DCE 25
6th DOCTORAL CONGRESS IN ENGINEERING
U. PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
30 JUN - 1 JUL | 2025

Development of Earthen Materials for 3D Printing in Construction

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INTRODUCTION

The construction sector accounts for a significant portion of global carbon emissions, driven by energy-intensive materials and inefficient, labor-intensive processes. Additive Manufacturing (AM), or 3D printing (3DP), offers a transformative extrusion-based approach by enabling automation, reducing material waste, and enhancing geometric flexibility. However, concrete-based AM often relies on high cement content, contributing to environmental degradation [1]. Earth-based materials, composed of locally sourced soils, present a low-carbon alternative for sustainable construction. This study aims to develop and characterize printable earthen composites reinforced with recycled paper fibers, optimizing their rheological properties for 3DP and evaluating their printability and mechanical performance for structural applications. Figure 1 shows the graphical abstract of this experimental study.

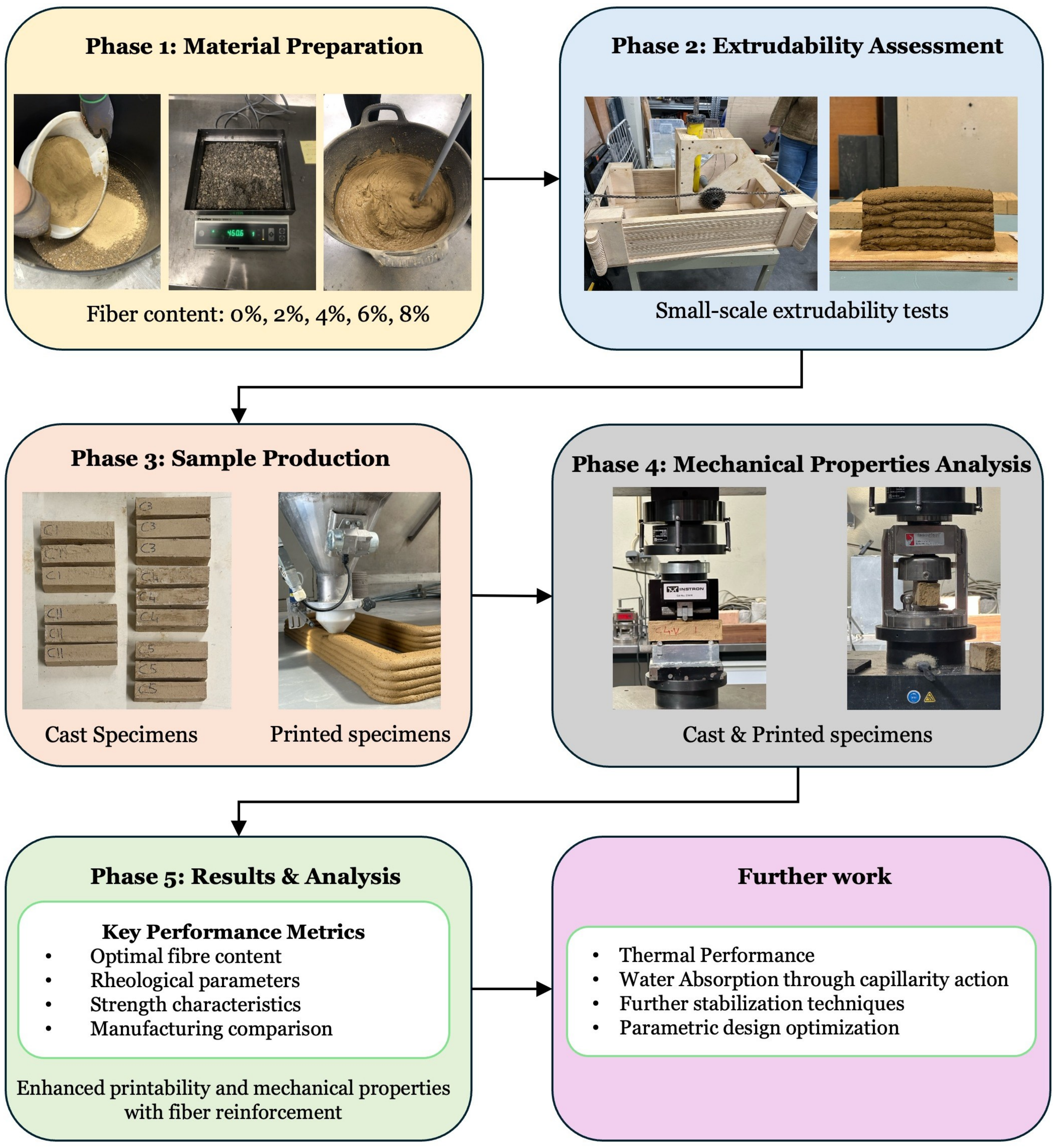

Fig. 1. Logical flow and graphical abstract of the experimental campaign

MATERIALS & METHODS

Soil from Melides, Portugal, was characterized for particle size distribution, clay content, and Atterberg limits: 29% clay, 29% silt, 39% sand, and 3% fine gravel. The liquid and plastic limits are 34% and 18%, respectively, and the coefficient of expansiveness is 14.7%. Recycled paper fibers from waste plant were incorporated at varying weight percentages (C1: 0%, C2: 2%, C3: 4%, C4: 6%, C5: 8%). Test specimens measuring 40 by 40 by 160 mm were prepared via casting. C4 was 3D-printed using a BE MORE 3D SMART 3000 printer with a circular 35 mm nozzle. Printing was carried out with a speed of 40 mm/s and a layer height of 20 mm which resulted to a layer thickness of 70 mm. Mechanical properties, including compressive and flexural strengths, were evaluated following ASTM standards C348 [2] for both cast and printed specimens.

RESULTS & DISCUSSION

Composition 4 (6 wt% fibers) allowed the successful pumping and printing of six layers (12 cm high) (Fig.2.a). Printed specimens exhibited shrinkage cracking (Fig.2.b), likely due to high water content or insufficient stabilization, requiring further investigation. At higher heights, buckling occurred due to insufficient yield stress, highlighting the need for further rheological tuning. The addition of fibers at 8% of the soil weight increased the compressive strength by 160% and the flexural strength by 80% (Fig.3), however, printed specimen (C4p) exhibited a lower compressive strength (3.62 MPa) compared to the casted specimen (C4) (5.07 Mpa), with a printed-to-cast strength ratio consistent with prior composite studies [3], validating the material's reliability.

