PEEK/Alumina interface, with no visible interfacial gaps or delamination areas. The polymer phase appeared to have successfully penetrated the porous ceramic structure, filling the gyroid channels effectively.
- Micro-CT scans revealed that the hybrid material achieved good densification, with no significant voids or unfilled regions detected throughout the analysed volume.

References

[1] Zhang, J.; Pou, P.; Hodásová, L.; Yarahmadi, M.; Elizalde, S.; Cabrera, J.-M.; Llanes, L.; Armelin, E.; Fargas, G. Polymer-Infiltrated ceramic network produced by direct ink writing: the effects of manufacturing design on mechanical properties. Ceramics 2024, 7, 436–451. https://doi.org/10.3390/ceramics7020028

[2] Douglas Fabris, Joana Mesquita-Guimarães, Paulo Pinto, Júlio C.M. Souza, Márcio C. Fredel, Filipe S. Silva, Bruno Henriques, Mechanical properties of zirconia periodic open cellular structures, Ceramics International, Volume 45, Issue 13, 2019, Pages 15799-15806, ISSN 0272-8842. https://doi.org/10.1016/j.ceramint.2019.05.010

[3] Benjamin Pomès, Pascal Behin, Laurence Jordan, Stéphane Legoff, Gregory Stoclet, Emmanuel Richaud, Jean-François Nguyen, Influence of polymerization pressure and post-cure treatment on conversion degree and viscoelastic properties of polymer infiltrated ceramic network, Journal of the Mechanical Behavior of Biomedical Materials, Volume 115, 2021, 104286, ISSN 1751-6161. https://doi.org/10.1016/j.jmbbm.2020.104286

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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New Frontiers in Mechanical Engineering

ISO 9001 Certification: Ensuring Quality Excellence at the Mechanical Testing Laboratory

L. Rocha (lrocha@ua.pt), R. Beja, A. Bastos

Abstract

This work presents an overview of the implementation of a Quality Management System (QMS) within a laboratory at a Higher Education Institution, highlighting its benefits and its role in enhancing operational efficiency, service quality, and risk mitigation - ultimately leading to higher customer satisfaction. To this end, the Mechanical Testing Laboratory (LEM) will be presented as a case study. Located within the Department of Mechanical Engineering (DEM) at the University of Aveiro (UA) and integrated into the Centre for Mechanical Technology and Automation (TEMA), LEM's mission is to perform mechanical tests - tensile, compression and bending - for students, researchers, and external clients.

Six key processes have been identified within LEM's activities, and their performance has been monitored using the following tools: 1) the definition of specific targets and corresponding key performance indicators, including the number of essays performed, service requests and the overall customer count; 2) satisfaction surveys (targeting both staff and customers).

The ISO 9001 certification, combined with LEM's commitment to excellence, has ensured the consistent delivery of reliable and robust results to its users. This sustained dedication has played a vital role in helping TEMA and DEM in aligning their policies and objectives, as well as allocating the necessary resources to maintain LEM's ISO 9001 certification.

ENTIDADE CERTIFICADA

eiC ISO 9001 Qualidade

1. Contextualization

ISO 9001 is an international standard that establishes guidelines for implementing a Quality Management System (QMS) aimed at enhancing an organization's effectiveness and customer satisfaction. In 2019, the **Mechanical Testing Laboratory** (LEM) achieved its **certification** in accordance with the normative requirements of **NP EN ISO 9001:2015** (Fig 1).

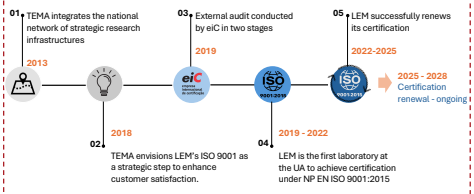
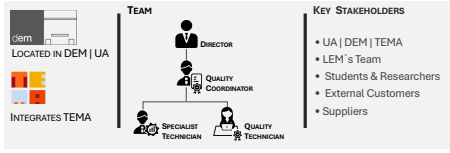


Fig 1. LEM certification process timeline.

2. LEM's Mission, Team & Stakeholders



LEM: the aim of this laboratory is to **perform tensile, compressive** and **bending mechanical tests**, using for that 4 machines and 2 video extensometers (Fig.2).

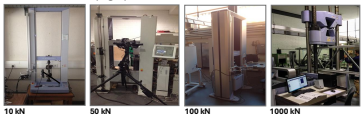
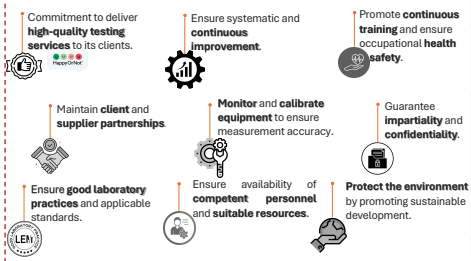


Fig 2. LEM's mechanical testing machines.

3. Quality Policy

The quality policy aims to implement and uphold a system aligned with NP EN ISO 9001 standard. For LEM, quality means:



4. LEM's Processes and Monitoring Tools

LEM undertakes a variety of activities, structured into **six identified processes**, which are interconnected as illustrated in Fig 3.

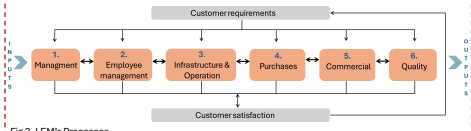


Fig 3. LEM's Processes.

Each process:

- Has defined inputs, outputs, supporting documentation and an assigned lead.
- Is monitored to assess its efficiency to control risks and maximize opportunities.

Process effectiveness is continuously monitored by:

- No. of essays performed | No. Service requests | Customer volume
- Satisfaction surveys (staff and customers)
- Others

5. Monitoring

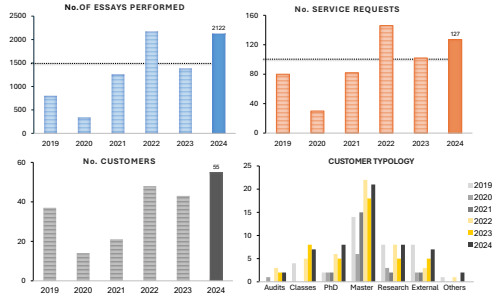


Fig 4. Performance key indicators of the LEM between 2019 and 2024.

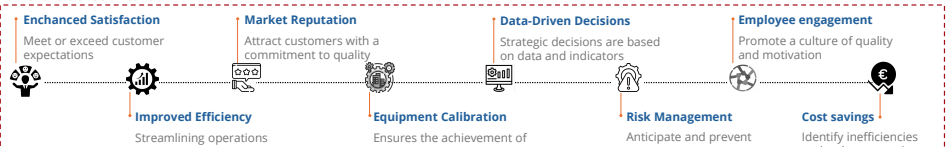
In 2024:

- No. Essays: **2122** (indicator > 1500)
- No. Services: **127** (indicator >100)
- No. Thesis: **8 PhD | 21 MSc** (indicator >15)
- No. External customers: **7** (indicator >3)

Other indicators in 2024:

- Health: **0** accidents
- No. of Complaints: **0**
- Staff Satisfaction Surveys : **3.81** (out of 4.00)
- Customers Satisfaction Surveys : **4.00** (out of 4.00)
- No. Opportunities for Improvement: **17** (indicador >7)

6. Beneficts of Certification



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New Frontiers in Mechanical Engineering

Multiscale analysis of fused filament fabrication 3D printed CNT/PLA nanocomposites

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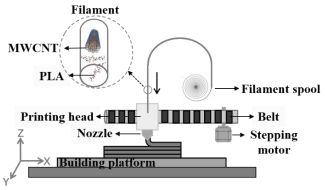
Abstract

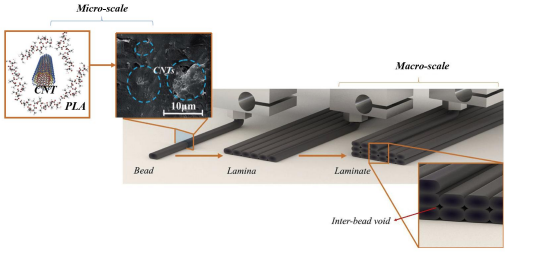
Additive Manufacturing (AM), also known as 3D printing, have been showing significant advantages on raw materials saving, fast operation, and customized geometries for complex structure components [1]. Adding nanomaterials such as carbon nanotubes to host matrices via AM technologies has the potential to enable greater capabilities in 3D printed parts production. The design and analysis of 3D printed parts is a key challenge in the field of AM. The final properties of 3D printed parts differ from those of the materials fabricated by traditional manufacturing methods, due to their anisotropy, internal void array and infill design. Anisotropy and internal voids are mainly due to variation in the mesostructure, which is produced while the part is fabricated by deposition of material layer upon layer. In the present work, a multiscale analysis of fused filament fabrication 3D printed CNT/PLA nanocomposites was developed. In macroscale, homogeneous FEM model and model considering internal void array were built. It is expected that with more accurate modeling, the later model showed closer numerical results to experimental results than the homogeneous one. However, the accurate modeling also takes more consumption, which could not be extended to complex and large-scale engineering cases. In mesoscale, the mesostructure of layers of the printed parts was considered for finite element modeling of the representative volume element (RVE), and to determine their elastic moduli. The mechanical behaviors of the printed parts are governed by the constitutive behavior of the material. The constitutive material modeling of the printed parts using numerical homogenization procedure is emphasized in this work. The elastic moduli of the present method accurately characterized the mechanical behavior of printed parts using laminate theory. Since the filler chosen in the present work is CNT, which cannot be characterized in mesoscale model, therefore, nanoscale modeling considering geometry and distribution of CNT was also carried out. The effect of CNT walls, CNT numbers, curvature, wave numbers, wave direction of CNT on elastic moduli of nanocomposites. In summary, the multiscale computational models provided more insights on the final properties of 3D printed parts for different materials, representing an important step towards enabling the effective design and analysis of 3D printed structures using both experimental investigation and computational methodology.

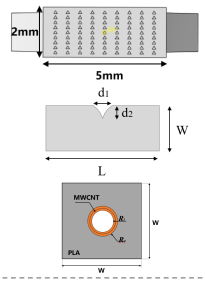
Introduction

- Additive Manufacturing (3D printing) show significant potential for raw materials saving, fast operation, and customized geometries;
- Nanocomposites attract researchers and industry due to their potential combination of properties from both the nanofillers and the host matrix;
- The marriage of nanomaterials and AM offer new opportunities to each other;
- 3D printed nanocomposites presents variable features in different scales;
- Multiscale modeling , including macroscopic, mesoscopic and nanoscopic modeling can give comprehensive numerical analysis for 3D printed nanocomposites.

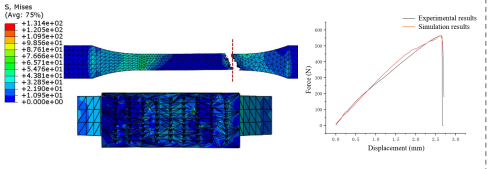


Materials and methods

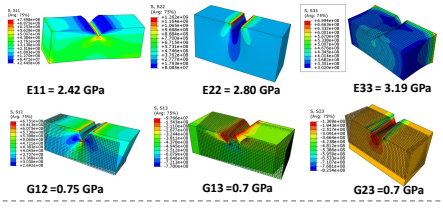




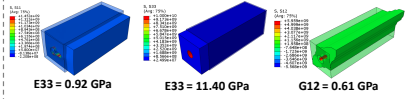
Macroscale modeling



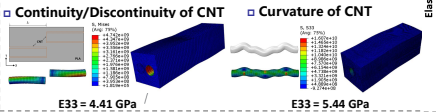
Mesoscale modeling

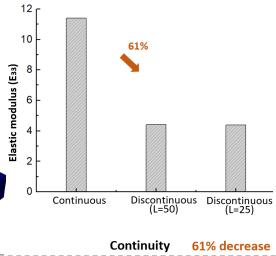


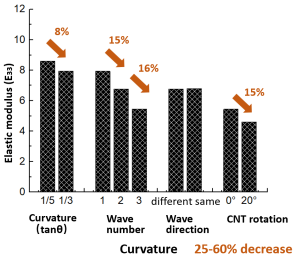
Nanoscale modeling



Reason why CNT/PLA RVE showed 3 times higher E_{33}:







Conclusion

- Multiscale modeling of 3D printed parts via FFF was developed;
- Macroscale: FEM model considering internal void arrays showed more accurate results but also higher consumption than homogeneous model;
- RVE can be used to predict the effective constitutive relations of parts with periodic architectures;
- Microscale: Discontinuous and curvature of CNT showed significant effect on mechanical properties of nanocomposites.

ACKNOWLEDGMENTS

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New Frontiers in Mechanical Engineering

SMART Mould@Footwear

André Quintã [a, b, c], Ricardo Torcato [a, d, e], Paulo Lima [a, b, c, e], José Martinho Oliveira [a, d, e]

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(b) Centre for Mechanical Technology and Automation (TEMA), University of Aveiro
(c) Intelligent Systems Associate Laboratory (LASI)
(d) Aveiro Institute of Materials (CICECO), University of Aveiro
(e) EMaRT Group—Emerging: Materials, Research, Technology, School of Design, Management and Production Technologies Northern Aveiro, University of Aveiro
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Abstract

The footwear market is seeing a surge in demand for personalized products, which creates production challenges due to the need for numerous, constantly evolving sole moulds. This project, **SMARTMould@Footwear**, addresses these issues by leveraging additive manufacturing (3D printing) and automation. Through the development of hybrid moulds with evolutive cavities that can produce various sole sizes and models, it will significantly reduce the quantity of moulds needed. This approach, complemented by real-time quality monitoring and robotics, aims to create a more sustainable, flexible, and efficient footwear manufacturing process, cutting down on design time, costs, and raw material consumption.

Project Co-Promoters

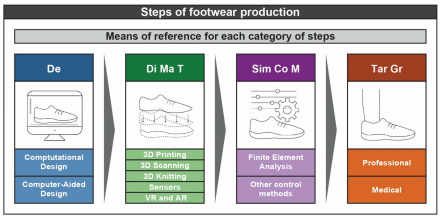
Context

Portuguese footwear: quality, exports

Challenges: labour shortages, fast fashion competition

Alignment: sustainable modular moulds

Benefits: fewer moulds, rapid customisation



Firtikiadis et al., 2024 doi.org/10.3390/designs8030049

Hybrid Evolutionary Moulds

Adaptable: sizes, models

Efficient, rapid customisation

Reduce waste and energy

Soft and hard tooling

Increased production flexibility

Fernando Ferro & Irmão www.m-tec.pt

Additive Manufacturing

Complex geometries

Reduced material waste

Enables rapid prototyping

Key for hybrid mould components

Supports customisation and unique designs

Optimises weight, performance

ESAN-UA www.ua.pt/pt/esan

Direct injection process

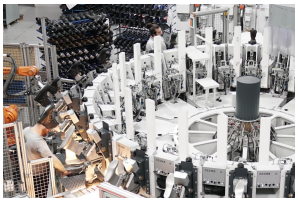
Integrates sole directly

Eliminates gluing, stitching

Automated mould processes

Faster, unified production

Core for evolutive moulds



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Smart Tooling Exchange

Robotics for Mould Adaptability

Integrated Automated Production

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This work is supported by SmartMould - COMPETE2030-FEDER-01435800 and project CICECO-Aveiro Institute of Materials, UIDB/50011/2020 (DOI 10.54499/UIDB/50011/2020), UIDP/50011/2020 (DOI 10.54499/UIDP/50011/2020) & LA/P/0006/2020 (DOI 10.54499/LA/P/0006/2020), financed by national funds through the FCT/MCTES (PIDDAC).

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New Frontiers in Mechanical Engineering

Piezoelectric PLLA-based fibrous scaffolds for myocardial regeneration

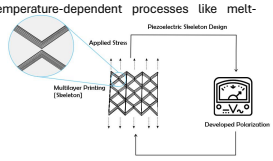
Luís Nascimento, Gavin Richardson, André Pereira, Mateus Marta, Paula A. A. P. Marques, Priscila Melo, Nathalie Barroca**

Abstract

- Within cardiovascular diseases, four out of five fatalities occur due to heart attacks and strokes.
- After myocardial infarction, cardiac tissue undergoes physiological and molecular changes in response to injury, leading to gradual loss of function.
- Current implantable smart piezoelectric devices are composed of non-degradable materials (PZT, PVDF) requiring post-surgery removal.
- Poly-L-lactic acid (PLLA) represents an excellent biodegradable and safe alternative.
- In this work, we explored the potential of different e-field assisted techniques to produce piezoelectric PLLA-based nano and micro fibrous patches.

The Problematic

- Cardiovascular diseases stand as the foremost catalyst behind mortality, taking approximately **17.9 million lives** (approximately 32.7% of mortalities worldwide.
- Current regenerative techniques explore injectable hydrogels and **cardiac patches.** Existing FDA-approved patches primarily serve as supportive materials, lacking inherent regenerative capacities.
- Leveraging electro-mechanical stands as a promising biomimetically approach. However, processing piezoelectric materials into fibrous-based structures has been restricted to electrospun mats. Over the **last 2 years**, advances on electrohydrodynamic printing have allowed printing several synthetic and natural polymers, avoiding temperature-dependent processes like melt-electrowritting.



Aims and Objectives

- Explore electrospinning and electrohydrodynamic printing to produce piezoelectric PLLA-based nano and micro-fibrous patches;
- Assess structural, physico-chemical, and piezoelectric properties of the produced platforms;
- Pre-assess adhesion and cytocompatibility of the manufactured platforms.

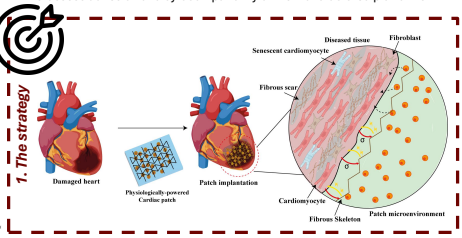


Fig 1. Schematic representation of the aim of the work. Utilizing piezoelectric actuation, an *in situ electrical* stimulation can be used to improve cardiac regeneration post-myocardial infarction.

Results and Discussion

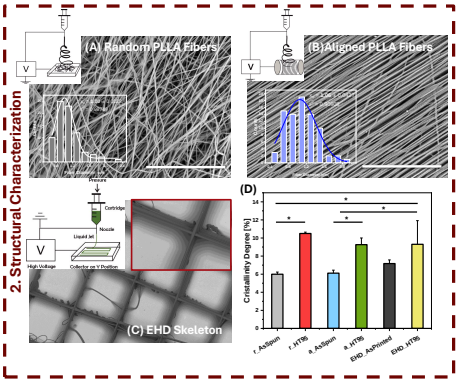


Fig 2. Structural characterization of produced PLLA platforms. Scanning electron microscopy images of electrospun random (A) and aligned (B) mats and electrohydrodynamic printed square shape skeleton (C). Scale bar 50 µm. Crystallinity degree (D) assessed using differential scanning calorimetry (DSC).

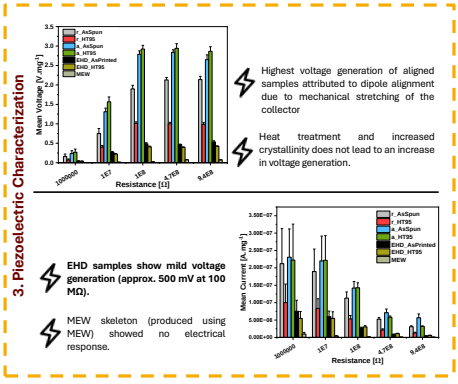


Fig 3. Mean voltage (top) and current (bottom) outputs for the different fibrous platforms produced. Voltage and current were assessed using an in-house-made impact testing. Impact was done at a frequency of1.6 Hz.

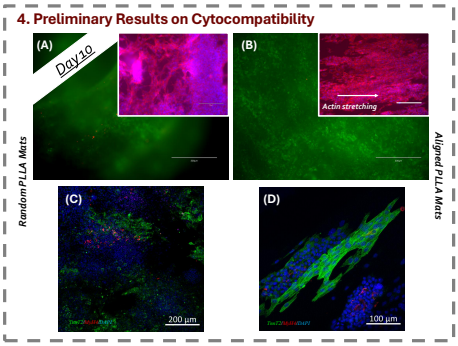


Fig 4. Preliminary cellular results on HL-1 cells seeded on electrospun mats. Live/Dead imaging at day 10 on random PLLA (A) mats and aligned mats (B) showing cell colonization (high number of live cells stained in green). Insets represent DAPI (blue) and actin (red) stain at day 10. Bottom images showcase immunofluorescence images of HL-1 cells in random and aligned mats. Cells were immunolabeled for troponin I (green), myosin heavy chain (red) and Dapi (Blue).

Main Conclusions

- *EHD was successfully used to print a PLLA-based ink, enabling fabrication of different architectures.*
- *EHD skeletons electrical generation hints chain alignment during fiber stretching.*
- *Aligned electrospun mats exhibit highest voltage generation. However, the geometric diversity achieved in EHD can provide a better match towards heart mechanical necessities.*
- *Initial cytocompatibility show HL-1 adhesion, proliferation and expression of cardiac markers.*

Future Perspectives

- *Cytocompatibility screening on EHD structures.*
- *Bioreactor adaptation for uniaxial actuation*
- *Cellular senescence studies*

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA). Luís Nascimento thanks FCT for the Ph.D. grant (10.54499/2023.01401.BD). This work was supported by the project Flexobone 2022.02424.PTDC, supported by the Foundation for Science and Technology, in its State Budget component (OE), DOI: 10.54499/2022.02424.PTDC

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New Frontiers in Mechanical Engineering

In situ plasticization for continuous extrusion of starch-based foams: toward scalable production of biodegradable materials

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Abstract

Plastic pollution and environmental regulation are driving demand for scalable, biodegradable materials like thermoplastic starch (TPS). While TPS foams are used in niche applications, broader adoption is hindered by processing and performance challenges. This study explores an *in-situ* plasticization strategy for continuous TPS foam extrusion using a twin-screw extruder, a volumetric feeder, and peristaltic pump. Water–glycerol mixtures were used as plasticizers, while sodium bicarbonate acted as a blowing agent. A design of experiments assessed the effects of screw design and plasticizer composition on starch processability and foaming behavior. Results reveal a narrow processing window: water-rich plasticizers promoted expansion but reduced melt strength, leading to cell collapse; glycerol-rich blends enhanced stability but suppressed foaming. Ongoing work focuses on optimizing formulations for scalable production of lightweight, bio-based foams.

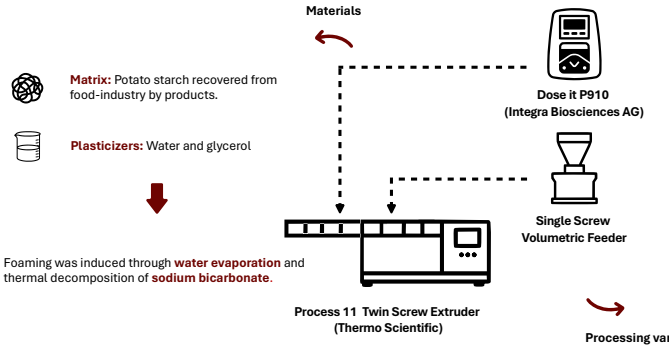
Framework and hypothesis

- **Foamed plastics** are major contributors to plastic pollution.
- Thermoplastic starch (TPS) is a **natural polymer** that is **renewable** and **biodegradable**.
- However, its **difficult processability** and **lack of funcional properties** limit its broader utilization.
- This study explores whether ***in-situ* plasticization** improves TPS **processability** and **foaming behavior** under **continuous extrusion**.

Objectives

- Develop an *in-situ* extrusion strategy for converting **native starch** into **extruded foam** using a twin-screw setup.
- Systematically investigate **key process parameters** including **screw design** and **plasticizer composition**.
- Identify formulation–process combinations that enable starch processing, promote foam expansion, and support **scalable sustainable manufacturing**.

Methodology



Controlled variables:

Starch-to-plasticizer ratio was fixed at 70:30 by adjusting liquid flow, dry starch feeder, and screw speed.

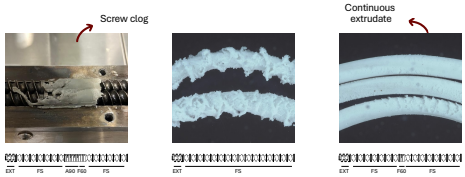
Temperature profile was 120 ºC (die), 95 ºC (liquid injection), and 75 ºC (starch feeding).

Independent variables:

Screw configuration was varied from "standard", to "all-forward" and "gentle mixing".

Plasticizer composition of 100:0, 70:30, 50:50, 30:70, and 0:100 water-glycerol were considered.

Results



Standard | **All-forward** | **Gentle mixing**

Standard screw configuration for twin-screw compounding led to screw clogging due to high restrictive mixing zone.

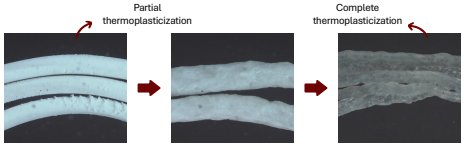
Extrusion **without mixing zones** led to a non-homogeneous extrudate due to incomplete mixing.

Including smaller, but targeted mixing zones was key to achieve a **continuous extrudate**.

FS = Feed screw, A90 = Neutral mixing, F60 = Medium mixing, F30 = Minimal mixing, EXT = Discharge

Glycerol-plasticized starch did not fully plasticize, while using **water** as a plasticizer led to a continuous, transparent material.

*Open discharge; **Slit die



Glycerol-plasticized | **Water-plasticized*** | **Water-plasticized****

Conclusions

- ***In situ* starch plasticization** and foaming is achievable via twin-screw extrusion.
- **Screw design** and **plasticizer composition** strongly influence **starch plasticization**.

Future work

- Implement acquisition and analysis of **processing metrics** (torque, die pressure) to guide formulation and process development.
- Optimize **plasticizer ratio** and **feed conditions**.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project UID/00481 – Centre for Mechanical Technology and Automation (TEMA) and CICECO – Aveiro Institute of Materials (UIDB/50011/2020, UIDP/50011/2020, and LA/P/0006/2020). FCT is also acknowledged for the CMC's PhD grant with ref. 2021.01412.BD (DOI 10.54499/2023.01412.BD) and by the Individual Call to Scientific Employment Stimulus (IG, DOI 10.54499/CEECIND/00430/2017/CP1459/CT0032).

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TEchMA 2025

New Frontiers in Mechanical Engineering

Effect of Polymer Reprocessing on the Bending Behaviour of Thermoresponsive multi-material 4D Printed Structures

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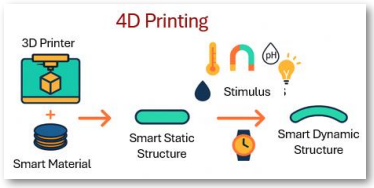
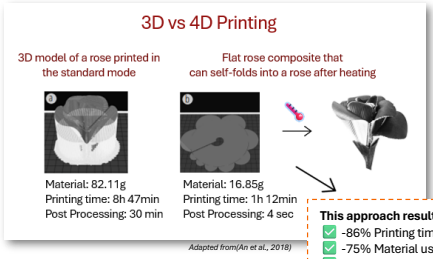
(a) - Department of Mechanical Engineering; Centre for Mechanical Technology and Automation (TEMA), University of Aveiro

Abstract

4D printing combines additive manufacturing with stimuli-responsive materials to create structures that evolve over time in response to external stimuli. When combined with thermoplastics such as Polylactic Acid (PLA) and Thermoplastic Polyurethane (TPU), this technology enables the fabrication of lightweight, low-cost, and programmable mechanisms capable of shape transformation without external actuators. It holds strong potential in areas such as soft robotics, biomedical devices, deployable structures, and smart textiles. The intelligent behaviour of these systems is typically encoded during printing, through geometric design, material selection, spatial distribution, and printing parameters, and later activated by stimuli like heat. Despite significant progress in functional development, the use of reprocessed polymers remains underexplored. Most studies rely on virgin materials, limiting the understanding of how material history may influence actuation behaviour. Reprocessed polymers can exhibit altered mechanical, thermal, and viscoelastic properties, potentially affecting the time-dependent performance of shape-morphing structures. This work investigates how reprocessing affects curvature behaviour in PLA/TPU bilayers produced by Fused Deposition Modelling (FDM). Virgin and reprocessed filaments, obtained by grinding and re-extruding printed parts, are used to fabricate bilayer strips. Samples are subjected to a constant thermal stimulus and their curvature evolution is tracked via image analysis. Mechanical testing will assess tensile properties, thermal analysis will detect transition changes, DMA will probe viscoelastic performance, and melt-state rheology will characterise flow behaviour. It is expected that reprocessed materials will show reduced curvature and slower actuation due to degradation. However, this study also considers whether these changes can be exploited to design alternative actuation profiles. Ultimately, it aims to broaden the understanding of how material history affects 4D printing performance and inform new material-driven design strategies for shape-morphing systems.

Background and Motivation





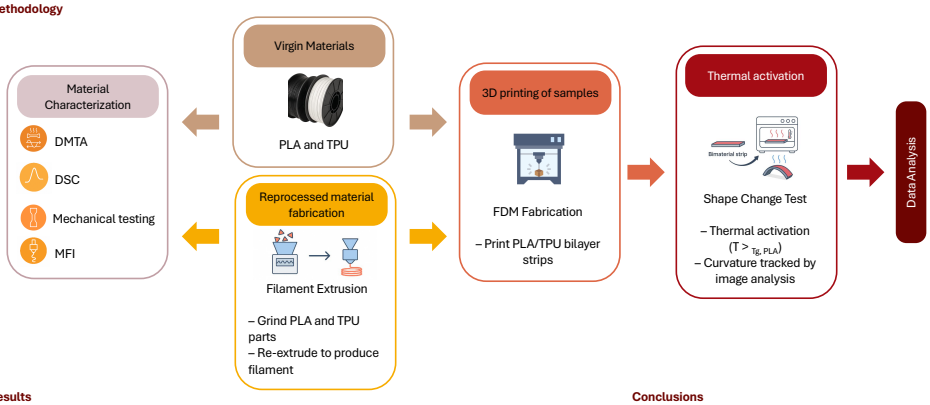
Plastic production is expected to increase in the coming years, with **recycled plastics gaining greater prominence**. As such, it is crucial to understand their properties and assess how they can be effectively integrated into functional products *(Plastics Europe 2025)*.

Objectives

Goal: Demonstrate that recycled materials can support programmable shape change in 4D printing

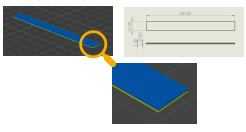
- **Evaluate the impact of material reprocessing**
  Assess how PLA and TPU reprocessing affects the functional behaviour of 4D printed structures
- **Characterize thermal and mechanical properties**
  Investigate the thermal, mechanical, and viscoelastic behaviour of the materials through standard characterization techniques
- **Compare curvature and actuation time**
  Quantify the differences in shape transformation and response delay between virgin and reprocessed PLA/TPU bilayers
- **Determine shape-change capability**
  Test if reprocessed materials retain the ability to respond predictably under thermal stimulation

Methodology



Results

1st Step- Sample parametrisation and fabrication



Printing parameters
Printing temperature PLA: 220 °C
Printing temperature TPU: 240 °C
Layer height: 0.1mm
Printing speed: 60mm/s
Bed temperature: 55°C

2nd Step - Quality assessment

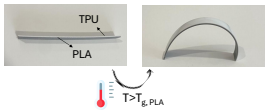
Visual and qualitative assessment

Evaluation of inter-material adhesion (PLA/TPU interface)

Assessment of intra-material lateral adhesion (within each material)

No visible delamination or major defects observed

3rd Step - Thermal activation



Conclusions

- **4D printing enables the creation of volumetric structures from compact, flat prints**, reducing material usage, printing time, and post-processing.
- Initial tests confirm that **PLA and TPU can be printed together with good adhesion and show consistent bending** when exposed to heat, demonstrating the feasibility of programmable behaviour.
- Although still in early stages, this work sets the foundation for **exploring the use of reprocessed materials in shape-morphing systems, combining functional design with circularity**.

References

An, B., Tao, Y., Gu, J., Cheng, T., Chen, X., Zhang, X., Zhao, W., Do, Y., Takahashi, S., Wu, H. Y., Zhang, T., & Yao, L. (2018). Thermorph: Democratizing 4D printing of self-folding materials and interfaces. Conference on Human Factors in Computing Systems - Proceedings, 2018-April. https://doi.org/10.1145/3173574.3173834

Plastics Europe. 2025. "The Plastics Transition." Retrieved July 23, 2025 (https://plasticseurope.org/changingplasticsforgood/the-plastics-transition/).

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TEchMA 2025
New Frontiers in Mechanical Engineering

Tensile and flexural characterizations of biaxial non-crimp fabric composites for sustainable, two-wheeled electric vehicle chassis

G. Constantinescu, A. Horovistiz, S. T. A. Shah, J. P. O. Santos, A. M. de B. Pereira, J. P. Alves, L. Salomé, M. J. de S. Henriques

Abstract

The rising demand for sustainable automotive materials has driven research into renewable composite solutions. This study evaluates the tensile and flexural properties of biaxial non-crimp fabric (NCF) laminates—carbon fibre (post-cured for 4 h and 10 h), glass fibre, and flax (linen)—intended for lightweight two-wheeled electric vehicle chassis applications. Mechanical tests followed ISO 527-4 for tension and ISO 14125 for flexure, with full-field strains recorded via 3D Digital Image Correlation (GOM ARAMIS) during tensile tests. Carbon-fibre laminates exhibited superior properties; the 10 h post-cured samples reached tensile strengths of approximately 1.13 GPa, a Young's modulus of 60 GPa, and notably low Poisson's ratio (0.038). Their flexural strength and modulus were around 696 MPa and 43 GPa, respectively. Reducing cure duration to 4 h decreased tensile and flexural strengths to about 0.85 GPa and 633 MPa, highlighting cure time as critical to stiffness and strength. Glass-fibre laminates provided balanced, cost-effective performance, with tensile strengths near 351 MPa, a modulus of 17 GPa, and flexural strengths around 350 MPa, combined with substantial mid-span deflections (16.7 mm). Flax laminates, despite lower tensile strengths (~102 MPa), showed excellent ductility, with tensile rupture strains near 2% and flexural deflections exceeding 11 mm, ideal for energy-absorbing, non-critical structural areas. The findings confirm that both synthetic and natural fibre-based NCF composites can effectively replace conventional metallic components, delivering significant weight reduction and sustainability benefits. Future research will focus on fatigue performance, environmental ageing, and life-cycle assessment to further support their integration into durable, circular mobility solutions.

1. Introduction & State-of-the-art

Biaxial non-crimp fabric composites—leveraging carbon, glass and flax fibres—emerge as lightweight, high-performance and eco-friendly chassis materials that reconcile mechanical demands with sustainability goals for next-generation two-wheeled electric vehicles.

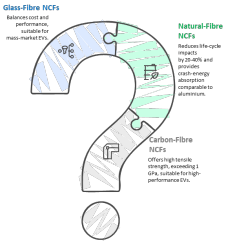

Figure 1. Which NCF material should be used for lightweight EV chassis?

2. Materials & Methods

Three ±45° biaxial non-crimp-fabric laminates—300 g m^{-2} carbon, 300 g m^{-2} glass, and 422 g m^{-2} flax—were vacuum-infused; carbon and glass fabrics used low-viscosity Biresin CR83 epoxy, while flax used 38 % bio-based InfuGreen 810. After room-temperature cure (24 h), panels were post-cured (carbon 70 °C × 4 or 10 h; glass 70 °C × 10 h; flax 80 °C × 8 h), sawn into adequate (tabbed) specimens of standard sizes, and mechanically tested. Tensile tests (ISO 527-4, 2 mm min^{-1}) and three-point bending tests (ISO 14125, 5 mm min^{-1}, 80 mm span) were performed on Shimadzu frames/machines, with full-field 3-D strain captured by GOM ARAMIS in the case of the tensile tests. The derived/calculated properties included Young's and flexural moduli, tensile and flexural strengths, Poisson's ratio, rupture strain, maximum deflection, and flexural strain at break.

3. Results & Discussions

Table 1. Calculated tensile and flexural properties (mean values) of the different composite laminates.

Property	Carbon 10H	Carbon 4H	Glass	Linen (Flax)
Poisson's Ratio	0.038	0.071	0.062	0.134
Young's (Tensile) Modulus [GPa]	60	59	17	6
Tensile Stress at Failure [MPa]	1126.25	852.40	351	102
Tensile Strain at failure [%]	1.765	1.448	1.561	2.025
Flexural Stress at Failure [MPa]	696	633	350	133
Flexural Modulus [GPa]	43	41	18	8
Maximum Deflection at Failure [mm]	8.56	9.014	16.704	11.606
Flexural Strain at Failure	0.01752	0.017104	0.031757	0.037332

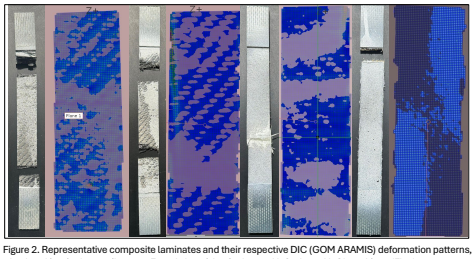

Figure 2. Representative composite laminates and their respective DIC (GOM ARAMIS) deformation patterns, after breaking, in the tensile tests. From left to right: Carbon 10H, Carbon 4H, Glass, Linen (Flax).

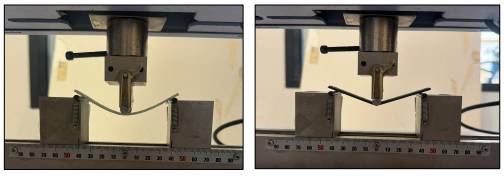

Figure 3. Typical elastic (left) and plastic (right) deformations/behaviour in 3-point bending tests, of/for the different composite laminates.

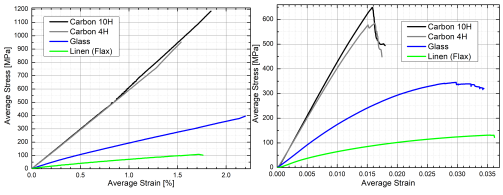

Figure 4. Experimental tensile (left) and flexural (right) stress-strain curves (averaged values) for the 4 different composite laminates.

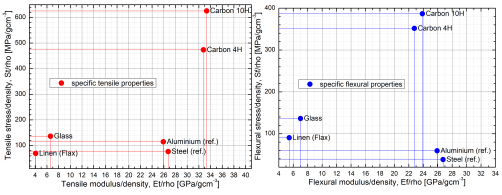

Figure 5. Ashby-type plots for specific tensile (left) and flexural (right) properties of the 4 different composite laminates, together with reference values for steel and aluminium.

4. Conclusions & Future Work

This study highlights the significant potential of biaxial non-crimp fabric (NCF) composites—carbon (post-cured for 4 h and 10 h), glass, and linen (flax)—as sustainable, lightweight materials for two-wheeled electric vehicle chassis. Carbon fibre composites, particularly those post-cured for 10 hours, demonstrated the highest mechanical performance, achieving tensile strengths around 1.13 GPa, flexural strengths of approximately 696 MPa, and superior stiffness properties. Shorter curing times (4 h) notably reduced strength, indicating the critical influence of post-cure duration on mechanical properties.

