WORKSHOP Geopolymer for Environmental Remediation

February 14th 2025, Faenza, Italy

GEopolymer based Adsorbents

Advancing wastewater treatment systems with 3D-printed AAMs

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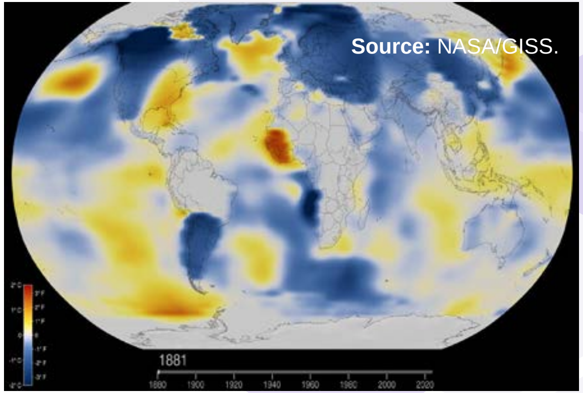
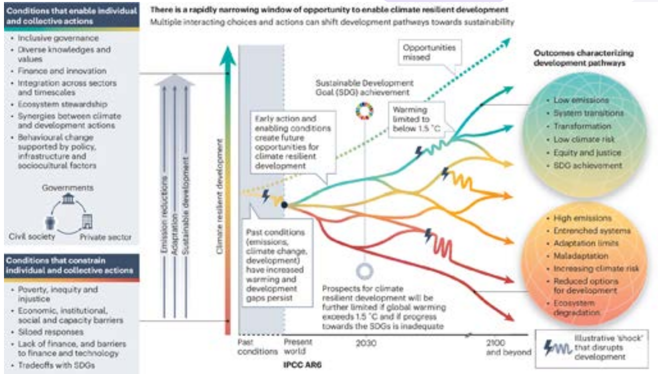
February 14, 2025

Navigating Climate Realities: The Present and Future of Our Planet





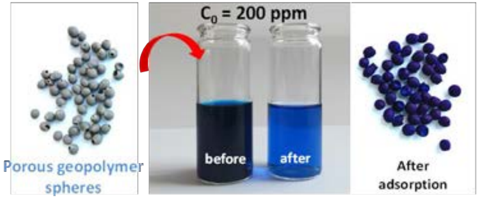
Eriksen *et al.*, Nature Climate Change (2024).

"We do have a choice (…). This is an all-in moment. (…). Tomorrow is too late. Now is the time to mobilise, now is the time to act, now is the time to deliver."

António Guterres (Secretary-General, UN)

AAMs & Geopolymers – potential applications

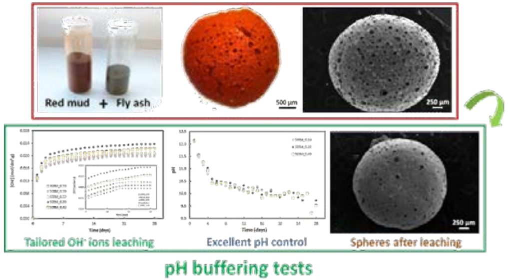
1 Heavy metals & dyes sorbents

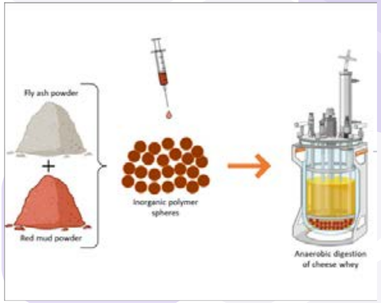


Novais *et al.*, *Journal of Cleaner Production* 207, 350-362 (2019).

Novais *et al.*, *Journal of Environmental Management* 272, 111049 (2020).

2 pH regulators & AD enhancers



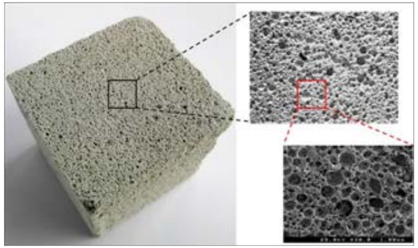


Novais *et al.*, *Journal of Cleaner Production* 178, 258-267 (2018).

Gameiro *et al.*, *Bioresource Technology* 316, 123904 (2020).

Gameiro *et al.*, *Bioprocess and Biosystems Engineering 44 (6), 1167-1183* (2021).

3 Thermal insulation



Senff *et al.*, *Construction and Building Materials* 239 (2020).

Novais *et al.*, *Ceramics International* 44 (2018).

Acoustic insulation

Novais *et al.*, *Energy and Buildings* 210, 109739 (2020).

Novais *et al.*, *Journal of Building Engineering* 42 (2021).

Moisture regulation

Gonçalves *et al.*, *Building and Environment* 205, 108281 (2021).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Geopolymer foams: An overview of recent advancements

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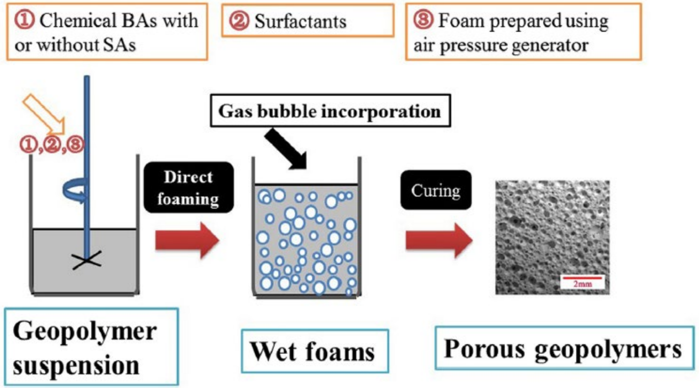
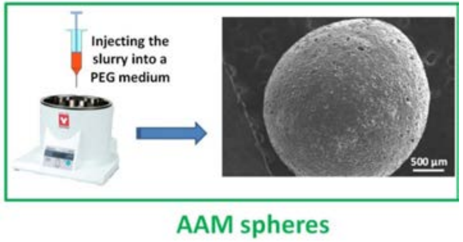
Porous AAMs– Synthesis