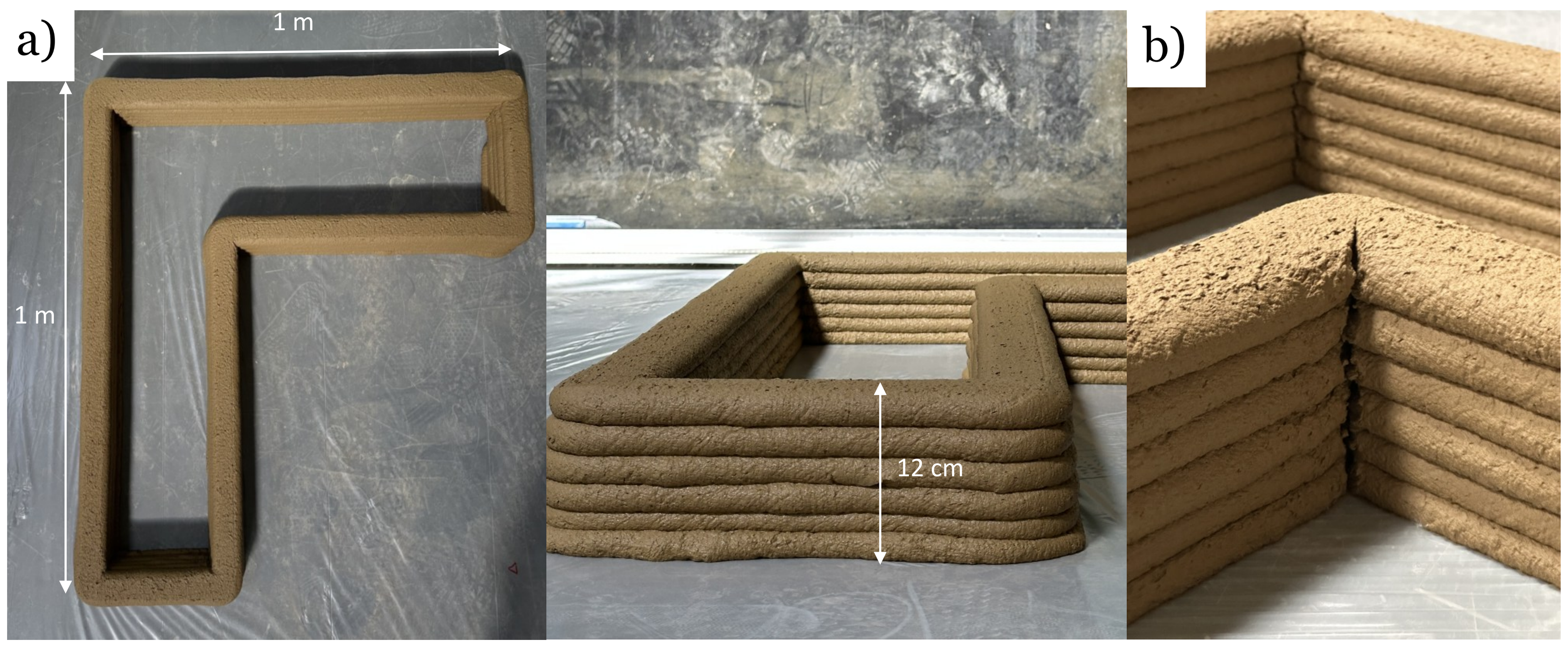

Fig. 2. a) Top and side view of printed element, b) Cracking failure

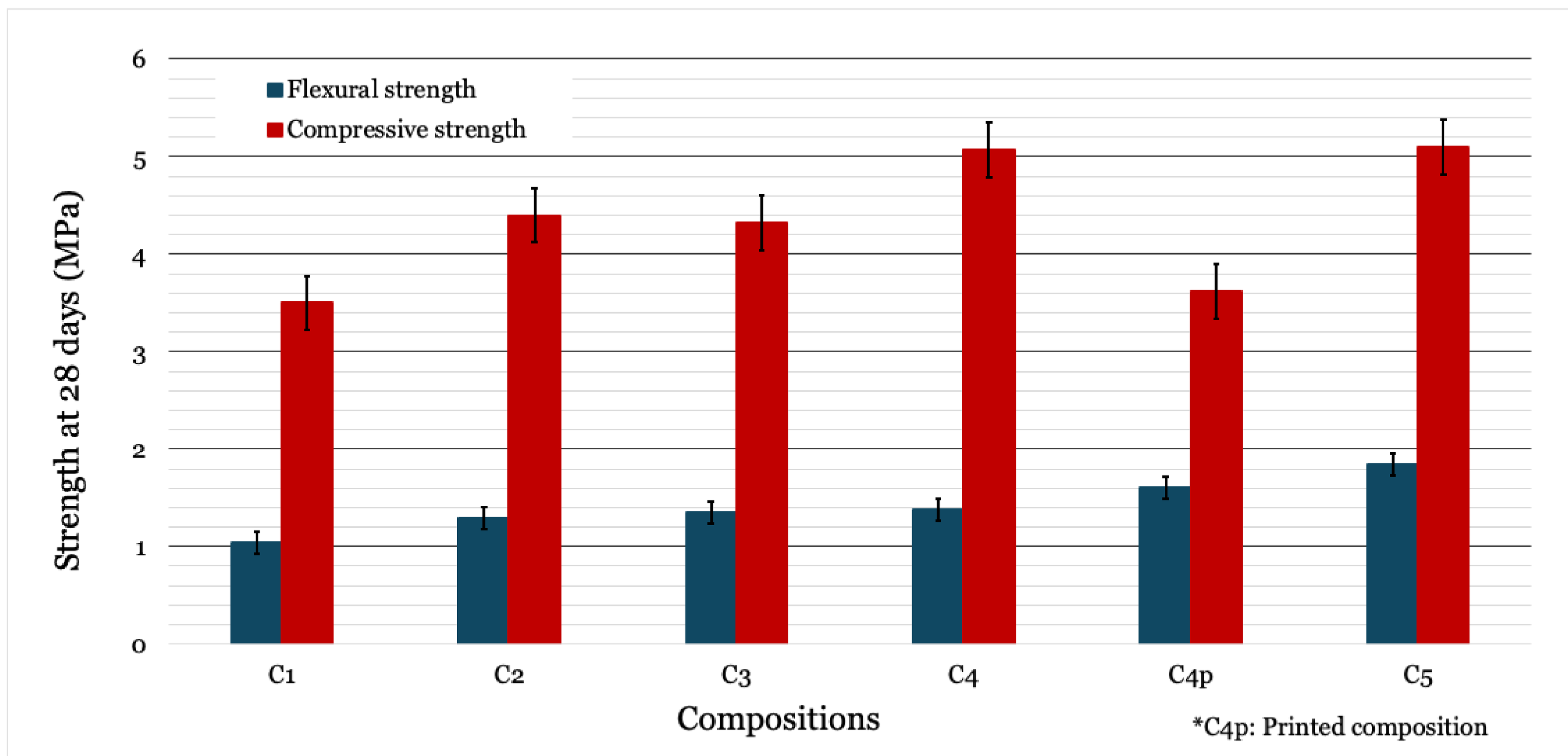

Fig. 3. Comparison of mechanical properties

CONCLUSION

This study demonstrates the feasibility of paper fiber-reinforced earthen composites for 3DP in sustainable construction. The composition with 6% fiber content (C4p) achieved adequate printability and enhanced mechanical properties, though challenges such as shrinkage cracking and buckling at greater printing heights and speeds remain. Future work will focus on mitigating shrinkage through optimized stabilization techniques and exploring additional soil types to establish a comprehensive database of printable earth-based materials. These advancements support the scalability of sustainable AM for structural applications.

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ACKNOWLEDGEMENTS
This work was carried out within the scope of the project EcoMIT – Eco Construções Modulares Impressas em Terra with the reference COMPETE2030-FEDER-00979400, project number 14650, co-financed by the European Union through Programa Inovação e Transição Digital (COMPETE 2030) and Regional Programs, under PORTUGAL 2030. Funding was provided by CONSTRUCT's Base Funding (UIDB/04708/2020) and Programmatic Funding (UIDP/04708/2020) through FCT/MCTES. Special thanks to master's students Renzo Feliciano, Roshaan Malik, and Juan Bugarin for assisting in the experimental campaign.

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