Glass fibre composites presented a balanced, cost-effective solution with moderate stiffness, strength, and significant deformation capacity. In contrast, flax fibre composites exhibited lower tensile and flexural strengths but showcased exceptional ductility and energy-absorption capabilities, positioning them as ideal candidates for non-critical structural areas that require impact mitigation.

Future work proposes to explore fatigue resistance and environmental ageing to ensure long-term performance and reliability. Comprehensive life-cycle assessments will also be conducted to further quantify the sustainability and circular economy advantages, underpinning broader adoption of these advanced composites in electric mobility solutions.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).
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New Frontiers in Mechanical Engineering

Compressive and shear behaviour of novel non-crimp fabric composites for sustainable and lightweight electrical mobility

G. Constantinescu, A. Horovistiz, S. T. A. Shah, J. P. O. Santos, A. M. de B. Pereira, J. P. Alves, L. Salomé, M. J. de S. Henriques

Abstract

The transition to lightweight electric-vehicle (EV) chassis demands composites with well-characterised compressive and in-plane shear responses. We investigated biaxial non-crimp fabric (NCF) laminates reinforced with carbon fibre (post-cured for 4 h and 10 h), glass fibre, and flax (linen) following ISO 14126 and ISO 14129 standards. Carbon laminates exhibited superior compressive performance: the 10 h cure achieved a modulus of 49 GPa and a strength of 367 MPa, while a shorter 4 h cure unexpectedly enhanced both modulus (54 GPa) and strength (377 MPa), suggesting moderate post-curing optimises matrix–fibre bonding without causing embrittlement. Glass laminates offered moderate performance (25 GPa modulus, 263 MPa strength), and flax laminates provided exceptional ductility, enduring four to five times more compressive strain (≈4.6%) at lower modulus (6 GPa) and strength (74 MPa), ideal for energy-absorbing applications. Shear testing reinforced these findings, with carbon laminates reaching shear strengths of 70–78 MPa, shear moduli around 3.7–3.8 GPa, and large failure strains (24–29%), making them suitable for complex load scenarios. Glass laminates matched carbon stiffness (3.8 GPa) and achieved a shear strength of 73.5 MPa, proving a cost-effective structural alternative. Flax laminates, with a shear modulus of 1.6 GPa and strength of 29.8 MPa, are limited to deformation-tolerant areas but add valuable compliance and ecological benefits. Overall, the results affirm carbon and glass-fibre NCF composites as viable candidates for demanding EV chassis components, while flax composites effectively address sustainability and ductility requirements in non-critical areas.

1. Introduction & State-of-the-art

Electrified mobility hinges on lightweight primary structures that preserve stiffness, crashworthiness and circularity. Biaxial non-crimp fabrics (NCFs) are increasingly favoured because their straight, minimally crimped tows let designers tailor fibre orientation with high volume fractions while retaining good drape—an advantage over traditional woven plies. Previous work has firmly established their tensile and flexural credentials for two-wheeled electric-vehicle (EV) frames, with carbon-NCF laminates exceeding 1 GPa tensile strength and 43 GPa flexural modulus, glass-NCF offering balanced cost-performance, and flax-NCF delivering unmatched ductility for energy-absorbing zones.Yet an EV chassis is governed by compressive column loads and multi-axial shear paths (e.g., steering head, battery box nodes) where failure is dominated by micro-buckling and matrix shear. Benchmark data remain scarce: for comparable lay-ups, literature reports carbon-NCF compressive strengths of ≈ 370 MPa (modulus ≈ 50 GPa) and in-plane shear strengths of 70–78 MPa (G_{12} ≈ 3.7–3.8 GPa); glass-NCF reaches ~260 MPa and 73 MPa respectively, while flax-NCF, although limited to ~74 MPa compression and 30 MPa shear, tolerates ≥ 4 % strain before failure.ISO 14126 and 14129 standardise these measurements, but design allowables integrating sustainability aspects (bio-epoxy matrices, end-of-life valorisation) are still absent. Against this backdrop, the present study delivers the first cohesive compressive–shear data-set for carbon, glass and flax NCF laminates cured under industrially relevant cycles, providing immediate input for finite-element models and life-cycle-oriented material selection of next-generation EV chassis..

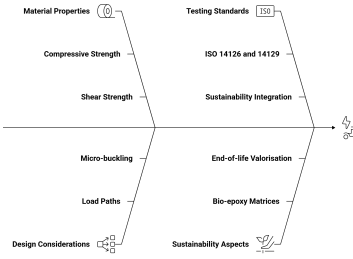

Figure 1. Challenges in NCF laminate application for EV chassis

2. Materials & Methods

Table 1. Combinations of reinforcements and matrices studied.

Reinforcement origin	Reinforcement	Matrix
Synthetic	Carbon	Biresin® CR83 + Biresin® CH83-2
	Glass	Biresin® CR83 + Biresin® CH83-2
Natural	Linen (Flax)	SR InfuGreen 810 + SD8824

Table 2. Laminates produced for specimen production.

Type of fibre	Dimensions (mm)	Ply thickness (mm)	N° of plies	Lay-up	N° laminates
Carbon	350 x 300	0.4	6	$[0^\circ,90^\circ]_{3S}$	2
Glass		0.3	8	$[0^\circ,90^\circ]_{4S}$	1
Linen (Flax)		0.8	4	$[0^\circ,90^\circ]_{2S}$	1
Carbon	300 x 300	0.4	6	$[45^\circ,45^\circ]_{3S}$	2
Glass		0.3	8	$[45^\circ,45^\circ]_{4S}$	1
Linen (Flax)		0.8	4	$[45^\circ,45^\circ]_{2S}$	1
Carbon	300 x 150	0.4	12	$[0^\circ,90^\circ]_{6S}$	2
Glass		0.3	14	$[0^\circ,90^\circ]_{7S}$	1
Linen (Flax)		0.8	6	$[0^\circ,90^\circ]_{3S}$	1

Table 3. Post-cure cycles used on the different composite materials.

Material	Post-cure Cycle			
	Heating rate (°C/min)	Temperature (°C)	Time (h)	Cooling rate (°C/min)
Carbon	0.2	70	4	N.C. (1)
Carbon	0.2	70	10	N.C. (1)
Glass	0.2	70	10	N.C. (1)
Linen (Flax)	0.2	80	8	N.C. (1)

(1) N.C. - Not controlled. To prevent distortions during the cooling stage, steel plates were placed on top of each laminate.

3. Results & Discussion

Table 4. Calculated compressive and shear properties (mean values) of the different composites

Property	Carbon 10H	Carbon 4H	Glass	Linen (Flax)
Modulus of Elasticity in Compression [GPa]	49	54	25	6
Maximum Compressive Stress at Failure [MPa]	367	377	263	74
Maximum Compressive Strain at Failure [%]	0.865	0.84	1.21	4.56
Maximum Shear Stress at Failure [MPa]	32.8	33.5	26.5	14.8
In-Plane Shear Modulus, G_{12} [GPa]	3.8025	3.68	3.8025	1.618
Maximum Shear Stress at Failure, $\tau_{12,max}$ [MPa]	73.5	77.5	73.5	29.8
Maximum Shear Strain at Failure, $\gamma_{12,max}$ [%]	24.595	28.91	9.5875	5.26
Maximum Shear Stress at Shear Strain γ_{12} = 0.05 [MPa]	45.75	46	62.5	29.2

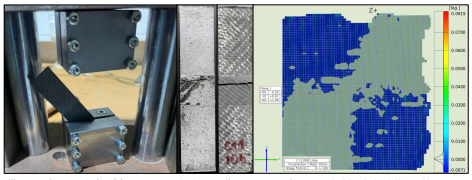

Figure 2. Custom-built, ISO 14126 standard-compliant compression setup holder (left), followed by a typical composite laminate sample (both sides) and its respective digital GOM ARAMIS deformation pattern, after testing.

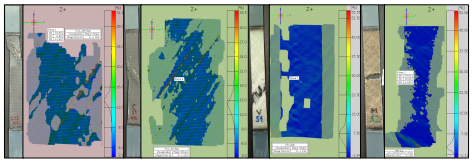

Figure 3. Representative composite laminates and their respective DIC (GOM ARAMIS) deformation patterns, after breaking, in the shear tests. From left to right: Carbon 10H, Carbon 4H, Glass, Linen (Flax).

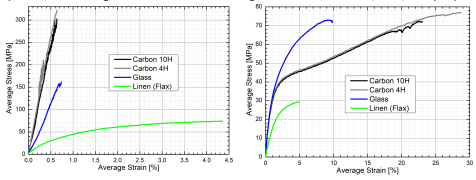

Figure 4. Experimental compressive (left) and shear (right) stress-strain curves (averaged values) for the 4 different composite laminates.

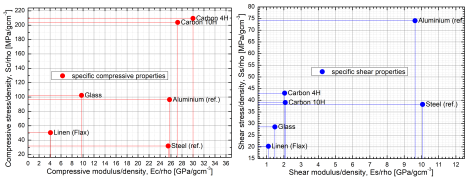

Figure 5. Ashby-type plots for specific compressive (left) and shear (right) properties of the 4 different composite laminates, together with reference values for steel and aluminium.

4. Conclusions & Future Work

The performed compressive and shear tests confirm that biaxial NCF laminates can be assigned clear structural roles: carbon- and glass-fibre systems deliver the compressive (E ≈ 49–54 GPa; $\sigma_{c,max}$ ≈ 263–377 MPa) and in-plane shear stress ($\tau_{12,max}$ ≈ 73–78 MPa; G_{12} ≈ 3.7–3.8 GPa) required for load-bearing EV-chassis members, while flax composites, though far weaker ($\sigma_{c,max}$ ≈ 74 MPa; $\tau_{12,max}$ ≈ 30 MPa), accommodate up to five-fold higher failure strains and thus suit energy-absorbing zones. A shorter 4 h post-cure even sharpens carbon performance without harming shear ductility, suggesting that moderate thermal cycles optimise the fibre–matrix interface. This new compressive–shear data set therefore supplies immediate design specs for finite-element models and material selection in lightweight electric mobility. Future work proposes to couple these findings with fatigue, impact and hygrothermal ageing studies, explore hybrid carbon–flax or glass–flax lay-ups for graded stiffness–ductility, and integrate life-cycle and recyclability assessments to validate the composites' circular-economy promise.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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New Frontiers in Mechanical Engineering

From ride data to carbon credits: a LCA-based mobile solution for sustainable EV usage

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Abstract

Electrified micro-mobility can substantially support Sustainable Development Goals (SDGs), yet robust, user-level evidence of its impact remains limited. This study presents a life cycle assessment (LCA) workflow, developed in SimaPro and integrated into a cross-platform mobile app (MariaBike), that quantifies real-time carbon savings of a prototype two-wheeled electric vehicle (EV), translating these savings into verifiable carbon credits. Telemetry data from IoT sensors, GPS, and MQTT messaging are combined with ISO 14040/44-compliant inventory data covering manufacturing, energy use, and end-of-life stages. The MariaBike app visualises emission reductions compared to internal combustion vehicles, providing transparent carbon-credit issuance and behavioural insights. The solution advances multiple SDGs by promoting active, low-emission travel (SDG 3), clean energy use (SDG 7), and new income streams via carbon markets (SDG 8). Its modular, interoperable architecture fosters innovation and sustainable infrastructure (SDG 9), while validated location-based tracking supports equitable transportation access (SDG 10) and enhances urban sustainability planning (SDG 11). Real-time LCA integration encourages responsible consumption patterns aligned with SDG 12. Comparative results confirm that e-bikes emit up to 88% less CO_2-e per kilometre than average European cars, generating approximately 0.001–0.002 carbon credits per typical urban trip. By combining rigorous LCA methods with mobile technology, the MariaBike app provides a scalable blueprint for data-driven sustainability in electric micro-mobility.

1. Introduction & State-of-the-art

Electrified micromobility is praised as a low-carbon alternative, yet most LCAs stop at manufacturing averages. They ignore real-world charging mixes, rider behaviour and end-of-life credits. The MariaBike pilot closes that gap by fusing ISO 14040/44-compliant LCA with live IoT telemetry, turning every ride into a verifiable carbon-credit stream. Prior studies prove e-bikes emit up to 88 % less CO_2-eq km^{-1} than European cars, but none has delivered a turnkey app that quantifies (and monetises) those savings in real time.

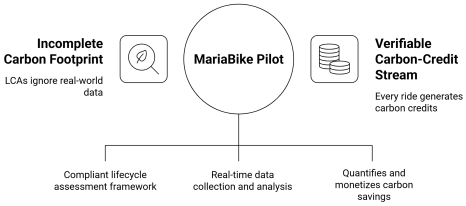

Figure 1. Real-time micromobility carbon credit stream concept.

2. Methodology & Workflow

- **Functional unit** — One shared MariaBike e-moped operated for 20 000 km;
- **System boundary** — Full cradle-to-grave coverage: raw-material extraction → manufacture → ocean & road freight → charging with the Portuguese medium-voltage grid (57 % RES) → end-of-life recycling credits;
- **Inventory build** — 300-row bill-of-materials (BoM) mapped to ecoinvent 3.9; key masses in Table 1;
- **Impact assessment** — ReCiPe 2016 Mid- & End-point (H) inside SimaPro;
- **Telemetry bridge** — GPS + wheel-RPM → distance; INA226 current sensor → Wh; MQTT/JSON payload every 30 s to the LCA back-end;
- **Carbon-credit logic** — Ride-level ΔCO_2-eq versus EU fleet average (164 g km^{-1}); issuance via Gold-Standard micro-methodology.

Table 1. Major inventoried blocks & curb mass (kg $bike^{-1}$)

Component	Mass
Custom-Made Frame (GFRP)	14.0 kg
Battery (NMC 756 Wh)	6.4 kg
Aluminium (primary + recycled)	7.3 kg
Electronics / wiring / sensors	0.97 kg
Tyres + misc. polymer/steel parts	5.8 kg
*Total curb mass = **29.7 kg**, matching the baseline LCI*	

In the Figure 2 below, you can see the heart of the MariaBike R&D: the on-board sensors capture every ride's distance and energy use via MQTT/JSON, then split the data two ways—one path sends it straight to the carbon-market registry for instant credit issuance, while the other feeds our Flutter app and SimaPro LCA back-end for real-time life-cycle analysis. This unified pipeline ties together our material testing, digital LCA and mobile dashboard into a single, seamless system that turns every urban trip into verifiable carbon savings.

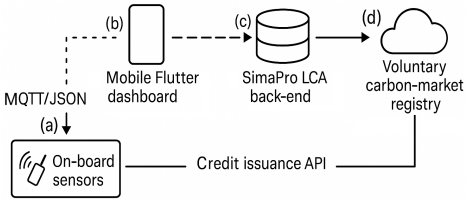

Figure 2. Modular workflow: (a) on-board sensors → MQTT; (b) Flutter dashboard; (c) SimaPro back-end; (d) voluntary-market registry connector.

3. Preliminary Results & Discussions

TelemetryBloc Code

```
// MariaBike Telemetry BLoC: emits MQTT payload every 30s

class TelemetryBloc extends Bloc<TelemetryEvent, TelemetryState> {
  Timer? _timer;

  TelemetryBloc() : super(TelemetryInitial()) {
    on<StartTelemetry>((event, emit) {
      _timer = Timer.periodic(Duration(seconds: 30), (_) async {
        final distance = await Sensors.getDistance();
        final wh = await Sensors.getEnergy();
        final payload = {
          "device_id": event.deviceId,
          "timestamp": DateTime.now().toIso8601String(),
          "distance_km": distance,
          "energy_wh": wh,
        };
        await MqttClient.send("mariabike/lca", jsonEncode(payload));
        emit(TelemetrySent(payload));
      });
    });

    on<StopTelemetry>((event, emit) {
      _timer?.cancel();
      emit(TelemetryStopped());
    });
  }
}
```

Figure 3. MariaBike Flutter application VSC Dart/BLoC code snippet: MariaBike app logic for packaging ride telemetry (distance, Wh) and sending JSON to the LCA server every 30 seconds via MQTT.

Following the Dart/BLoC snippet, the core life-cycle performance of the MariaBike emerges clearly in both tabular and visual form

Table 2. Life-cycle impact metrics per functional unit (one MariaBike, 20 000 km service life).

Impact metric	Total	Production	Use (charging)	Transport	End-of-life credit
GWP$_{100}$ (kg CO_2-eq)	327	231	173	17	−94
Fossil energy (MJ)	4 760	2 950	1 690	240	−120
Single-score (Pt)	1.16 Pt	—	—	—	—

Table 2 shows that over its 20 000 km lifetime, the MariaBike emits 327 kg CO_2-eq, of which 231 kg (71 %) comes from production, 173 kg (53 %) from charging, 17 kg (5 %) from transport, and recycling credits shave off 94 kg (−29 %) at end of life. In energy terms, the bike consumes 4 760 MJ overall—with 2 950 MJ for production, 1 690 MJ for use, 240 MJ for transport and a 120 MJ credit for recycling—and scores 1.16 Pt on the ReCiPe single-score scale.

4. Conclusions & Future Work

In this work we have demonstrated a preliminary, fully integrated R&D pipeline in which ISO-compliant LCA models, live IoT telemetry and a cross-platform Flutter app converge to quantify and monetise real-world carbon savings from a shared MariaBike e-moped, resulting in a 327 kg CO_2-eq footprint over 20 000 km with 0.001–0.002 carbon credits issued per 10 km trip. Our black-box BLoC telemetry module reliably captures distance and energy data via MQTT/JSON, feeds it into SimaPro for cradle-to-grave impact assessment (ReCiPe 2016), and issues verified credits to a voluntary registry. Charging electricity dominates with 53 % of GWP, production hotspots remain in the battery (23 %) and GFRP frame (20 %), and end-of-life recycling recovers nearly 29 % of embodied emissions. Future work will focus on integrating depot PV charging to further cut GWP, extending fatigue-adjusted battery LCAs, implementing blockchain-based credit verification, and piloting user-behaviour feedback loops to drive even greater sustainability impacts.

Used Acronyms:

API – Application Programming Interface; BLoC – Business Logic Component (Flutter state-management pattern); BoM – Bill of Materials; CO_2-eq – Carbon Dioxide Equivalent; EU – European Union; GFRP – Glass-Fibre-Reinforced Polymer; GWP$_{100}$ – Global Warming Potential over a 100-year horizon; H – Hierarchist (default model) in ReCiPe 2016; ISO – International Organization for Standardization; JSON – JavaScript Object Notation; LCA – Life Cycle Assessment; MJ – Megajoule; MQTT – Message Queuing Telemetry Transport; NMC – Nickel-Manganese-Cobalt (battery chemistry); PV – Photovoltaic; Pt – Points (ReCiPe single-score unit); ReCiPe – Life-cycle impact assessment method (2016 Midpoint & Endpoint); RES – Renewable Energy Sources; SDG – Sustainable Development Goal..

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TEchMA 2025
New Frontiers in Mechanical Engineering

Simulation and shape prediction strategies in 4D printing

Tiago Andrade, Mylene S. Cadete, João Dias-De-Oliveira

Abstract

In today's competitive manufacturing landscape, balancing cost and performance is crucial. Additive Manufacturing (AM) offers a path to efficient, functional designs, with four-dimensional (4D) printing emerging as a key innovation [1]. By using materials responsive to external stimuli, 4D printing enables objects to change shape over time, opening new possibilities in adaptive design [2]. Building on this, research into the shape morphing behaviour of 4D-printed objects was conducted through simulation. Based on a literature review, this process can be effectively approached as a thermomechanical problem [3]. Bearing this in mind, this work first simulated the shape morphing of two-layer structures. Multiple parameters were varied through Finite Element Analysis (FEA) to assess both their independent influence and this method's feasibility. The study then analysed the use of orthotropic properties to evaluate control over deformation direction. Finally, insights from these phases were applied to more complex geometries. It is concluded that the printing process can be planned computationally with a thermomechanical approximation, paving the way for the incorporation of the influence of parameters such as printing speed, pattern design and strategic division into active/passive regions. Notably, this approach represents a simplified and first approximation with inherent limitations in simulation fidelity regarding physical behaviour, requiring further future experimental validation and an introduction of numeric models that better reflect the 4D morphing's physics. Nevertheless, this study provides a foundation for future work in 4D printing, especially regarding shape prediction of printed objects.

Thermal stimuli simulation approach

A thermomechanical approach was adopted to simulate – via Finite Element Analysis (FEA) – the shape-shifting behavior of temperature-responsive 4D-printed structures. Instead of replicating every physical aspect of the FDM printing process, the chosen approach models shape morphing as a mechanically driven deformation problem resulting from internal stress imbalances. These stresses emerge due to mismatches in thermal expansion coefficients and stiffness between bonded material layers when subjected to a uniform temperature increase.

Firstly, the modeling process began with simplified bilayer beam geometries, chosen for their clarity and computational efficiency. These structures enabled controlled parametric studies, isolating the influence of key variables on the morphing response. Parameters such as the coefficient of thermal expansion (CTE), Young's modulus, activation temperature, layer thickness and beam length were systematically varied throughout the FEA simulations. For each case, both linear and nonlinear formulations were compared, using small and large deflection solvers with linear and quadratic elements.

Notably, results demonstrated that CTE and stiffness contrast between the layers was the primary driver of curvature, dictating the deformation direction. On the other hand, nonlinear large-deflection solvers proved essential to capture the true behavior of highly deformed geometries, especially for larger displacements and more complex loading scenarios. The findings from this initial phase validated the conceptual approach and provided a robust digital framework for later studies involving directionality and complex shape programming.

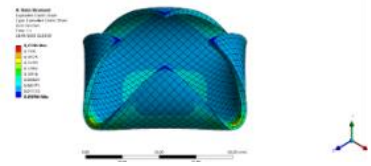

Fig 1 – Displacement in the Y direction obtained for a variation of the CTE ration between layers.

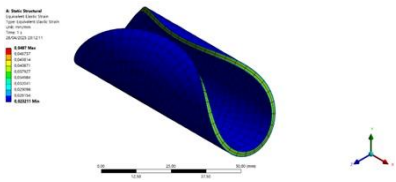

Fig 2 - Equivalent elastic strain results acquired from a cylindrical orthotropic model.

Implementing directional control via Orthotropy

In order to introduce programmable directionality into 4D-printed components, orthotropic material properties were implemented to mimic the anisotropic behavior observed in real FDM printing, particularly the effects of printing patterns on thermal expansion. Parametric simulations were then conducted on both cylindrical and square bilayer models with the purpose of evaluating the use of spatially defined material axes. While cylindrical geometries preserved radial symmetry regardless of material directionality, the square configurations revealed a strong dependency on material orientation. This effectively confirmed that deformation direction could be tailored through anisotropic design. In this case, by adjusting the principal material directions and CTEs along specific axes, a wide range of morphing behaviors were achieved. Notably, these findings demonstrated that orthotropy enables fine-tuned directional control, allowing deformation to be steered without altering overall material composition. This capability complements the previously explored thermal property contrast and provides an additional design lever for shaping actuation behavior.

From concept to shape prediction

Building upon the earlier findings, a shape prediction methodology was developed to program and simulate complex 2D-to-3D morphing transformations. This process started with an origami-inspired cube that used distinct active and passive regions to trigger localized deformation under thermal activation. The concept was progressively scaled to more intricate structures, including a chair, flower, and snake model—each requiring custom segmentation and directional material assignment. These designs tested multi-axial bending, opposing petal motion, and torsional actuation, respectively. The results showed that strategic combination of geometry, orthotropy and regional activity enabled precise control over morphing sequences. While experimental validation with 3D-printed prototypes revealed deviations due to residual stresses and imperfect layer adhesion, the overall deformation patterns aligned with simulation outcomes. This effectively confirmed the method's potential for programmable shape design and highlighted its scalability and adaptability for diverse morphing applications in 4D printing.

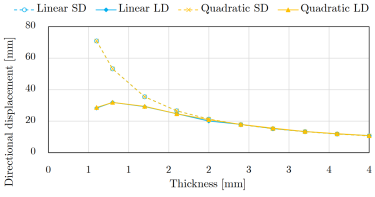

Fig 2 – Data acquired from a variation of the thickness ratio in a bilayer beam, while also comparing linear and quadratic element orders as well as nonlinear solvers

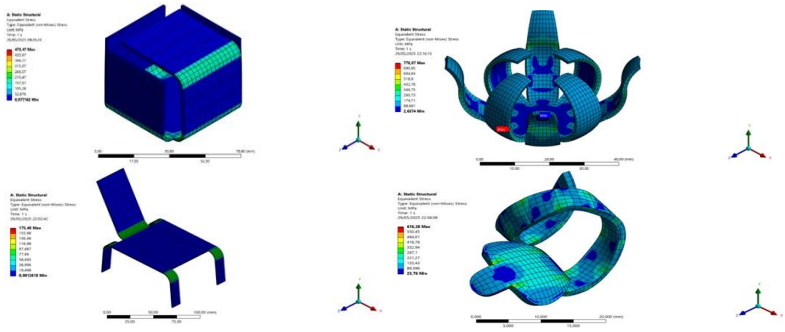

Fig 3 – Illustration of results for cube, chair, flower and snake's morphing process.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).
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TEchMA 2025
New Frontiers in Mechanical Engineering

Enhancing Cooling Efficiency of Power Transformers: A CFD Approach

Diogo Ventura, Sandra Sorte, Nelson Martins

Abstract

Power transformers require effective thermal management to ensure operational reliability and longevity [1]. Passive **Oil-Directed Air-Natural (ODAN)** cooling systems are widely used due to their simplicity and lack of energy consumption [2]. However, their performance degrades significantly with rising ambient temperatures—by up to 60% between 20 ° C and 35 ° C [3], highlighting the need for passive efficiency enhancements. This study presents a high-fidelity CFD model of a dual-radiator ODAN system developed in ANSYS Fluent with only a 1.9% deviation in heat dissipation. To address thermal performance losses under elevated temperatures, two parametric studies were conducted: one evaluated the effect of varying air and oil temperatures, while the other assessed the impact of a chimney-like structure of different heights mounted above the radiator assembly. Results indicate that increasing oil temperature, while preserving its thermophysical properties, can enhance cooling capacity up to threefold at 20 ° C and nineteen-fold at 50 ° C, underscoring oil temperature control as a key strategy against climate-induced thermal stress. Additionally, the chimney retrofit improved cooling performance by up to 10%, offering a practical and low-cost solution for passive system enhancement.

Acknowledgments

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA). The authors acknowledge the support of the Mobilizing Agenda for Business Innovation "ATE - Alliance for Energy Transition" reference BI/UI64/11373/2024.

Introduction

Power transformers are critical to electrical distribution but face cooling challenges that can lead to faults and shorten service life. Elevated temperatures accelerate insulation ageing and reduce the efficiency of dielectric fluids [1]. Efficient cooling is thus essential. Among passive solutions, ODAN radiator systems are valued for their simplicity and independence. This study investigates enhancements to improve their thermal performance.

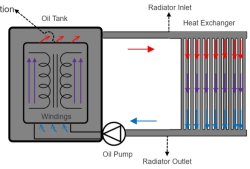

Fig 1 / Representation of ODAN cooling system.

Methodology

The system comprises four identical FG-type stainless-steel radiators, each with 22 fins and 1.5 m in height. Full-scale CFD simulation is computationally demanding, so a preliminary study was conducted to assess possible simplifications. A full radiator simulation confirmed symmetrical oil distribution from the leading distributor (Fig. 2), validating the use of a reduced, symmetric domain in further analyses.

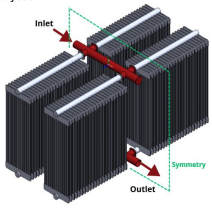

Fig 2/ Computaional domain for the initial simulation.

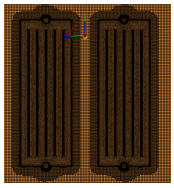

Fig 3 / Mesh of two fins located centrally within the two-radiator domain.

To preserve thermal fidelity, the simplified geometry maintained key parameters: hydraulic diameter, perimeter, and heat transfer area.

CFD Model Summary

Software
Ansys Fluent 2024 R2

Mesh Quality
~11 million poly-hexcore cells
- Skewness: **0.53**
- Orthogonality: **0.29**

Within accepted CFD thresholds

Turbulence Model
k–ω SST

Radiation Model
Surface to Surface

Numerical Schemes
- **Coupling:** *COUPLED*
- **Discretisation:**
  – *Second Order Upwind* (momentum, energy, turbulence)
  – *PRESTO!* (pressure)

Solid Regions
Shell conduction

Validation

An experimental setup was used to measure key parameters, such as inlet and outlet oil temperatures and heat dissipation, for validating the numerical model, as presented in Table 1.

Tab 1 / Comparison between experimental and CFD-predicted heat dissipation for operating conditions under AN regime.

Oil Q [m^3/h]	Mode	ΔT_{Up} [K]	ΔT_{Low} [K]	Q_{EXP} [kW]	Q_{CFD} [kW]	Dev. [%]
5.45	AN	34.8	30.2	11.7	11.5	1.9

Comparison with experimental data showed only a 1.9% deviation in heat dissipation, confirming the model's accuracy and reliability.

Parametric Studies

Two parametric studies were conducted to explore thermal performance improvements. The first analysed the effect of air and oil temperatures on cooling capacity - the second evaluated chimney integration, testing different heights to enhance natural convection and heat dissipation.

Tab 2 / Specific objectives, tested variables, and KPIs considered in the parametric studies.

Objectives	Variables	Indicators (KPIs)
1. Impact of Rising AmbientTemperatures on Natural Convection Cooling	T_{Amb}: 20, 25, 35,40, 45, 50°C; T_{Oil} : 55, 65, 75, 85, 95, 105°C	Dissipated heat (kW)
2. Effectof Chimney Cap Geometry on Radiator Performance	Chimney Height: 750, 1000, 2000mm; Chimney Material: Stainless Steel	

Results

1. Impact of Rising Ambient Temperatures on Natural Convection Cooling

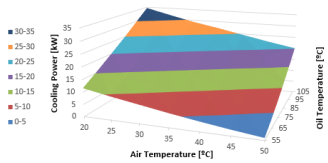

Fig 4 / Impact of ambient and oil temperatures on the radiators cooling capacity.

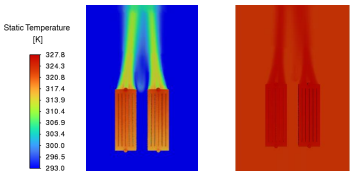

Fig 5 / Temperature distribution for ambient temperatures (left to right): 20ºC and 50ºC

- Cooling capacity decreases linearly with ambient temperature, up to 91% at 20 ° C.
- Higher oil temperatures increase performance up to 3 × (20 ° C) and 19 × (50 ° C).

2. Effect of Chimney Cap Geometry on Radiator Performance

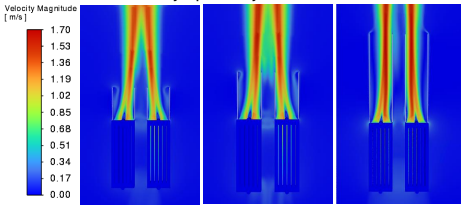

Fig 6 / Velocity distribution for chimney heights (left to right): 750 mm, 1000 mm, 2000 mm

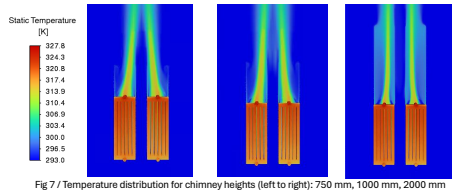

Fig 7 / Temperature distribution for chimney heights (left to right): 750 mm, 1000 mm, 2000 mm

- Chimneys with heights of 750 mm and 1000 mm led to improvements lower than expected in cooling capacity, with increases of 1% and 2%, respectively.
- A chimney height of 2000 mm yielded ~10% improvement, showing greater potential for optimisation.

References

(1) Sorte, S.; Monteiro, A. F.; Ventura, D.; Salgado, A.; Oliveira, M. S. A.; Martins, N. Power Transformers Cooling Design: A Comprehensive Review. Energies 2025, Vol. 18, Page 1051 2025, 18 (5), 1051. https://doi.org/10.3390/EN18051051.
(2)Koca, A.; Senturk, O.; Akbal, Ö.; Özcan, H. A-Techno-Economic Optimization of Radiator Configurations in Power Transformer Cooling. Designs (Basel) 2024, 8 (1). https://doi.org/10.3390/designs8010015.
(3) Anishek, S.; Sony, R.; Jayadeep Kumar, J.; Kamath, P. M. Performance Analysis and Optimisation of an Oil Natural Air Natural Power Transformer Radiator. Procedia Technology 2016, 24, 428–435. https://doi.org/10.1016/J.PROTCY.2016.05.059.

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New Frontiers in Mechanical Engineering

Design and Performance Trade-offs in ODAF Transformer Cooling Systems: A Numerical Investigation

André Monteiro, Sandra Sorte and Nelson Martins

Abstract

Power transformers are vital to electrical distribution networks, ensuring efficient energy transfer and grid stability. As energy demands grow and renewables expand, effective thermal management becomes critical. Overheating degrades Kraft-paper insulation, reducing transformer lifespan and increasing costs [1]. ODAF systems dominate current cooling strategies, using oil to transfer heat to external radiators where fans promote forced convection. Radiator geometry—especially fin spacing and fan configuration—has a significant impact on performance. This study presents a CFD-based porous-media model validated against experimental data. It explores fin spacing (32.58–67.5 mm), fin count, and fan speed/configurations. Wider fin gaps reduced cost-effectiveness by 11.94%, confirming trends seen in natural convection. Dual-fan setups performed worst in terms of cost-benefit. While higher fan speeds improved heat removal, they increased energy use and noise. The results offer practical guidance for optimizing radiator design and suggest dynamic fan/oil flow control to adapt to varying loads and ambient conditions.

Acknowledgement

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA). The authors acknowledge the support of the Mobilizing Agenda for Business Innovation "ATE - Alliance for Energy Transition" reference BI/UI64/11373/2024 with the Center for Mechanical Technology and Automation (TEMA).

Introduction

The studied system is an Oil-Directed Air Forced (ODAF) setup, with an oil pump circulating fluid through critical winding areas to improve heat exchange [1]. External fans enhance air-side heat transfer via forced convection.

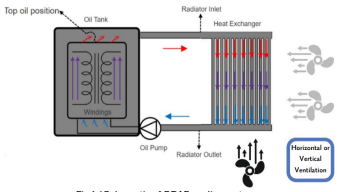

Fig 1 / Schematic of ODAF cooling system.

The analysed case consists of a group of four radiators. Each radiator unit is equipped with 22 fins and measures 1500 mm in height and 520 mm in width, with a fin spacing of 45 mm. These FG-type radiators, as specified in standard [2], are constructed from stainless steel, feature DN 80 collectors, and have a wall thickness of 3.2 mm. The case is evaluated through Computational Fluid Dynamics (CFD) simulations using Ansys Fluent 2024 R2.

Methodology

To overcome the high expense of computational resources and time, the Porous Media Approximation was used to decouple the heat transfer phenomena, aiming to analyze the external heat transfer phenomena (metal-air).

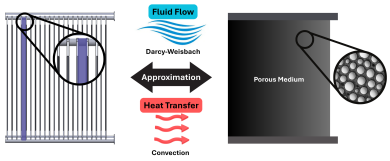

Fig 2 / Porous Media Work Methodology.

To effectively approximate the radiator geometry as an equivalent porous medium, two main physical phenomena must be considered: fluid flow (e.g., the pressure drop induced by the radiator on the airflow) and heat transfer between the radiator and the surrounding air.

Temperature Profile Implementation:

- Linear temperature gradient imposed on porous domain's metallic region.
- Temperature values based on experimental measurements from radiator inlet (upper collector) to outlet (bottom collector).

Buoyancy Influence:

- Significant in outdoor ventilation scenarios.
- Fan-induced forced flow may vary along radiator sections.

Fan Modelling:

- 2D fan boundary condition utilised.
- Driven by real fan performance curves.

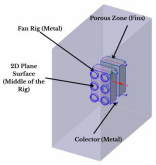

Fig 3 / Case Study Geometry.

Fluid Flow Analysis:

- Pressure drop evaluated in a single air channel between adjacent radiator fins.
- Air velocity range tested: 1–10 m/s.
- Results applied using Darcy–Forchheimer model to define equivalent anisotropic porous medium.

Heat Transfer Evaluation:

- Small air channel section analysed (negligible fin temperature variation).
- Heat dissipation measured over the same velocity range.
- Developed specific Nu–Re correlation for forced convection including buoyancy effects.

Validation of Computational Model

For validation purposes, two experiments were conducted with fans operating at 1350 RPM and different oil flow rates.

The oil temperatures at the inlet and outlet were measured during the tests and subsequently used to calculate the dissipated cooling power [W].

Table 1 / Comparison between experimental and CFD-predicted heat dissipation for two operating conditions under AF regime.

Exp.	Oil Q [m³/h]	Regime	ΔT_{Up} [K]	ΔT_{Low} [K]	$\dot{Q}_{EXP}$ [W]	$\dot{Q}_{CFD}$ [W]	Dev. [%]
1	3.5	AF	32.5	5.4	44300	22208.6	0.3
2	11.5	AF	17.4	1.5	36279	16177.8	-10.8

When the results from Experiments 1 and 2 are combined, the average deviation is approximately 5.7%. This small discrepancy suggests that the model can be considered reliable for the purposes of this study.

Parametric Studies

Parametric studies were conducted to assess how changes in radiator geometry and fan operation affect cooling performance. These insights support optimised thermal design and energy-efficient operation of ODAF systems.

Table 2/ Specific objectives, tested variables, and KPIs considered in the parametric studies.

Specific Objective	Variables	Indicators (KPIs)
1. **Cooling Power over Fan Speed variations**	▪ **Fan RPM:** 400, 600, 900, 1200, 1500, 2000, 3000	▪ FOM (*Factor of Merit*) ▪ Q_{th} [W] ▪ Noise [dB]
2. **Effect of Fin Number and Fin Spacing**	▪ **Fin spacing:** 32.6–67.5 mm ▪ **Number of fins:** 15–30	▪ MCPI (*Metal Cost Performance Index*) [€/kW] ▪ FOM (*Factor of Merit*) ▪ Q_{th} [W]

Results

1. Cooling Power over Fan Speed variations

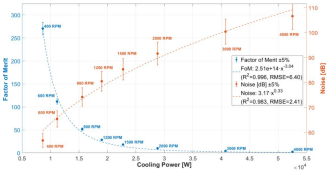

Fig 4 / FOM and Noise Production over Dissipated Cooling Power.

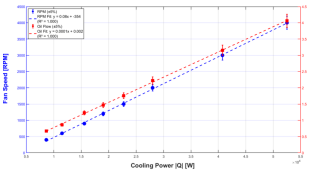

Fig 5 / Oil massflow and Fan velocity over Dissipated Cooling Power

- **Factor of Merit (FOM)** decreases significantly with increasing fan RPM.
- **Noise generation** increases sharply at higher RPMs.
- Need to define **operational thresholds** for energy consumption and noise.