Chemical foaming



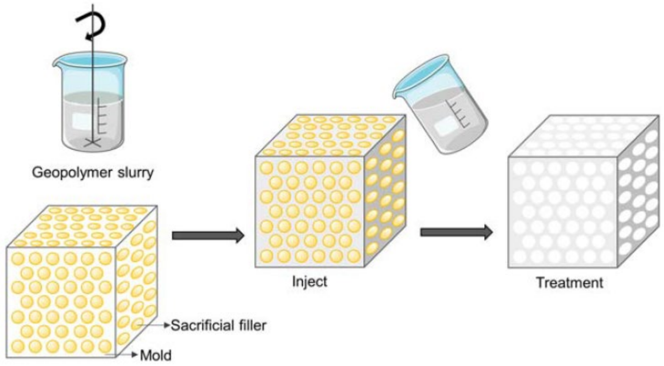
Source: Bai & Colombo. Ceramics International 44 (2018) 16103–16118.

Suspension & solidification

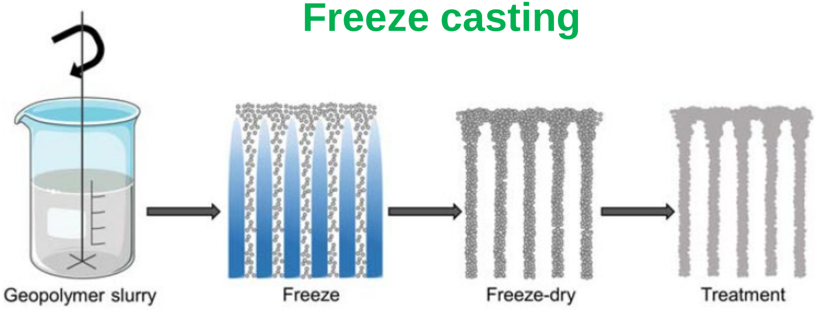


Novais *et al.*, *Materials Today* 23, 105-106 (2019).

Sacrificial fillers



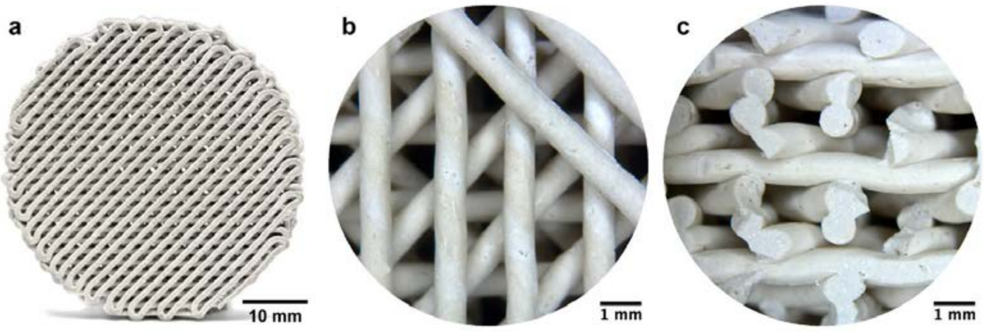
Freeze casting



Source: Renata Botti and Giorgia Franchin. Highly porous alkali-activated materials. In: Luukkonen T (Editor), Alkali-Activated Materials in Environmental Technology Applications. Woodhead Publishing, Kidlington, United Kingdom, 2022. ISBN: 978-0-323-88438-9, Chapter 4 (2022).

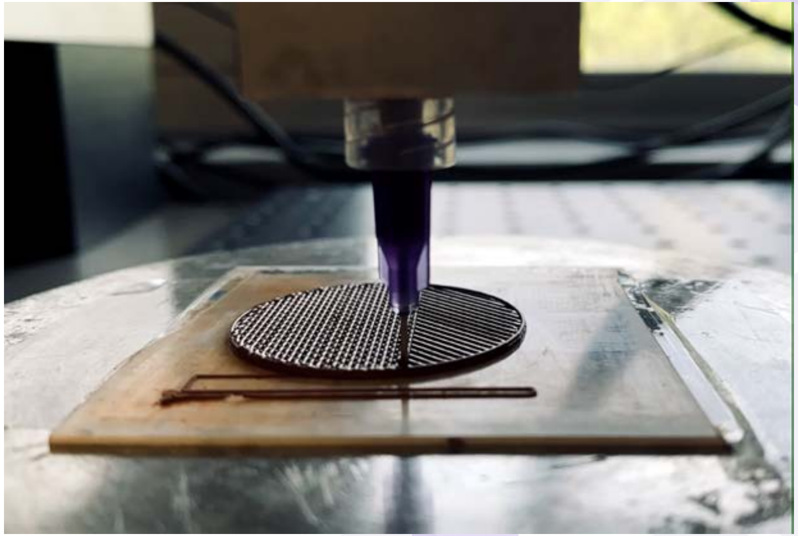
Porous geopolymers – Synthesis

Direct ink writing (DIW)



Source: Franchin *et al.*. Materials and Design 195 (2020) 109006.