- **Monitoring interface and data source** required for control.
- **Dynamic control strategy:**
  i. Forecast electrical demand – estimate Qt(W)
  ii. Adjust **the pump RPM**
  iii. Adjust **fan RPM**
  iv. Apply **a feedback loop** for real-time optimisation

2. Effect of Fin Number and Fin Spacing

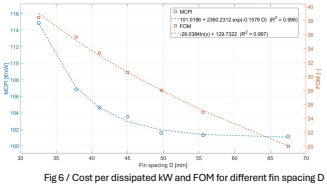

Fig 6 / Cost per dissipated kW and FOM for different fin spacing D

- **Wider fin spacing** tends to offer better cost-effectiveness (optimal spacing: 50 mm).
- **Narrower fin spacing** provides higher thermal performance per unit volume for the exact operational cost.

References

[1] S. Sorte, A. Salgado, A. F. Monteiro, D. Ventura, N. Martins, and M. S. A. Oliveira, "Advancing power transformer cooling: The role of fluids and nanofluids—a com prehensive review," Materials, vol. 18, no. 5, 2025
[2] International Electrotechnical Commission (IEC), IEC 60076-22-2:2019 Power Transformers - Part 22-2: Power Transformer and Reactor Fittings - Removable Radiators (2019).

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New Frontiers in Mechanical Engineering

Stress distribution analytical analysis in the vicinity of cooling channels during injection moulding

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(b) - Intelligent Systems Associate Laboratory (LASI), Guimarães, Portugal

Abstract

The use of tailored Temperature Control Systems (TCS) in injection moulding (IM) is increasing due to their ability to meet stricter part requirements with increase process productivity. Nevertheless, designing these TCS is challenging, and requires guidelines with a compromise between thermal and structural constraints. This PhD work was designed to tackle these issues, aiming to develop a tool to assist the design of tailored TCS. Previous work has shown that a comprehensive understanding of the thermal, fluid dynamics and mechanical processes intrinsic to the IM process can lead to the development of new guidelines for optimal channel design. The thermal analysis of TCS was previously studied and depicts that the cooling process is governed by two heat transfer mechanisms — convection and conduction. Having identified the key parameters for the thermal analysis, the structural analysis was investigated to determine the stress distributions around the cooling channels (CC) during an IM cycle. The latter is modelled considering CC enclosed in a mould and subjected to the process representative distributed load. To ensure proper coupling between both models, the same assumptions and simplifications were considered. Moreover, it was assumed that the mould was a homogeneous, isotropic, linear elastic semi-infinite solid. The analysis was undertaken considering the combination of two problems, using the principle of superposition: 1: the mould was taken as a semi-infinite solid without CC, but subjected to a uniformly distributed load, and 2: the CC were considered enclosed in the mould, a semi-infinite solid, loaded by prescribed displacements along its boundary. Following the definition of the structural model, the subsequent steps will involve its validation and integration with the thermal model via optimisation algorithms. The resulting coupled thermo-mechanical model is expected to enable the design and evaluation of TCS solutions across a range of component geometries.

Aim and Methodology

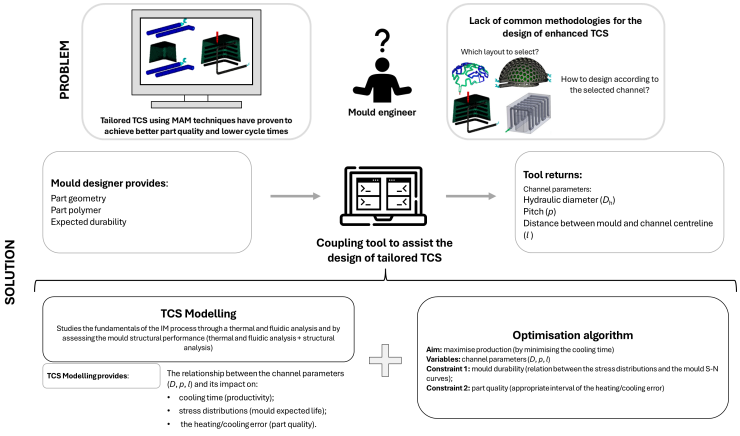
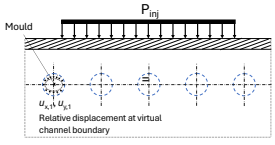


Fig 1/ Illustration of the aim and methodology to solved the research problem.

TCS Modelling: The Structural analysis

Application of the principle of superposition :



Problem 1
Solved using the Flamant solution

$$\sigma_{xx,1} = -\frac{P_{inj}}{\pi}\cdot\left[\arctan\left(\frac{x+W}{y}\right) - \arctan\left(\frac{x-W}{y}\right) + \frac{y\cdot(x-W)}{(x-W)^2+y^2} - \frac{y\cdot(x+W)}{(x+W)^2+y^2}\right]$$

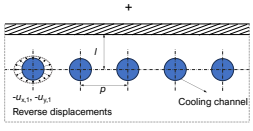
$$\sigma_{yy,1} = -\frac{P_{inj}}{\pi}\cdot\left[\arctan\left(\frac{x+W}{y}\right) - \arctan\left(\frac{x-W}{y}\right) + \frac{y\cdot(x+W)}{(x+W)^2+y^2} - \frac{y\cdot(x-W)}{(x-W)^2+y^2}\right]$$

$$\tau_{xy,1} = -\frac{P_{inj}}{\pi}\left[\frac{y^2}{(x-W)^2+y^2} - \frac{y^2}{(x+W)^2+y^2}\right]$$

The stress state of Problem 1 is influenced by:
- injection pressure;
- length of the pressure (length of the part).

↑ P_{inj} leads to ↑ $\sigma_{xx,1}$, $\sigma_{yy,1}$, $\tau_{xy,1}$

↑ W leads to ↑ $\sigma_{xx,1}$, $\sigma_{yy,1}$, $\tau_{xy,1}$



Problem 2
Solved through the Complex Variable Method

$$\sigma_{xx,2} + \sigma_{yy,2} = 2\cdot\left[\varphi'(z) + \overline{\varphi'(z)}\right]$$

$$\sigma_{yy,2} - \sigma_{xx,2} + 2\cdot\tau_{xy,2} = 2\cdot\left[\bar{z}\cdot\varphi''(z) + \psi'(z)\right]$$

$$\varphi(z) = \varphi_o(z) \quad \psi(z) = \psi_o(z)$$

Conformal mapping

Channel 1 Channel n

$$\varphi_o(z) = \varphi_{o,1}(\zeta_1) + \ldots + \varphi_{o,n}(\zeta_n)$$

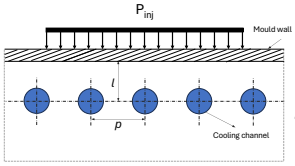
$$\psi_o(z) = \psi_{o,1}(\zeta_1) + \ldots + \psi_{o,n}(\zeta_n)$$

Conformally mapped plane of channel 1
Related to:
channel position in the x-y plane;
D and l

The stress state of Problem 2 is influenced by:
- Channel diameter;
- Channel position in the x-y plane (p and l).

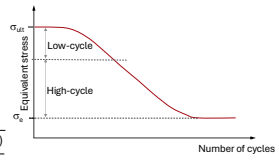
↑ l leads to ↑ $\sigma_{xx,1}$, $\sigma_{yy,1}$, $\tau_{xy,1}$

↑ p leads to ↑ $\sigma_{xx,1}$, $\sigma_{yy,1}$, $\tau_{xy,1}$



$$\sigma_{xx} = \sigma_{xx,1} + \sigma_{xx,2} \quad \sigma_{yy} = \sigma_{yy,1} + \sigma_{yy,2} \quad \tau_{xy} = \tau_{xy,1} + \tau_{xy,2}$$

$$\sigma_{eq} = \sqrt{\frac{(\sigma_{xx}-\sigma_{yy})^2 + (\sigma_{xx}-\sigma_{yy})^2 + (\sigma_{xx}-\sigma_{yy})^2 + 6\,(\tau^2_{xy}+\tau^2_{xz}+\tau^2_{yz})}{2}}$$



- The S-N curves can provide the expected life of the mould.
- For a higher life expectancy, the equivalent stress should be minimised.
- As σ_{xx}, σ_{yy} and τ_{xy} are influenced by the injection pressure and channel diameter.

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New Frontiers in Mechanical Engineering

Advances in Nanofluid-Enhanced Cooling for Power Transformers

Alexandre Salgado, Mónica S. A. Oliveira , Nelson Martins

Abstract

This study presents a computational framework to evaluate and optimise nanofluids as insulating fluids for power transformers, aiming to enhance thermal performance while maintaining dielectric reliability. Using Effective Medium Theory, the model predicts key thermophysical properties independently of nanoparticle type. CFD simulations indicate that increased nanoparticle concentration improves heat transfer (up to 0.89%) but also raises operational pressure losses (up to 12%) due to increased viscosity. Dielectric analyses confirm that nanofluids maintain or enhance electrical properties such as breakdown voltage and permittivity. Economically, nanofluids demonstrate advantages over conventional auxiliary cooling methods despite additional pumping requirements. The framework also successfully extends to biodegradable ester oils, broadening its sustainable applicability. Practical guidelines recommend particle volume fractions near 1% to balance thermal benefits and manageable pressure-loss increases.

Thermo-hydraulic enhancement of transformer cooling fluids

Oil-immersed power transformers increasingly hit a thermal ceiling as utilities demand compact, high-current designs. To accelerate the search for superior insulating fluids without costly prototyping, a four-stage digital platform was developed. Stage I synthesises temperature-dependent density, viscosity, permittivity, and conductivity via Effective-Medium Theory (EMT) for any nanoparticle/ester blend. Stage II automatically injects these properties into a validated CFD template of a single-fin channel operating under laminar regime conditions. Stage III executes a full-factorial Design of Experiments with two coded levels for particle volume fraction ϕ, intrinsic conductivity k_p, density ρ_p, and specific heat c_p, resulting in 16 simulation runs. Stage IV integrates thermo-hydraulic and dielectric outputs with pumping-and-ventilation cost models, producing direct techno-economic metrics. The platform thus connects molecular-scale additives to sub-hour operating expenditures, offering a holistic decision-making tool for utilities and oil formulators.

Thermo-hydraulic enhancement of transformer cooling fluids

Figure 1 evidences a clear thermo-hydraulic hierarchy: particle volume fraction (ϕ) governs performance, driving an almost step-wise rise in transferred thermal power, while enhanced conductivity (κ) accelerates the trend once ϕ surpasses the lower design. Density and specific heat exert only a secondary influence. Figure 2 exposes the attendant hydraulic penalty: viscosity-dominated pressure loss escalates linearly with ϕ, yet the slope is moderated when nanoparticles simultaneously raise κ, indicating superior heat-transfer efficacy per unit pumping. Collectively, both scatter plots endorse restricting ϕ to intervals that secure a favourable power-to-pressure ratio and prioritising intrinsically conductive, low-viscosity resulting fluids for sustained transformer reliability.

Dielectric Integrity under nanoparticle loading

EMT analysis revealed nanofluid effective permittivities spanning from 2.2 to 3.2, strongly dependent on the intrinsic permittivity contrast of selected nanoparticles. Breakdown voltage (BDV) assessment via trap-depth extrapolation models indicated notable improvements in dielectric strength, attributed primarily to minimized nanoparticle clustering and enhanced dielectric uniformity. Quantitative analysis demonstrated compatibility between enhanced thermal conductivity and dielectric properties, suggesting an optimal nanoparticle concentration range where both thermal and dielectric enhancements converge effectively. Results validate the potential for optimized nanofluid formulations to significantly enhance power transformer cooling efficiency and dielectric reliability simultaneously.

Techno-economic Pay-off

Thermo-hydraulic and dielectric data were routed to cost models for vertical and horizontal forced-air paths. Even when the viscosity-induced pumping penalty and the marginal BDV derating are accounted for, the dimensionless pumping-to-ventilation ratio Γ remains lower than 7 % in the worst-case vertical scenario and <1.5 % for optimised horizontal flow. Absolute production margins stay positive across all fluids (median 1.14–1.19 × 10^{-3} € kW^{-1} h^{-1}), proving that enhanced cooling and reliable insulation can be achieved without eroding operating budgets. The platform therefore delineates a commercially viable window—moderate ϕ paired with high k_p—unlocking extra thermal headroom while safeguarding dielectric integrity, and thus accelerating adoption of nanofluids in utility-scale transformer fleets.

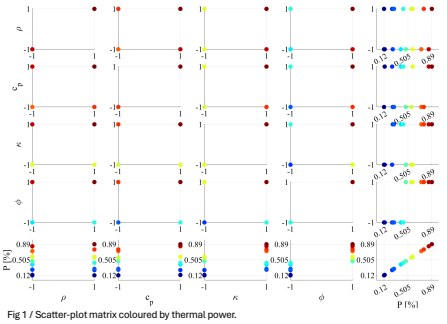

Fig 1 / Scatter-plot matrix coloured by thermal power.

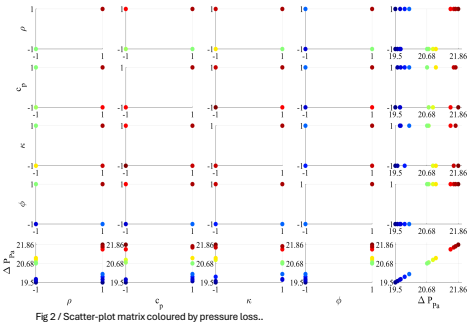

Fig 2 / Scatter-plot matrix coloured by pressure loss..

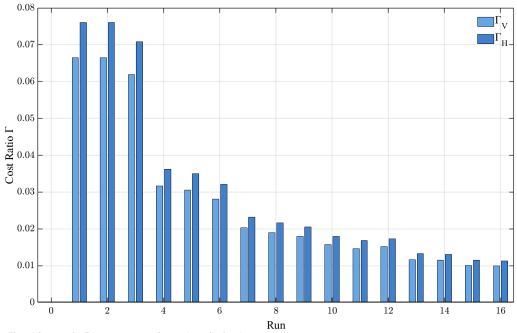

Fig 3 / Cost-ratio, Γ, between pumping and ventilation for each test run.

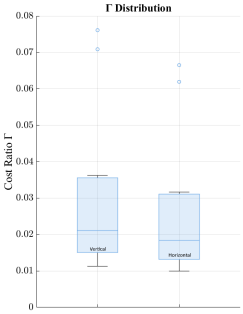

Fig 4 / Economic margin per unit of heat removed.

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New Frontiers in Mechanical Engineering

PLA:LnMOFs nanocomposites: A study of polymeric nanotags for anticounterfeiting applications

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Abstract

The counterfeiting of polymer-based products and packaging presents a serious global challenge across commercial, industrial, and everyday contexts leading to a growing demand for secure information handling and counterfeit prevention. More recently, optically responsive markers, such as luminescent polymer composites that react to external stimuli, have garnered significant attention as anticounterfeiting solutions [1]. Their ability to modulate optical output under selective excitation conditions makes them especially promising for security-related applications [2]. Luminescent materials are available in large varieties and are relatively straightforward to manipulate, further enhancing their appeal in anti-counterfeiting strategies [3]. In this study, we investigated the optical properties of lanthanide-based metal-organic frameworks (LnMOFs), specifically those incorporating europium (EuMOF), terbium (TbMOF), dysprosium (DyMOF), and praseodymium (PrMOF), embedded within a biodegradable matrix (polylactic acid (PLA)). Steady-state photoluminescence (PL) analysis of these nanocomposites revealed strong and distinct luminescent emissions upon targeted excitation. Notable intraionic emission lines were observed for: the EuMOF at 615 nm ($^5D_0 \rightarrow {}^7F_2$), TbMOF at 542 nm ($^5D_4 \rightarrow {}^7F_5$), and DyMOF at 570 nm ($^4F_{9/2} \rightarrow {}^6H_{13/2}$). In the case of PrMOF, characteristic intraionic absorption bands corresponding to transitions from the $^3H_4$ to ^3P_J levels were observed in the 445–485 nm range.

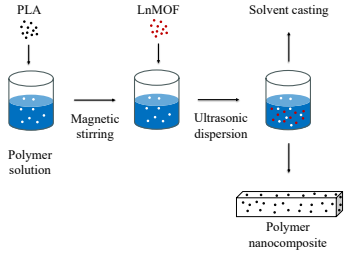
To support the feasibility of multi-tiered security tagging, we further examined the nanocomposites' luminescent behaviour under varying excitation wavelengths and temperatures. A selected hybrid nanocomposite was tested with the aim of obtaining color-tunable emissions, reinforcing the potential of these PLA-LnMOF nanocomposites as advanced, trackable optical markers suitable for high-level anti-counterfeiting applications.

Motivation

- Development of biodegradable luminescent nanocomposites for anti-counterfeiting optically active smart tags;
- Exploring LnMOFs luminescent properties;
- Production of PLA:LnMOFs composites: EuMOF, TbMOF, DyMOF and PrMOF;
- Study of irradiation time, wavelength- and temperature-dependent PL behavior of selected hybrid nanocomposites.

Experimental details:

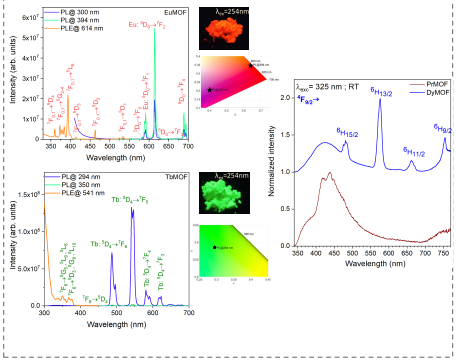
- PLA:LnMOFs nanocomposites preparation by solvent casting: 10 different nanocomposites with different LnMOFs concentrations and ratios of LnMOFs in the same sample.



LnMOFs characterization: RT PL

Bright intraionic luminescence for: Eu^{3+} at 615 nm (red); Tb^{3+} at 477 and 542 nm (green/orange); Dy^{3+} at 576 nm (orange) and; Pr^{3+}no blue/red emission was observed with the used excitation conditions.

LnMOFs characterization: PL & PLE

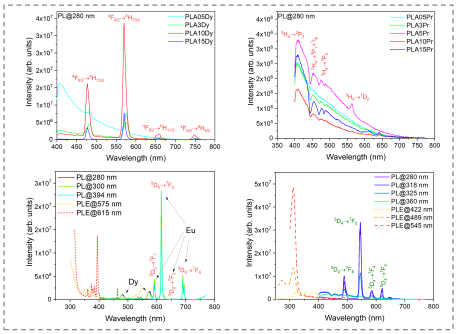


PLA:LnMOFs characterization: RT PL

PLA:DyMOF - Two well identified emission bands at 477 (blue) e 570 (orange) nm with good intensity and two weaker ones at 660 e 748 nm (red/IR);

PLA:PrMOF - Auto-absorption lines from the ion ground state to the excited levels, which occur when emitted light from the host is in the same spectral spectral region that the ion absorbs;

PLA:Dy10Eu3 – Observation of the characteristic emission bands from EuMOF (at 614 nm), but also of the DyMOF characteristic emission bands, with excitation energy dependent behavior.



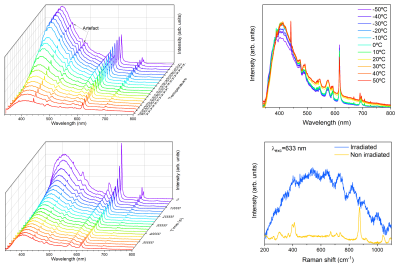
PLA:LnMOFs characterization: irradiation time & temperature dependent PL

Temperature-dependent (14 K – RT) PL (excitation with a 325 nm laser): Decrease in intensity of the PLA broad luminescence; decrease of the Eu^{3+} and Dy^{3+} intraionic emission;

Irradiation time @RT: Influence of continuous 3h of UV sample irradiation results in the overall decrease of the PL and sample degradation;

Temperature-dependent (-50 °C to 50 °C) PL (excitation with a 325 nm laser): Decrease in intensity of the PLA broad luminescence; decrease of the Eu^{3+} and Dy^{3+} intraionic emission;

Irradiation time @RT: Sample degradation measured by Raman spectroscopy.



Conclusions

- Successful incorporation of luminescent LnMOFs (Eu, Tb, Dy and Pr) on a biodegradable polymer matrix (PLA), the PLA:DyMOF exhibited well-identified intraionic Dy^{3+} emission lines at 477 nm (blue) and 570 nm (orange) nm, auto-absorption Pr^{3+} lines were identified for the PLA:PrMOF;
- The hybrid nanocomposite sample PLA:10Dy3Eu was selected for excitation wavelength and temperature-dependent PL measurements, but unfortunately, irradiation time with UV laser excitation leads to sample degradation that influences the measured optical properties.

ACKNOWLEDGMENTS

This work is supported by the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia. This work was supported by the projects LA/P/0037/2020, i3N UIDB/50025/2020&UIDP/50025/2020, LA/P/0037/2020 financed by I.P./MCTES FCT (Fundação para a Ciência e Tecnologia). Raul Simões also acknowledges the support of FCT for the Scholarship 2021.07198. Gil Gonçalves thanks to the FCT for the financial support of project CarboNCT - 2022.03596.PTDC (DOI: 10.54499/2022.03596.PTDC). Joana Rodrigues also acknowledges FCT for Program Stimulus of Scientific Employment–Individual Support (2022.00010.CEECIND).

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References

[1] [2] [3]

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TEchMA 2025

New Frontiers in Mechanical Engineering

Design Tool for Optimizing PCM-Based Energy Storage in Refrigeration Systems

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Abstract

By 2019, an estimated two billion domestic refrigeration systems (DRSs) were running worldwide, accounting for 4% of the global electricity demand [1] (Fig. 1). Cold chain-related markets are projected to grow at a compound annual rate of 8.60% until 2030 [2] . This is while the cooling provision for perishable food remains under 35% of the demand in developing nations, and the yearly production of refrigerators and freezers exceeds 80 million. Thus, actions are required to ensure sustainable growth [3]. Advanced technologies for storing surplus energy from RES are thus needed to face the growing supply-demand imbalances, intermittency, and volatility challenges associated with the expansion of RES power plants [4]. In this context, Thermal Energy Storage (TES), specifically by using Phase Change Materials (PCMs) in refrigeration systems, is a promising solution to enhance energy efficiency and store renewable energy. This study introduces a custom TRNSYS module for PCM-based thermal energy storage (TES) to improve energy efficiency in domestic refrigeration. It employs a one-dimensional heat transfer model with an implicit time-stepping scheme, achieving an average temperature and energy error of below 5% when validated against ANSYS-Fluent CFD simulations. The module was further tested by simulating refrigeration systems, demonstrating its real-world applicability with experimental results from chest freezers and PCM-modified prototypes. Numerical data showed strong alignment with experimental findings, effectively capturing thermal effects and extending autonomy during power outages, with relative errors under 0.5% and 1%. Simulations of 100-hour outages were completed in under 2 minutes, highlighting the model's computational efficiency. This validation positions the module as a valuable tool for design-stage studies and optimisation in PCM-enhanced refrigeration, with future work focusing on energy reduction strategies and the role of refrigeration as thermal energy storage in renewable energy systems.

Keywords

Phase change materials;
Energy storage;
Dynamic simulation;
Parametric study;
Refrigeration systems;

Acknowledgments

This work was supported by the FCT grant number 2021.06083.BD; An acknowledgement to TENSAI Indústria SA for sharing the experimental data.

Introduction

Phase Change Materials (PCMs) have gathered interest for their application in refrigeration systems, leading to extensive experimental investigations that provide valuable information on their benefits. These tests are resource-intensive and lack the flexibility to systematically explore numerous design configurations and operating conditions. Alternatively, numerical analysis through Computational Fluid Dynamics (CFD) entails high computational costs and requires skilled human resources, which limits the viability of vast and fast parametric studies at the system project stage. This highlights a critical need for simplified, validated numerical tools capable of supporting rapid parametric studies to guide and optimise system design of PCM-integrated refrigeration systems – an objective of this work.

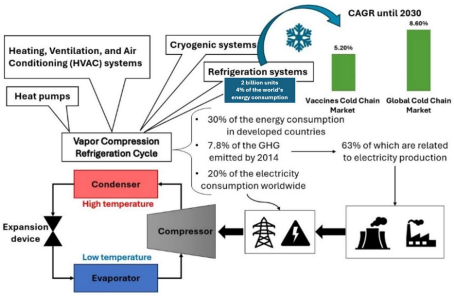

Fig. 1 - Overview of the preponderance of Vapour Compression Refrigeration Systems in the world

Methodology (Fig. 2)

- A math model to simulate PCMs' behaviour based on 1D heat transfer and the finite differences method is coded in Fortran with Microsoft Visual Studio (Fig. 3).
- The model's source code is compiled into a new component (TYPE5959) in TRNSYS software, and the graphical interface (proforma) is developed with inputs, outputs, parameters, and related files matching the source code (Fig. 3).
- An equivalent CFD model is established in ANSYS-Fluent to serve as the validation benchmark of the novel TRNSYS type, avoiding experimental rigs.
- The new TYPE is tied with a 0D transient model of domestic refrigeration systems (TYPE963), forming the final simulation tool for PCM-integrated units (Fig. 3).
- An ordinary chest freezer and four prototypes with additional latent TES capacity are experimentally tested following the European Standard EN62552:2013.
- Experimental data of temperature rise time tests, from which freezers' autonomy in power cuts is calculated, is used for validating the global model (Fig. 4).

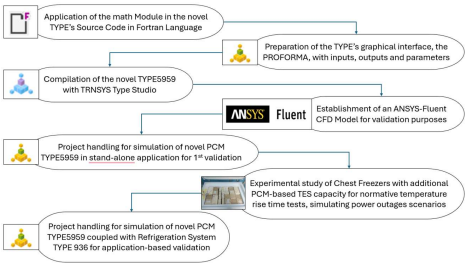

Fig. 2 – Framework of the methodology adopted in this study

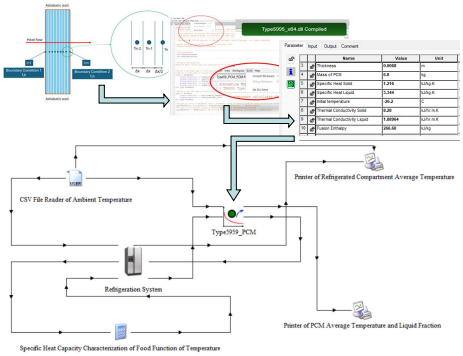

Fig. 3 – Schematic of PCM domain's discretisation method used in Type5959; Implementation in Fortran Language and compilation into a new component with graphical interface development; Simulation diagram in TRNSYS studio of the final simulation tool – PCM-integrated Refrigeration system.

Results

- TYPE5959 closely replicates the phase-change dynamics predicted by equivalent CFD models. Temperature, Liquid fraction and Internal Energy of the PCM are estimated with average relative differences below 5%.
- Building on the validation of TYPE5959, when coupled with TYPE936, the global model was accurate in predicting the average temperatures of test packs in frozen compartments during autonomy tests - average relative errors below 0.5% (Fig. 4).
- Freezers' autonomy - defined by the time needed for the hottest test package (replicating portions of lean beef) to rise from -18ºC to -9ºC – calculated with numerical data differed from the experimental observations in 1% to 15% (Fig. 5).

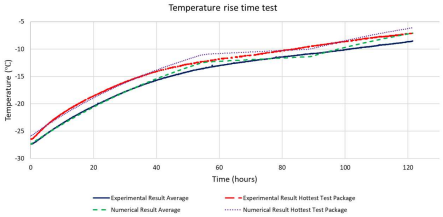

Fig. 4 – Results of temperature rise time tests in a PCM-integrated chest freezer; Experimental and numerical data for the average and hottest temperatures of test packages in the frozen compartment.

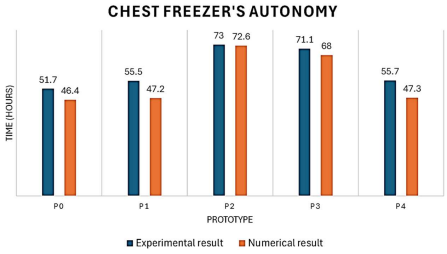

Fig. 5 – Summary of the freezers' autonomy to power outages obtained experimentally and numerically

Conclusions

A 1D heat transfer model for PCM use in refrigeration systems was validated with CFD models, avoiding extra experimental rigs. Its coupling with a 0D model for refrigerated compartments is computationally efficient. While maximum relative errors were below 1%, deviations in autonomy estimation to experimental values of 3-4 hours were deemed acceptable in 100-hour-long tests. The results suggest the utility of the model as a practical tool for assisting the project of PCM-integrated refrigeration systems through parametric studies. Future work includes model validation for energy consumption tests. This will enable the use of the tool to tailor PCM units for increased resilience to power outages and reduced operational costs of domestic refrigerators and freezers, while optimising the thermal energy storage capacity.

References

[1] Dupont J-L. The Role of Refrigeration in the Global Economy (2019), 38th Note on Refrigeration Technologies. 2019. https://doi.org/10.18462/iif.NItec38.06.2019.
[2] InsightAce Analytic. Vaccine Cold Chain Logistics Market Expected to Reach US$ 4.90 Billion by 2030 - Growing Beyond COVID-19 Application 2022. https://www.prnewswire.com/news-releases/vaccine-cold-chain-logistics-market-expected-to-reach-us-4-90-billion-by-2030---growing-beyond-covid-19-application-301686152.html (accessed December 13, 2022).
[3] James C, Onarinde BA, James SJ. The Use and Performance of Household Refrigerators: A Review. Compr Rev Food Sci Food Saf 2017;16:160–79. https://doi.org/10.1111/1541-4337.12242.
[4] Schleicher-Tappeser R. How renewables will change electricity markets in the next five years. Energy Policy 2012;48:64–75. https://doi.org/10.1016/j.enpol.2012.04.042.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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TECHNOLOGIES FOR THE WELLBEING

TEchMA 2025
New Frontiers in Mechanical Engineering

DEVELOPMENT OF AN INSTRUMENTED IMPLANT COMPRISING CAPACITIVE SENSING TO MONITOR THE FRACTURE BONE HEALING

Diogo G. Pires, A. Completo e Marco P. Soares dos Santos

Abstract

Bone fractures are a common health problem worldwide. The increasing number of people diagnosed with osteoporosis disease in active age groups highlights the crucial role that prevention and improved treatment play in reducing the consequences of disability, including productivity and quality of life. Currently, the monitoring techniques rely on image analysis, which involves subjectivity, exposes patients to high rates of accumulated radiation, incurs high maintenance costs, lacks information about the biomechanical state of the fracture, and lacks continuous monitoring. Therefore, it is mandatory to develop new methods capable of quantitatively assessing the bone healing process. This will enable the adoption of preventive protocols, such that the treatment time can be reduced, or additional surgical interventions can be avoided. Therefore, it will support to decrease hospital costs and improve the patient's quality of life. This work presents promising preliminary results from a new bioelectronic osteosynthesis plate with integrated capacitive sensors, designed to monitor bone fracture healing through its four stages: hematoma, soft callus, hard callus, and remodeling. The monitoring ability relies on electrical capacitive changes in different bone tissues during the fracture healing process.

Objective

New bioelectronic implant that continuously monitors the healing status of a fracture via Bluetooth and sends the results to a platform for medical analysis (Fig. 1).

Fig 1 / Illustration of the objective of the bioimplant operation

Methodology

Bone healing progression was simulated using 4 stage-specific computational models developed in SolidWorks, while COMSOL was used to predict sensors responses (Fig 2). A new osteosynthesis plate, capable of integrating the electronic circuit, was developed based on a commercialized one, while preserving the mechanical properties (Fig. 3a). Capacitive sensing technology was selected for its capabilities of sensing and stimulation, high precision, miniaturization potential, and low power consumption. The system includes: a BLE module for wireless transmission; a matrix-structured network of interdigitated and striped capacitive system; an analog-digital convertor for data acquisition; a multiplexer to allow communication with multiple sensors; a PIC16 microcontroller for system management; a miniaturized battery for autonomous operation (Fig. 3b). *In vitro* validation was performed using porcine femur samples with a 1 mm fracture gap. Each healing stage was mimicked using: clotted blood (hematoma), crushed cartilage (soft callus), crushed trabecular bone (hard callus), and intact bone (remodeling) (Fig. 3c). The system was positioned over the samples, capacitive measurements were acquired, transmitted via Bluetooth to a smartphone, and subsequently processed on a computer.

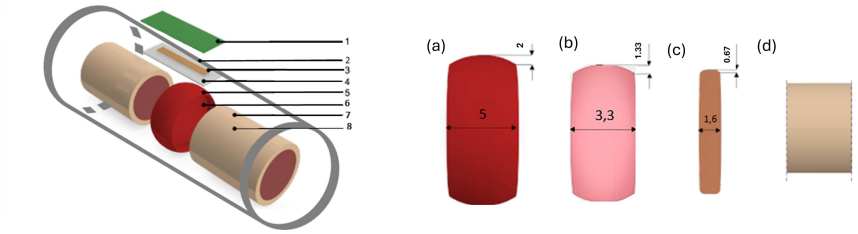

Fig 2 / Illustration of computational model components: 1- PCB; 2- Air ; 3- Electrodes; 4- Polymer; 5- Callus region; 6- Fracture region; 7- Cortical Bone; 8- Trabecular bone. Modulation of the four healing stages: (a) Hematoma; (b) Soft callus; (c) Hard callus; (d) Remodulation.

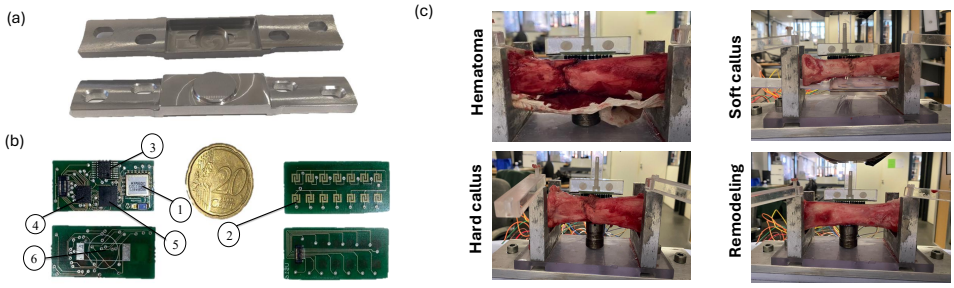

Fig 3 / (a) New Osteosynthesis plate. (b) Electronic system: 1- BLE module; 2- capacitive matrix; 3- ADC; 4- multiplexer; 5- PIC16; 6- battery CR1216. (c) *In vitro* setup of each stage.

Results

The system demonstrated a clear, progressive decrease in capacitive variation across the four bone healing stages, confirming its ability to distinguish each phase through measurable electrical signals. Measured variations decreased significantly from Stage 1 (0.494 pF), Stage 2 (0.163 pF), Stage 3 (0.090 pF) to Stage 4 (1.13 fF), reflecting the biological progression of the callus (Fig. 4).

Conclusion

This novel bioelectronic implant can provide personalized and remote monitoring of fracture healing, enabling early detection of complications and clear differentiation between healing stages. By supporting customized follow-up and reducing hospital translations, this technology represents a promising advancement in orthopedic care and the future of intelligent, implantable devices.

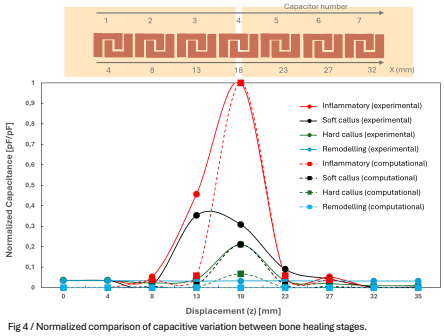

Fig 4 / Normalized comparison of capacitive variation between bone healing stages.

Acknowledgments

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TEchMA 2025

New Frontiers in Mechanical Engineering

Anomaly Detection using Machine Learning Models in Water Supply Systems

Ana Luís Sousa, Eugénio Rocha and António Andrade-Campos

Abstract

Water loss remains a critical global concern, particularly in the context of increasing water scarcity. Water supply systems (WSS) face significant challenges due to leakage, which can persist undetected for long periods and severely impact system efficiency. The occurrence of water leakage in these systems can range from 3% to over 50% depending on the level of system network maintenance performed, since it happens in pipe and/or junctions by uncontrolled actions [1]. Moreover, and according to the Portuguese regulator ERSAR in the RASARP 2024 [2], actual water leakage in Portugal in 2023 was 5.5 m^3/(km day) for the bulk side, which corresponds to a loss of more than 21 billion m^3/year. On the other hand, on the distribution side the value was 2.4 m^3/(km day) representing 4.6 billion m^3/year. Addressing this issue requires effective detection and localization techniques, where Machine Learning (ML) and digital twin technologies offer promising solutions for automated data analysis and hydraulic simulation. This work presents a novel ML-based sub-framework for detecting anomalies in pressure time series, where minor discrepancies may indicate potential leakage scenarios in the water system. This approach is implemented on a benchmark dataset, the BattLeDIM network [3], in which different ML-based models, such as Neural Networks, Convolutional Neural Networks, and Gated Recurrent Units, were evaluated and then compared with prior baseline results. Where DL-based methods achieved an improvement of 40% in classification performance.

Acknowledgement

This work is supported by the doctoral grant (Ref. 2023.02917.BDANA https://doi.org/10.54499/2023.02917.BDANA) financed by the Portuguese Foundation for Science and Technology (FCT), and under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA). And through the FEDER and Regional Operational Program of the Center Region (CENTRO2030) within project I-ReTiS-LeaksD&Op nº 17304 (CENTRO2030-FEDER-01177300) and through the Portuguese Foundation for Science and Technology (FCT), supported by the Recovery and Resilience Plan (PRR), within project I-ReTiS-Leaks (2024.07270.IACDC).

Introduction

Water leakage is a problem in WSS, which can be caused by infrastructure conditions as pipe material, age-related conditions, inadequate fittings, etc [4] and/or mechanical damage such as pipe loading, system pressure, pipe defects, among others [5].

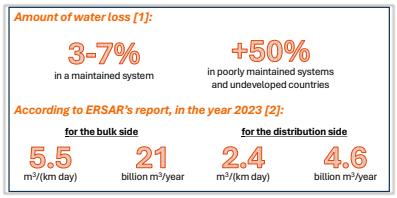

Fig 1 / Statistics about water loss in water supply systems.

Methodology

A pre-detection leak alarm framework is proposed, where ML-based techniques are applied to detect anomalies in pressure time series.

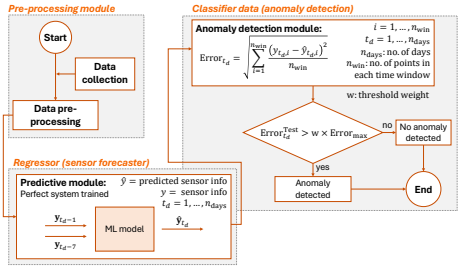

Fig 2 / Proposed methodology: pre-detection leak alarm model.

Pre-processing module:

- Create daily sequences and samples of the day t_d with pressure and flow values for day (P_{t_d}, Q_{t_d}); previous day (P_{t_d-1}, Q_{t_d-1}); previous weekday (P_{t_d-7}, Q_{t_d-7}); and status ('ok' or 'leak')

Regressor (sensor forecaster):

- ML-based model with input: P_{t_d-1}, P_{t_d-7}, Q_{t_d}, Q_{t_d-1}, Q_{t_d-7} and output: P_{t_d}
- Loss calculation with RMSE

Classifier data (anomaly detection):

- Mathematical approach of an anomaly condition: threshold of the maximum train RMSE, with a weight value (calibrated with 'ok' and 'leak' data)
- Test performance metrics: f1 score; mcc and confusion matrix

This methodology was applied to a case study benchmark "Battle of Leakage Detection and Isolation Methods (BattLeDIM)" [5]. The network has:

- 3 DMA
- data from 2018 and 2019
- pressure and flow time series (values for each 5min)
- leak information (for day:hour and pipe location)

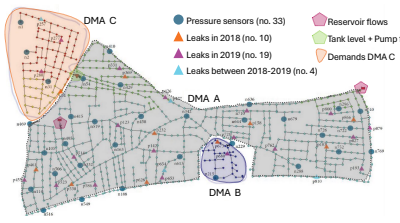

Fig 3 / BattLeDIM benchmark network configuration.

Results

The ML-based model tested for the regressor module were: Neural Network (NN), Convolution Neural Network (CNN) and Gated Recurrent Neural Network (GRU)

Results from the proposed methodology:

- GRU regressor tends to overfit (best RMSE in train -> worst in test)
- NN and CNN very similar
- All classifiers with high TPR and low FPR

Tab 1 / Results of the proposed methodology concerning the regressor metrics.

Model	Average RMSE train data	Average RMSE classifier data	Average RMSE test data
NN	0.3979	0.6696	0.6683
CNN	0.2962	0.6668	0.6699
GRU	0.2944	0.9468	0.9369

Tab 2 / Results of the proposed methodology regarding the test metrics.

Model	Threshold weight	F1 score	MCC score	True Positive Rate (TP/anomalies)	False Positive Rate (FP/n-anomalies)
NN	0.737	0.919	0.778	88.5% (85/96)	8.3% (4/48)
CNN	0.834	0.910	0.754	86.0% (86/100)	6.7% (3/45)
GRU	0.640	0.911	0.747	87.0% (87/100)	8.9% (4/45)

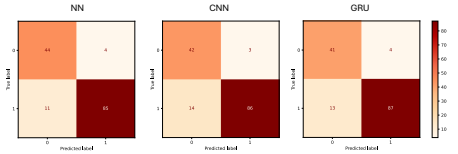

Fig 4 / Confusion matrix regarding the anomaly detection using the different models for the proposed methodology.

Results from BattLeDIM (Leakbusters team):

- Linear regression applied for the 5min sampling
- Results adapted for 1day sample to have comparable results

Tab 3 / Results of the Leakbuster team from the BattLeDIM benchmark.

Model	Threshold weight	Sample sequence	F1 score	MCC score	True Positive Rate (TP/anomalies)	False Positive Rate (FP/n-anomalies)
Linear regression	5	1 day	0.627*	0.560*	99.1% (325/328)	56.8% (21/37)
		5 min	0.944	0.686	89.5% (83956/93851)	0.6% (67/11269)

*comparable results

Conclusions

MCC improvement of 40%
DL-based methodology is better when considering 1day sample analysis

Balanced results
Despite different regression errors, all classifiers present similar good results (high F1, MCC and TPR and low FPR)

Linear regression with high FPR
The linear regression with 1day samples, applied by the Leakbusters, has a very high FPR – leading to many "false alarms"

References

[1] R. Puust, Z. Kapelan, D. A. Savic, and T. Koppel. A review of methods for leakage management in pipe networks. Urban Water Journal, 7(1): 25–45, February 2010. Doi: 10.1080/15730621003610878.

[2] ERSAR. Edições anuais do RASARP – Vol 1, 2024. https://www.ersar.pt/informacao-relevante-setor/.

[3] Vrachimis, S. G., Eliades, D. G., Taormina, R., Kapelan, Z., Ostfeld, A., Liu, S., Kyriakou, M., Pavlou, P., Qiu, M., and Polycarpou, M. M. (2022). "Battle of the leakage detection and isolation methods." Journal of Water Resources Planning and Management, 148(12), 04022068. Doi: 10.1061/(ASCE)WR.1943-5452.0001601.

[4] Zaman, D., Tiwari, M. K., Gupta, A. K., and Sen, D. (2020). "A review of leakage detection strategies for pressurised pipeline in steady-state." Engineering Failure Analysis, 109, 104264. Doi: 10.1016/j.engfailanal.2019.104264.

[5] Lopez, L. L., Van Zyl, J. E., and Kelly, P. A. (2025). "Conceptual Framework for Leak Development in Water Distribution Systems." Journal of Water Resources Planning and Management, 151(6),118204025011. Doi: 10.1061/JWRMD5.WRENG-6673.

TEchMA 2025

New Frontiers in Mechanical Engineering

Comparison of palladium-modified WO_3 sensors for hydrogen detection: synthesized vs. commercial WO_3

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TEMA, Department of Mechanical Engineering, University of Aveiro, Portugal , LASI, Portugal

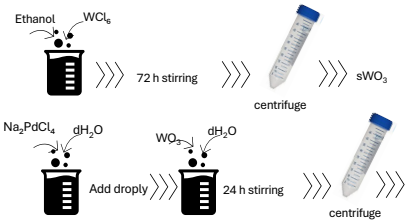
Abstract

Hydrogen is pivotal for a clean energy economy, but its safe use demands reliable gas detection technologies. Gasochromic sensors, which change color upon hydrogen exposure, provide low-cost, power-free solutions for industrial and domestic settings. This study explores palladium-modified tungsten trioxide (Pd-WO_3) particles for hydrogen detection, comparing synthesized and commercial WO_3. Synthesized Pd-WO_3 sensors exhibited complete reversibility, returning to their original color after air exposure. The color change (ΔE) due to H_2 exposure was 18.8 and the time to reach 90 % ΔE_{max} (T_{90}) was 190.6. Inversely, Pd-WO_3 fabricated from commercial WO_3 showed limited reversibility, with color changes barely visible to the naked eye. Based on reported studies, the compact surface morphology of the commercial sample likely traps hydrogen, hindering reversibility. These findings highlight the potential of exploring green routes to synthesize WO_3, while evidencing the need to further optimizations for guaranteeing high sensing efficiency and durability.

1. Introduction

Hydrogen, a highly flammable gas with a wide flammability range (4%–75% in air), requires simple, rapid-detection monitoring systems to prevent hazards [1]. Tungsten trioxide (WO_3), a versatile n-type semiconductor, is widely used in eye-readable hydrogen gas sensors due to its high sensitivity, tunable morphology, and gasochromic properties [2,3]. This study evaluates palladium-modified tungsten trioxide (Pd-WO_3) sensors for hydrogen detection, comparing synthesized WO_3 (sWO_3) and commercial WO_3 (cWO_3).

2. Methods



3. Results

Based on the graphs (Fig. 1, 2), which highlight the color rate and the relationship between Pd weight percentage (wt% Pd) and T_{90}, the decision was made to focus further investigation on the 10% and 20% Pd samples due to their higher color rates (0.12 and 0.14 s^{-1}, respectively) and shorter T_{90} (169.8 and 176.5 s, respectively), indicating improved sensor responsiveness. Additionaly these compositions displayed a visual output (ΔE>5) within 115 s, wich was significantly higher than 2%Pd-cWO_3 (172 s) and 5% Pd-cWO_3 (136 s).

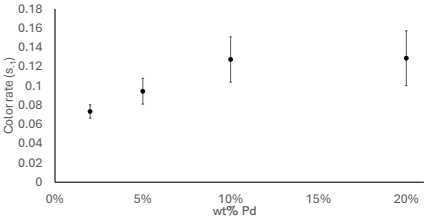


Fig 1. Coloring rate of Pd-cWO_3 samples under 10% H_2/N_2 for 5 minutes

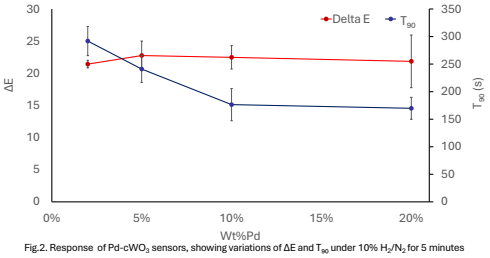
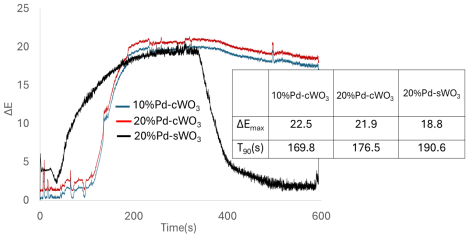


Fig.2. Response of Pd-cWO_3 sensors, showing variations of ΔE and T_{90} under 10% H_2/N_2 for 5 minutes

The sensors were tested in a glass chamber under 10% H_2/N_2 and air cycles at a flow rate of 2 L/h. The synthesized 20%Pd-sWO_3 sensor showed a ΔE of 18.8, (T_{90} = 190.6 s), fully reverting to its original color within 200 s of air exposure, indicating complete reversibility . In contrast, the 10%Pd-cWO_3 and 20%Pd-cWO_3 sensors achieved ΔE values of 22.5 (T_{90} = 169.8 s) and 21.9 (T_{90} = 176.5 s), respectively, but showed no visible color change after 300 s of air exposure, suggesting poor reversibility (Fig. 3). Based on prior studies, the compact surface morphology of cWO_3 likely traps H_2, limiting its reversibility.



	10%Pd-cWO_3	20%Pd-cWO_3	20%Pd-sWO_3
ΔE_{max}	22.5	21.9	18.8
T_{90}(s)	169.8	176.5	190.6

Fig.3. Response of Pd-WO_3 sensors, including Pd-cWO_3 and Pd-sWO_3. Tests occurred under 10 % H_2/N_2 (0 to 300 s) and synthetic air (300 to 600 s)

The color change behavior of Pd-WO_3 sensors is illustrated in the Fig.4, comparing synthesized (20%Pd-sWO_3) and commercial (10%Pd-cWO_3 and 20%Pd-cWO_3) samples at 0 s, 300 s (end of 10 % H_2/N_2 exposure), and 600 s (end of the synthetic air exposure). Initially, all samples exhibit a light brown color, but upon exposure to 10% H_2/N_2, 20%Pd-sWO_3 displays a dark blue color and partially reverts to its pristine color after air exposure. In contrast, both 10%Pd-cWO_3 and 20%Pd-cWO_3 darken significantly to a deep dark blue after 300 s of exposure to 10% H_2/N_2, with no visible return to their original color after 300 s of exposure to air, suggesting poor reversibility.

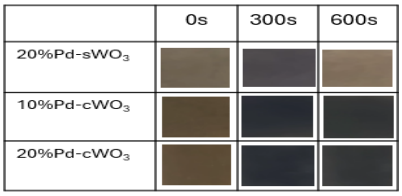


Fig 4. Color change in WO_3 sensors for sensitive hydrogen detection. 300 s of H_2/N_2 exposure followed by 300 s of air exposure

Fig.5 shows the XRD pattern of the synthesized 20Pd-sWO_3sample, confirming a hexagonal WO_3 phase (ICSD 080634) with main peaks at 12.82° (100, most intense), 23.94° (020), and 27.16° (200). In contrast, the cWO_3 samples displays a monoclinic structure (ICSD 016080) with peaks at 23.11° (002) and 23.59° (200). Beyond their distinct structures, the lack of reversibility in cWO_3, as noted in prior studies, may be due to its denser morphology [4].

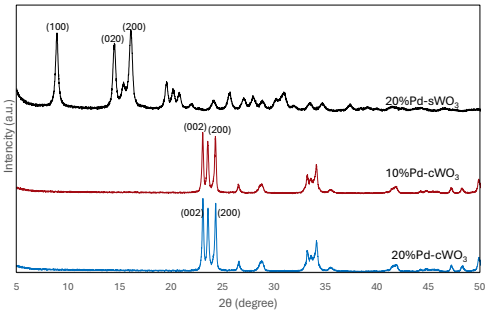


Fig.5, XRD patterns of 10%Pd-cWO_3 , 20%Pd-cWO_3 and 20%Pd-sWO_3

4. Conclusion

The 20%Pd-sWO_3 sensor, outperformed the commercial samples in H_2 detection, offering full reversibility without compromising ΔE, while the commercial samples showed limited color recovery due to their compact morphology. Despite similar detection performance across both samples, the synthesized sensor's potential for reliable and intuitive H_2 monitoring stands out. Future efforts should focus on optimizing the synthesized sample's structure to enhance T_{90} and ΔE .

•Reference

•[1] A. F. Girão and A. Completo, "Eye-readable sensors for intuitive hydrogen monitoring," Int. J. Hydrogen Energy, vol. 65, pp. 593–605, 2024.

•[2] Cho, S. H. *et al.* Substantially Accelerated Response and Recovery in Pd-Decorated WO_3 Nanorods Gasochromic Hydrogen Sensor. *Small* **20**, (2024).

•[3] Takahashi, H., Okazaki, S., Nishijinia, Y. & Arakawa, T. Optimization of hydrogen sensing performance of Pt/WO_3 gasochromic film fabricated by sol-gel method. *Sensors and Materials* **29**, 1259–1268 (2017).

•[4] Ambardekar, V., Bhowmick, T., & Bandyopadhyay, P. P. (2022). Understanding on the H_2 detection of plasma sprayed tin oxide/tungsten oxide (SnO_2/WO_3) sensor. Int. J. *Hydrogen Energy*, *47*(33), 15120-15131.

Acknowledgments

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New Frontiers in Mechanical Engineering

Recapitulating the Mechanical Anisotropy of the Spinal Cord via 3D Printing

João M. G. Fitas, Nathalie Barroca and Paula A.A.P. Marques

Abstract

Spinal cord injuries (SCI), such as spinal cord contusion, can have devastating effects on quality of life. Neuronal cell behaviour is highly sensitive to the mechanical properties of their microenvironment, making mechanical mimicry a critical aspect in the development of effective regeneration strategies through scaffolds.

This work proposes a biomimetic design that replicates the anisotropic mechanical behaviour of spinal cord white matter based on its morphology through engineered sinusoidal scaffolds. We relied on a design of experiments (DOE) approach to identify the optimal sinusoidal parameters—specifically amplitude and wavelength—while simultaneously accounting for printing constraints and the mechanical properties of native tissue. The concept structures were not only 3D modelled and simulated via finite element analysis (FEA) but also fabricated using 3D Melt-Electrowriting (MEW). Mechanical testing, such as tensile testing, validated the design and simulations in each direction. Finally, the structure was improved in terms of its Poisson ratios to ensure greater similarity to the native tissue.

Future work includes testing the developed structure with neuronal cells.

Framework

Challenge: Spinal cord injuries lack natural healing capacity. Full functional regeneration remains unachieved.

Proposed Approach: Engineer scaffolds that mimic the spinal cord anisotropic mechanical properties for spinal cord contusion

Objective: Design a Scaffold with sinusoidal geometries to reflect spinal cord's white matter *Young*'s modulus and *Poisson* Ratios, to influence cell response and prevent abnormal growth.

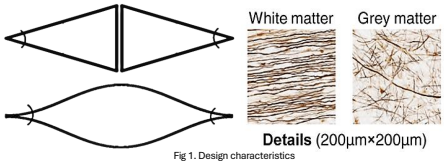

Fig 1. Design characteristics

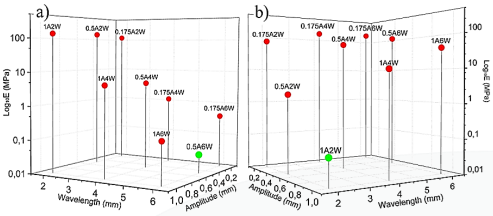

Fig 3. DOE results for the a) longitudinal and b) transversal directions.

-DOE implemented by varying the amplitude and wavelength of the sinusoids via multiple FEA simulations for each direction .

Fig 2. Initial design for the DOE.

-For guiding axon growth :
- Acute angle formation;
- Unidirectionality of the W.M..

-One sinusoid from each direction was chosen, leading to the first structure.

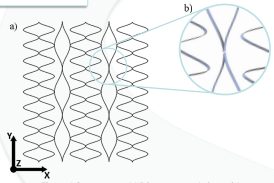

Fig 4. a) Structure 1, b) Disconnected sinusoids.

-Flaws from structure 1:
- Excessive elongation;
- Lack of structural integrity.

- Structure 2:
- Controlled elongation;
- Reinforced structural integrity.

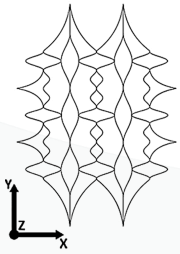

Fig 5. Structure 2.

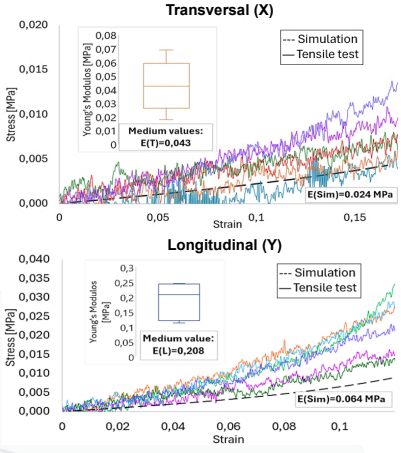

Fig 6. Tensile tests and FEA simulation results for each direction in the first 3mm of stretch (TOE region).

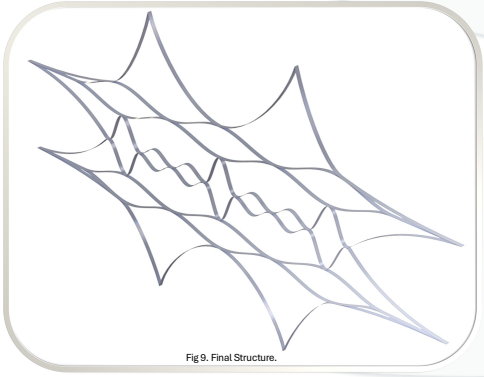

Fig 9. Final Structure.

Direction	Structure 2
Longitudinal	$\upsilon = 0.8$
Transversal	$\upsilon = 0.4$

Fig 7. Structure 2 Poisson ratios.

Poisson Ratios evaluation:
- Structure 2 longitudinal Poisson ratio was too elevated; leading to a new structure

Direction	Final Structure
Longitudinal	$\upsilon = 0.5$
Transversal	$\upsilon = 0.4$

Fig 8. Final structure Poisson ratios.

- Longitudinal Poisson ratio reduced, ensuring more similarity to the native tissue.

Final structure:
- The inside core geometry preserved the mechanical rigidity, while the outside geometry dictates how it deforms.

This work was supported by the project FlexiBone 2022.02424.PTDC, supported by the Foundation for Science and Technology, in its State Budget component (OE) (DOI: 10.54499/2022.02424.PTDC), the European Union's Horizon 2020 research and innovation programme under grant agreement No 829060 (FETOPEN project: NeuroStimSpinal).

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New Frontiers in Mechanical Engineering

Synergistic Impacts of CAVs on Traffic Flow and Emissions

Design of an intelligent traffic management system

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Abstract

This study investigates how Connected and Autonomous Vehicles (CAVs) influence urban traffic and emissions, addressing challenges like congestion and pollution. Using PTV VISSIM, we simulated traffic in Aveiro, Portugal, modelling scenarios with conventional vehicles (CVs) and 30% cautious or optimised CAVs. Our results show optimised CAVs significantly improve traffic flow and energy efficiency, positively impacting even CVs by harmonising driving patterns. This demonstrates a synergistic effect, where CAVs enhance the performance and environmental impact of the entire vehicle fleet. Ongoing work focuses on optimising CAV deployment and understanding behavioural propagation. This research contributes to developing smarter, sustainable urban mobility systems and will inform policy through a graphical interface for scenario evaluation.

Introduction

The Challenge: Road traffic remains a major source of congestion and air pollution (CO_2 - carbon dioxide, NOx - nitrogen oxides), especially with our current fleet.

Our Focus on Critical Regions of Interest: area around the University of Aveiro Campus, a nearby kindergarten, a primary school and a hospital.

The Solution: Connected and Autonomous Vehicles (CAVs) with specific driving behaviour!

Revolutionising Transport: CAVs connect with each other and infrastructure, creating a smarter, more efficient network. CAVs are anticipated to revolutionise transport, influencing conventional vehicles (CVs), and studies explore their potential impacts (Bandeira et al., 2021; Matin & Dia, 2023; Rafael et al., 2022; Richter et al., 2022).

Beyond Autonomy – What are their impacts?

- Studies suggest increasing CAV penetration rate can lead to increased network delays and stops (Abdelghaffar & Menendez, 2024).
- Other studies show potential for significant NOx emission reduction at certain penetration levels (e.g., 30%) (Rafael et al., 2022).
- Environmental impact of CAVs on conventional vehicles (CVs) can vary based on factors like driving conditions and market penetration (Bandeira et al., 2021).
- CVs following CAVs have been shown to experience reduced speed/acceleration volatility, improved safety, and lower fuel consumption and emissions (Wei & Shao, 2024).

Methodology

Case Study: *Understanding Local Effects*

Explore CAVs impact on traffic and pollution in Aveiro, near sensitive areas like a kindergarten and essential health services.

Simulating the Future with PTV VISSIM:

We modelled how traffic changes with different levels and types of CAVs. This allows us to predict future traffic dynamics and environmental outcomes.

Cautious vs. Optimised: Which CAV is Best?

Our research compares two types of CAVs: "cautious" ones that prioritise safety, and "all-knowing" ones that optimise their driving. We are finding out which operational behaviours lead to the best results for traffic flow and the environment.

Seeking Emission Reductions:

We quantify the environmental benefits of CAVs, specifically estimating reductions in CO_2 and NOx emissions using the Vehicle-Specific Power (VSP) methodology.

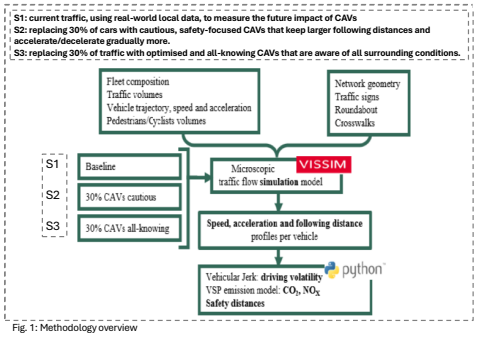

Fig. 1: Methodology overview

Results

1. CAVs Induce Smoother, More Efficient Driving Behaviour

The presence of CAVs with smoother operational behaviour changes traffic dynamics, inducing other vehicles to adopt a more harmonised and efficient operational profile.

Quantitative Finding: In the baseline scenario (S1), driving is characterised by a wide distribution of VSP modes, indicating frequent, aggressive acceleration (high VSP modes) and inefficient idling (low VSP modes). With 30% "cautious" CAVs (S2), the operational profile shifts dramatically, concentrating in the mid-range VSP modes (2-6) and significantly reducing high-power modes (>8).

2. Drastic Reductions in CO_2 Emissions for Light-Duty Vehicles

The combination of replacing internal combustion engines with electric CAVs and the overall smoothing of traffic flow leads to major reductions in CO_2 emissions.

Quantitative Finding: The introduction of 30% "cautious" e-CAVs (S2) resulted in CO_2 savings of 36.3% for Light Gasoline Vehicles (LGVs) and 32.4% for Light Diesel Vehicles (LDVs).

3. Even Greater Impact on NOx Emissions, a Key Urban Pollutant

The benefits of smoother driving are especially pronounced for NOx emissions, which are highly sensitive to sudden changes in acceleration.

Quantitative Finding: The "cautious" CAV scenario (S2) achieved remarkable NOx reductions of 42.9% for LDVs and 39.3% for LGVs. Even Heavy Goods Vehicles (HGVs), which were not replaced, yielded a 10.3% drop in NOx due to more stable traffic flow.

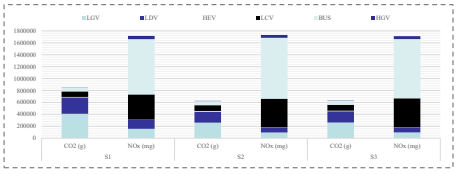

Fig. 2: Network overall emissions by each vehicle type for each scenario

Conclusions

Real-World Impact: Studies show how integrating CAVs, particularly those with optimised behaviours, can drastically improve traffic flow.

The "Synergy Effect": CAVs can positively influence nearby CVs, leading to smoother, more efficient driving.

Cleaner Air: Significant reductions in harmful emissions are expected, due to CAVs influence on CVs, making CVs drive more efficiently.

Safer Roads: Reducing aggressive driving and optimising driving behaviours lead to safer conditions for all road users.

What's Next?

Optimising Deployment: We are fine-tuning how CAVs can be best integrated into our roads for maximum benefit.

Policy Recommendations: Our work aims to provide actionable insights for urban planners and policymakers to build more sustainable transport systems.

References

Abdelghaffar & Menendez, 2024: Abdelghaffar, H. M., & Menendez, M. (2024). Influential Control Parameters for Autonomous Vehicles in a Mixed Environment. IEEE Open Journal of Vehicular Technology, 5, 927-939.

Bandeira et al., 2021: Bandeira, J. M., Macedo, E., Fernandes, P., Rodrigues, M., Andrade, M., & Coelho, M. C. (2021). Potential pollutant emission effects of connected and automated vehicles in a mixed traffic flow context for different road types. IEEE Open Journal of Intelligent Transportation Systems, 2, 364-383.

Matin & Dia, 2023: Matin, A., & Dia, H. (2023). Impacts of Connected and Automated Vehicles on Road Safety and Efficiency: A Systematic Literature Review. IEEE Trans. on Intell. Transp. Systems, 24 (3), 2705-2736.

Rafael et al., 2022: Rafael, S., Fernandes, P., Lopes, D., Rebelo, M., Bandeira, J., Macedo, E., Rodrigues, M., Coelho, M. C., Borrego, C., & Miranda, A. I. (2022). How can the built environment affect the impact of autonomous vehicles operational behaviour on air quality? Journal of Environmental Management, 315 (November 2021).

Richter et al., 2022: Richter, M. A., Hagenmaier, M., Bandte, O., Parida, V., & Wincent, J. (2022). Smart cities, urban mobility and autonomous vehicles: How different cities needs different sustainable investment strategies. Technological Forecasting and Social Change, 184, 121857.

Wei & Shao, 2024: Wei, S., & Shao, M. (2024). Existence of connected and autonomous vehicles in mixed traffic: Impacts on safety and environment. Traffic Injury Prevention, 25(3), 390-399.

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Evaluation of Google Maps Eco-Routing Performance in Portugal

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Abstract

This study explores the real-world performance of Google Maps' eco-routing feature within the Portuguese context, contributing to the broader goal of sustainable mobility. Field tests were conducted using gasoline, diesel, and electric vehicles across urban, suburban, and intercity routes. The results revealed notable energy savings — up to 39% for electric vehicles and 16% for internal combustion engines — when following eco-routes. However, these routes frequently pass through densely populated urban areas, raising important concerns regarding pedestrian safety, local air pollution, and increased stress for drivers. Despite its environmental benefits, eco-routing still lacks a holistic optimization approach. Future developments must consider not only energy and emissions reduction, but also delivery time constraints, driver wellbeing, and minimal disruption to urban environments. These findings provide valuable insights for smart city strategies and support ongoing initiatives such as the SPOTLOG project, which focuses on sustainable urban logistics.

Objectives

We present a practical case study conducted in the Aveiro region to investigate whether the eco-route suggested by Google Maps is indeed the most energy-efficient option also from air quality point of view. The evaluation compares the eco-route provided by the navigation system with the fastest available route. Since the fastest route often coincides with the eco-friendliest one, we also considered the second-fastest route as an alternative benchmark. The main objective is to assess whether Google's eco-routing algorithm consistently selects the option with the lowest energy or fuel consumption.

Methodology

- Field experiments were carried out using diesel, gasoline, electric, and hybrid vehicles.
- Portable Emissions Measurement Systems (PEMS), GPS receivers, and On-Board Diagnostics (OBD) units were used to record vehicle-specific power and emission factors.
- These emissions data were then used to categorize different routes, with five trips conducted per route.
- The results contribute to understanding eco-routing reliability in real-world scenarios, especially within medium-sized urban contexts like Aveiro.
- Compare the eco-friendly route with the route associated with the highest stress level.

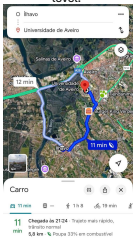

Fig.1- Estimations provided by Google Maps – Hybrid

Fig. 2 - Estimations provided by Google Maps – Diesel

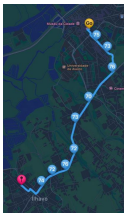

Fig. 3 – Heartrate during the eco-route

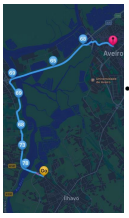

Fig. 4 – Heartrate during the alternative route

Preliminary results

- A case study connecting the University of Aveiro to Ílhavo, encompassing urban and rural segments, was chosen for its representative characteristics.
- Google Maps estimates show eco-routes can reduce fuel consumption by approximately 24% for diesel vehicles (Fig. 1) and about 33% for hybrid vehicles (Fig 2).
- Tests confirmed that eco-friendly routes consistently led to lower emissions of CO_2, CO, NOX, and HC across all trials (Fig. 5, 6, 7, 8).
- Observed reductions in pollutant emissions ranged between 20% and 30%.While exact matches between estimated and measured values weren't observed, due to vehicle-specific factors, the estimated and measured values were reasonably close, and the eco-friendly route consistently had the lowest overall emissions.
- It was observed that eco-friendly routes tended to be the shortest ones. However, these routes frequently pass through densely populated urban areas, raising concerns about pedestrian safety, local air pollution, and increased stress for drivers. Therefore, despite direct emission benefits, the external cost of emissions and air pollution within these denser urban environments may not necessarily result in an overall better outcome for urban sustainability.
- To evaluate the potential stress induced by different routes, we use a smartwatch to continuously measure heart rate during each trip, allowing us to determine whether the eco route results in higher physiological stress levels than alternative paths (Fig. 3, 4).

References

Bandeira, Jorge M., Claudio Guarnaccia, Paulo Fernandes, and Margarida C Coelho. 2018. "Advanced Impact Integration Platform for Cooperative Road Use." International Journal of Intelligent Transportation Systems Research 16(1): 1–15. http://link.springer.com/10.1007/s13177-016-0133-z.

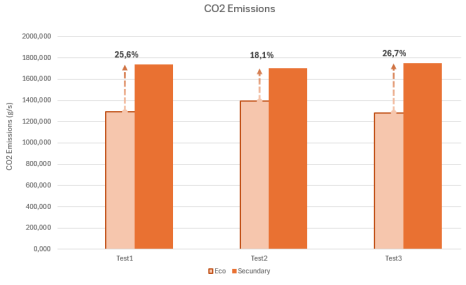

Fig. 5 - CO_2 Emissions

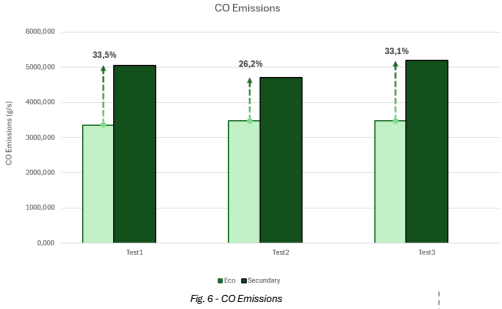

Fig. 6 - CO Emissions

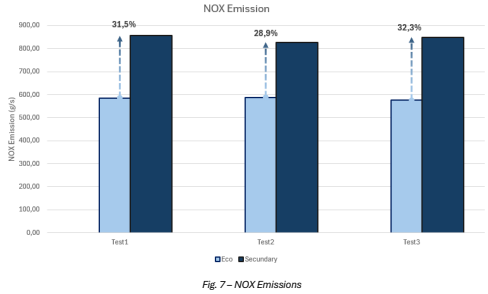

Fig. 7 – NOX Emissions

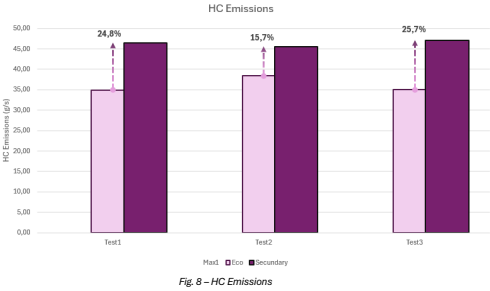

Fig. 8 – HC Emissions

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TEchMA 2025
New Frontiers in Mechanical Engineering

Demand-Responsive Transport for Sustainable Mobility

(A case study of SIT-Flexi in the Coimbra Region)

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Abstract

This study explores the SIT-Flexi demand-responsive transport service in the Coimbra Region, Portugal, covering 18 municipalities. Based on a survey of 407 users and official data, results show higher usage in low-density areas, especially among elderly women, highlighting the service's role in promoting social inclusion. Future work includes a new user survey to assess evolving needs and improve service accessibility, sustainability, and integration with public policies.

Acknowledgments

This work is supported by the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia. This work was supported by the research unit on Governance, Competitiveness and Public Policy (UIDB/04058/2020) + (UIDP/04058/2020), and by the PhD grant no. 2023.00282.BD, funded by national funds through FCT - Portuguese Foundation for Science and Technology.

References

Introduction

Urban and rural mobility has become a central issue in ensuring equitable access to essential services and opportunities. In low-density areas, where conventional public transport is often limited or economically unviable, flexible and user-centered models such as Mobility on Demand (MoD) and Mobility as a Service (MaaS) have emerged as innovative solutions [1] [2]. These models integrate digital technologies and sustainability principles to promote inclusive, efficient, and environmentally responsible mobility systems. [3] [8]

Case Study – SIT-Flexi

The SIT-Flexi service, implemented by the Intermunicipal Community of the Coimbra Region, operates across 18 municipalities and is designed to address the mobility needs of populations in geographically isolated areas. It functions on a reservation basis, offering dynamic routes and affordable fares, and is particularly tailored to elderly users and those without access to private vehicles. The service adapts to user demand, allowing for shared rides and exceptions for health-related or special-needs trips, thereby enhancing accessibility and social inclusion. [6]

Results

A statistical analysis based on a survey of 407 users and demographic data reveals that SIT-Flexi is predominantly used by elderly women in rural municipalities such as Penacova, Pampilhosa da Serra, and Góis. These areas show the highest usage rates, confirming the service's role in reducing territorial inequalities. More rural and less populated municipalities (with low population density) show proportionally greater use of the service, while more urban and densely populated municipalities show, on average, relatively lower use. Although it is not a perfect correlation, the value of -0.62 is considerably far from 0, suggesting that population density explains a substantial part of the variation in the use of SIT-Flexi. [5]

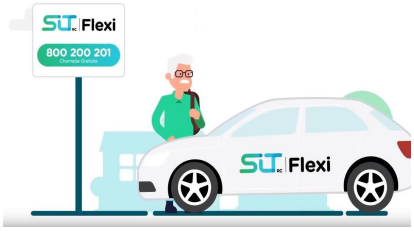

Fig 1. Flexible Transport SIT-Flexi

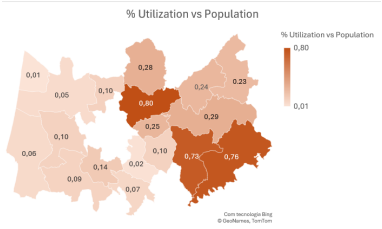

Fig 3. Percentage of service usage among the population of each municipality

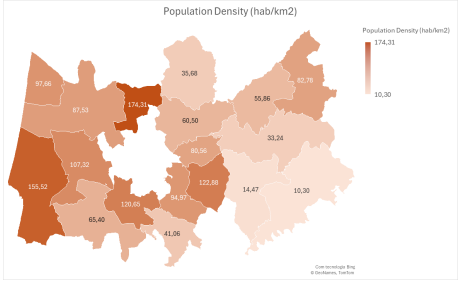

Fig. 4 – Population Density

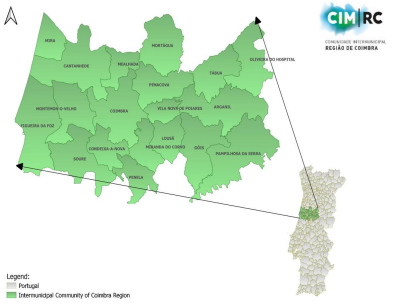

Fig 2. Municipalities in the Coimbra Region with SIT-Flexi service implementation

Methodology and Future Research

It is important to emphasize that this study is not yet complete. We are currently conducting surveys of SIT-Flexi users to understand how they feel about the service, what aspects could be improved, and whether they consider transportation to be environmentally sustainable. To ensure the sustainability and efficiency of a flexible transport service, it is essential to start by conducting a comprehensive cost-benefit analysis, which involves formally quantifying the social benefits of the service—such as improved access to healthcare, employment opportunities, and reduced isolation—while also monetizing positive externalities like support for the local taxi economy and the time saved for family members who would otherwise need to provide transportation. These quantified benefits must then be compared to the public subsidy required, which allows for a clear assessment of the service's net value. At the same time, service efficiency and sustainability should be optimized by implementing measures that encourage shared rides—increasing the number of passengers per trip—and by exploring the transition from diesel to electric or hybrid vehicles, aiming to decrease long-term environmental impacts and operational costs. Finally, effective integration with the public transport network is key: flexible transport can provide important first and last mile solutions, linking users to existing fixed-route bus lines, while the adoption of integrated ticketing and scheduling systems helps create smooth, multi-modal travel experiences for residents.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

TEchMA 2025

New Frontiers in Mechanical Engineering

A Stage-Wise Literature Review Toward Smart Digital Twin Developments of Wastewater Treatment Plants

Sara Mota, António Andrade-Campos

Abstract

WWTPs are essential for safeguarding public and environmental health. However, they are energy-intensive infrastructures, consuming over 1–3% of global electricity and more than 233 GWh annually in Europe [1]. These challenges are compounded by increased inflow variability due to climate change and more restrictive environmental regulations. To address these issues, data-driven modelling and smart digital tools have become pivotal in enhancing WWTP operational efficiency and sustainability. This systematic review explores recent advances in ML, the IoT, and Digital Twin technologies applied to WWTPs. Recent studies have revealed two primary modelling categories: (1) system simulation and (2) energy optimisation. Hybrid models that combine physics-based simulations with ML techniques, such as neural networks, reinforcement learning, and AI-CFD, show improved prediction accuracy and generalisability. While these technological advances show promising results, the practical, widespread implementation of full-scale digital twins encounters significant obstacles. This review identifies, amongst others, a significant research gap: the lack of integrated, cross-stage optimisation strategies that bridge localised model insights and global plant performance. The novelty of this work lies in its stage-wise analysis of the literature, providing a structured perspective that helps identify specific WWTP stages where optimisation is most effective. It also serves as a foundational assessment for the design of Smart Predictive Digital Twins (SPDTs) that combine real-time data, ML-driven modelling, and modular architectures to enable adaptive, efficient, and resilient WWTP operations.

Acknowledgement

This research was supported by the FEDER and Regional Operational Program of the Center Region (CENTRO2030) within project I-ReTiS-LeaksD&Op nº 17304 (CENTRO2030-FEDER-01177300) and through the Portuguese Foundation for Science and Technology (FCT), supported by the Recovery and Resilience Plan (PRR), within project I-ReTiS-Leaks (2024.07270.IACDC). This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

Introduction

Wastewater treatment plants (WWTPs) are among the most energy-intensive components of urban infrastructure, with aeration alone accounting for over 50% of total energy consumption [2]. In recent years, the increasing frequency of extreme rainfall events, driven by climate change, has led to frequent sewer overflows. This not only raises the energy demands and operational costs for treating excess inflow but also put at risk compliance with environmental regulations, potentially resulting in untreated discharges and legal penalties.