filaments rotated at 90º

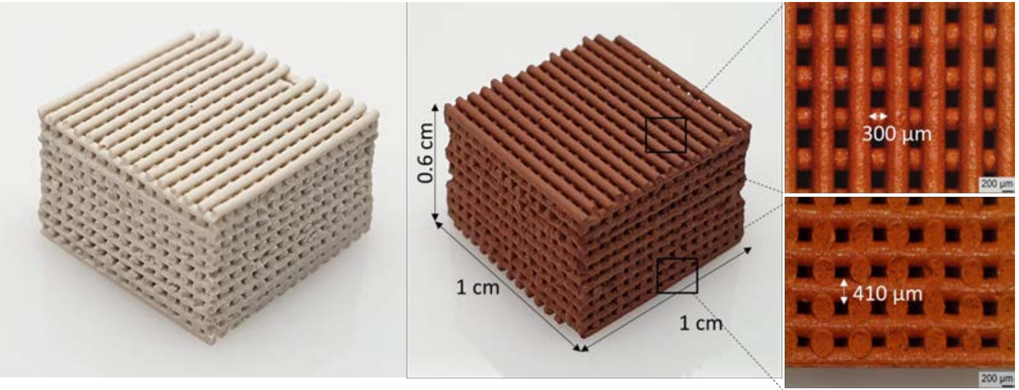


M. Almeida *et al.*, *Waste Management 190 (2024) 35–44.*

AAMs–novel sorbents

Results

3D Printed lattices: properties

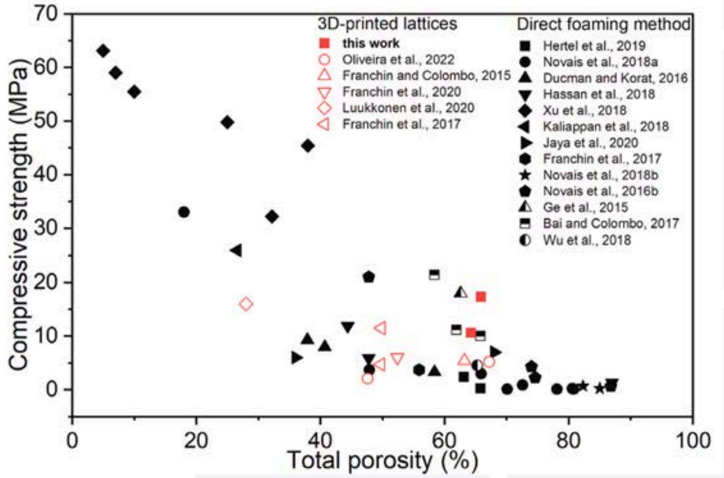


Metakaolin-lattice

SSA = 100 m^2/g
Open porosity = 61.1%
Compressive strength = 17.3 ± 1.1 MPa

Metakaolin/red mud-lattice

SSA = 55 m^2/g
Open porosity = 59.0%
Compressive strength = 10.7 ± 0.7 MPa



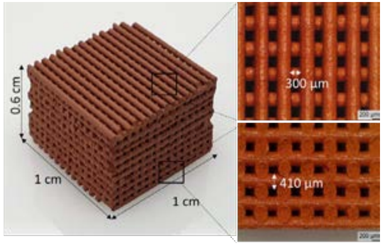
N. Gonçalves *et al.*, *Journal of Cleaner Production 383 (2023).*