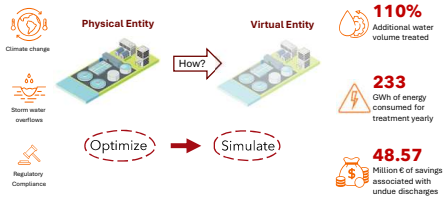

Fig 1 / Challenges and associated numbers for wastewater treatment plants, in Europe, for the year of 2022. [4]

Methodology

This work investigates how data-driven techniques, including Machine Learning, Digital Twins, and IoT, can enhance decision-making and energy efficiency in WWTPs. By conducting a systematic, stage-wise review of recent studies, the research identifies how these technologies support predictive control, optimize energy-intensive processes like aeration, and enable real-time process adjustments. A commercial review was also conducted in order to identify some practical implementation

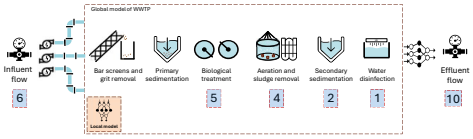

Fig 2 / Discretization of a WWTP different stages and associated number of related works. Each numbered box represents the number of research studies identified in the literature that apply data-driven techniques, at that specific treatment stage.

A preliminary treatment, removes coarse debris and grit to protect downstream equipment. In the primary treatment stage, heavier solids settle by gravity in primary sedimentation tanks. The core of the treatment occurs during secondary treatment, where biological processes, primarily using microorganisms, degrade organic pollutants, followed by secondary sedimentation to separate biomass from treated water. Tertiary treatment then further refines the effluent through advanced filtration and disinfection methods (e.g., UV) to meet high-quality discharge or reuse standards. Finally, effluent monitoring ensures that water released into the environment complies with all regulatory requirements.

Results

- Majority of studies focus on the entire WWTP rather than isolated processes.
- The highest research concentration is seen in secondary treatment, particularly the aeration process, due to its high energy demand.

Fig 3 / Number of wors by research scope on the field of WWTP modeling.

Individual process simulation

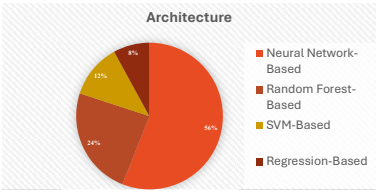

Fig 4 / Most used ML architectures for individual stage simulation of a WWTP.

Software	Key Features	Best For
GPS-X	Advanced dynamic simulation, user-friendly interface	Comprehensive plant modeling
BioWin	Robust activated sludge modeling, integrated processes	Industrial & municipal WWTPs
SIMBA#	Flexible dynamic simulation, control strategy tools	Process optimization
STOAT	Freeware, sludge & recycling modeling	Educational & small-scale plants
WEST	Detailed process design, advanced optimization tools	Control strategy development

Table 1 / Overview of software solutions for WWTP simulation.

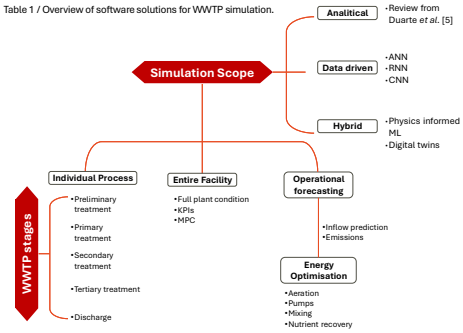

Fig 4 / Structured summary of WWTP simulation literature: stages, research scope, and applied techniques

Conclusion

- ✓ Stage-wise analysis reveals that smart technologies can enhance energy efficiency, particularly in aeration, as it improves effluent quality, and enables predictive maintenance.
- ✓ Real-world adoption remains limited due to challenges such as poor data quality, limited expertise, and high computational demands.

The development of Smart Predictive Digital Twins (SPDTs) with modular, hybrid architectures are proposed as a promising path toward more adaptive, efficient, and sustainable WWTP operations.

References

[1]I. C. for Resource Recovery from Water, "Circular economy: Tapping the power of wastewater."

[2]G. Sabia et al., "Energy saving in wastewater treatment plants: A methodology based on common key performance indicators for the evaluation of plant energy performance, classification and benchmarking", Energy Conversion and Management, vol. 220, 2020

[3]J. F. de Canete et al., "Control and soft sensing strategies for a wastewater treatment plant using a neuro-genetic approach", Computers & Chemical Engineering, vol. 144, 2021.

[4]ERSAR - Dados de base. Retrieved March 16, 2024, from https://www.ersar.pt/pt/setor/factos-e-numeros/dados-de-base

[5] Duarte, M. S., Martins, G., Oliveira, P., Fernandes, B., Ferreira, E. C., Alves, M. M., Lopes, F., Pereira, M. A., & Novais, P. (2024). A Review of Computational Modeling in Wastewater Treatment Processes. Doi: https://doi.org/10.1021/acsestwater.3c00117

TEchMA 2025

New Frontiers in Mechanical Engineering

Real-World Assessment of Integrated Driving Performance in Urban Traffic Singularities: A Multi-Parameter Approach to Safety, Emissions, and Volatility

Elisabete Ferreira, Paulo Fernandes, Eloísa Macedo, Margarida C. Coelho

Abstract

Urban transport must balance safety and environmental concerns. This research examines real-world driving behaviour, vehicle performance, and emissions across different urban road types, comparing shared spaces with conventional infrastructure.

This work uses an integrated Driving Indicator (iDI) that combines safety measures (headway and stopping distance), driving behaviour (acceleration and vehicular jerk), and emissions (carbon dioxide – CO_2 and nitrogen oxides – NOx) [1]. The study represents the first empirical application of an integrated indicator using real-world data to quantify how road designs affect driver behaviour and environmental impact.

Data were collected along a 1,100m corridor in Aveiro, Portugal, including roundabouts, shared road sections, mini-roundabouts, and urban roads. Three diesel vehicles equipped with PEMS, OBD readers, GPS, and cameras collected nearly 3,400 seconds of valid PEMS data and 6,800 seconds of OBD/GPS data.

Results reveal clear differences among traffic configurations. Roundabout influence areas produced the highest emissions and driving irregularities, exceeding manufacturer standards. Conversely, shared road sections yielded the lowest emissions per distance and smoothest driving patterns. Emissions concerns dominated all road types (>60%), followed by safety considerations (~30%).

The study demonstrates that shared spaces outperform conventional roads environmentally and safety-wise, supporting urban planning strategies that include shared space design [2]. The iDI methodology provides a practical tool for transport professionals to assess how different road designs affect driver behaviour, emissions, and safety.

References

[1] E. Ferreira, P. Fernandes, E. Macedo, and M.C. Coelho. "Driving Safety-Volatility-Emissions integrated indicator application to urban road environment." Transp. Res. Procedia., vol. 86, pp. 572-579, 2025. 10.1016/j.trpro.2025.04.072

[2] A. Karndacharuk, D.J. Wilson, and R.C.M. Dunn. "Qualitative evaluation study of urban shared spaces in New Zealand." Transp. Res. Part D Transp. Environ, vol. 42, pp. 119–134, 2016. 10.1016/j.trd.2015.10.020

Acknowledgments

This work is supported by the project : the Interreg Europe projects SPOTLOG 01C0655 and EMBRACER 01C0656. (LA/BD/151254/2021 (https://doi.org/10.54499/LA/BD/151254/2021) and 2021.02488.CEECIND (https://doi.org/10.54499/2021.02488.CEECIND/CP1659/CT0013), respectively.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

Methodology

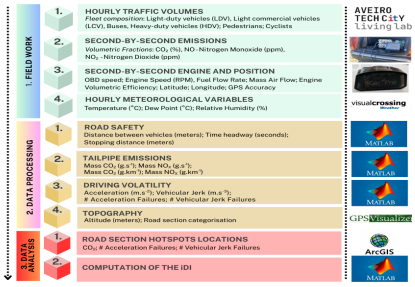

Fig. 1 / Methodology overview.

Fig. 2 / Case study with identification of the road section types and camera location.

Vehicle ID	FV	LV day 1	LV day 2
Year	2017	2006	2007
Emission Standard	Euro 6d	Euro 4	Euro 4
Engine displacement (L)	1,6	1,7	1,4
Vehicle Category	C	M	S
Power (kW)	98	125	68
Length (mm)	4,427	4,820	3,860
# trips	13	10	3

Fig. 3 / Fleet and equipment used (PEMS; OBD-II, and smartphone)

Computed parameters:

- ✓ **Acceleration** – First derivative of speed [1];
- ✓ **Vehicular jerk** – First derivative of acceleration [1];
- ✓ **Distance between vehicles** – GPS coordinates and the Haversine formulae;
- ✓ **Time headway (THW), stopping distance;**
- ✓ **Mass CO_2 and NOx** using Code of Federal Regulations of the Environmental Protection Agency [1].

Driving behaviour assessment is made using the iDI formulae directly, and assessing driving failures [1]

$$iDI\ (\%) = 0.30\ x_1 + 0.10\ x_2 + 0.18\ x_3 + 0.22\ x_4 + 0.10\ x_5 + 0.10\ x_6 \quad \text{Eq. (1)}$$

THW | Stop. Dist. | Acc. | Jerk | CO_2 | NOx

Driving failures of FV for each trip, were evaluated based on the following thresholds (already validated by the authors [1]):

- ✓ minimum THW value **of 2.5 seconds**;
- ✓ maximum acceleration and deceleration values of **2.16 m/s² and 3.4 m/s²**, respectively;
- ✓ minimum and maximum vehicular jerk of **-0.95 m/s³ and 0.9 m/s³**, respectively;
- ✓ a maximum CO_2 (g/km) value of **135 g/km** is considered, representing the 2012–2019 EU CO_2 target;
- ✓ a maximum NOx emission value of **80 mg/km**, which corresponds to the Euro 6 emission standard limit for diesel passenger cars.

Failure percentage for each variable is **updated in Eq. (1)** to obtain the final score.

Results

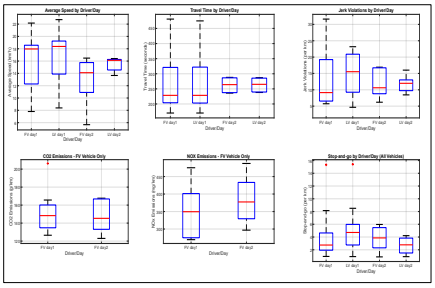

Fig. 4 / Summary of different metrics.

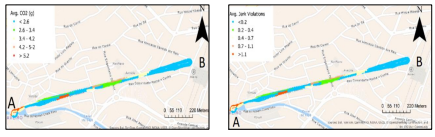

Fig. 5 / Hotspot locations in each 100-m length by trip: (a) Average CO_2 (g), and (b) Average Vehicular Jerk Violations

Tab. 1 / Driver Performance Matrix: Analysis of Time, Safety, and Environmental Impact.

Direction	# Trips	Travel Time (s)	Safety failures (%)	Volatility failures (%)	Emissions failures (%)	iDI score (%)
A-B	7	214.0 ± 35.6	52.3 ± 19.1	3.8 ± 0.8	93.2 ± 3.7	30.8 ± 7.8
B-A	6	293.0 ± 72.0	55.3 ± 20.5	6.5 ± 1.4	88.8 ± 5.6	29.9 ± 8.3

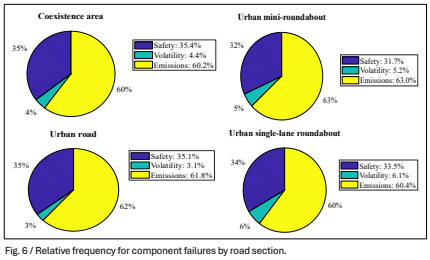

Fig. 6 / Relative frequency for component failures by road section.

Final Remarks

Key Validation Results

- ✓ CO_2 emissions **exceeded manufacturer values** with NOx levels **surpassing Euro 6 limits;**
- ✓ Roundabouts showed the highest frequency of **vehicular jerk violations** and driving volatility failures;
- ✓ Shared spaces achieved the **lowest emissions and volatility failures**, operating as maximum safety zones;
- ✓ Emission-related failures **dominated 60%,** followed by safety-related failures (30%).

Future Research Directions

- ✓ Expand fleet to multiple road segments and vehicle types and powertrains;
- ✓ Develop refined vulnerable road users' interaction models;
- ✓ Test driver feedback systems based on iDI metrics;
- ✓ Evaluate the duration of acceleration and vehicular jerk violations.

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TEchMA 2025
New Frontiers in Mechanical Engineering

Real-Time Monitoring of Porto's Urban Tunnels for Enhanced Incident Response

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Abstract

In urban environments, road tunnels pose significant safety and operational challenges due to limited visibility and restricted access. To address this, we are developing an intelligent, real-time monitoring tool for the urban tunnels of Porto. The system uses the YOLOv8n architecture for efficient object detection and an identity-based tracking system to monitor vehicles and vulnerable road users. Key functionalities include detecting stationary vehicles and the presence of pedestrians, triggering immediate on-screen alerts to operators. Developed in collaboration with the Porto City Council, this data-driven platform aims to significantly improve incident response, traffic management, and overall safety in a critical infrastructure.

Introduction

Road tunnels are critical points in urban infrastructure, but their inherent characteristics - such as poor lighting, confined spaces, and complex visibility - make real-time incident detection a formidable challenge. Standard video surveillance is often insufficient, as the sheer volume of data requires an automated and robust system to detect anomalies like stopped vehicles, accidents, or unauthorized individuals. A delayed response in such an environment can have severe consequences [1-3].

The Challenge: Urban Tunnel Safety & Efficiency; Limited Natural Light: Poor visibility; Complex Visibility Conditions: Difficult to detect objects; Restricted Emergency Access: Slow response times; High Data Volume & Dynamic Nature: Requires automated solutions.

The Solution: *Intelligent Surveillance Platform*

Core Technology: YOLOv8n Architecture [3]

Why YOLOv8n? Excellent balance of speed, accuracy, and resource efficiency for real-time processing.

Purpose: Precise detection of objects in Porto City Council's tunnels.

Methodology

Key System Components & Functionalities

Object Detection & Tracking:

YOLOv8n Integration: Detects vulnerable road users (pedestrians, cyclists) and vehicles.
Identity-Based Tracking System: Identifies and tracks moving objects across different video frames.

Incident Detection & Alerting:

Stationary Vehicle Detection: Triggers alerts if a vehicle remains stationary beyond a defined threshold.
Vulnerable Road User Detection: Warning messages for pedestrians/cyclists in monitored areas.
Future Expansion: Potential to include detection of animals and other undesirable objects.

User Interface & Alerts:

Dashboard: Easy-to-use platform for monitoring.
Dynamic Pop-up Alerts (PyQt6):
- Strategically placed for high visibility.
- Non-obtrusive, clear visual notifications.
- Easy user interaction.

Performance Enhancements & Optimization:

Region of Interest (ROI) Design:
- Focuses processing on relevant areas.
- Reduces data processing load.
- Minimizes false positives.

Multi-threaded Architecture:
- For reading video streams.
- Automatic camera reconnection for system stability.

YOLO Input Frame Resizing: Improves performance.
Processing Frequency Management: Essential for reducing system crashes.

Impact:
- Improved operational efficiency in traffic management (e.g., queue detection).
- Enhanced response to accidents, vandalism, and other risks.
- Proactive incident management in urban road tunnels.

Results

The developed system successfully detects and tracks relevant objects in real-time, providing crucial alerts for predefined risk scenarios. The following images from the system's dashboard illustrate its core functionalities.

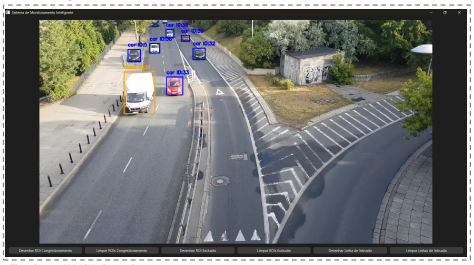

Fig 1 General Vehicle Detection

The system effectively identifies multiple vehicles in the scene, including cars and a van. Each vehicle is enclosed in a bounding box and assigned a unique ID (e.g., car ID:5, car ID:33), demonstrating the foundational detection and tracking capability.

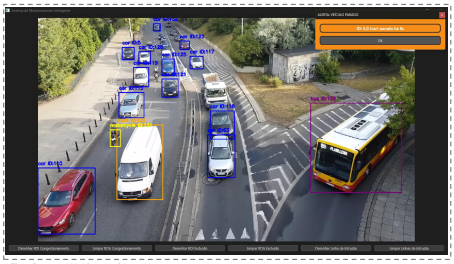

Fig 2 Stopped Vehicle Incident Alert

This image showcases a critical safety feature. The system has identified that vehicle ID: 5.0 (car) has been stationary for 8 seconds (parado há 8s), automatically triggering a high-visibility pop-up alert for the operator. This allows for immediate verification and response.

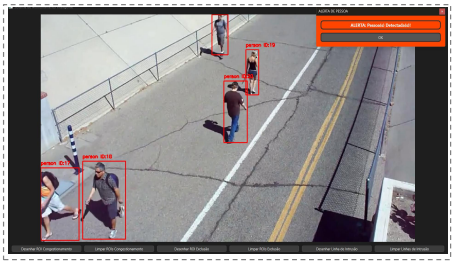

Fig 3 Vulnerable Road User Detection

Here, the system detects multiple pedestrians within the monitored area. The presence of a person in a vehicle-only environment like a tunnel is a major risk. The system immediately notifies the operator with an alert: "ALERTA: Pessoa(s) Detectada(s)!" (ALERT: Person(s) Detected!).

Conclusions

This work successfully demonstrates the development of an efficient and intelligent monitoring tool tailored for the unique environment of urban road Porto City Council's tunnels. By integrating the YOLOv8n model with a robust tracking system, our platform provides reliable, real-time detection of critical incidents such as stationary vehicles and the presence of pedestrians.

The use of a dedicated Region of Interest (ROI) and performance optimizations ensures the system is both accurate and resource-efficient. The pop-up alert mechanism, built with PyQt6, guarantees that operators are immediately and clearly notified of potential dangers.

Future work will focus on expanding the system's capabilities to include the detection of other hazards, such as animals or debris, further enhancing the safety and operational efficiency of Porto's tunnels.

References

[1] Borghetti F, et al. Road Tunnels Operation: Effectiveness of Emergency Teams as a Risk Mitigation Measure. Sustainability. 2022; 14(23):15491.
[2] Wei Y, et al. An Adaptive Vehicle Detection Model for Traffic Surveillance of Highway Tunnels Considering Luminance Intensity. Sensors. 2024; 24(18):5912.
[3] Li Y, et al. Lightweight Tunnel Obstacle Detection Based on Improved YOLOv5. Sensors. 2024; 24(2):395.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).
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New Frontiers in Mechanical Engineering

Development of a 3D-Printed PEGDA Microneedles Patch for Gingival Application: Design and Fabrication Approach

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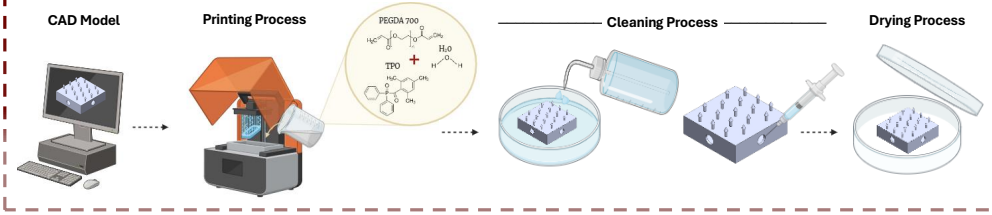
Abstract

Maintaining good oral health is essential for overall well-being, yet it remains undervalued in many healthcare systems. Periodontal diseases such as gingivitis and periodontitis affect nearly half of the global population, including approximately 50% of adults in Portugal. Conventional treatments involve invasive procedures and the use of systemic antibiotics, which, despite high patient compliance, may lead to side effects such as antimicrobial resistance, dysbiosis, and systemic complications. As an alternative, localized drug delivery has emerged as a promising strategy, promoting more effective gingival regeneration while minimizing systemic risks. In this context, this work presents the development of a hydrogel microneedles (MNs) patch made from polyethylene glycol diacrylate (PEGDA), fabricated using masked-stereolithography. PEGDA was chosen for its excellent biocompatibility and stability in moist environments. The MNs patch features an anchor-shaped design to enhance penetration and fixation in gingival tissue, along with an internal reservoir for precise drug loading. This design allows for controlled, gradual drug release into the targeted gingival area. Dimensional control was evaluated using SEM (for the microneedles) and Micro-CT (for the reservoir). Both components were resized, resulting in microneedles with a height of 1.5 mm and a 42% reduction in the top wall thickness of the reservoir. Swelling behaviour was assessed in a simulated oral environment using artificial saliva over 24 hours, with dimensional stabilisation observed after 8 hours. Maximum swelling was reached between 5 and 30 minutes for 50T, resulting in a vertical expansion of ~0.5 mm. Microneedles did not suffer any fracture during penetration pull-out tests, and a single MN resistance is ~0.0117 N.

Acknowledgements

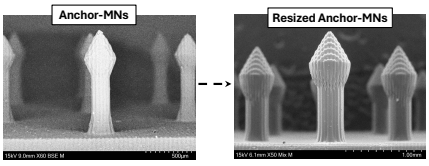
This research had the financial support of the following projects UID/00481 - Centro de Tecnologia Mecânica e Automação (TEMA) and UID/50011 - CICECO-Aveiro Institute of Materials, LA/P/0006/2020, financed by national funds through the FCT/MCTES (PIDDAC), FCT - Fundação para Ciência e Tecnologia; and CENTRO-01-0145-FEDER-022083 - Centro Portugal Regional Operational Programme (Centro2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund.

Methodology



Results

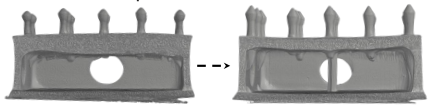
Dimensional analysis



MNs Dimensions and Shrinkage

	Total height (µm)	Cylinder height (µm)	Cone height (µm)	Cylinder diameter (µm)	Cone diameter (µm)
CAD initial	1500	900	600	350	550
Anchor-MNs	1094 ± 19	566 ± 44	528 ± 37	213 ± 17	352 ± 13
Shrinkage (%)	27	37	12	39	36
CAD resized	1905	1233	672	487	743
Resized Anchor-MNs	1431 ± 19	742 ± 50	689 ± 51	323 ± 18	514 ± 22
Shrinkage (%)	5	18	15	8	7

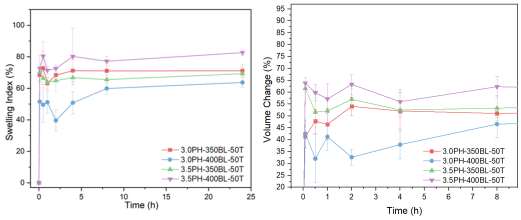
Reservoir Dimensions Optimisation



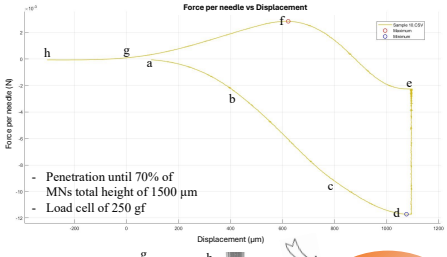
Reservoir Dimensions and Shrinkage

CAD	Top wall thickness (µm) Measurements Average	Std. Dev.	Shrinkage (%)	CAD	Lateral wall thickness (µm) Measurements Average	Std. Dev.	Shrinkage (%)	CAD	Bottom wall thickness (µm) Measurements Average	Std. Dev.	Shrinkage (%)
50	522	33	945	350	312	21	11	350	388	36	11
50	579	59	1057	400	379	34	5	400	405	18	1
100	915	78	815	350	344	63	2	350	361	14	3
100	987	131	887	400	349	21	13	400	392	31	2

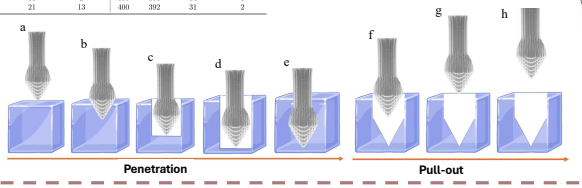
Artificial Saliva Swelling Analysis



Penetration and Pull-out tests in agarose



The top wall thickness was reduced 42% to enhance drug delivery efficiency



No microneedles fractured during the tests. A penetration force of 0.0117 N per needle and a pull-out force of 0.0028 N per needle were obtained

Conclusions

- It was possible to achieve a significant reduction in the shrinkage of Anchor-MNs, with values initially ranging from 12% to 39%, falling to a considerably lower range, between 5% and 18%, after geometric resizing (resized Anchor-MNs).
- The thickness of the top wall was significantly reduced, from 915–987 µm to 522–579 µm, representing a decrease of 42%.
- All samples showed similar height variations after 8 hours of swelling, with increases between approximately 0.4 and 0.6 mm, regardless of the initial height (3.0 or 3.5 mm), indicating a uniform pattern of vertical expansion. It is observed rapid absorption, reaching maximum swelling between 5 and 30 minutes. After this initial peak, there is a slight reduction in mass, with stabilisation after 8 hours.
- No microneedles fractured during the tests. A penetration force of 0.0117 N per needle and a pull-out force of 0.0028 N per needle were obtained.

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).
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TEchMA 2025
New Frontiers in Mechanical Engineering

Optimization of the operation of Flexible Transport in the Region of Coimbra

Towards Integrated Passenger and Parcel Mobility

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Abstract

Demand-Responsive Transport (DRT) is expanding across low-density european regions, where ageing populations and limited public transport restrict mobility and access to essential services. These same areas are increasingly affected by logistical inefficiencies due to rising e-commerce demand and sparse parcel delivery coverage. This study, developed under the Interreg Europe projects SPOTLOG and EMBRACER, investigates the integration of First-Last Mile logistics and passenger transport using SIT Flexi, the DRT system in the Coimbra Region. By optimising routes with GIS tools and promoting intermodality with CPT, the aim is to improve service efficiency, reduce emissions, and enhance regional accessibility. Incorporating parcel delivery into taxi-based DRT routes can increase vehicle utilisation and revenue, while also supporting fairer, more inclusive access in remote areas. Regulatory constraints remain a barrier, but integrated transport solutions offer environmental and social benefits with scalable potential.

Introduction

Low-density areas often lack Conventional Public Transport (CPT), so implementing Demand Responsive Transport (DRT) is especially critical given that these places are usually home to elderly populations with limited mobility. On the other hand, First-Last Mile (FLM) parcel delivery or pick up in such areas is difficult and costly due to their isolation [1,2,3].

Although passenger and parcel transport are still managed separately in the Coimbra Region, SIT FLEXI has the potential to connect both systems, improving efficiency, reducing costs, and increasing accessibility in low-density areas [4].

Fig 1. SIT FLEXI stop in Louredo (Mealhada).

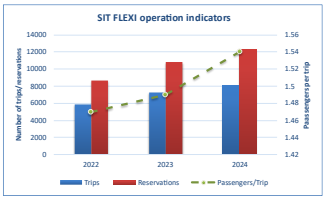

Fig 2. Graphic with the number of trips, number of reservations and passenger trip ratio in the first 3 full years of SIT FLEXI operation.

SIT FLEXI operation indicators

SIT FLEXI has grown steadily in recent years, with a 42% increase in reservations and a 36% rise in trips. The passengers-per-trip ratio also improved, from 1.47 to 1.54, signalling better efficiency and lower environmental impact (Figure 2).

SIT FLEXI operation

SIT FLEXI is now expanding to serve intermunicipal routes, connecting users to Coimbra and nearby municipal centres. To support this expansion, the locations of taxi ranks, pick-up points and destinations were mapped using GIS.

This DRT system is already well spread across the region, meaning that empty runs have strong potential to support parcel delivery. With around 80 taxi ranks and 700 pick-up spots (Figure 3 (a) and (b)), many of the unused kilometres could be repurposed to improve FLM efficiency.

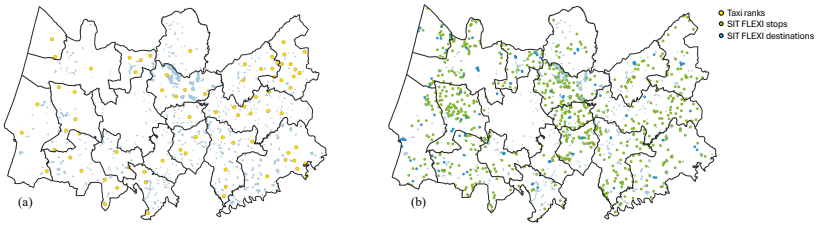

Fig 3. Maps of Coimbra Region with location of towns with less than 40 hab. (blue areas), (a) location of taxi ranks and (b) location of SIT FLEX stops and destinations.

This analysis shows how current regulations, which only allow activating the taxi rank closest to the origin or destination, limit operational flexibility. In Figure 4, Arganil (destination) is allowed, while Folques (on-route) and Moura da Serra (within a defined buffer) are excluded, despite all generating the same paid distance and an empty trip difference of less than 3 km. However, calculating the exact distances for all routes is computationally demanding. To address this, a buffer can be used to simplify the process and help identify additional stops that can be included without requiring long or inefficient detours.

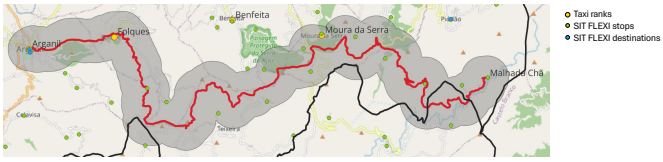

Fig 4. Route example (Malhada Chã-Arganil Centre) with 1km buffer.

Conclusion

SIT FLEXI shows strong potential to enhance regional mobility by connecting isolated areas and reducing transport disparities. Its integration with FLM services creates new opportunities to optimise both systems by maximising the use of existing operational capacity. With the expansion to intermunicipal routes, demand is expected to rise, making it even more important to repurpose the empty runs. Future work could explore current FLM operations in the region and define models to integrate both systems efficiently.

References

[1] Kostovasili M, Kanellopoulos J, Amditis A. Integrated Passenger and Freight Transport: Seamless Door-to-Door Mobility and Optimal Use of Resources. In 2025. p. 569–75.
[2] Mo P, Yao Y, Li P, Wang Y, Liu Z, D'Ariano A. Synergising urban freight transportation in passenger-oriented transit corridors: An efficient Mixed-Integer Linear Programming approach. Transp Res Part C Emerg Technol [Internet]. 2024 Jun 1;163:104644.
[3] Xue S, Zhang Q, Shiwakoti N. Sharing a Ride: A Dual-Service Model of People and Parcels Sharing Taxis with Loose Time Windows of Parcels. Systems [Internet]. 2024 Aug 14;12(8):302.
[4] Cavallaro F, Eboli L, Mazzulla G, Nocera S. Design of integrated passenger-freight transport: A multi-stakeholder perspective. J Public Trans [Internet]. 2023 Jan 1;25:100069.

Acknowledgments

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This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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New Frontiers in Mechanical Engineering

Design and Fabrication of microchip able to emulate tumor microenvironment and metastasis

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Abstract

Cancer remains one of the leading causes of death worldwide, yet traditional research models, such as 2D cell cultures and animal xenografts, fall short in replicating the complexity of tumor microenvironments (TMEs). These limitations hinder the development of effective therapies and the advancement of personalized medicine. In response, tumor-on-chip (ToC) technology has emerged as a promising solution, combining microfluidics, 3D cell culture, and patient-derived tissues to model cancer biology with greater physiological relevance. ToC platforms closely mimic key aspects of TME. Through microfluidic perfusion, they recreate dynamic biochemical gradients of oxygen, nutrients, and signalling molecules, allowing detailed studies of tumor heterogeneity and drug diffusion. Functional vasculature can be achieved via endothelial-lined channels or bioprinted networks, enabling realistic modelling of nutrient transport, tumor cell intravasation, and anti-angiogenic therapies. The inclusion of multiple cell types, such as cancer-associated fibroblast and immune cells, allows investigation of tumor-stroma interactions and immune suppression. Importantly, the use of biopsy-derived spheroids or organoids ensures patient specificity, capturing genetic diversity and enabling personalized drug screening. Innovations in ToC design further enhance its potential. Advanced biomaterials like collagen, decellularized extracellular matrix (ECM), and hydrogels replicate the physical and biochemical properties of the ECM, influencing cell invasion, drug resistance, and mechanotransduction. Despite recent advancements, challenges remain, particularly in sustaining vascular networks, scaling for high-throughput screening, and standardizing patient-derived models. Looking forward, integrating ToC systems with AI-driven analysis and multi-organ platforms will be key to improving clinical relevance and supporting precision oncology.

Why do we need better cancer models?

Cancer continues to be one of the main causes of premature death globally. Based on data acquired in 2022 by the WHO, there were around 20 million new cases and almost 10 million deaths (Fig 1/3). The deadliest types include lung, breast, liver, colon and stomach cancer. Despite advances in research, fundamental challenges remain, such as tumor heterogeneity, therapeutic resistance and recurrence.

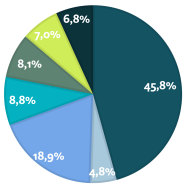


Fig 1 / 3. Global distribution of the main types of cancer in 2022. Data taken from the GLOBOCAN 2022 platform, International Agency for Research on Cancer (IARC), available at https://gco.iarc.fr/today.

Tumor-on-Chip

ToC platforms combine **microfluidics** and **tissue engineering** to recreate key aspects of the TME in a **controllable** and **observable** format (Fig 2/3). These devices feature interconnected **microchannels** and **chambers** where human cells grow under continuous flow, replicating physiological conditions such as **oxygen** and **nutrient gradients**, **fluid shear stress**, **cell-ECM interactions**, and **drug delivery** through perfusion. ToCs can incorporate **immune cells**, **stromal components**, and **patient-derived organoids**, enabling studies of **immune evasion**, **stromal activation**, and **drug resistance** in realistic contexts. Their transparent, standardized design supports **live imaging** and integration of **biosensors** for **real-time monitoring** of parameters such as oxygen, pH, temperature and metabolic activity. ToC architecture is tailored to tumor type and phenotypes.

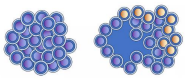
Breast cancer models may use duct-like channels or fibroblast co-cultures to investigate ECM stiffness and stromal signaling. **Lung and colorectal models** use dual chamber or multi-organ systems to simulate metastatic dissemination and drug metabolism. In the case of **Brain and Bone metastases**, the chips reproduce the blood-brain barrier or the bone matrix, integrating endothelial cells and mechanical signals to study extravasation.

Personalized approaches using **patient-derived tumor cells** enable **individualized drug screening** and real-time analysis of **angiogenesis** and **tumor-immune** interactions. Materials and complexity vary, from **PDMS-based systems** to **3D-printed chips** with **built-in gradient systems** that recreate hypoxia and tumor heterogeneity.

Current Models

Preclinical cancer research has traditionally relied on a sequence of models:

- **2D cell cultures**, which are still widely used, are extremely simplified. Tumor cells grow on a flat substrate, which alters their morphology, gene expression and response to drugs. It does not allow cell-extracellular matrix interactions to occur, nor with stromal cells or the immune system, unlike what happens in vivo;
- **Animal models**, such as patient-derived xenografts, offer greater complexity, but are expensive, time-consuming and, above all, do not reproduce the human immune system. This makes them unreliable for modeling specific human processes, such as immune evasion or the response to immunotherapy;
- **3D models**, such as **spheroids** and **patient-derived organoids**, improve this situation by recreating some structural complexity and heterogeneity. However, they remain static, with no perfusion, no nutrient gradients and no ability to monitor responses in real time.



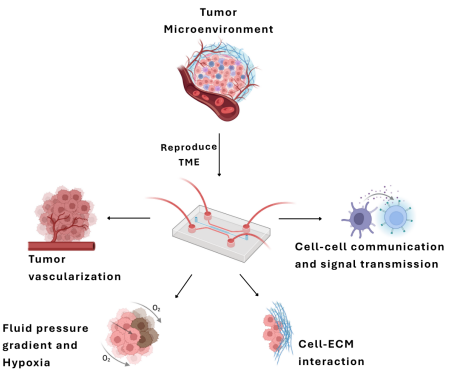


Fig 2 / 3. ToC suitability for TME replication (Addapted from Xu et al. Cell Communication and Signaling, 2024, 22(1), 515).

Experimental Work

The main goal of this project is to develop and validate a physiologically relevant breast ToC platform that supports dynamic perfusion and real-time imaging, enabling long-term culture and functional analysis of patient-derived tumor organoids.

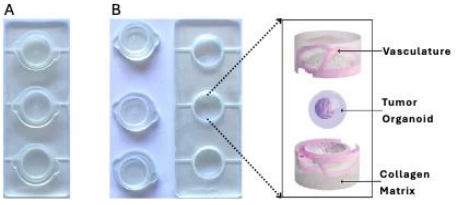


Fig 3 / 3. Schematic of ToC device. (A) Complete device with its covers on. (B) Complete device with the covers removed and multiple characteristics required for use as a tumor model.

The following specific objectives will be pursued:

- **Design microfluidic chip** geometry and channel layout with optimal placement of input/output ports and optical access for confocal microscopy;
- **Fabrication** of the **device using SLA 3D printing** with biocompatible, transparent materials suitable for cell culture and imaging;
- **Development of perfusable microchannels** within a collagen-based hydrogel matrix;
- **Integration of patient-derived breast tumor organoids** into the hydrogel-lined chip to recreate the tumor microenvironment;
- **Dynamic perfusion assays** to evaluate organoid viability, growth kinetics, and expression of key phenotypic markers.

Acknowledgements

This work is supported by Fundação para a Ciência e a Tecnologia (FCT) through the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) and project CarboNCT - 2022.03596.PTDC (DOI: 10.54499/2022.03596.PTDC).

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New Frontiers in Mechanical Engineering

Noise Matters: Evaluating How Noise Interference Affects an Acoustic Camera Performance

Ângela Semitela, Rita Plaza, Samuel Verdasca e António Completo

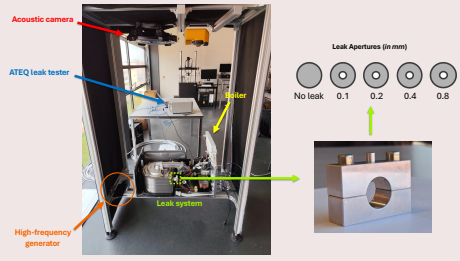
Motivation

Nowadays, ensuring product quality and safety in globally competitive markets requires a rigorous leak assessment after the manufacturing process. Indeed, undetected leaks, particularly in pressurized systems, not only can compromise their performance, but also introduce significant safety, environmental and health risks. In this context, robust and efficient technologies for leak detection and localization are highly sought out for implementation in industrial quality control stations.

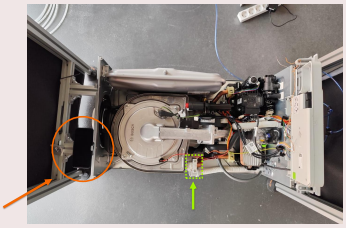
Objectives

The goal was to assess the influence of acoustic interference on leak detection using an acoustic camera in laboratory and industrial-like conditions. The interference in the performance of the camera of high-frequency sounds in the line-of-sight and out-of-sight was also evaluated.

Metodology



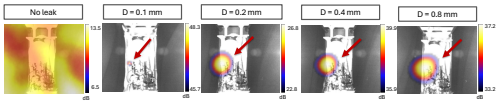
Front view of the experimental setup for detecting and locating leaks with line-of-sight interference.



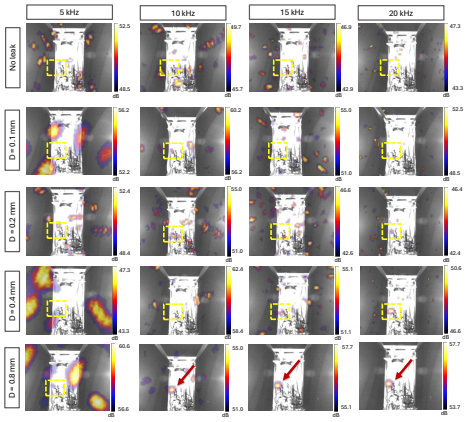
Top view of the experimental setup for detecting and locating leaks with line-of-sight interference.

Experimental setup in the simulated industrial environment.

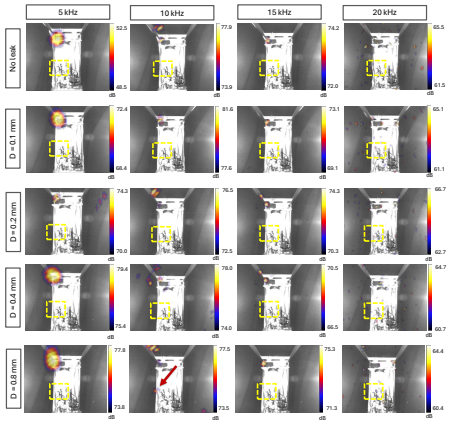
Results



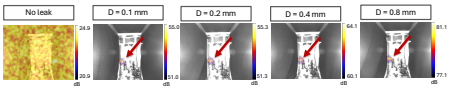
Acoustic images of leaks in low noise conditions.



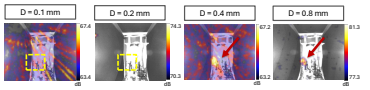
Acoustic images of leaks with acoustic interference out-of-sight of the camera.



Acoustic images of leaks with acoustic interference line-of-sight of the camera.



Acoustic images of leaks in a simulated industrial environment.



Acoustic images of leaks in a simulated industrial environment with high interferences

The results reveal that:

- without interfering noise, all leaks were successfully detected;
- with interfering signals out-of-sight of the camera, three leaks were detected;
- with interfering signals in the line-of-sight, only one leak was localized;
- during testing in a simulated industrial environment, all leaks are localized, but the camera's detection ability may be momentarily compromised by unforeseen acoustic interferences.

Conclusions

The acoustic camera successfully localized all leaks with diameters ranging between 0.1 mm to 0.8 mm without interfering noise. However, its performance is severely compromised by high-frequency acoustic interferences, whether in the line-of-sight or out-of-sight. Nevertheless, in the simulated industrial scenario, all leaks were visible at some point during the experiment, despite the intermittent interferences of the surrounding equipments.

Acknowledgements

This work was developed in the scope of the project "Agenda ILLIANCE" [C644919832-00000035 | Project nº 46], financed by PRR – Plano de Recuperação e Resiliência under the Next Generation EU from the European Union.

This work was also funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

TEchMA 2025

New Frontiers in Mechanical Engineering

MnO_2 as a potential sintering additive for the development of Metal-Supported Proton-Conducting Electrochemical Cells

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Abstract

An emerging structural class of ceramic electrochemical devices, known as metal-supported protonic ceramic electrochemical cells (MS-PCECs), is gaining interest due to offering combination of the excellent mechanical properties of metal supports and the high efficiency and low-temperature operation of proton-conducting ceramics that can permit them to work in challenging environments, especially those where they are exposed to pressurisation gradients or rapid temperature fluctuations [1].

However, several critical challenges have been identified for the processing of these structures, including chemical compatibility issues, incomplete electrolyte sintering, and evaporation of barium-based compositions upon electrolyte densification. To address these issues, decreasing the sintering temperature can be beneficial by using sintering additives [1,2]. Nonetheless, limited information on potential additives is currently available because these devices must be prepared in complex reducing conditions to avoid the oxidation of the metal support. Hence, in this study, we assess the impact of adding minor amounts of MnO_2 on the sintering behaviour of the electrolyte material $BaCe_{0.4}Zr_{0.4}Y_{0.2}O_{3-\delta}$ (BCZY44), performed under reducing conditions.

A range of characterisation techniques, including XRD, SEM/EDS, dilatometry, and electrochemical impedance spectroscopy (EIS), are used to characterize the processed materials.

Our findings indicate that the addition of MnO_2 successfully improves the sinterability of BCZY44 electrolyte under reducing conditions, resulting in both an increase in grain growth and a reduction in the densification temperature, as assessed by dilatometry and microstructural observations.

Through these studies, the current work sets out the groundwork necessary to assess the use of MnO_2 as a possible sintering aid for the development of low-temperature MS-PCEC cells; studies that can open their potential use as robust electrochemical devices that can function in complex application environments.

Structural Characterization

Figure 1 shows the diffractograms obtained for the prepared powders with varying additions of MnO_2 to BCZY44 powders. All samples exhibited the characteristic cubic symmetry (Pm-3m) of BCZY44 composition. However, the MnO_2 phase could not be detected for the compositions analysed, potentially due to its low stoichiometric amount and its nano-scale, preventing its identification under the resolution limits of the technique.

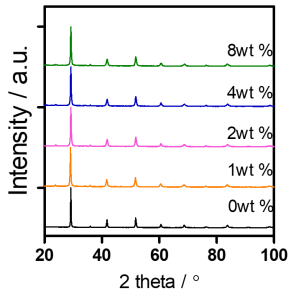
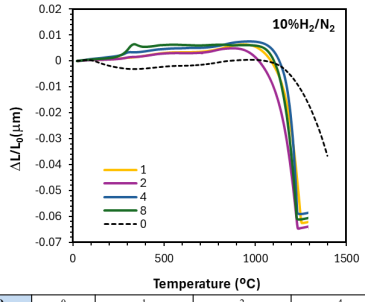


Fig 1 - XRD patterns of BCZY44 with 0%, 1%, 2%, 4%, and 8% by weight of MnO_2.

Dilatometric characterization

The sintering behavior of BCZY44 with varying amounts of MnO_2 (0, 1, 2, 4, and 8 wt%) was analyzed using dilatometry in a reducing atmosphere (10% H_2/N_2). The dilatometric curves illustrate the dimensional changes of the samples as a function of temperature. The results show that for the 2wt% sample the addition of MnO_2 decreases the onset temperature by approximately 100° C, indicating that MnO_2 can effectively function as a sintering aid. Conversely that at higher MnO_2 contents this advantage is lost, possibility due to the initiation of MnO_2 segregation, as shown in Figure 3.



wt% of MnO_2	0	1	2	4	8
Onset temperature (°C)	1386	1239	1217	1217	1216

Fig 2 - Dilatometry curve of BCZY44 with 0%, 1%, 2%, 4%, and 8% by weight of MnO2, showing the sintering behavior during the heating cycle in 10% H_2/N_2.

Microstructure Characterization

Figure 3 illustrates micrographs acquired through scanning electron microscopy (SEM). All the tested MnO_2 containing compositions are noted to be dense. Small additions of MnO_2 are also shown to be beneficial to enhance the grain size. Meanwhile, in the samples containing 4 wt% MnO_2 and above, segregation of manganese starts to be observed, as confirmed by the EDS results (exhibited here for the 4wt% composition, as an representative example).

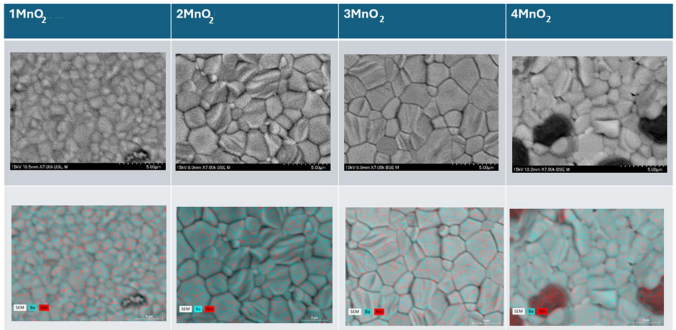


Fig 3 - Microstructural and elemental characterisation (SEM/EDS) of BCZY–%wt MnO_2 bar after exposure to 10% H_2/N_2 at 1400ºC. Elemental mapping reveals the distribution of barium (blue) and manganese (red) across the sample.

References

[1]https://doi.org/10.1016/j.ijhydene.2019.03.181

[2] https://doi.org/10.1149/MA2021-03183mtgabs

Acknowledgements

The authors acknowledge the grants/projects with references: 2023.05868.CEECIND, 2020.02797.CEECIND/CP1589/CT0030(https://doi.org/10.54499/2020.02797.CEECIND/CP1589/CT0030),2022.09319.PTDC(https://doi.org/10.54499/2022.09319.PTDC),2022.02498.PTDC(https://doi.org/10.54499/2022.02498.PTDC),UIDB/00481/2020(https://doi.org/10.54499/UIDB/00481/2020),and UIDP/00481/2020 (https://doi.org/10.54499/UIDP/00481/2020) from Fundação para a Ciência e a Tecnologia (FCT), and COMPETE2030-FEDER-00744500, COMPETE2030-FEDER-00770000, COMPETE2030-FEDER-00820300 from Centro Portugal Regional Operational Programme (Centro2030), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF).This work is supported by the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia.

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New Frontiers in Mechanical Engineering

LCA of Fischer-Tropsch fuel production:

comparing different gasification routes

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Abstract

Fischer-Tropsch (FT) fuels produced from municipal solid waste (MSW) offers a low carbon alternative to fossil fuels. This cradle-to-gate life cycle assessment (LCA) compares four process configurations that combine direct and indirect gasification with the water gas shift (WGS) reaction and the use of a solid oxide electrolyzer (SOEC) for the correction of the H_2/CO ratio.

It is seen that direct gasification combined with an SOEC leads to the lowest environmental impacts with a 23% lower global warming potential as compared to WGS. The main hotspots in the process are the drying of MSW, H_2/CO ratio correction, and syngas cleanup steps. FT-synthesis acts as a net carbon sink. The use of MSW derived FT-fuels can reduce emissions and help waste management.

Introduction and objectives

- Combustion of liquid fossil fuels contributes 33% of the world's GHG emissions [1], with 15% coming from transport alone [2].
- A rapid shift to low carbon fuels is necessary to meet strict climate change targets.
- Fischer-Tropsch (FT) fuels from municipal solid waste (MSW) are a promising alternative [3].
- **Objective 1:** Evaluate environmental performance of FT-fuel production from MSW using LCA.
- **Objective 2:** Compare four process configurations to identify most environmentally friendly.

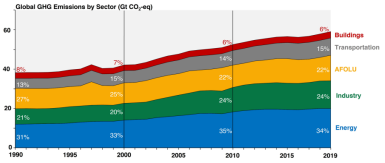

Fig 1. Contribution of transportation to global GHG emissions. [2]

Methodology

- Cradle-to-gate life cycle assessment (LCA) evaluating the production process.
- System boundary includes four process configurations that integrate MSW gasification and FT-synthesis.
- Functional unit is 48.5 MJ of FT-fuel produced.
- Impacts quantified using ReCiPe 2016 midpoint methodology.
- Six impact categories are considered.
  - Global Warming Potential (GWP)
  - Ozone Formation Potential (ODP)
  - Fine Particulate Matter Formation Potential (FPMFP)
  - Terrestrial Acidification Potential (TAP)
  - Freshwater Ecotoxicity Potential (FETP)
  - Fossil Resource Scarcity (FRS)
- LCA modelled on SimaPro 10.2
- Solid Oxide Electrolyzer (SOEC) operated at thermoneutral potential.
- Syngas composition calculated using Gibbs free energy minimization method.

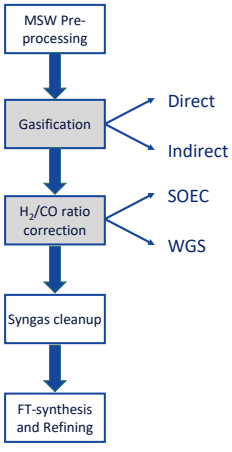

Fig 2. Flow diagram of the FT-fuel production process.

Results

- MSW drying is the main hotspot due to the high energy demand associated with the reduction of moisture content to 10-20%.
- Other hotspots are H_2/CO ratio correction and syngas cleaning.
- FT-synthesis acts as a net sink to emissions because,
  - Highly exothermic in nature
  - Waste heat recirculated within the system
  - Displaces heat from natural gas combustion.

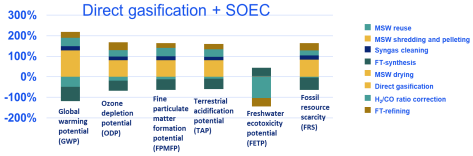

Fig 3. Environmental impacts of direct gasification combined with an SOEC, by subprocess.

- Direct gasification + SOEC is the best performing configuration.
- Leads to 23% lower GWP than Direct gasification + WGS.
- Lowest total normalized impact and cumulative rank based score.
- This is due to the lower overall carbon conversion efficiency associated with the WGS reaction [4].
- Only minor differences between direct and indirect gasification.
- Indirect gasification requires more energy but has a higher H_2/CO ratio and syngas volume [5,6].

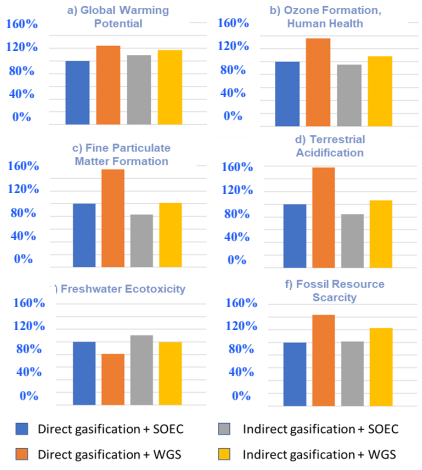

Fig 4. Comparison of the different process configurations.

Conclusions

Direct gasification combined with an SOEC leads to the lowest environmental impacts among categories studied. The key hotspots are MSW-drying, H_2/CO ratio correction and syngas cleaning. FT-fuels produced from MSW offers a solution to both decarbonization of transport and waste management.

References

[1] U. Energy Information Administration, Monthly Energy Review – published: February 2025. www.eia.gov/mer.
[2] IPCC, Emissions trends and drivers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022. https://doi.org/10.1017/9781009157926.004.
[3] I.J. Okeke, S. Mani, Techno-economic assessment of biogas to liquid fuels conversion technology via Fischer-Tropsch synthesis, Biofuels, Bioproducts and Biorefining 11 (2017) 472–487. https://doi.org/10.1002/bbb.1758.
[4] E. Baraj, K. Ciahotný, T. Hlinčík, Advanced Catalysts for the Water Gas Shift Reaction, Crystals (Basel) 12 (2022). https://doi.org/10.3390/cryst12040509.
[5] D. Venugopal, L. Thangavelu, A. Natarajan, Investigation of gasification reactions and h2/co ratio analysis for rice husk air gasification simulation, Thermal Science 27 (2023) 881–890. https://doi.org/10.2298/TSCI220119087V.
[6] S. Khalilarya, A. Chitsaz, P. Mojaver, Optimization of a combined heat and power system based gasification of municipal solid waste of Urmia University student dormitories via ANOVA and taguchi approaches, Int J Hydrogen Energy 46 (2021) 1815–1827. https://doi.org/10.1016/j.ijhydene.2020.10.020.

Acknowledgements

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New Frontiers in Mechanical Engineering

Experimental methodology for temperature distribution in domestic gas ovens

Ana Delgado, Vitor Costa, Fernando Neto, Luís Tarelho

Abstract

The decarbonization of domestic energy systems is central to global climate strategies, particularly with the EU's goal of 75% renewable energy use by 2050 [1]. Blending natural gas with hydrogen offers a transitional solution that reduces emissions without full infrastructure replacement [2] but introduces challenges in combustion performance and safety.

Most studies on temperature distribution in domestic ovens - such as those by Mistry et al., Park et al., and Hincapié et al. - used conventional natural gas and diverse setups (e.g., J-type thermocouples, infrared imaging, CFD validation). However, these do not consider hydrogen-enriched blends and often omit standardized parameters like timestep intervals, setpoints, and test durations, which are key to assessing thermal stability.

Hydrogen affects combustion: Zhao et al. reported improved flame stability, increased burner temperatures, and reduced CO emissions with up to 25% hydrogen by volume. These effects need revised testing protocols.

To address this gap, it is proposed a standardized methodology for evaluating thermal behavior in ovens operating with hydrogen–natural gas blends. This includes fixed thermocouple positioning, defined sampling intervals, precise setpoints, and steady-state criteria—allowing for accurate assessment of thermal asymmetries and safety.

In conclusion, establishing robust, reproducible testing protocols is essential for integrating hydrogen into domestic ovens. This work contributes a foundational methodology for thermal assessment tailored to hydrogen-enriched fuels, supporting safer and more consistent appliance design in the transition to low-carbon energy.

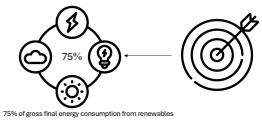
Introduction

Within the residential sector, cooking appliances represent the second-largest share of household energy consumption in Europe.

Although electric ovens dominate the EU market, gas ovens remain relevant in Southern European countries.

Hydrogen has emerged as a clean fuel alternative capable of reducing greenhouse gas emissions and mitigating climate change [6] and can be directly injected into the natural gas pipelines.

Integrating hydrogen into the natural gas grid for domestic ovens presents a valuable pathway to reduce greenhouse gas emissions, support the EU's 2050 climate targets [1].



75% of gross final energy consumption from renewables

Changing the fuel to a blend of natural gas and hydrogen can potentially affect oven performance, including combustion efficiency, emissions, and cooking results. Although several studies have examined temperature distribution in domestic gas ovens using conventional natural gas, as shown in Table 1, none have focused on hydrogen–natural gas blends—highlighting a clear gap in the literature.

Table 1- Summary of temperature measurement methodologies in experimental studies on domestic gas ovens.

Study	Measurement technique	Sensor setup
Mistry et al.	J-type thermocouples (0.254mm) + IR thermography	Thermocouples at vertices + center; blackbody (emissivity 0.95) for IR calibration; co-located sensors for validation
Park et. al	Thermocouples (100 total)	4 vertical layers of 25 sensors each, distributed in the cavity
Hincapie et. al	Type-K thermocouples (6 mm casing)	18 sensors: aligned along z-axis and left half of FBP; fixed to avoid burner interference

Zhao et al. in their study on the effects of blending natural gas with hydrogen, reported that the mixture enhanced flame stability, increased burner temperatures, and significantly reduced CO emissions when up to 25% hydrogen by volume was used.

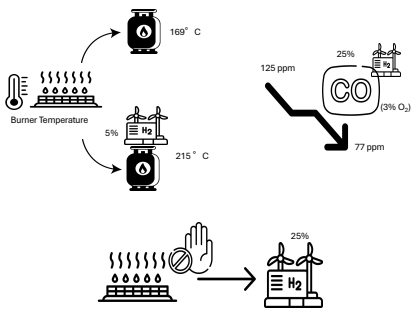


Fig 1- Main results from Zhao et al.

Experimental methodology

1. **Thermocouple placement:**
   - Positioned at key points inside the oven rack to assess temperature distribution.
2. **Setpoint temperature:**
   - Defined at 175ºC to represente typical cooking conditions.
3. **Heating cycle duration:**
   - Burner operated for 35 minutes, followed by manual shut-off.
4. **Analysis Criteria:**
   - Heating time: Time required to reach peak temperature, before automatic gas valve regulation.
   - Temperature variations: Differences in both maximum temperature and at minute 25, used to assess thermal non-uniformity.

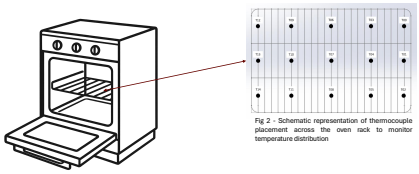


Fig 2 - Schematic representation of thermocouple placement across the oven rack to monitor temperature distribution

The experimental oven contains four internal racks, allowing for multi-level temperature assessment.

Preminary Results

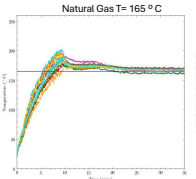


Fig 3 - Temporal temperature profile recorded at thermocouple location on rack 4

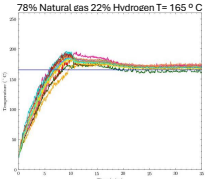


Fig 5 - Temporal temperature profile recorded at thermocouple location on rack 4

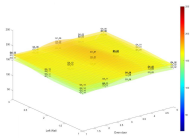


Fig. 4 – Three-dimensional representation of the oven cavity at minute 25

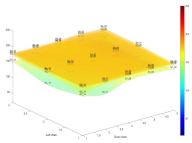


Fig. 6 – Three-dimensional representation of the oven cavity at minute 25

Conclusion

- **Natural gas:**
  - Max. temperature: 202.7 ° C at 9.2 minutes
  - Max. temperature difference (TCs): 40.3 ° C
  - At 25 min: 170.3 ° C, with 8.4 ° C variation
- **78% natural gas + 22% hydrogen:**
  - Max. temperature: 196 ° C at 10. 4 minutes
  - Max. temperature difference (TCs): 45.3 ° C
  - At 25 min: 172.4 ° C, with 12 ° C variation

Preminary results

- Adding hydrogen delays the gas valve activation (slower rise to peak temperature).
- Better thermal uniformity at peak with hydrogen.
- Natural gas performs better at 25 min, allowing more uniform temperature distribution.

Referências

[1] European Commission, "Energy roadmap 2050," https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0885, accessed March 13, 2025 (2011).

[2] H. Yang, X. Lin, H. Pan, S. Geng, Z. Chen, and Y. Liu, "Energy saving analysis and thermal performance evaluation of a hydrogen-enriched natural gas-fired condensing boiler," Int. J. Hydrogen Energy, Jun. 2023.doi:10.1016/j.ijhydene.2023.02.027. [3] H. Mistry, S. Ganapathisubbu, S. Dey, P. Bishnoi, and J. L. Castillo, "A methodology to model flow-thermals inside a domestic gas oven," Appl. Therm. Eng., vol. 31, no. 1, pp. 103–111, 2011. doi:10.1016/j.applthermaleng.2010.08.022

[4] S. P. Park, Y. H. Kim, Y. S. Kim, Y. G. Park, and M. Y. Ha, "Numerical study on the effect of different hole locations in the fan case on the thermal performance inside a gas oven range," Appl. Therm. Eng., vol. 137, pp. 123–133, 2018. doi:10.1016/j.applthermaleng.2018.03.087.

[5] F. F. Hincapié and M. J. García, "A surrogate model of heat transfer mechanism in a domestic gas oven: A numerical simulation approach for premixed flames," Appl. Mech., vol. 5, no. 2, pp. 391–404, 2024.

[6] Y. Zhao, V. McDonell, and S. Samuelsen, "Experimental assessment of the combustion performance of an oven burner operated on pipeline natural gas mixed with hydrogen," Int. J. Hydrogen Energy, vol. 44, no. 47, pp. 26049–26062, 2019. doi:10.1016/j.ijhydene.2019.08.011. 2024.

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New Frontiers in Mechanical Engineering

Polyvinylpyrrolidone-Prussian blue electrospun sensor for visual detection of hydrogen

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LASI, Portugal

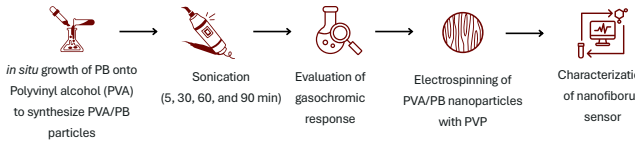
Abstract

Hydrogen has emerged as a key element in the global transition towards cleaner and more sustainable society. However, its safe application depends on the availability of reliable and accessible sensors. Particularly, visual sensors that change color upon exposure to hydrogen support universal, low-cost and power-free alternatives for domestic and industrial settings. This work presents a gasochromic hydrogen sensor based on electrospun nanofibres able to incorporate Prussian blue (PB) nanoparticles. The particles were prepared by dispersing PB in a poly(vinyl alcohol) solution using ultrasonic energy. Sonication was tested at different durations (5, 30, 60 and 90 minutes) to study its influence on particle morphology, dispersion stability and sensor performance. Chemical, morphological and structural analysis showed that shorter sonication resulted in better dispersion and homogeneity of gasochromic particles. The most promising formulations were electrospun with polyvinylpyrrolidone into gasochromic nanofibrous sensors. Mechanical testing showed limited tensile strength, which remains a challenge. Functional performance was assessed under cycles of 100% hydrogen and synthetic air. Color change was quantified using the CIELAB model and the ΔE parameter. Gasochromic particles with 5 minutes of sonication showed higher response (ΔE > 45), with a response time (t_{90}) of 300 s. However, total recovery was incomplete during the period of air exposure. Overall, this sensor shows potential for safe, low-cost sensing, though improvements in robustness and stability are needed.

Objective

Hydrogen (H_2) is key to a sustainable energy future, and eye-readable sensors enable safe, intuitive detection without electronics [1]. Herein, visual H_2 sensors based on electrospun Polyvinylpyrrolidone-Prussian Blue (PVP/PB) nanofibers are developed with the purpose of combining user-friendliness functionality with cost-efficient and green manufacturing.

Methods:



Results:

The performance of the H_2 sensors was directly influenced by the morphology and dispersion state of PB embedded in the PVA matrix. SEM analysis (Fig. 1) showed that 5 minutes sonication produced smaller, well-distributed PVA/PB particles, while longer times (30, 60 and 90 minutes) led to re-agglomeration and less favorable morphologies.

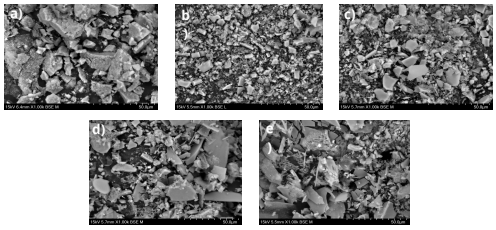


Fig. 1: SEM images of nanofibers with PB particles after (a) 0, (b) 5, (c) 30, (d) 60, and (e) 90 minutes of sonication.

Based on morphological analysis and color response (Fig. 2), the 0, 5 and 90 minutes PVA/PB particle formulations were selected for electrospinning with PVP: the 0 minutes sample as a control, the 5 minutes sample for its strong color response, and the 90 minutes sample for its faster recovery among the longer sonication times.

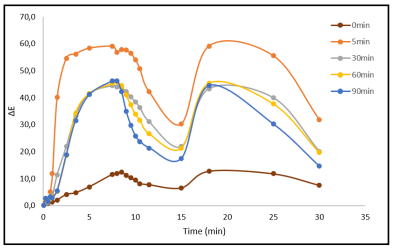


Fig. 2: Optical response (ΔE) of particles after 0, 5, 30, 60, and 90 minutes of sonication. 2 cycles of sequential H_2 exposure (7,5 min) and synthetic air (7,5 min).

The selected composites were incorporated into a PVP matrix to produce PVP–PVA/PB electrospun sensors, which were tested under 100% H_2 (30 min) and synthetic air (15 min). The sensor comprising the gasochromic particles with 5 min of sonication displayed the highest color contrast and the fastest response, although with partial reversibility (Fig. 3).

Conclusion:

The electrospun sensor incorporating PVA/PB particles sonicated for 5 min demonstrated the best visual response when exposed to H_2. Despite its potential for low-cost and intuitive H_2 monitoring, mechanical fragility and signal fatigue still limit its current application. Future work should focus on enhancing the long-term durability and mechanical robustness.

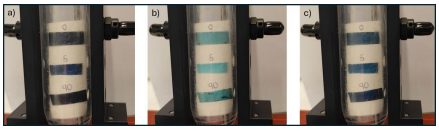


Fig. 3: Photos of the PVP-PVA/PB sensors. a) before H_2 exposure; b) after 30 minutes of exposure to 100% H_2; c) after 15 minutes of exposure in synthetic air.

The sensor developed from gasochromic particles with 90 min of sonication showed moderate coloring but faster recovery, while the control revealed a weak response due to poor particle dispersion (Fig. 4).

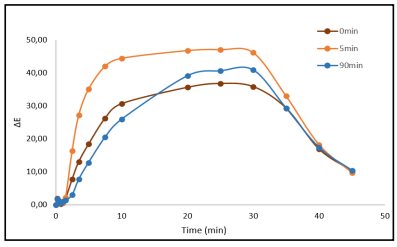


Fig. 4: Optical response (ΔE) of electrospun sensors under H_2/air cycles.

Tensile testing revealed low mechanical strength across all electrospun membranes. Although the 5 minutes formulation showed slightly improved stress–strain behaviour, all samples exhibited brittle fracture, indicating the need for further reinforcement strategies to enhance durability (Fig. 5).

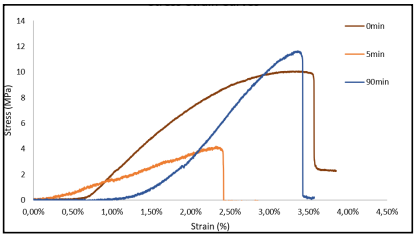


Fig. 5: Stress–Strain Curves.

References:

[1] A. F. Girão and A. Completo, "Eye-readable sensors for intuitive hydrogen monitoring," Int. J. Hydrogen Energy, in press. DOI: 10.1016/j.ijhydene.2024.04.014

Acknowledgments

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New Frontiers in Mechanical Engineering

Finite-Element Modeling of Electroporation Dynamics in Tumor-on-a-Chip

João F. Gil[a,c,d], Carla Moura[b] , Vania Silverio[c], Gil Gonçalves[d,e]

(a) CDRSP; PLeiria; (b) i2A; IPC; (c) INESC-MN; (d) TEMA - University of Aveiro; (e) LASI

Abstract

Tumor-on-a-Chip (ToC) devices are microfluidic systems able to recreate key features of the tumor microenvironment, mimicking extracellular matrix (ECM) architecture, cellular organization, and vascularization in a three-dimensional (3D) manner. ToC platforms enable physiologically relevant studies for tumor biology fundamental research and high-throughput therapeutic screening.

Electroporation is a technique that applies short and high electrical field pulses to transiently increase the permeability of cell membranes. This process enhances intracellular delivery of drugs and genes. Yet, defining optimal protocols remains challenging, particularly in complex 3D tissues.

Here, we present a finite element model of electroporation dynamics in a ToC system, using COMSOL Multiphysics to solve coupled charge-conservation and pore evolution equations. The spheroid is embedded in collagen and exposed to a decaying exponential pulse (0.71 kV/cm; $\tau = 0.1$ ms) via two electrode configurations: needle and concave.

Simulations show that transmembrane voltage (TMV) reaches around the 1 V threshold within 2 µs. This triggers pore nucleation, with peak densities in the order of 10^{11} pores/m^2 and maximum pore radius of 270 nm by 75 µs, followed by pore radius normalization around 290 µs. Pore density displayed spatial decay with increasing distance from the electrodes. Cells closest to the field source underwent high pore formation, while those farther showed limited electroporation. Needle electrodes produce more focused fields and higher local pore densities, whereas concave electrodes induce a broader but milder effect.

This framework enables the prediction of pore dynamics in spheroid loaded ToC systems and supports the optimization process of electroporation protocols. Future work includes extending the model to incorporate cells and ECM heterogeneity and co-cultures.

Introduction

ToC replicate the tumor microenvironment by assembling ECM, cellular architecture, and dynamic perfusion in a 3D *in vitro* device. These platforms allow the creation of *in vitro* models for tumor progression, therapeutic evaluation and drug screening. Electroporation involves applying short, high-voltage pulses to induce transient pores in cell membranes, enhancing intracellular delivery of therapeutic agents. Although widely studied, its behavior in multicellular 3D systems remains difficult to predict. Here, we model electroporation dynamics in such devices to predict tumor responses and allow for protocol optimization.

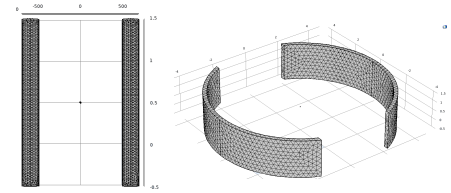

Fig 1 / Geometries implemented in the COMSOL simulations. (left) 100 µm radius needle electrodes 1 mm apart. (right) Concave semicircular sheet electrodes with 5 mm radius and 4 mm edge-to-edge. The electrodes are 2 mm deep in the ECM. The cell has 10 µm radius.

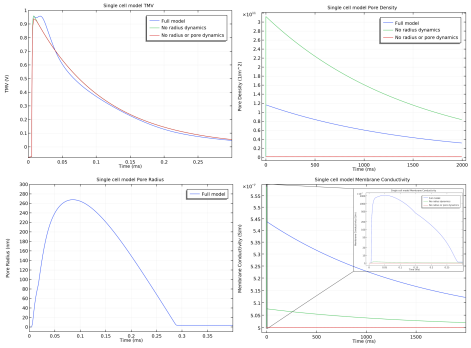

Fig 2 / Single cell electroporation dynamics under increasingly complex models. (top left) Maximum TMV vs time. (top right) Maximum pore density vs time. (bottom left) Maximum pore radius vs time. (bottom right) Maximum membrane conductivity vs time.

Methods

A multiphysics model was implemented in COMSOL to simulate electroporation in a ToC platform. The domains include a central tumor entity embedded in a collagen matrix, flanked by electrodes in two configurations: needles and concave sheets. Simulation were made for single-cell and for a 200 µm spheroid with 460 cells. The simulation solves:

- Laplace's equation for electric potential $-\nabla(\sigma\nabla V) - \nabla\frac{\partial(\varepsilon_0\varepsilon_r\nabla V)}{\partial t} = 0$
- ODE for pore density $\frac{\partial N}{\partial t} = \alpha e^{\left(\frac{V_m}{V_{ep}}\right)^2}\left[1 - \frac{N}{N_0}\alpha e^{-q\left(\frac{V_m}{V_{ep}}\right)^2}\right]$
- ODE for pore radius $\frac{\partial r_p}{\partial t} = \frac{D}{kT}\left(\frac{{V_m}^2 F_{max}}{1 + r_h/(r_p + r_t)} + 4\beta\left(\frac{r_*}{r_p}\right)^4\frac{1}{r_p} - 2\pi\lambda + 2\pi\gamma_{eff}r_p\right)$

Membrane properties (conductivity and permittivity) were updated dynamically. A single exponential pulse (0.71 kV/cm, $\tau = 0.1$ ms) was applied across the system.

Single cell model

The TMV increases and reaches around 1 V within the first 2 µs after pulse rise, initiating pore nucleation. The pore density peaks at approximately 10^{11} pores/m^2, while the pore radius grows to 270 nm by 75 µs and returns to normal size by 290 µs. The increase in membrane conductivity reflects the cumulative pore surface area and self-limits and shapes the TMV decay profile. Models without radius dynamics showed slightly higher pore densities due to sustained TMV, resulting from a lower conductivity increase. This absence of radius feedback allows TMV to remain elevated longer, sustaining additional pore nucleation. The full model includes radius expansion which accelerates conductivity rise and reduces the TMV driving force, leading to moderated pore densities.

Spheroid simulation and electrode effect

Spatially, pore density decreases with increasing distance from the electrodes. Cells at the interface undergo stronger electroporation, while deeper cells remain are less affected by electroporation. Its also noticeable that the cells in the positive electrode side are greatly electroporated.

While Fig 3 (left) and Fig 3 (middle) seem to have no visible differences, by normalizing its values and calculating its difference we could access that needle electrodes produced sharply localized electric fields with high TMV and pore density concentrated near the tips. Concave electrodes, on the other hand, resulted in a broader and more uniform electroporation profile, with reduced peak intensity. This distinction has implications for electrode use, while needle configurations are advantageous when electroporating single cells, concave electrodes offer better coverage for tissue-level or spheroid electroporation, where uniform permeabilization is desired.

Conclusion

This computational framework allows prediction of spatial and temporal electroporation dynamics in a 3D spheroid embedded in a extracellular matrix. It reduces experimental iterations, tailoring pulse parameters, materials properties and geometries before experimentation. Future developments include cell, spheroid and ECM heterogeneity and co-cultures. Computational models allied to ToC electroporation will not only develop the fundamental research on electroporation and its effects but also assist toward the development of precision and personalize therapeutic treatments.

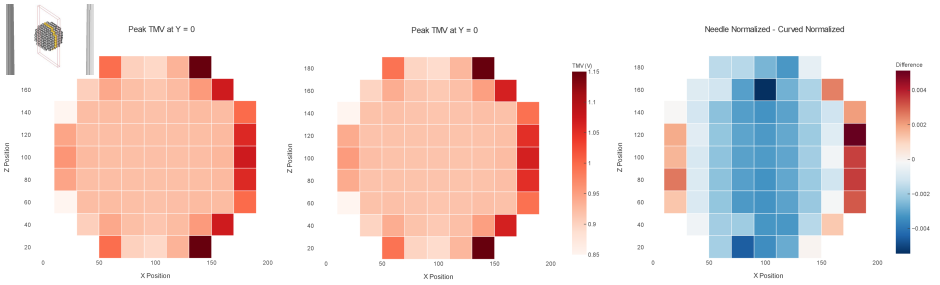

Fig 3 / Electroporation effects on a spheroid and comparison of these effects using needle and curved electrodes. (left) TMV distribution for needle electrodes. (middle) TMV distribution for concave electrodes. (right) Difference map of the normalized TMV values (Needle – Concave)

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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New Frontiers in Mechanical Engineering

Embracing Autonomous Mobility? Survey Evidence from the Portuguese Context

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Abstract

Automated vehicles (AVs) offer promising benefits for mobility systems, such as improved safety, energy efficiency, and accessibility. However, public acceptance remains a major barrier, especially in countries like Portugal, where AV development is still emerging.

This study explores the willingness of Portuguese citizens to adopt AVs for both public and private transport. A structured survey of 425 participants assessed perceptions of safety, trust, environmental awareness, and knowledge about AVs.

Results show that technological optimism and positive environmental views are key drivers of acceptance. In contrast, rural living experience was associated with lower willingness, reflecting concerns about infrastructure and trust. Age had a marginal positive effect, while gender and income had limited influence.

Participants preferred partially automated vehicles and showed greater interest in shared or public AV use than in private ownership.

Findings provide insights to guide inclusive AV implementation strategies, helping address public concerns and bridge urban-rural differences in AV adoption.

Introduction

Automated Vehicles (AVs) are increasingly discussed as innovative solutions to mobility challenges, offering potential improvements in road safety, energy efficiency, and transport accessibility [1–3]. Yet, public acceptance remains a key barrier to adoption, particularly in countries like Portugal, where AV development is still at an early stage, with limited pilot projects and regulatory support [4–5].