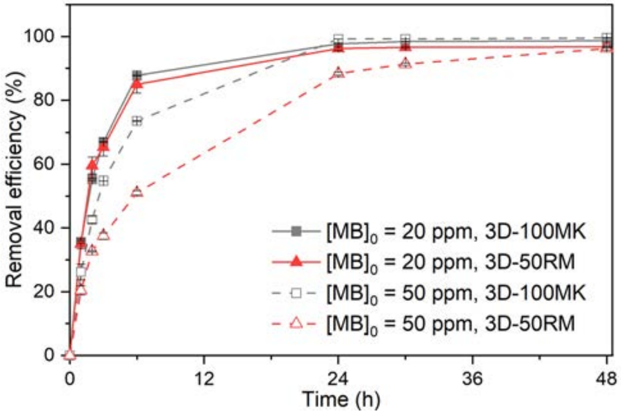
Remediation of synthetic wastewaters

Results

3D Printed lattices: cationic dye removal

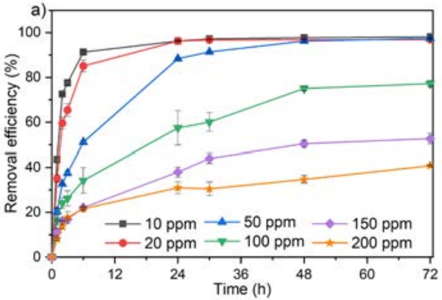
Effect of red mud in the 3D lattice

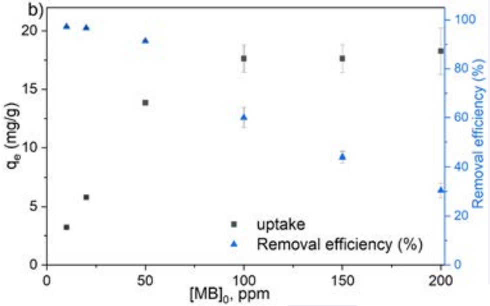


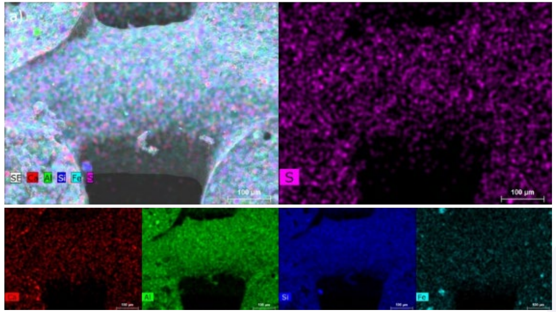


3D-RM50

3 g/L adsorbent

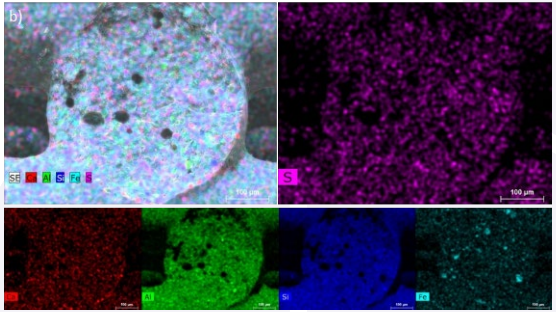






Filament surface

Inner part

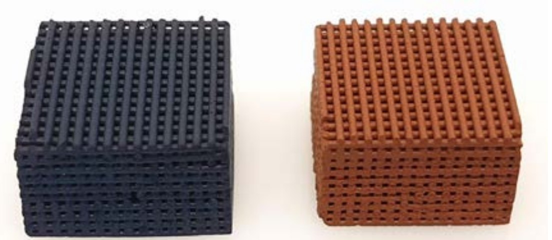


Remediation of synthetic wastewaters

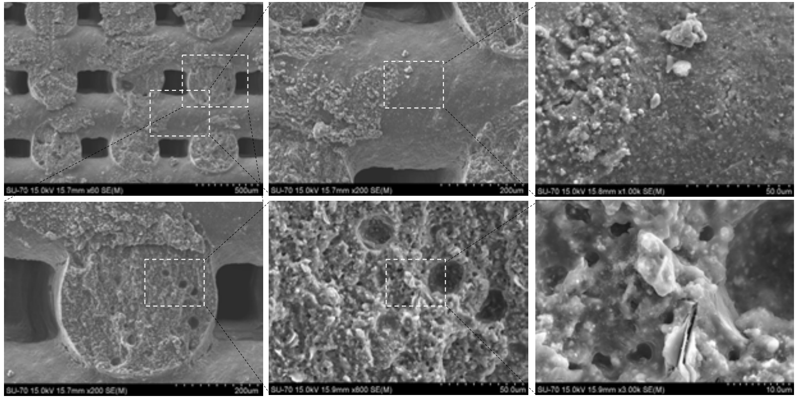
Results

3D Printed lattices: regeneration and reusability

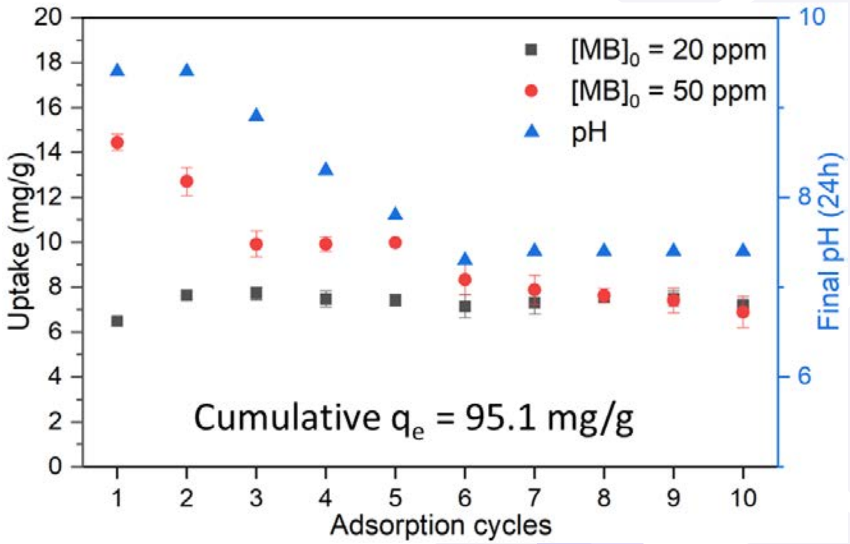
Thermal treatment (400°C/2h):



24h after $[MB]_0$ = 50 ppm   After regeneration



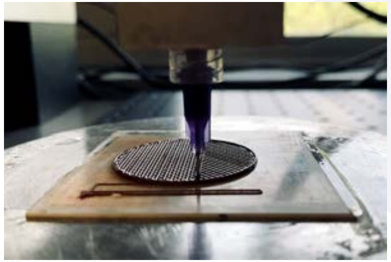
3D-RM50

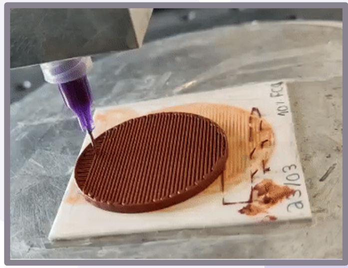


Lattice after 10 adsorption & regeneration cycles

Boosting the performance of bulk-type sorbents

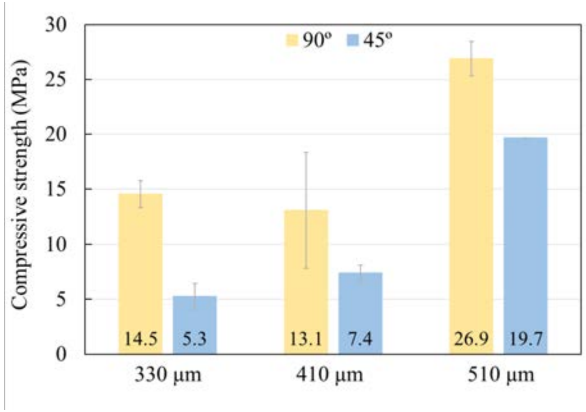
Waste-based 3D printed AAMs



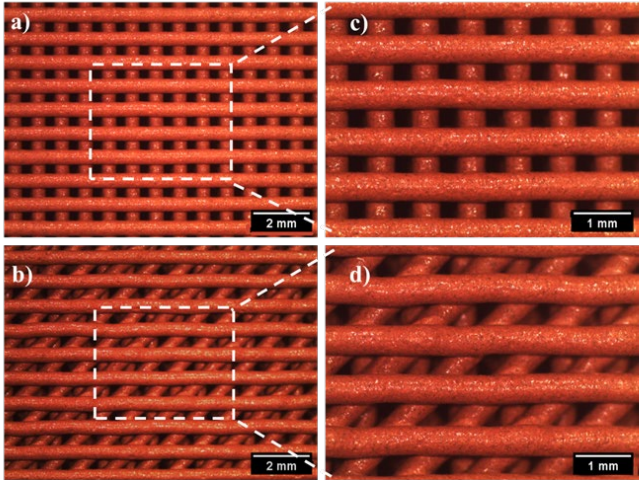


Nozzle size
Ø=330, 410 and 510 µm

34 mm



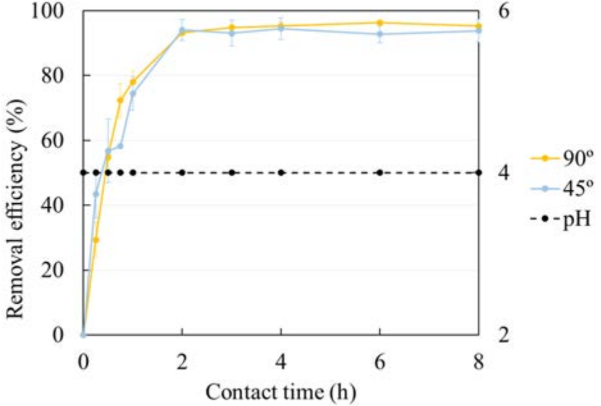
filaments rotated at 90º



filaments rotated at 45º

Column tests

(continuous flow adsorption)