In the Portuguese context — marked by a strong urban–rural divide — questions arise regarding how factors such as trust, safety perception, and infrastructure influence public willingness to adopt AVs. Previous studies indicate generally favorable attitudes, though concerns persist about information gaps and system reliability.

Objectives

To understand the willingness of Portuguese citizens to adopt automated vehicles, in both **private** and **public** contexts, considering **behavioural**, **environmental**, and **contextual** factors.

Specific Objectives

I. Assess willingness to adopt AVs in both private and public transport

II. Identify the key influencing factors

III. Develop a predictive model based on those factors

IV. Support mobility planning and AV implementation policies in Portugal

Literature Overview

Research identifies several key factors shaping the acceptance of automated vehicles (AVs). Among them are safety perception, trust in technology, awareness and experience, environmental values, and socioeconomic context [1–4].

Urban–rural differences are especially relevant in Portugal, where limited infrastructure and exposure to AVs remain barriers in non-urban areas [5].

Studies also highlight that younger and more educated individuals, as well as those with sustainable mobility preferences, show higher willingness to adopt AVs [2,4].

The adjacent map illustrates the main dimensions emerging from international and Portuguese studies that influence AV adoption.

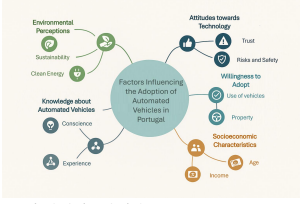

Fig 1. Literature overview (author's production).

Methodology

This study followed a five-step process, beginning with the design and application of a structured online survey to 425 participants across Portugal.

Explanatory variables were grouped into four thematic dimensions, and individual factors—such as age, gender, driving habits, public transport use, and rural experience—were added to capture personal and contextual differences.

A robust regression model was used to predict willingness to use AVs in both private and public transport scenarios.

The diagram below summarises the full methodological approach.

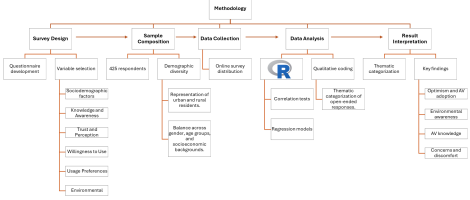

Fig 2. Methodology

Results & Discussion

I. Participant Profile

- Sample: 425 individuals
- 55% female, mostly aged 40–59
- High education levels; 68% employed full-time
- 91.5% hold a driving licence
- Low public transport use (64% rarely or never)
- 44% reported rural experience

II. Awareness, Trust & Attitudes

- 72% had heard of AVs, but 69% rated their own knowledge as low
- Most trust levels were neutral (mean = 4), yet 35% scored 1–3
- Top concerns: safety, tech failures, infrastructure readiness
- Community benefits (e.g., accessibility, environment) rated positively (α = 0.92)
- Information demand: over 45% rated clear communication as "extremely important"

III. Willingness to Use AVs

- ~70% expressed moderate willingness to adopt AVs
- Preference for partial automation (60%); only 10% chose full automation
- Preferred contexts: healthcare, commuting, emergencies
- Private ownership less attractive (mean = 3.09); more openness to public/shared models

IV. Environmental Motivation

- High agreement with using AVs if:
  - They are low-emission
  - Promote sustainability
  - Run on clean energy (electric/hydrogen)
- All three items strongly correlated (ρ > 0.82)
- Environmental perception strongly associated with overall willingness (p < 0.001)

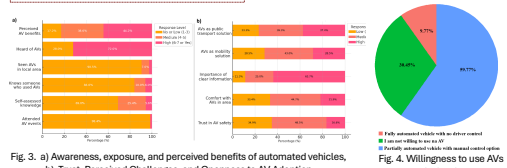

Fig. 3. a) Awareness, exposure, and perceived benefits of automated vehicles, b) Trust, Perceived Challenges, and Openness to AV Adoption

Fig. 4. Willingness to use AVs by level

V. Predictive Modelling

Model: Robust Linear Regression (MM estimators)

$$Y = -2.1243 + 0.0659 \cdot X_{OA} + 0.2695 \cdot X_{EP} - 0.2841 \cdot X_{RA} + +0.0121 \cdot X_A + \epsilon$$

Final predictors:

- X_{OA} – Optimism & Adoption (p < 0.001)
- X_{RA} – Rural Experience (p < 0.1)
- X_{EP} – Environmental Perception (p < 0.001)
- X_A – Age (p ≈ 0.087)

The model shows that positive attitudes and environmental perceptions are the strongest predictors of willingness to adopt AVs, both with statistically significant positive effects. Rural living experience has a negative influence, and age a small but positive one. The robust regression (MM estimator) ensured reliability despite outliers and assumption violations.

Conclusions

- The study reveals that technological optimism, environmental perception, and transport experience are key drivers of willingness to adopt AVs. In contrast, rural living experience negatively impacts acceptance, underscoring challenges in low-density areas.
- Using Robust Linear Models, the analysis offers statistically sound insights into AV acceptance in Portugal. These findings support the development of context-specific policies and implementation strategies for future mobility systems.

References

[1] Becker, F. and Axhausen, K.W., 2017. Literature review on surveys investigating the acceptance of automated vehicles. Transportation, 44(6), pp.1293–1306.

[2] Litman, T., 2017. Autonomous vehicle implementation predictions. Victoria, BC: Victoria Transport Policy Institute.

[3] Lee, C., Ward, C., Raue, M., D'Ambrosio, L. and Coughlin, J.F., 2017. Age differences in acceptance of self-driving cars: A survey of perceptions and attitudes. In: A. Gao and J. Zhou, eds., Human Aspects of IT for the Aged Population. Aging, Design and User Experience. ITAP 2017. Lecture Notes in Computer Science, vol 10297. Cham: Springer, pp.3–13.

[4] Gkartzonikas, C. and Gkritza, K., 2019. What have we learned? A review of stated preference and choice studies on automated vehicles. Transportation Research Part C: Emerging Technologies, 98, pp.323–337.

[5] Yuen, K.F., Huyen, D.T.K., Wang, X. and Qi, G., 2020. Factors influencing the adoption of shared automated vehicles. International Journal of Environmental Research and Public Health, 17(13), p.4868

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Microfluidic fabrication of protein-based nanoparticles for cancer

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Abstract

Cancer remains a major global health challenge, with rising incidence and limitations in current treatments due to side effects and lack of specificity. Standard therapies like chemotherapy and radiotherapy are often non-selective, affecting healthy tissues and reducing quality of life. Emerging strategies such as photothermal therapy (PTT) and photodynamic therapy (PDT) offer more targeted approaches, especially when combined with nanotechnology. Nanoparticles (NPs), with their small size and tunable surfaces, enable targeted drug delivery and improved imaging. Protein-based, biomimetic NPs provide enhanced biocompatibility, reduced immunogenicity, and selective tumor accumulation.

Despite their promise, conventional production methods for these NPs face challenges, including high cost, poor size control, and scalability issues. Microfluidic systems address these limitations by precisely manipulating fluids at the microscale, allowing for controlled, reproducible, and efficient NP synthesis . This review explores the use of microfluidics for fabricating protein-based NPs for cancer applications, focusing on how device design influences NP properties. Both in vitro and in vivo studies demonstrate their strong potential in cancer diagnosis and therapy.

Why the use of microfluidics?

Microfluidic devices offer superior control over critical reaction conditions such as flow rate ratio (FRR), mixing efficiency, and temperature, ensuring consistency, reproducibility, and functionality of produced NPs.

These systems enable efficient mixing at the microscale, reduce reagent consumption, and allow for continuous, scalable production of highly uniform NPs.

The role of protein-based biomimetic nanoparticles

Protein-based biomimetic NPs combine biocompatibility, biodegradability, and the ability for precise drug delivery. These NPs can be engineered to carry therapeutic agents directly to tumor cells, minimizing adverse effects on healthy tissue, and they are easily modified with targeting molecules or drugs. Their natural origins allow for mild preparation conditions without toxic solvents.

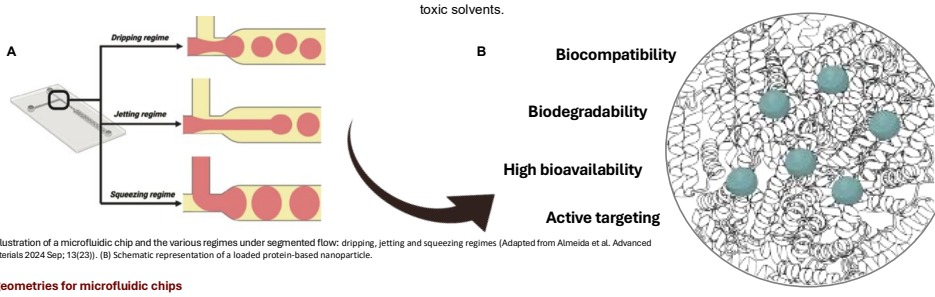


Fig 1 / 3. (A) Illustration of a microfluidic chip and the various regimes under segmented flow: dripping, jetting and squeezing regimes (Adapted from Almeida et al. Advanced Healthcare Materials 2024 Sep; 13(23)). (B) Schematic representation of a loaded protein-based nanoparticle.

Existing geometries for microfluidic chips

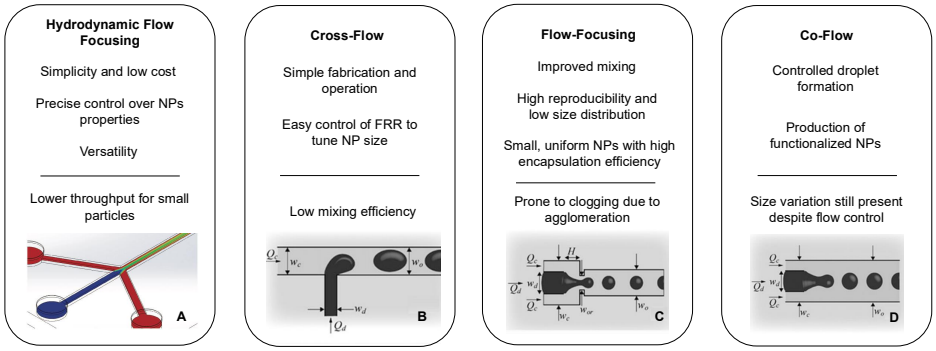
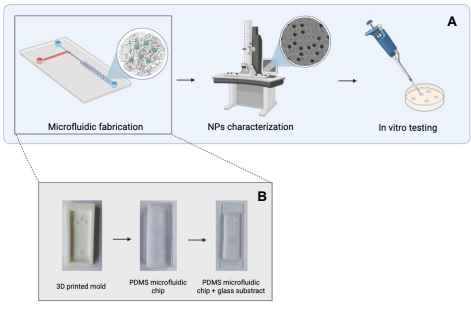


Fig 2 / 3. Schematic of various microfluidic chips setups: (A) Hydrodynamic flow focusing (Adapted from Almeida et al. Advanced Healthcare Materials 2024 Sep; 13(23)). (B) Cross-flow. (C) Flow-focusing. (D) Co-flow. (Adapted from Glawdel et al. Encyclopedia of Microfluidics and Nanofluidics 2013 Apr)

Experimental work



This work aims to develop a microfluidic chip as a platform for the synthesis of small, uniform and polydispersed protein-based NPs.

The following steps will be taken:

- Design of the microfluidic chip architecture, including channel layout.
- Fabrication of the device through SLA 3D printing using transparent, biocompatible materials suitable for both imaging and cell culture.
- Fabrication and physicochemical characterization of protein-based nanoparticles, with systematic optimization of formulation parameters.
- In vitro testing on 3D cell culture models of cancerous and normal cells to assess biocompatibility, cytotoxic effects, and additional functional responses.

Fig 3 / 3. (A) Schematic representation of the work flow to be carried out. (B) Fabrication process of the microfluidic chips.

Acknowledgements

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Optimizing the Operational Efficiency of the Municipal Solid Waste Collection System

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Abstract

This project aims to analyze the feasibility of replacing a part of or a total fleet of the municipal solid waste collection system, specifically its vehicles, currently powered by diesel with alternative propulsion sources, such as biodiesel and electric vehicles. The evaluation considers various technical and functional, economic, energy, environmental, and labor aspects. The study includes an analysis of acquisition, maintenance, and fuel costs, environmental impacts such as pollutants and greenhouse gas emissions, and also, the technical suitability of new technologies to operational conditions. The main objective is to produce a strategic guide that promotes environmental sustainability and economic and energy efficiency in the waste management sector.

Contextualization and Methodology

Road transport accounts for 71% of the total GHG emissions in the transport sector, whilst the entire sector represents 25% of the GHG emissions in the EU. In Portugal, the average waste production per capita in 2023 was 502 kg, implying that waste collection requires a daily, non-stop operation. This project intends to evaluate the feasibility of different energy sources, such as electricity, 100% HVO Biofuel, and a 54% HVO blend. Figure 1 presents the main pillars of the analysis, with a special focus on the economical, environmental and technical feasibility, these were all of the considered parameters do determine the best solutions. For the technical feasibility, different specifications were considered, such as load capacity, engine power, overall dimensions and battery capacity for the EV, all of the data was extracted from manufacturers. The economical viability included the costs for acquisition, maintenance, fuel and government subsidies if applicable. The environmental analysis covered both the current and future pollutant emissions. On the other hand, the energetic analysis compared directly the consumption of all solutions in kWh/km and the social implications listed the possible scenarios related to this kind of alteration on a fleet. All of the mentioned analyses were developed over real operational data from the trucks.

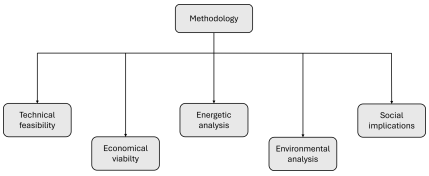
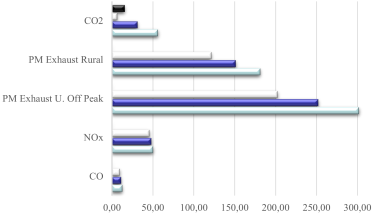


Fig 1 / General Methodology

Results and Conclusions

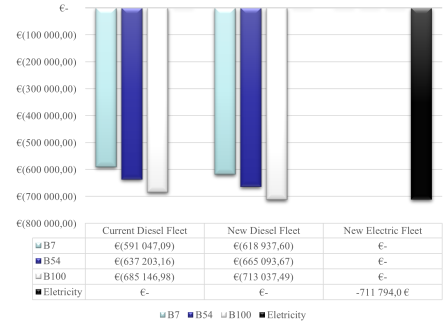
The environmental one in Figure 2, where the units are CO2 (ton/year), PM (g/year), Nox, and CO (kg/year), highlights the decrease in all pollutants by using the alternative sources, with a special decrease in CO2. Figure 3 presents the economics of the solutions, revealing the current solution with regular B7 diesel as the cheapest option, although, besides being more expensive, there is no significant difference from a new diesel fleet to an electric one. Energy-wise, Figure 4 presents the electric fleet as the most efficient solution and among the fuels, the higher the HVO blend, the less efficient the solution is due to the lower HHV of HVO. Finally, Figure 5 plots the current fleet's specific consumption, creating a ranking for the most urgent replacements, in this case, the least fuel-efficient ones.



	CO	NOx	PM Exhaust U. Off Peak	PM Exhaust Rural	CO2
Eletricity	0	0	0	0	15,48
B100	9,54	45,66	202,28	121,37	6,17
B54	11,04	47,92	252,09	151,26	31,15
B7	12,55	50,18	301,91	181,14	56,13

Eletricity B100 B54 B7

Fig 2 / Results for the Environmental Implications analysis



	Current Diesel Fleet	New Diesel Fleet	New Electric Fleet
B7	€(591 047,09)	€(618 937,60)	€-
B54	€(637 203,16)	€(665 093,67)	€-
B100	€(685 146,98)	€(713 037,49)	€-
Eletricity	€-	€-	-711 794,0 €

B7 B54 B100 Eletricity

Fig 3 / Results for the Economic Viability analysis

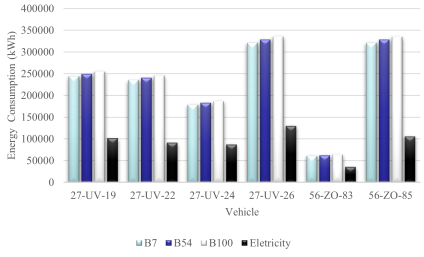


Fig 4 / Results for the Energy analysis

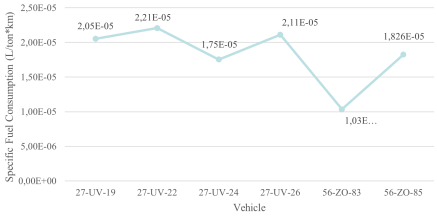


Fig 5 / Specific fuel consumption for each vehicle

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New Frontiers in Mechanical Engineering

Magnesium for Rechargeable Battery Applications

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Abstract

Magnesium (Mg) is emerging as a promising, strategically important material in the field of rechargeable batteries, owing to its intrinsic qualities such as ore abundance, cost efficiency, and multifunctionality across diverse electrochemical systems [1]. Recent research works suggest that it is possible to deploy Mg for electrochemical energy storage either through Mg ion secondary battery systems or through Mg based electrodes assisted Li/Na ion battery systems [2]. While Mg-ion batteries are still in their infancy due to the intrinsic difficulty of intercalating divalent Mg^{2+} ions into the host materials, our research suggest that, by using right combination of materials it is possible to overcome such limitations. In this context, we report the synthesis of a MgO-pillared reduced graphene oxide (rGO) composite via a solid-state reaction between magnesium hydride (MgH_2) and graphene oxide (GO) and apply this material as anode for Li/Na/Mg ion batteries. This nanostructured material, when employed as an anode, delivers specific capacities of ~445 mAh g^{-1} in Li ion coin cells and ~225 mAh g^{-1} in Na ion coin cell systems. We have observed only ~28 $mAhg^{-1}$ in Mg-ion coin cell batteries, however, this value is higher than that observed with pure rGO anode (22 $mAhg^{-1}$), underscoring the potential of MgO pillared rGO nanostructure for electrochemical energy storage.

Keywords:
Sustainable Energy;
Rechargeable Batteries;
Pillared Nanostructures;
Battery Anodes.

Methods and Materials

All electrochemical measurements in this study were conducted using CR2032-type coin cells in half-cell configuration. The electrolytes employed were 1 M $LiPF_6$ in EC/DMC (1:1 v/v) for Li-ion batteries, 1 M $NaPF_6$ in EC/PC (1:1 v/v) for Na-ion batteries, and 0.4 M $Mg(ClO_4)_2$ in acetonitrile for Mg-ion systems. Cycling was performed over a wide current density range from 100 mA g^{-1} to 2 A g^{-1} using NEWARE battery testing system.

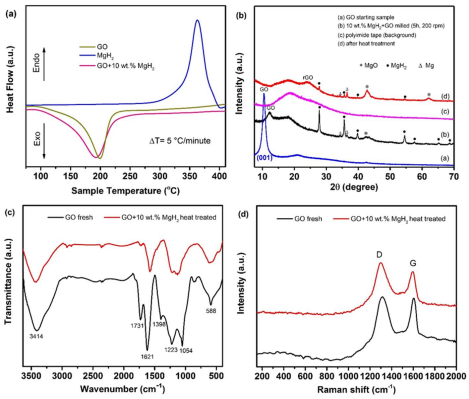

Fig.1 (a) DSC profiles of GO, MgH_2 and 10 wt.% MgH_2 added GO, (b) XRD patterns of the 10 wt.% MgH_2 added sample, after ball milling and after heating isothermally at 200 ° C (profiles of GO and polyimide tape are provided for reference), (c) FT-IR spectra corresponding to GO and the temperature treated GO+10 wt.% MgH_2 sample, (d) Raman spectra corresponding to GO and the temperature treated GO+10 wt.% MgH_2 sample.

Discussion

An important aspect of this study is the direct deployment of MgH_2 as a high-capacity anode active material. This is known that MgH_2 theoretically undergoes a two-electron conversion reaction [1,2] with lithium as follows, $MgH_2 + 2Li^+ + 2e^- \rightarrow Mg + 2LiH$ (1). This electrochemical reaction theoretically provides a capacity of 2038 $mAhg^{-1}$. Despite this promise, pure MgH_2 exhibits limited reversibility and poor electrochemical activity under practical conditions due to sluggish kinetics and low electronic conductivity. We explore that incorporating just a 5 wt.% of MgO-pillared rGO as an additive for MgH_2 significantly promotes the reaction (1). For instance, the forward conversion can be fully realized and also a 25% of reversible conversion can be achieved (See Fig.4 (right) for more details).

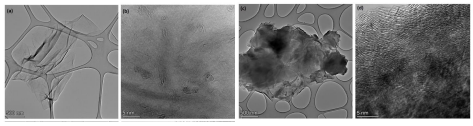

Fig.2 Transmission electron microscopy images correspond to (a, b) fresh GO, (c, d) 200 °C temperature treated GO+10 wt.% MgH_2.

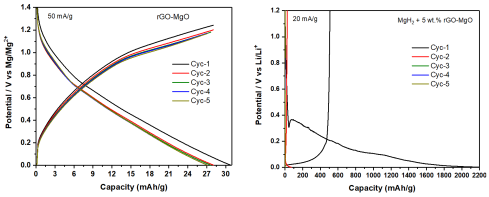

Fig.4 (left) charge / discharge profiles recorded for the MgO-rGO employed anode active material in a Mg-ion rechargeable battery. This battery uses 0.4 M $Mg(ClO_4)_2$ at acetonitrile as electrolyte and Mg metal as counter electrode, Fig. 4 (right) a 5 wt.% MgO-rGO incorporated MgH_2 as anode active material employed in a Li ion battery. Totally 5 charge / discharge profiles are provided in the figure. The employed electrolyte in this case is 1 M solution of $LiPF_6$ in 1 v/v EC/DMC. The employed charge / discharge rates in both the cases are provided in the figure.

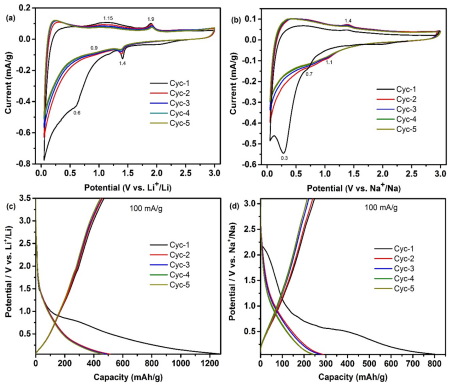

Fig.3 (a) The CV profiles obtained for the Li ion battery, (b) The CV profiles obtained for the Na ion battery, (c) First five cycles charge-discharge at the current density of 100 mA/g observed for the Li ion battery, and (d) First five cycles charge-discharge at the current density of 100 mA/g observed for the Na ion battery.

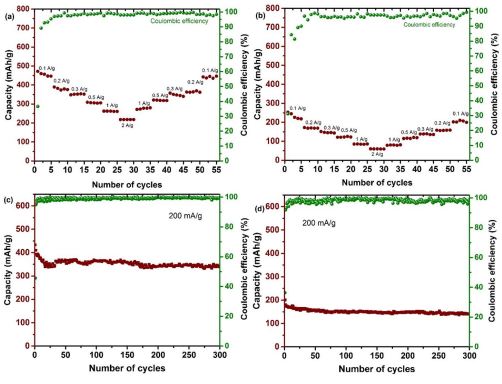

Fig.5 Capacity retention analyses at various rates (between 100 mA/g to 2000 mA/g) performed for (a) Li ion battery, (b) Na ion battery. The cycle test performed for 200 cycles at the current density of 200 mA/g for (c) Li ion battery, and (d) Na ion battery.

Conclusion

Our findings highlight the potential of magnesium-based materials for energy storage applications, not only as redox-type active species for Li, Na and Mg ion rechargeable batteries but also as a direct conversion type anode active material for Li ion batteries. This underscores the importance of Mg/MgH_2 in advancing both conventional and emerging battery chemistries. Our results sheds light on a viable pathway for leveraging Mg in the design of next-generation energy storage systems.

References

[1] D. Pukazhselvan, I. Çaha, C. Lemos, S.M. Mikhalev, F.L. Deepak, D.P. Fagg, "Understanding the catalysis of chromium trioxide added magnesium hydride for hydrogen storage and Li ion battery applications" J. Magnes. Alloy, 12(3), 1117-1130, 2024, https://doi.org/10.1016/j.jma.2024.03.007.
[2] A.G. Olabi, Q. Abbas, P.A. Shinde, M.A. Abdelkareem, "Rechargeable batteries: Technological advancement, challenges, current and emerging applications", Energy, 266, 126408, 2023, https://doi.org/10.1016/j.energy.2022.126408.

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INTELLIGENT SYSTEMS

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New Frontiers in Mechanical Engineering

Performance Analysis of a Comprehensive IIoT Framework for Smart Manufacturing

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Abstract

The current Industry 4.0 revolution is redefining the traditional paradigms employed in industrial companies. The Internet of Things (IoT) represents the Industry 4.0 field responsible for interconnecting various diverse intelligent devices onto a common unified platform.

In our previous work, we presented a conceptual solution for an easy-to-use, open-source medium-size Industrial IoT (IIoT) platform. Our main objective is to provide an entry point for small to medium industries to explore and develop new solutions for each specific use cases, aiding with the digitalization of production lines and processes. In contrast to solutions proposed by other authors, which mainly focus on supervision and monitoring services, this solution aims to provide a complete package of IoT services capable of satisfying the minimum requirements of a IIoT platform, such as data acquisition, industrial supervision and dynamic remote control of equipment, while allowing users to easily develop their own applications, such as machine learning algorithms for predictive maintenance and production management.

The platform must be capable of integrating custom data acquisition and control with a wide range of industrial communication protocols for shopfloor implementation, devices and user management, a customizable monitorization interface, and options for long-term data storage and memory management, functionalities essential for smart manufacturing development. Due to its open-source nature, the platforms offer a set of features for the development of new functionalities, varying between easily integrating custom applications for predictive and energy management, to adding new communication protocol with equipment or connection with new databases, allowing the user to customize the platform to his needs.

In this poster we present the development of the conceptual solution, describing the modifications conducted and their respective impact on the platform's performance via a set of analyses carried out locally, thus providing the best possible outcomes regarding latency and jitter between different intra-platform microservices, specially for most basic interactions, e.g. data acquisition sequence, command messages sequence and permanent data storage.

Acknowledgements

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Introduction

The fourth Industrial revolution adopts the concepts of production digitalization, aiming towards a complex infrastructure where everything is interconnected. This interconnected infrastructure creates a rich environment which provides vital information for **production optimization**, **reduce ecological footprint** and **improve** the overall **security**. One big disadvantage on this approach is the **high amount of data created,** not only by all the sensors used to monitor industrial equipment, but also the command messages and information used by advanced algorithms to extract useful information from historical data.

In our previous work we proposed a **conceptual IIoT platform** aiming in its **simplicity, flexibility and customization**. In this poster we will present **the current platform's latency and jitter performance** for different synthetic use cases with different loads and conditions.

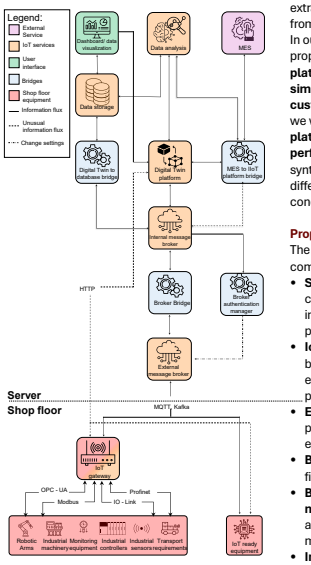

Fig 1: IIoT conceptual architecture.

Proposed Solution

The IIoT platform is composed by:

- **Shopfloor equipment**: conglomerating all industrial equipment present in the shopfloor;
- **IoT gateway**: interface between shopfloor equipment and the IIoT platform's server side;
- **External broker**: platform's interface for external use;
- **Broker Bridge**: message filtering and forwarding;
- **Broker authentication manager:** devices' authentication management;
- **Internal Broker:** platform's interface for internal use;
- **Digital Twin platform:** manages physical devices' digital counterpart;
- **Database bridge:** filters and structures data according to the database's parameters;
- **Data storage:** permanent data storage;
- **Dashboard:** User's Interface (UI) with the platform (monitorization and simple remote-control options);
- **Data analysis:** processing and analysis of long-term and real-time data for industrial optimization;
- **MES to IIoT Bridge:** interface between Industrial MES and IIoT platform;
- **MES:** Manufacturing Execution System.

Methodology

- Analysis of the **latency between data creation and database injection**, using timestamps, by measuring its **impact** on database bridge's **First In First Out** (FIFO).
- Tests conducted within the same computer, using the **internal network** for the **best-case scenario**, and with **synthetic loads**.
- 3 testing configurations:
  - **Latency difference** between **different time intervals** (20, 50 and 100ms) and **messages sizes** (200, 500 and 1000 Bytes) – Fig. 2;
  - **Impact of "burst" loads** (5 200 Bytes messages with 10ms interval every 1 second) on the **latency** for 200B messages with **3 different time intervals** – Fig. 3;
  - Impacted inducted by the **worst-case scenario** for **command messages latency**– Fig.4.

Results

- **Tighter time intervals** have a **higher impact** on database bridge's FIFO performance than the size of the message.
- **"Burst" messages can clog** the database bridge's **FIFO**, which can lead to its **oversaturation** if he's **unable to process** them when **the influx of data** is lower – Fig. 5.
- **Data acquisition inflow** has a **low impact** on the **latency** performance of **command messages**.

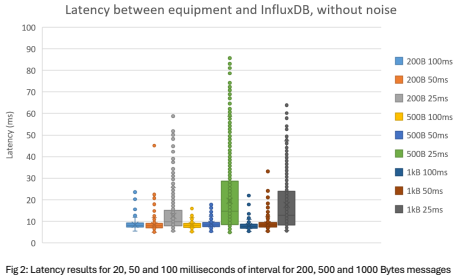

Fig 2: Latency results for 20, 50 and 100 milliseconds of interval for 200, 500 and 1000 Bytes messages

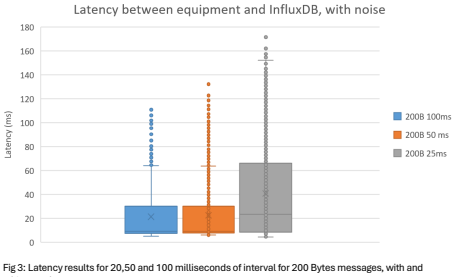

Fig 3: Latency results for 20,50 and 100 milliseconds of interval for 200 Bytes messages, with and without noise.

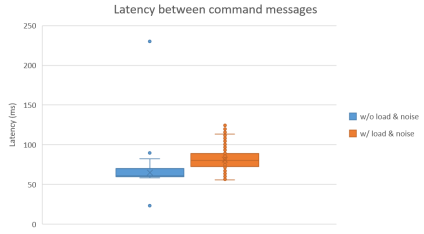

Fig 4: Latency results for command messages with the between best and worst-case scenarios.

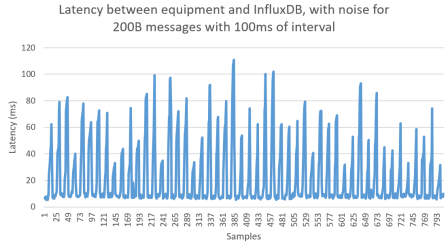

Fig 5: FIFO's latency records for 200 Bytes messages and 100ms interval, with noise

Conclusion

- **Database bridge's FIFO** is the **most sensitive element** of the architecture, thus requiring the implementation of a **load balancing system to minimizing clogging** in database injection.
- **Command messages' latency** is **slightly impacted** by the inner flow of information, but these **don't compromise** its **performance** for the expected tasks.

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New Frontiers in Mechanical Engineering

Rule-Based Leak Detection in Industrial Production Using Decision Tree Models

José Cação, José Paulo Santos and Mário Antunes

Abstract

This work introduces an interpretable machine learning solution for leak detection in a real industrial setting, developed in collaboration with Bosch Termotecnologia S.A. The proposed method replaces a rigid rule-based approach with a Decision Tree model that automatically learns detection logic from labelled test data. Applied during the final production testing phase, the model analyses compressed-air flow patterns to identify leaks. It is fully compatible with PLC deployment and offers transparency through extracted decision rules, probability estimates, and key time-point insights. Achieving over 95% accuracy, F1, and MCC scores, the system also enables a 40% reduction in test duration. This demonstrates how interpretable ML can improve performance and maintain trust in constrained manufacturing environments.

Acknowledgements

This work is supported by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA) – Fundação para a Ciência e a Tecnologia and by PRR - Plano de Recuperação e Resiliência under the Next Generation EU from the European Union, Project "Agenda ILLIANCE" [C644919832-00000035 | Project no. 46].

Introduction

The integration of Machine Learning (ML) into industrial processes offers significant potential for automation and efficiency, with proven success in predictive maintenance, anomaly detection, and product inspection. However, many manufacturing environments still face hardware and software limitations that prevent the use of complex ML models. In addition, the "black-box" nature of high-performing models often limits user trust and conflicts with regulatory demands for transparency.

To address these challenges, we propose an **interpretable ML framework tailored for resource-constrained industrial settings**. Developed in collaboration with **Bosch Termotecnologia S.A.**, the solution targets **leak detection using explainable models deployable on PLCs**. The **main goal is to reduce testing times while ensuring high performance, interpretability, and ease of deployment.**

Background/Case study

- **Case study:** adaptative air-based leak detection testing in final production stages.
- **Leak detection methodology:**
  - Test equipment and unit under testing (UUT) connected in a **closed air circuit**;
  - Measured control variable: **flow required to maintain constant operating pressure**;
  - Test with 4 stages: (1) pre-fill, (2) fill, (3) pre-stabilization, (4) stabilization, leading to a **50 second test**. Sampling rate of 0.5 secs leads to **100 points collected per test** – see Fig. 1;
  - Current leak detection strategy: **empirical criterion:**

$$\text{if } flow_{@50\text{secs}} > 13 \text{ SCCM} \rightarrow \textbf{LEAK}$$

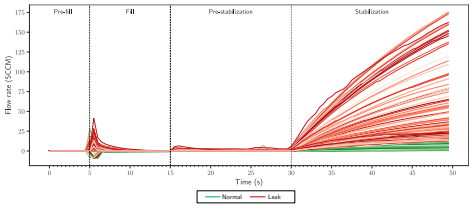

Fig 1: Graphical representation of the 4 testing phases for all samples in the collected dataset.

- **Main goal for industrial partner:** test time reductions, focusing on stage 3 – pre-stabilization;
- **Preliminary evidence:** through an ML-based analysis with the t-SNE clustering method, the 2D representation of the different phases demonstrates **potential for test time reductions in stage 3:** leak tests start to cluster on the right of the cluster representation – see Fig. 2.

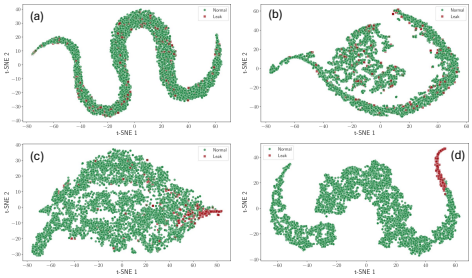

Fig 2: t-SNE analysis of the different stages of the testing procedure: (a) pre-fill, (b) fill, (c) pre-stabilization and (d) stabilization.

Proposed solution

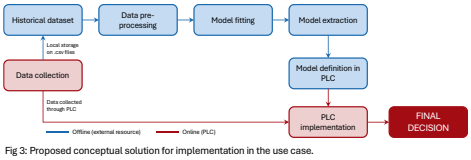

Fig 3: Proposed conceptual solution for implementation in the use case.

Main features:

- **2 complementary components:** ML-focused "offline" pipeline + implementation-oriented "online" workflow
- **Compatible with interpretable ML models:** after dataset collection, preparation and model fitting, it allows the **extraction of the model's structure** to be implemented in the PLC
- **PLC only implements model logic:** after model extraction, the PLC just needs to implement **logic-based rules** (if-else) or **basic arithmetic operations.**

Methodology

- **4 compared interpretable models:** Logistic Regression (LogReg), Gaussian Naïve Bayes (GaussianNB), Decision Tree (DT), and Random Forest (RF) – see Table 1.
- **4 testing configurations:** using different phase combinations – see Table 2.
- Performance comparison based on MCC for all test configs.
- Simulator for the DT model built to **validate potential of the proposed solution** (read QR code for demonstration).

Table 1: Comparison of the models compared and that are compatible with PLC implementation.

Model	Performance	Interpretability	Deployability	Implementation strategy
GaussianNB	●●○○○	●●●○○	●●●●○	Precompute probabilities; store as lookup tables or logic in PLC
LogReg	●●●●○	●●●●●	●●●●●	Precompute weights; implement as weighted sum in PLC
DT	●●●●○	●●●●○	●●●●●	Precompute and extract rules; implement with if-then logic
RF	●●●●●	●●○○○	●●○○○	Precompute, extract and compare tree rules; implement with if-then logic

Table 2: Different testing configurations assessed for the use case (target is to remove Config 4).

Configuration	Test phases	Dataset dimension
Config 1	Pre-fill	5 seconds → 10 features
Config 2	Pre-fill + fill	15 seconds → 30 features
Config 3	Pre-fill + Fill + Pre-Stabilization	30 seconds → 60 features
Config 4	Pre-fill + Fill + Pre-Stabilization + Stabilization	50 seconds → 100 features

Results

Performance Comparison

- **Low** model performance for **Configs 1 and 2** – aligned with t-SNE graphs. Proves that pre-fill and fill stage data **is mostly unrelated to output class**
- In Config 3, **model performance substantially increases**. LogReg, DT, and RF with MCC > 0.95, meaning they all are **feasible models for implementation**
- As such, it is possible to **reduce testing times in 40%** (20 seconds).

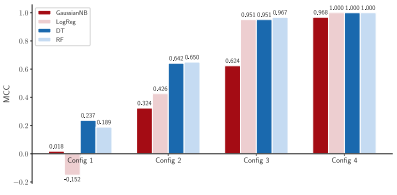

Fig 4: Performance comparison for the 4 models across the 4 explored testing configurations.

DT-based framework

- **Overall processing times:** leveraging a DT model, it is possible to implement the overall **ML pipeline in under 3 seconds** (data collection and preparation + model fitting + rule extraction).
- **DT interpretability potential:** DT models show **large interpretability potential**. It is possible to extract (1) **sets of if-then rules** (translatable to text), (2) **sample coverage** to demonstrate rule generalisability, and (3) **output certainty** (probability, based on training, of the tree output to comply with the rule).

Table 3: Average running times for the overall ML-based pipeline (averages for 10 runs, times in ms).