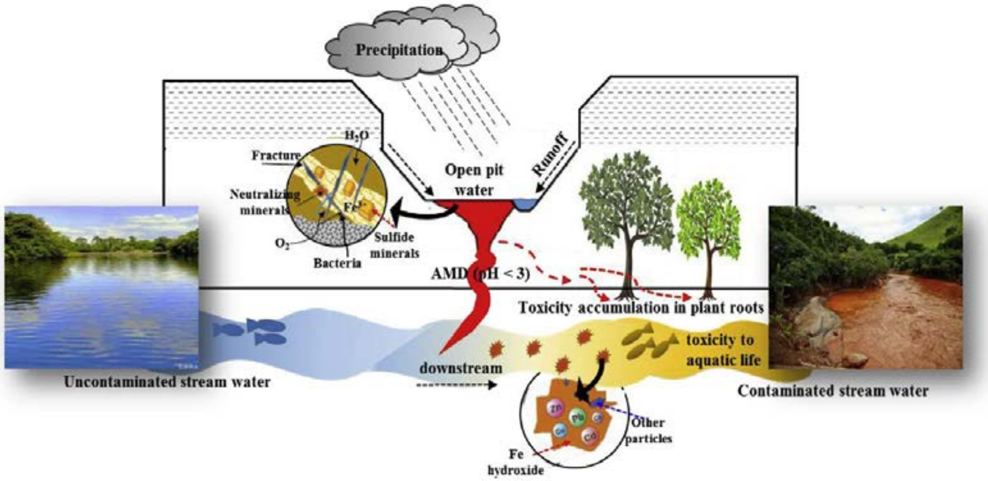


500 mL $[Pb^{2+}]$ = 50 ppm; (pH_0 = 4);
120 mL/min flow

M. Almeida *al.*, *Waste Management 190 (2024) 35–44.*

Acid mine drainage (AMD)

AMD is a highly acidic solution
(pH typically <3)



Naidu *et al.*, *Environmental Pollution 247 (2019).*

Contains several toxic elements
(As, Cd, Co, Cu, Pb, Ni, Zn)

Chen *et al.*, *Journal of Cleaner Production 329 (2021) 129666.*

Real AMD sample – São Domingos Mine, Portugal

138 – São Domingos Mine

Aerial view of São Domingos mine (Mértola, Portugal)

(Google Maps, 30.06.2023)

Element	Concentration
pH	**2.27**
SC µm/cm	**3091**
SO_4^{2-} [mg/L]	2077
Cl^- [mg/L]	65.3
Na [mg/L]	58.57
Mg [mg/L]	64.24
Al [mg/L]	126.4
K [mg/L]	2.665
Ca [mg/L]	93.69
Mn [mg/L]	8.716
Fe [mg/L]	**155.2**
Cu [mg/L]	**14.77**
Zn [mg/L]	**26.46**
Li [µg/L]	250
Be [µg/L]	3
B [µg/L]	68
P [µg/L]	29
Ti [µg/L]	63
V [µg/L]	2
Cr [µg/L]	49
Co [µg/L]	727
Ni [µg/L]	**211**
As [µg/L]	**197**

Element	Concentration
Rb [µg/L]	10
Sr [µg/L]	217
Cd [µg/L]	**107**
Sb [µg/L]	0.6
Cs [µg/L]	1.1
Ba [µg/L]	6
La [µg/L]	29
Ce [µg/L]	75
Pr [µg/L]	9
Nd [µg/L]	37
Sm [µg/L]	9
Eu [µg/L]	2
Gd [µg/L]	9
Tb [µg/L]	1.2
Dy [µg/L]	7
Ho [µg/L]	1.3
Er [µg/L]	3
Tm [µg/L]	0.4
Yb [µg/L]	3
Lu [µg/L]	0.3
Tl [µg/L]	7
Pb [µg/L]	322
U [µg/L]	3

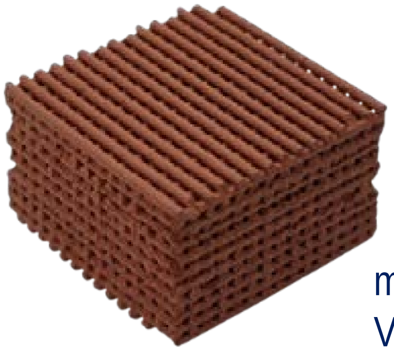
Remediation of synthetic wastewaters

Results

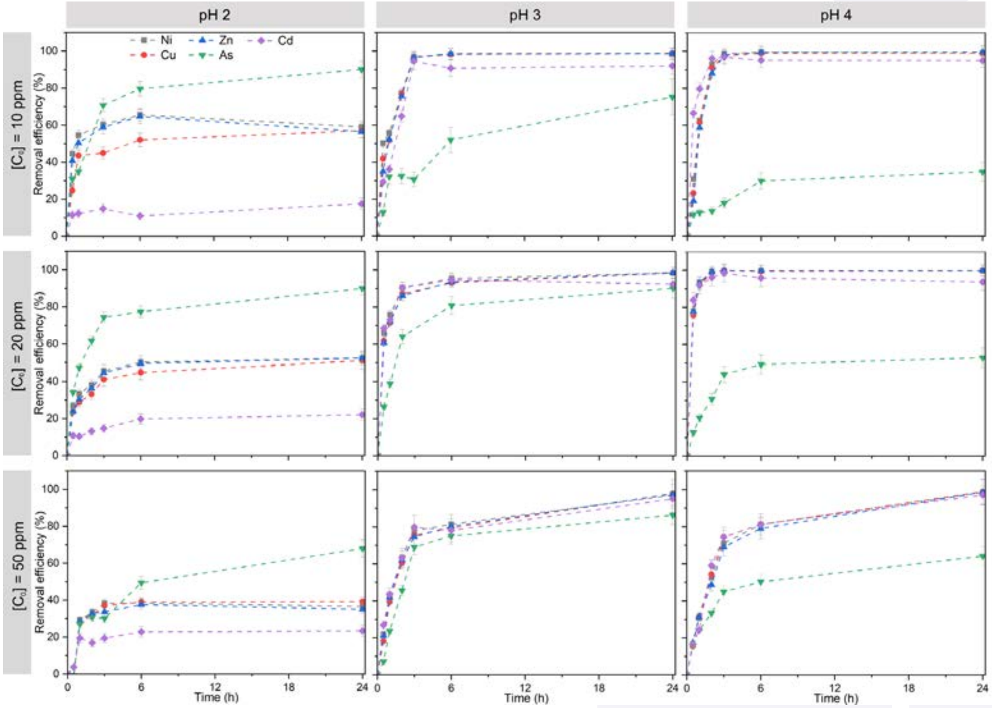
Printed lattices: Metal(loid) sorption – simultaneous removal of 5 cations

Effect of pH, initial concentration and contact time

HMs selected based on concentration on AMD



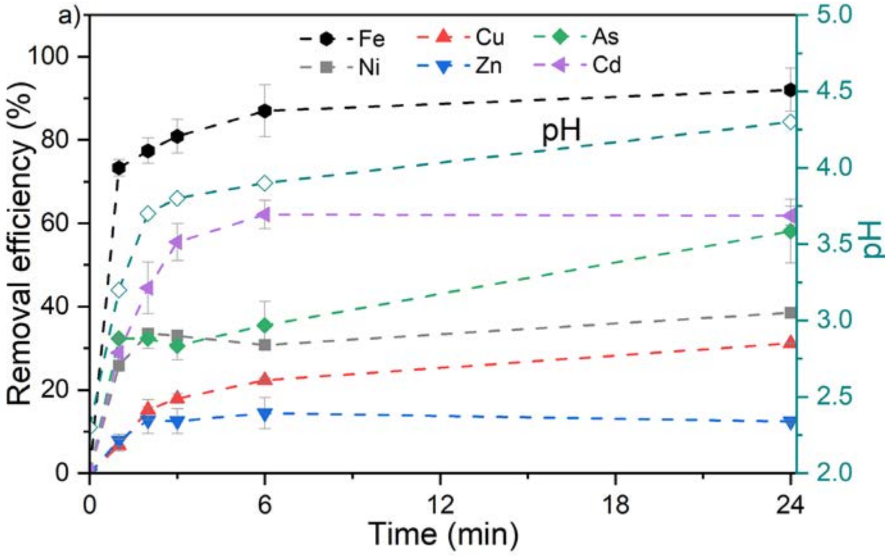
$m_{3D\text{-}50RM}$ = 600 mg
V_{AMD} = 50 mL
pH constant

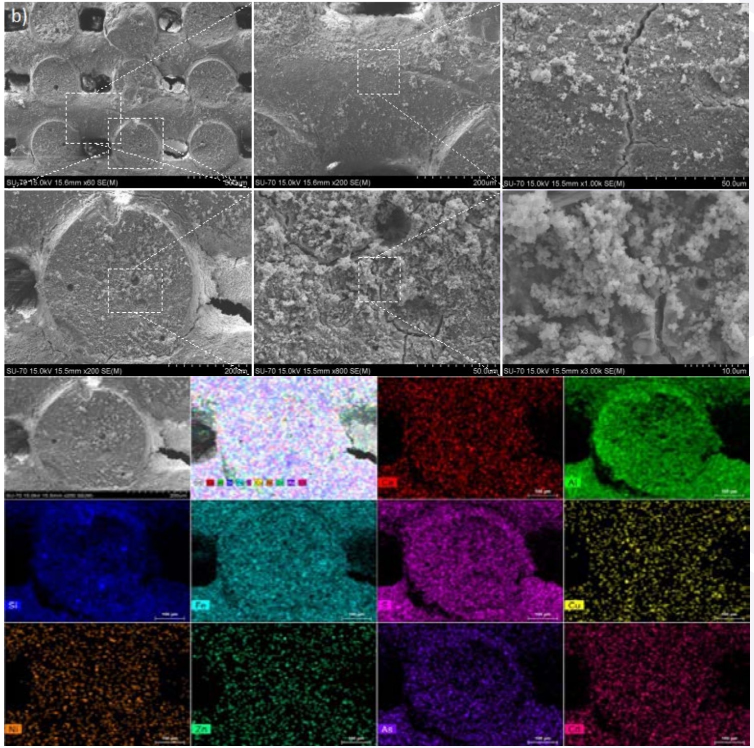


N. Gonçalves *et al.*, *Journal of Hazardous Materials* 462, *132718* (2024).

Remediation of real acid mine drainage (AMD)

Printed lattices: effect of contact time





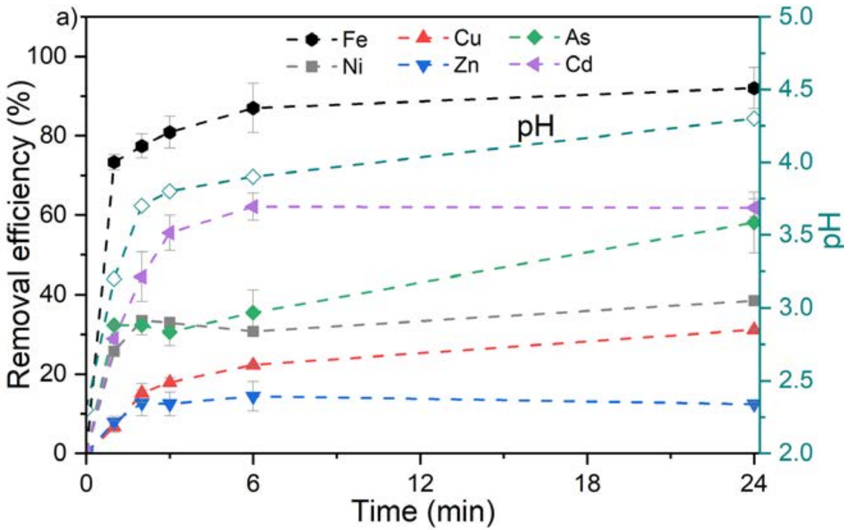
N. Gonçalves *et al.*, *Journal of Hazardous Materials* 462, *132718* (2024).