Dataset Preparation	Pre-processing	Model fitting	Rule extraction	Overall time
2684.39 ± 30.71 (ms)	9.59 ± 0.86 (ms)	111.30 ± 2.82 (ms)	1.19 ± 0.47 (ms)	**2808.47 ± 30.85** (ms)

Table 4: Examples of rules extracted from the tree structure

Rules	Target class	Sample coverage	Output probability
if $flow_{@2.5} > 0.128$ & if $flow_{@4.5} < -0.001$ & if $flow_{@29} > 0.079$	Leak	2739	98.2%
if $flow_{@2.5} > 0.128$ & if $flow_{@4.5} > -0.001$ & if $flow_{@28.5} \leq 0.125$	Normal	201	99.0%

Conclusions

- ML-based processing enabled a **40% testing time reduction** – most interpretable models achieve MCC > 0.95 with Config 3.
- DT classifier has a great **performance-interpretability trade-off**. It showcases high MCC scores, while having a **widely interpretable rule-based structure**.
- The proposed solution is **compatible with a PLC** implementation, and **highly efficient**, taking **just 3 seconds** to conduct all ML-based tasks.

Proposed solution simulator/demo

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New Frontiers in Mechanical Engineering

Performance and Robustness in Smart Predictive Digital Twins: A Review with Emphasis on Water Supply Systems

Mariana Alão, Ana Luísa Reis, António Andrade-Campos

Abstract

Water Supply Systems (WSS) play a critical role in ensuring a reliable and sufficient water supply to residential, agricultural and industrial sectors. In Europe, WSS consumes 1,13% of all energy, of which at least 60% is used by pumping stations [1]. Efficient WSS management is essential but complex due to factors like pumps' variable-speed drivers, dynamic energy tariffs, local energy production and staff shortages, especially as experienced personnel retire [2]. Digital Twins (DT) offer a promising solution by replicating real systems and supporting operational decision-making [3]. More mature DT - Smart Predictive Digital Twins (SPDT) - integrate cloud computing, predictive engines, and optimisation modules, functioning as decision support tools to reduce operational costs. Despite their potential, SPDT remain underused in real-time applications, reflecting their immaturity and limited trust, particularly in critical systems such as WSS.

This review investigates how SPDT performance and robustness are currently evaluated, with a focus on critical systems as WSS. A targeted literature review highlights the fragmented nature of performance assessment and the reactive implementation of robustness strategies. Few comprehensive frameworks exist, and approaches vary widely across studies and domains. This work synthesizes promising practices and underscores the need for systematic evaluation methods to build more trustworthy SPDT. Strengthening performance and robustness is essential for broader adoption and sustainable, efficient WSS operation.

Acknowledgments

This work is supported by the doctoral grant (Ref. 2024.04917.BDANA) financed by the Portuguese Foundation for Science and Technology (FCT), by the FEDER and Regional Operational Program of the Center Region (CENTRO2030) within project I-ReTiS-LeaksD&Op nº 17304 (CENTRO2030-FEDER-01177300) and through the Portuguese Foundation for Science and Technology (FCT), supported by the Recovery and Resilience Plan (PRR), within project I-ReTiS-Leaks (2024.07270.IACDC). This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

Motivation

Water Supply Systems (WSS) are essential to life, yet they face increasing challenges in terms of management [1, 2]. To solve these issues, there is a need to implement smarter and more adaptative tools for supporting real-time decision making.

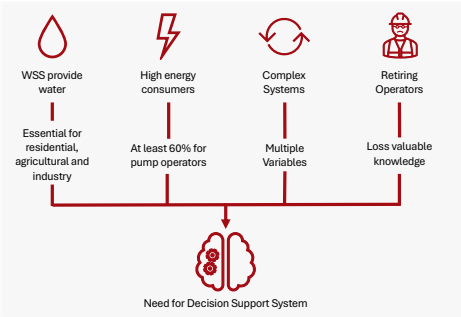

Fig 1 / Key challenges driving the shift in Water Supply System management.

Smart Predictive Digital Twins as Decision Support Systems

Digital Twins (DT) are dynamic digital replicas that can mimic the physical with the virtual world in real-time, making them indistinguishable [3].

They are composed by 3 core components:

- **Physical asset**, including the sensors and actuators connected to them;
- **Virtual asset**, that reproduces the physical asset with high fidelity;
- **Connection between them** allowing the communication and synchronization [3].

Smart Predictive Digital Twins (SPDT) are a more mature form of DT that have other components that allow more intensive calculus and providing them predictive and optimising capabilities.

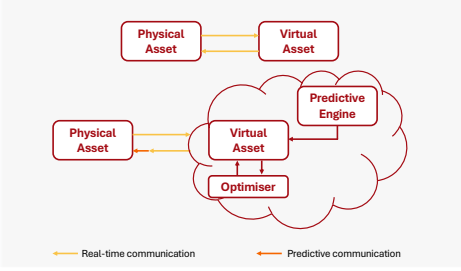

Fig 2 / Digital Twins and Smart Predictive Digital Twins composition.

They still face some issues, related with lack of robustness, real-time interoperability and model accuracy.

Objective

Through a **targeted literature search**, this work synthesises **how the performance and robustness** of SPDT are **currently addressed**, especially in their application in critical systems such as WSS.

Insights

Evaluation practices and robustness techniques were organised according to their timing in the SPDT development process, demonstrating how they are addressed across different phases.

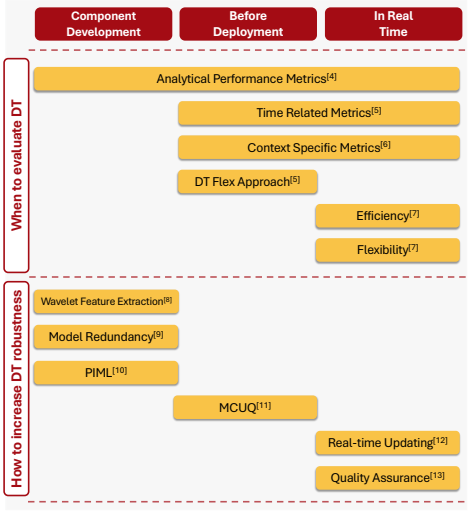

Fig 3 / Mapping evaluation metrics and robustness techniques to different stages of SPDT development.

Growing awareness for using evaluation frameworks
The need for these frameworks is frequently mentioned, when specific methods are not.

Evaluation methods are uncoordinated
Approaches vary widely depending on the problem with no standard framework

Robustness strategies are mostly reactive
Usually applied as workarounds instead of systematically

Lack of holistic evaluation framework
Currently the long-term performance and resilience are not addressed

Conclusions

This review support the development of a **structured evaluation framework**, which can increase operators' trust.

By organizing existing robustness techniques along the SPDT development process, it shows how these can be **integrated early** improving both interoperability and system resilience.

The adoption of trustworthy SPDT will enable **data-driven decision-making** and contribute to **more sustainable and efficient WSS operations**.

References

[1] - International Energy Agency, Energy, water and the Sustainable Development Goals: Excerpt from World Energy Outlook 2018, IEA, Paris, France, 2018. [Online]. Available: https://www.iea.org/reports/energy-water-and-the-sustainable-development-goals. [Accessed: 28 May, 2025].

[2] - C. Kalyani, K. Pradnya, C. Samkit, and V. Patil, 'Regular and Equal Water Supply System', SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, vol. 15, no. 01, pp. 34–37, Jan. 2023, doi: 10.18090/samriddhi.v15i01.05.

[3] – M. Segovia and J. García-Alfaro, "Design, modeling and implementation of digital twins," Sensors, vol. 22, no. 14, p. 5396, 2022. doi: 10.3390/s22145396

[4] – A. Chong, Y. Gu, and H. Jia, 'Calibrating building energy simulation models: A review of the basics to guide future work', Dec. 15, 2021, Elsevier Ltd. doi: 10.1016/j.enbuild.2021.111533.

[5] – F. Psarommatis and G. May, 'A standardized approach for measuring the performance and flexibility of digital twins', Int J Prod Res, vol. 61, no. 20, pp. 6923–6938, 2023, doi: 10.1080/00207543.2022.2139005.

[6] – J. Zeng et al., 'Machine learning enabled fusion of CAE data and test data for vehicle crashworthiness performance evaluation by analysis', Structural and Multidisciplinary Optimization, vol. 66, no. 4, Apr. 2023, doi: 10.1007/s00158-023-03553-5.

[7] – L. Hui, M. Wang, L. Zhang, L. Lu, and Y. Cui, 'Digital Twin for Networking: A Data-Driven Performance Modeling Perspective', IEEE Netw, vol. 37, no. 3, pp. 202–209, May 2023, doi: 10.1109/MNET.119.2200080.

[8] – X. Zhang and Y. Lu, 'Robustness of wavelet energy features for damage detection with neural network and digital twin', Proceedings of the Institution of Civil Engineers: Engineering and Computational Mechanics, Sep. 2024, doi: 10.1680/jencm.24.00008.

[9] – A. Di Meglio, N. Massarotti, and P. Nithiarasu, 'A physics-driven and machine learning-based digital twinning approach to transient thermal systems', Int J Numer Methods Heat Fluid Flow, vol. 34, no. 6, pp. 2229–2256, Jul. 2024, doi: 10.1108/HFF-10-2023-0616.

[10] – P. Laplante, 'Trusting Digital Twins', Computer (Long Beach Calif), vol. 55, no. 7, pp. 73–77, Jul. 2022, doi: 10.1109/MC.2022.3149448.

[11] - J. Jeon and G. Theotokatos, 'A Framework to Assure the Trustworthiness of Physical Model-Based Digital Twins for Marine Engines', J Mar Sci Eng, vol. 12, no. 4, Apr. 2024, doi: 10.3390/jmse12040595.

[12] – R. Vrabič, J. A. Erkoyuncu, M. Farsi, and D. Ariansyah, 'An intelligent agent-based architecture for resilient digital twins in manufacturing', CIRP Annals, vol. 70, no. 1, pp. 349–352, Jan. 2021, doi: 10.1016/j.cirp.2021.04.049.

[13] - M. Lezoche and H. Panetto, 'Cyber-Physical Systems, a new formal paradigm to model redundancy and resiliency', Enterp Inf Syst, vol. 14, no. 8, pp. 1150–1171, Sep. 2020, doi: 10.1080/17517575.2018.1536807.

TEchMA 2025
New Frontiers in Mechanical Engineering

Artificial Intelligence in Product Development: Transforming the Innovation Process

G. Garcia, S. Tavares, S. Soares

Introduction

Artificial Intelligence (AI) is transforming New Product Development (NPD), enabling faster, smarter, and more creative design processes. By supporting ideation, streamlining technical decisions, and accelerating development cycles, AI is reshaping how products are imagined, designed, and brought to market. Its growing presence in design and engineering reflects the need for more efficient, data-driven, and innovative approaches to product development in a rapidly evolving technological and sustainability-driven context.

Keywords

Artificial Intelligence;
New Product Development;
Innovation;
AI-Driven Innovation.

Key References

Brem, F. Giones, and M. Werle, "The AI digital revolution in innovation: A conceptual framework of artificial intelligence technologies for the management of innovation," *IEEE Trans. Eng. Manag.*, vol. 70, no. 2, pp. 770–776, 2023.

R. G. Cooper, "The AI transformation of product innovation," *Industrial Marketing Management*, vol. 119, pp. 62–74, 2024.

Objectives

The main objective of this research is to explore how Artificial Intelligence (AI) is being applied in New Product Development (NPD). Specifically, it aims to identify the phases where AI is used, understand the forms of integration, and evaluate the benefits and drawbacks of its adoption. The study also seeks to uncover the key barriers that prevent broader implementation. This mapping effort is grounded in a systematic literature review, with the goal of supporting future research and development of tools that facilitate effective human–AI collaboration in product innovation.

Methodology

This study presents a structured literature review on the integration of Artificial Intelligence (AI) into product design and development processes. The significance of this research area is exemplified by influential works such as Brem et al. (2023), who developed a comprehensive conceptual framework for AI in innovation management, and Cooper (2024), which provides empirical evidence of AI's transformative impact on product innovation processes. Together, these studies highlight both the theoretical foundations and practical implications, supporting the need for systematic investigation of this emerging field.

The review followed a systematic approach based on thematic analysis of academic and industry sources retrieved from Scopus, Web of Science, IEEE Xplore and ACM Digital Library, covering the period from 2015 to 2025. A systematic search using the query ("artificial intelligence") AND ("new product development" OR "product development" OR "product design") was conducted to identify relevant publications. The total number of publications retrieved per year is presented in Figure 1 to illustrate the growing interest in the field. After applying inclusion and exclusion criteria, only a subset of these publications was selected for in-depth analysis, focusing on those directly addressing the integration of AI into product development practices.

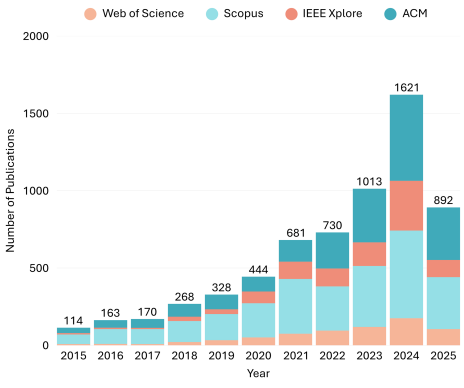

Fig 1/ Results of a systematic search (2015–2025). Total publications by year across Scopus, WoS, IEEE, and ACM.

Results

The results highlight three key domains where AI offers significant value:
[i] Creative support through generative models that enable divergent thinking, analogical reasoning, and ideation support;
[ii] Technical optimization, including AI-driven simulations, performance prediction, structural optimisation, material selection, and digital prototyping;
[iii] data-informed decision-making by creating enhanced data-driven knowledge to predict market behaviours and user needs.

While the benefits are promising, including reduced development and testing times, improved product quality, cost efficiency, and the contribution to the development of more sustainable outcomes, the review also identifies persistent challenges: usability barriers, algorithmic opacity and ethical concerns.

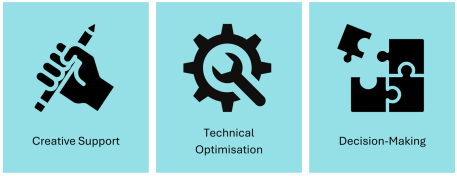

Fig 2 / Domains where AI offers significant value in Product Development.

Conclusions

This review consolidates current knowledge on how AI is reshaping product development. It highlights the transformative potential of intelligent systems and the limitations that require critical attention. Among the most pressing research challenges is understanding how to combine computational capabilities with human expertise in a meaningful way, a synergy often referred to as hybrid intelligence. AI is increasingly seen as a complement to human creativity and judgment, enhancing problem-solving while maintaining the need for human validation and oversight. As the field evolves, exploring how this collaborative model can be structured, evaluated and applied at scale will be essential for a responsible and impactful integration of AI in future product development practices.

Fig 3 / Main Challenge – Combine computational capabilities with human expertise (Hybrid Intelligence).

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New Frontiers in Mechanical Engineering

Patient-Specific Gyroid Scaffold Design via Machine Learning-Driven Optimization of DEXA T-score Data

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(b) CICECO - Aveiro Institute of Materials, University of Aveiro, Campus Universitário de Santiago, Aveiro, 3810-193, Portugal

(c) Unit of Materials Science and Environmental Engineering, Tampere University, 33014,Tampere, Finland.

(d) Institute of Electronics, Technical University of Łódź, Wólczańska 211/215, 90-924 Łódź, Poland

(e) LASI - Intelligent Systems Associate Laboratory, 4800-058 Guimarães, Portugal

Abstract

This study presents an advanced computational framework for designing gyroid scaffolds tailored to individual bone mineral density (BMD) profiles derived from DEXA data and T-score value.

Leveraging machine learning (ML) models trained on an open-access clinical dataset from Harvard University [1,2], the methodology predicts femoral neck BMD using relevant patient variables such as age, height, weight, blood biomarkers, cardiovascular health, and lifestyle factors. These predictions inform a parametric optimization algorithm that generates gyroid scaffold geometries aligned with clinically defined bone health categories: healthy, osteopenia, and osteoporotic.

The gyroid geometry was selected for its unique triply periodic minimal surface (TPMS) architecture, offering an optimal balance of high porosity, interconnected networks for biological activity, and superior mechanical properties crucial for bone regeneration.

The optimization process uses voxel-based modeling accelerated by GPU computing via OpenCL, enabling rapid and efficient exploration of geometric parameters to achieve target areal densities. Results demonstrate the feasibility of integrating patient-specific clinical data with ML and high-performance computing to inform scaffold design for additive manufacturing.

Future work involves fabricating the optimized scaffolds through 3D printing and validating density distribution using micro-CT imaging, aiming to calibrate and enhance the predictive model. This approach builds upon recent advances in ML-based BMD estimation and scaffold optimization techniques [3].

Conclusions

This study presents a successful integration of machine learning-based bone density classification with the parametric design of patient-specific Gyroid scaffolds.

Using clinical data to predict femoral neck T-scores, we enabled the generation of optimized scaffold geometries tailored to individual bone profiles.

The results confirm the feasibility of translating medical data into customized 3D-printable structures.

Future work will focus on 3D printing, micro-CT validation, and continued refinement of the models toward clinical application.

Acknowledgements

This work is supported by the project UID/00481 – Centro de Tecnologia Mecânica e Automação (TEMA) – Fundação para a Ciência e a Tecnologia and project MODS-3D - Machine learning approach for bOne Density classification and Scaffold 3D printing, with funds from the ECIU Seed Programme.

This work was carried out under the 'ATE-Alliance for the Energy Transition' project [C644914747-00000023| Project no. 56], funded by the PRR - Recovery and Resilience Programme, under the European Union's Next Generation EU, and with laboratory support from the Centre for Mechanical Technology and Automation (TEMA).

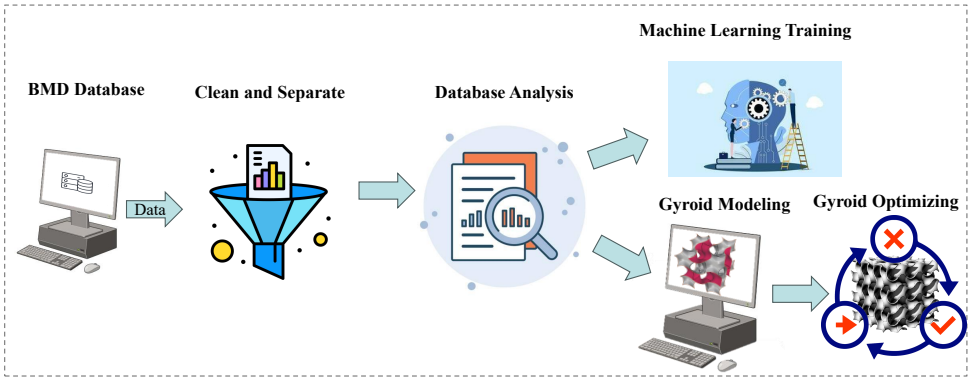
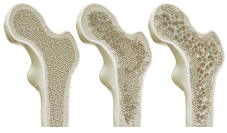


Fig 1 / **Methodology**



BMD (Bone Mineral Density) Values

Healthy: 0.941 g cm^{-2}
Osteopenia: 0.780 g cm^{-2}
Osteoporosis: 0.636 g cm^{-2}

Class	Precision	Recall	F1-score
Osteopenia	0.66	0.53	0.59
Osteoporosis	0.60	0.43	0.50
Healthy	0.57	0.80	0.67
Macro average	-	-	0.59
Global Precision	-	-	0.61

Classifier performance after threshold adjustment.

Healthy

Group Density = 0.941 $g \cdot cm^{-2}$
Areal Density= 0.9401 $g \cdot cm^{-2}$
Apparent Density = 0.6289 $g \cdot cm^{-3}$
Porosity = 80%
t = 0.224
a = 5.705
d =0.614

Osteopenia

Group Density = 0.780 $g \cdot cm^{-2}$
Areal Density= 0.7793 $g \cdot cm^{-2}$
Apparent Density = 0.5173 $g \cdot cm^{-3}$
Porosity = 83.6%
t = 0.2303
a = 5.9755
d = 0.5060

Osteoporosis

Group Density = 0.636 $g \cdot cm^{-2}$
Areal Density = 0.6354 $g \cdot cm^{-2}$
Apparent Density = 0.4211 $g \cdot cm^{-3}$
Porosity = 86,6%
t = 0.2303
a = 5.9755
d = 0.5060

Fig 2 / **Results**

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project/support UID/00481 – Centre for Mechanical Technology and Automation (TEMA).

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New Frontiers in Mechanical Engineering

Mesh Influence Reduction in Dataset Generation for ML-Based Prediction of Constitutive Parameters in Sheet Metal Forming

Dário Mitreiro, Pedro A. Prates, António Andrade-Campos

Abstract

Sheet metal-forming is critical in automotive and aerospace industries, with FEM simulations reducing costly trial-and-error in process design. However, accurate results rely on precise material parameter identification, which traditional methods fail to capture under complex strain paths [1–3]. Inverse approaches like FEMU and VFM improve accuracy but are computationally expensive [4]. Machine learning offers a data-driven alternative, particularly effective with full-field data from cruciform tests [2,5], though model performance is limited by mesh-dependent training data. This work introduces a mesh-independent dataset generation strategy using interpolated FEM outputs to train XGBoost models for Hill'48 parameters. Cubic and multiquadric interpolation methods, especially on high-resolution grids, enhance accuracy and generalization, confirmed by a synthetic DIC case study.

The full paper is available via the QR code below.

Acknowledgements

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Introduction

Accurate simulation of sheet metal forming via FEM relies on identifying complex material parameters, a challenge intensified by traditional test limitations. Emerging ML methods offer a faster, data-driven alternative, though their generalisation to experimental data remains constrained.

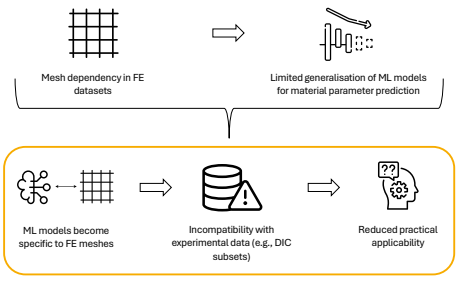

Fig 1 / Scheme regarding generalisation problem of ML models.

Methodology

A new methodology is introduced to reduce mesh dependency in dataset generation for ML models used to predict constitutive parameters in sheet metal forming.

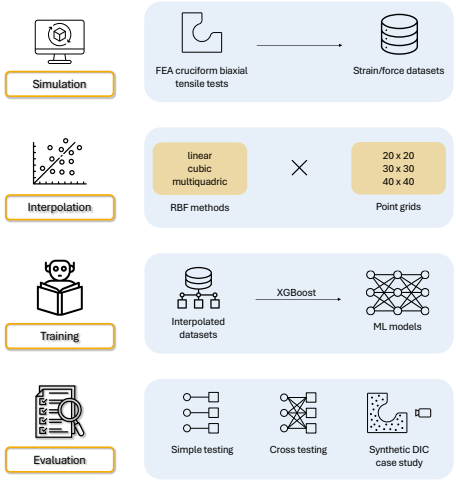

Fig 2 / Proposed methodology for mesh dependency reduction in datasets used for ML models.

- FEA cruciform biaxial tensile tests generates full-field strain and force data under varying material parameters, obtaining a total of 2260 useful samples.
- Strain data are treated and interpolated onto regular point grids using SciPy interpolation RBF methods to eliminate mesh dependency.
- The interpolated datasets are used to train XGBoost models for predicting constitutive parameters from strain/force inputs, generating 9 different models.
- Model accuracy and robustness are assessed through simple and cross testing, along with a synthetic DIC case study to evaluate practical applicability.

Results

Interpolation methods were evaluated by reversing interpolated data back to original FEM mesh points. Multiquadric and cubic methods achieved outstanding accuracy, with $R^2 > 0.99$ and MAPE < 0.4, particularly on denser grids. These results confirm the reliability of interpolated data for training mesh-independent models.

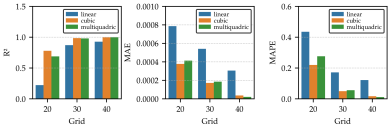

Fig 3 / Reverse interpolation metrics.

Predictions from a selected model from interpolated data (30 x30 grid and multiquadric method) were compared with results from the synthetic DIC sample and original FEM-trained models. Yield stress and anisotropy curves showed close agreement, with < 4% error in stress evolution and < 2% in initial yield stress. This demonstrates the model's robustness and suitability for use with experimental data.

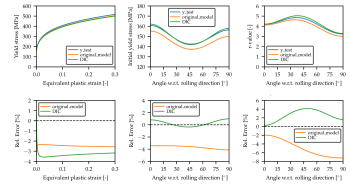

Fig 4 / Comparison of predicted material responses and relative errors using three sets of parameters.

Conclusions

Interpolation enables mesh-independent ML models
Interpolated strain fields using RBF methods (e.g., multiquadric) achieved $R^2 > 0.99$ and MAPE < 0.4, proving accurate data representation.

High predictive performance is maintained
XGBoost models trained on interpolated data achieved $R^2 > 0.99$, with MAE < 1.28 and MAPE < 0.016, matching original FEM-trained models.

Robustness and applicability are validated
Cross-tested models maintained $R^2 > 0.95$, and DIC-based predictions had < 4% error in stress and < 2% in initial yield stress curves, confirming practical applicability.

References

[1] Parreira, T.G.; Marques, A.E.; Sakharova, N.A.; Prates, P.A.; Pereira, A.F.G. Identification of Sheet Metal Constitutive Parameters Using Metamodeling of the Biaxial Tensile Test on a Cruciform Specimen. Metals, 14(2), 212, 2024. https://doi.org/10.3390/met14020212

[2] Bastos, N.; Prates, P.A.; Andrade-Campos, A. Material Parameter Identification of Elastoplastic Constitutive Models Using Machine Learning Approaches. Key Eng. Mater., 926, 2193–2200, 2022. https://doi.org/10.4028/p-zr575d

[3] Rabahallah, M.; Balan, T.; Bouvier, S.; Bacroix, B.; Barlat, F.; Chung, K.; Teodosiu, C. Parameter identification of advanced plastic strain rate potentials and impact on plastic anisotropy prediction. Int. J. Plast, 25, 491–512, 2009. https://doi.org/10.1016/j.ijplas.2008.03.006

[4] Kim, J.; Ebrahim, A.S.; Kinsey, B.L.; Ha, J. Identification of Yld2000–2d anisotropic yield function parameters from single hole expansion test using machine learning. CIRP Ann., 73, 233–236, 2024. https://doi.org/10.1016/j.cirp.2024.04.026

[5] Prates, P.; Pinto, J.; Marques, J.; Henriques, J.; Pereira, A.; Andrade-Campos, A. Influence of data filtering and noise on the calibration of constitutive models using machine learning techniques. Mater. Form., 41, 1807–1816, 2024. https://doi.org/10.21741/9781644903131-200

TEchMA 2025
New Frontiers in Mechanical Engineering

Visually Right, Structurally Wrong: The Risk of Machine Learning Predictors in Topology Optimization

Ricardo Bastos, Mafalda Gonçalves, João Dias-de-Oliveira

Abstract

Topology optimization enables efficient design by distributing material within a domain based on performance criteria, but traditional methods are computationally expensive due to repeated Finite Element Method (FEM) analyses. This work presents a metamodel to predict displacement fields in a cantilever beam problem, aiming to reduce computational cost. Various machine learning architectures were tested, with U-Nets with max pooling achieving the best trade-off between accuracy and training time. The metamodel, trained on data generated using the SIMP method, delivered a 6.5 times speedup over classical methods. Despite strong visual agreement, pixel-level differences led to suboptimal final topologies due to sensitivity discrepancies in regions with sharp displacement gradients. While challenges remain in replicating FEM precision, especially under complex physical behavior, the approach shows promise for accelerating topology optimization, particularly in non-gradient-based frameworks, and for general FEM applications.

Introduction

Topology Optimization (TO) is a powerful computational design method that determines the optimal material distribution within a domain to maximize structural performance under constraints. It is widely used in industries like aerospace and biomedical engineering. However, the repeated use of the Finite Element Method (FEM) for structural analysis in each iteration makes TO computationally expensive, especially for high-resolution problems. To address this challenge, Machine Learning (ML) methods have been explored to accelerate the most demanding steps. Metamodeling, in particular, replaces expensive simulations with fast, learned approximations. This study proposes a U-Net-based surrogate model to predict FEM displacement fields in TO problems, aiming to reduce computation time while maintaining acceptable accuracy.

Machine Learning Framework

The surrogate model is based on the U-Net architecture, originally developed for biomedical image segmentation [1]. Its encoder/decoder structure with skip connections, represented in Figure 1, enables the model to capture and reconstruct spatial features effectively. The input is a 5-channel tensor that includes the material density field, nodal loads, and boundary conditions. The output is a 2-channel tensor with displacements in the *x*- and *y*-directions.

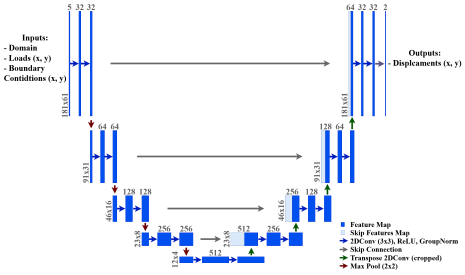

Fig. 1: Architecture of the developed U-Net model with max pooling.

The training dataset was generated using a parameterized SIMP-based TO framework on a cantilever beam. Variations in load magnitude, position, and volume fraction yielded 119 812 data instances from 9 240 unique problems. To reduce redundancy, early optimization iterations were saved in full, and later ones were sampled logarithmically.

The training procedure used the Adam optimizer with a learning rate of 0.001 and a batch size of 16, and Z-score normalization was used. The final model achieved a validation Mean Squared Error (MSE) of 2.34×10^{-4}. The average inference time was 10 milliseconds, about 6.5 times faster than FEM simulations.

Displacement Prediction Results

A test sample from the first iteration of a TO problem with homogeneous density confirmed the model's prediction quality. The predicted displacement fields closely matched FEM results, presenting Structural Similarity Index Measure (SSIM) values of 0.9902 and 0.9308 in the *x*- and *y*-directions, respectively. These results show that the U-Net model can approximate structural displacements accurately and rapidly, making it useful for standalone simulations.

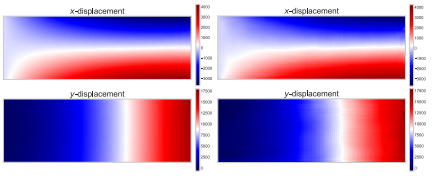

Fig. 2: Displacement results for a randomly selected test sample from the first iteration of topology optimization: ground truth (left) and prediction (right).

Integration of the Predictor in Topology Optimization

To evaluate the model's utility in a full TO pipeline, the FEM solver was replaced with the trained U-Net predictor. Despite the promising accuracy in displacement predictions, the optimization failed to converge. Material was incorrectly allocated, primarily around the load region, and the final topology diverged from expected results (*vd.* Fig. 3).

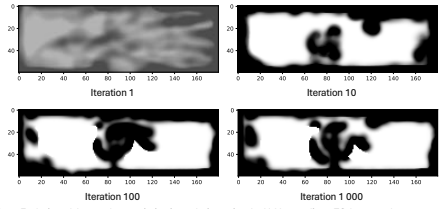

Fig. 3: Evolution of the topology optimization solution using the U-Net predictor TO framework.

The issue arose from inaccuracies in the sensitivity maps used for updating the material layout. These maps are derived from the predicted displacement fields, and small pixel-level errors in predictions led to amplified errors in the sensitivities. Compared to classical FEM-based sensitivities, the ML-based maps overestimated the importance of the loaded area and missed key structural regions (*vd.* Fig. 4). This misdirection resulted in suboptimal material distributions and inefficient structures. Artifacts were also present in inactive regions, further degrading optimization performance.

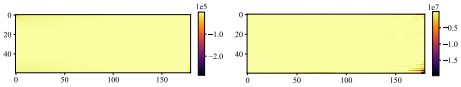

Fig. 4: Comparison between sensitivities of the original SIMP framework (left) and those originating from the machine learning model predictions (right), for the first iteration of topology optimization in a pure cantilever beam with a load of 50.

Although the displacement predictions were visually satisfying, their precision was insufficient for gradient-based methods, which rely on accurate local gradients. These results highlight the difficulty of using purely data-driven models in physics-sensitive workflows like TO.

Final Remarks

This study presented a U-Net-based surrogate model capable of accelerating FEM displacement predictions by a factor of 6.5. The model achieved high visual similarity with ground truth displacements and showed strong potential for fast, standalone simulations.

However, when integrated into the TO loop, the prediction errors significantly distorted sensitivity calculations, causing divergence in the optimization process. These findings emphasize that high visual accuracy is not enough when sensitivity precision is required. Gradient-based TO frameworks are particularly sensitive to small prediction errors, making direct replacement of the FEM solver challenging.

Despite this, the approach is promising for use in metaheuristic optimization methods, such as genetic algorithms or particle swarm optimization, which do not rely on gradients to optimize the solution. The modularity of the framework also allows for integration into alternative TO strategies, such as level-set methods.

In conclusion, while this U-Net metamodel is not yet suitable for driving classic TO pipelines, it is a valuable step toward accelerating structural optimization workflows and highlights the need for hybrid or physics-informed models in future work.

References

[1] Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. https://doi.org/10.48550/arXiv.1505.04597

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New Frontiers in Mechanical Engineering

Uncertainty Quantification in hydraulic prediction

Reframing Noise-Contrastive Estimation for Regression in Water Supply Systems

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Abstract

Water Supply Systems (WSS) are fundamental infrastructures for the general well-being of society, responsible for providing safe drinking water. These systems are faced with numerous challenges, such as aging components, climate change, and volatility in energy costs. Among many of its management facets, its primary task is to produce pump schedules that minimize costs, while respecting hydraulic constraints. This is often achieved with a pump scheduling optimization algorithm, which requires an accurate predictive component. In practice, a WSS is a critical system, hence its decision-making should be robust to avoid any malfunction. Subsequently, the prediction component of the pump scheduling algorithm should reflect this by being both accurate and robust.

In the context of regression tasks, Machine Learning (ML) techniques are widely used in numerous domains. However, conventional ML models provide only point estimates, which contain no information regarding the confidence of its prediction. Uncertainty Quantification (UQ) methodologies have emerged as approaches that enhance ML predictions by providing additional information regarding the certainty of the prediction. For instance, Bayesian Neural Networks (BNN) (e.g., [1]) are popular UQ methodologies with state-of-the-art results. Beyond BNN models, there is also a body of research in Density Regression that focuses on directly estimating the Probability Density Function (PDF) of target variables. Although Density Regression are often applied to unsupervised learning or generative tasks, this work showcases the effectiveness of one such technique in a supervised learning regression task.

This work proposes the use of a Density Regression technique, specifically Noise-Contrastive Estimation (NCE) [2], to quantify uncertainty in a water hydraulic prediction task. To the authors' knowledge the NCE technique has not been applied to a regression task, making the proposed work novel. Preliminary results both on synthetic and real-world hydraulic prediction datasets demonstrate that the developed methodology is promising. These results also suggest that Density Regression techniques, such as NCE, are viable alternatives to other UQ methodologies, with evidence of competitive performance.

Introduction

Water Supply Systems (WSS) are critical infrastructures for providing safe-drinking water. Their management must simultaneously be economically efficient and robust enough to avoid interrupting the operation due to catastrophic malfunctions. In this context, effective Decision Support Systems often employ hydraulic models that infer only point estimates, thus they do not contain any information regarding the confidence of predictions. Uncertainty Quantification (UQ) models are essential for the development of Uncertainty-Aware control algorithms, subsequently being fundamental for safety-critical systems.

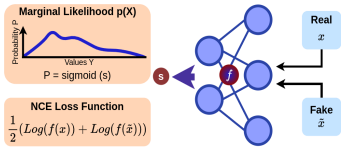

Fig 1 / Schematic of the NCE algorithm

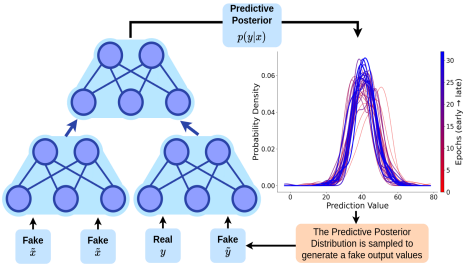

Fig 2/ Schematic of the proposed UQ approach.

Results

Preliminary results in benchmark datasets shows promising improvements in UQ performance. The proposed approach was applied on a real-world water network case study. Given a current water tank level, water demands and pump status, the model predicts the rate of change of water tank levels and pump power. Figure 2.a) illustrates a predictive posterior distribution for water tank OC's level at a representative sample. Furthermore, Monte Carlo sampling is applied over time to obtain the error propagation of the proposed model in water tank level prediction.

The Estimation problem

Given several **x** observations from vector space **X**, it is aimed to estimate the marginal likelihood p(**X**), i.e., the probability density function.. This problem inherently exists in unsupervised learning domains, such as generative tasks. Noise-Contrastive Estimation (NCE) algorithm [1] tackles this problem by applying a Machine Learning (ML) model to discriminate between real and fake inputs samples. (Fig. 1). NCE uses a sigmoid function to convert model's outputs (logits) into probabilities.

Proposed Method

This work leverages the NCE algorithm for regression tasks, with the main goal of quantifying the model's output uncertainty (Fig. 2). The proposed approach considers pairs of observations (**x**,**y**) and calculates the predictive posterior, i.e., p(**y**|**x**). Two main mechanisms are validated:

- Output Discrimination: Injection of noise on the output of fake samples, to train the model to discriminate between fake and real outputs, given specific inputs;
- Input Noise Robustness: Injection of noise on the inputs of both fake and real samples. It is argued that this helps the model to consider the noise in the inputs, when discriminating the real and fake outputs. It has been observed in experiments to enhance UQ performance significantly.

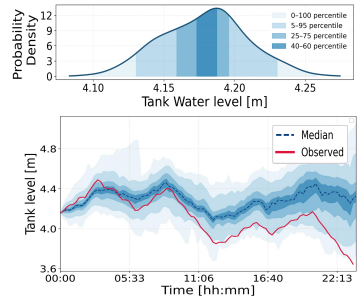

Fig 3 a) Probability Density Function of a sample of the water tank OC, produced by the proposed model. b) Application of the proposed model and Monte Carlo sampling to propagate error over time, regarding water tank OC's level .

Conclusion & Future Work

This work presents a novel UQ approach, which uses a well-established method for the estimation problem and repurposes it for regression tasks. The proposed method is suitable for hydraulic behavior prediction as it as shown promising performance on benchmark datasets and multi-modal behavior in its predictive posterior distributions. Future work mainly includes quantitative validation.

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References

[1] C. Blundell, J. Cornebise, K. Kavukcuoglu, and D. Wierstra, "Weight uncertainty in neural networks," International Conference on Machine Learning, pp. 1613–1622, 2015.

[2] M. Gutmann and A. Hyvärinen, "Noise-contrastive estimation: A new estimation principle for unnormalized statistical models," Journal of Machine Learning Research, vol. 9, pp. 297–304, 2010. [Online].

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Closing Remarks

As we conclude this edition of the TEchMA conference, we would like to express our sincere gratitude to all participants, speakers, and contributors who made TEchMA25 a success. Your engagement, knowledge-sharing, and passion for advancing mechanical engineering research have enriched the discussions and strengthened our community. We hope the insights and connections formed during the event will inspire future collaborations and innovations. Thank you for being a part of TEchMA25 — we look forward to seeing you at future editions.

Aveiro, September 10th, 2025

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