Remediation of real acid mine drainage (AMD)

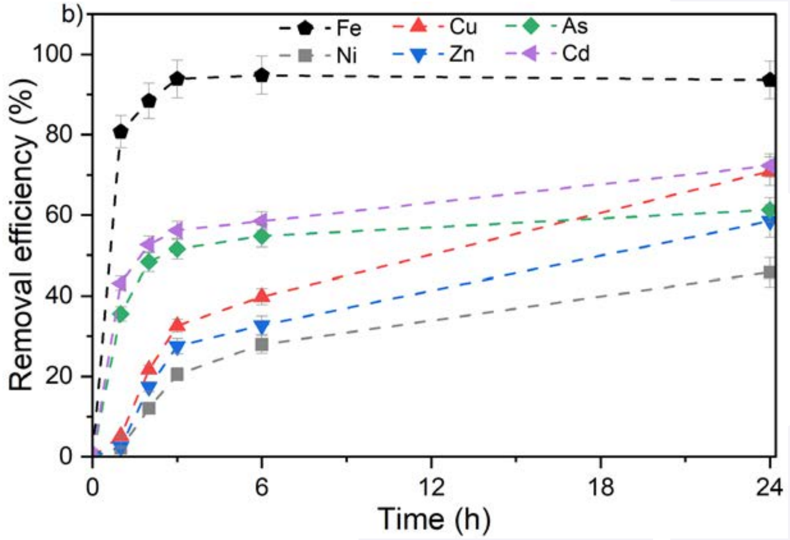
Results

Printed lattices: acid treatment

Lattice (as-prepared**)**



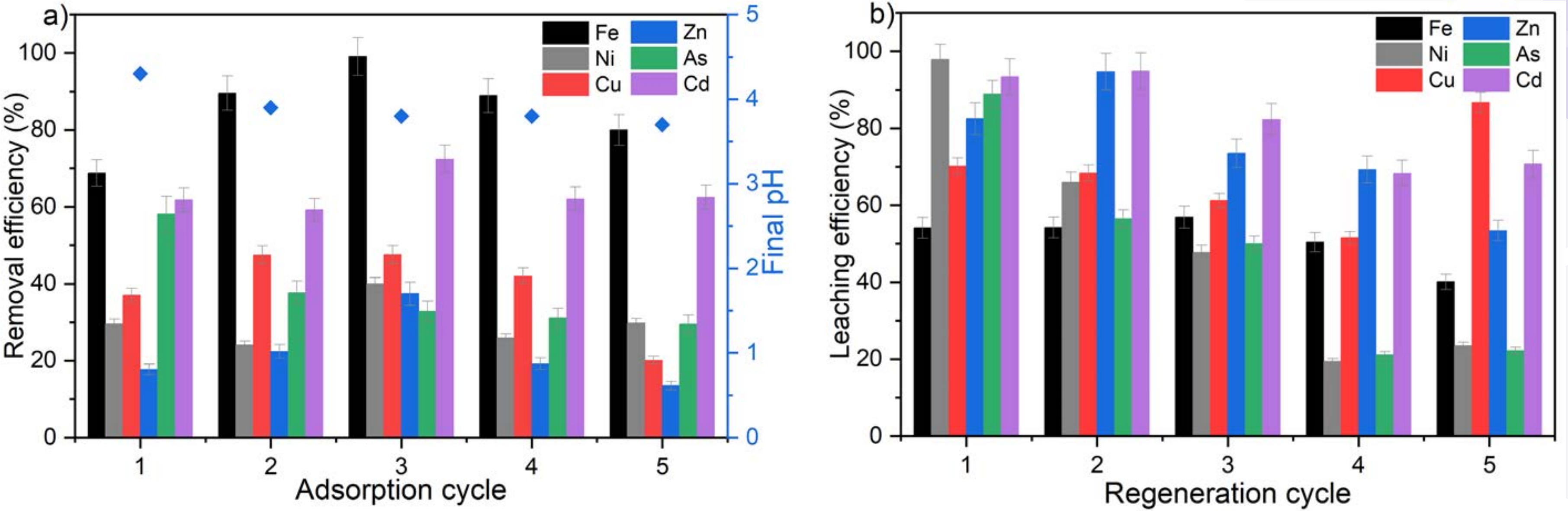
Lattice (after acid neutralization)



Remediation of real acid mine drainage (AMD)

Results

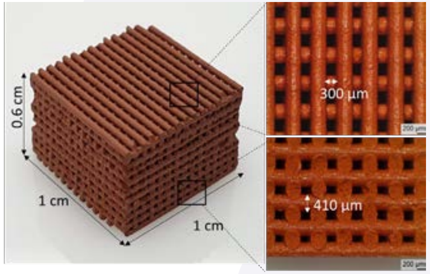
Printed lattices: regeneration and reusability

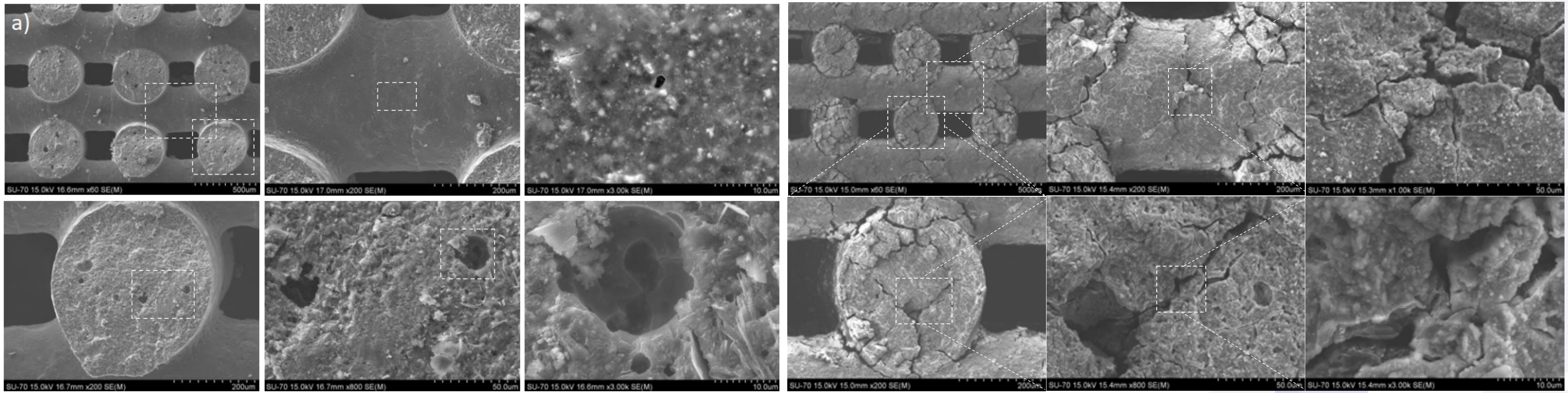


$m_{3D\text{-}50RM}$ = 600 mg
V_{AMD} = 50 mL
$[EDTA.2Na]_0$ = 0.05 M, 3h

Remediation of real acid mine drainage

Printed lattices: regeneration and reusability





Lattice before the tests

SSA = 55 m^2/g

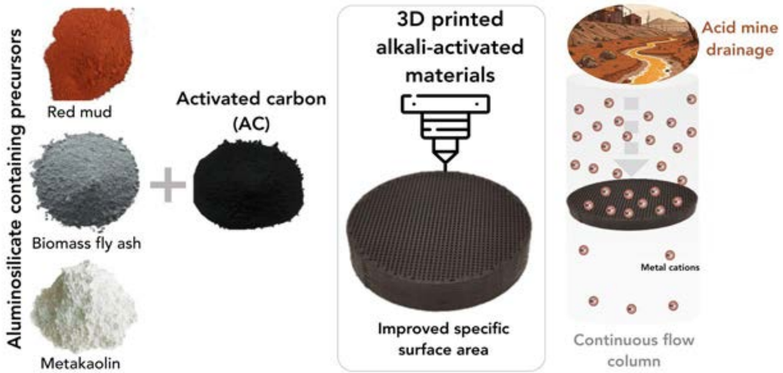
Lattice after 5 adsorption/regeneration cycles

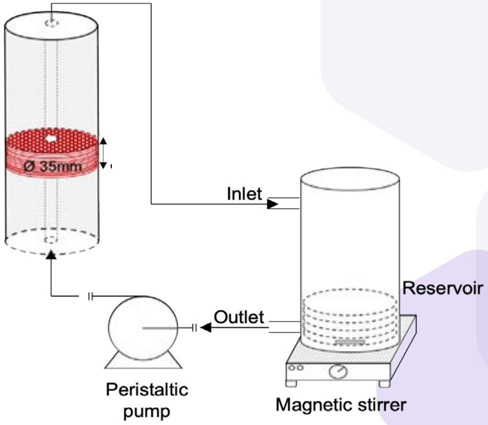
SSA = 71 m^2/g

Results

Boosting the performance of bulk-type sorbents

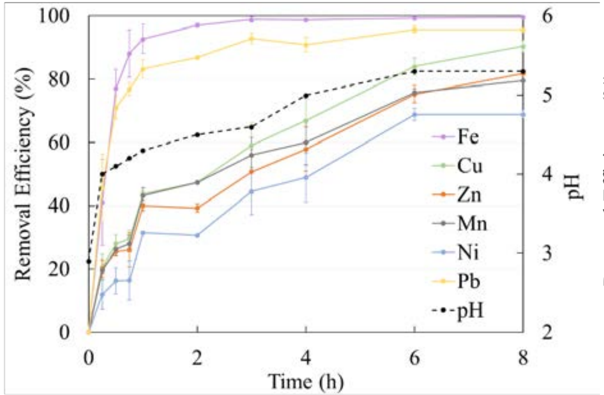
Waste-based 3D printed AAMs

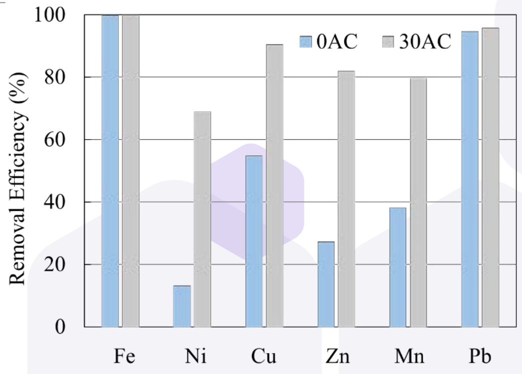




Pristine lattice – SSA = 40 m^2/g

AC-containing lattice – SSA = 95 m^2/g





M. Almeida *al.*, *Unpublished results.*

Conclusions

Water scarcity

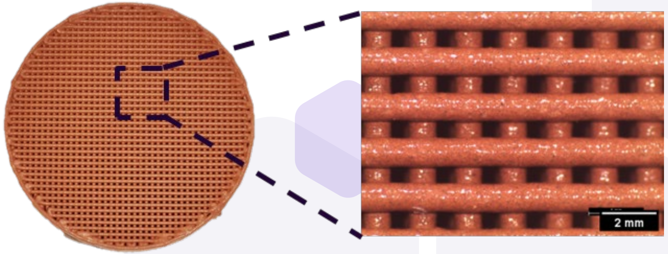
Wastewater treatment

SUSTAINABLE DEVELOPMENT GOALS

Bauxite residue

Biomass fly ash

Solution? AAM foams



Thank you for your attention!

Questions?

Collaboration?

university of aveiro
theoria poiesis praxis

CICECO

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edm Empresa de Desenvolvimento Mineiro, SA

MARIE CURIE ACTIONS

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UIDB/50011/2020, UIDP/50011/2020 & LA/P/0006/2020

Horizon Europe MSCA PF grant agreement No 101065059

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