INES FLORES-COLEN

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- **DEVELOPMENT OF INNOVATIVE AND SUSTAINABLE SOLUTIONS**
- **PERFORMANCE AND DURABILITY OF FACADES**
- **INSPECTION AND IN-SITU TESTING**
- **PATHOLOGY AND MAINTENANCE**
- **THERMAL REHABILITATION**

Associate Professor with Habilitation in Civil Engineering at DECivil, IST, University of Lisbon and research member of CERIS (Civil Engineering Research and Innovation for Sustainability) research unit. MSc and PhD in Civil Engineering.

Framework of conferences organized by L2MGC CY Cergy Université in acknowledgment and gratitude to Prof. George Wardeh.

L2MGC
laboratoire de mécanique et matériaux du génie civil

CERGY PARIS UNIVERSITÉ

Performance of innovative and sustainable solutions during the life cycle

Performance of innovative and sustainable solutions during the life cycle

Abstract :

The performance assessment of conventional and innovative constructive solutions of existent buildings poses various challenges to the construction industry. Several European Directives have been recently updated and implemented, related to the energy efficiency of buildings and sustainability (including circular economy). Furthermore, the pandemic and climate change effects have been a big concern and have created a lot of uncertainty on the performance, encouraging the development of more studies on resilient constructive solutions in new and retrofitted buildings.

In this session the performance of innovative and sustainable solutions will be discussed, presenting the research that has been carrying out within CERIS (Civil Engineering Research and Innovation for Sustainability), a research unit from IST, University of Lisbon-Portugal, under the supervision of Prof. Inês Flores-Colen.

Topics: ETICS; aerogel-based renders; fibres; rice husk composites; plastic-waste incorporation.

Speaker : Prof. Inês Flores-Colen

CERIS Civil Engineering Research and Innovation for Sustainability | TÉCNICO LISBOA | DECIVIL DEPARTAMENTO DE ENGENHARIA CIVIL, ARQUITECTURA E GEORRECURSOS

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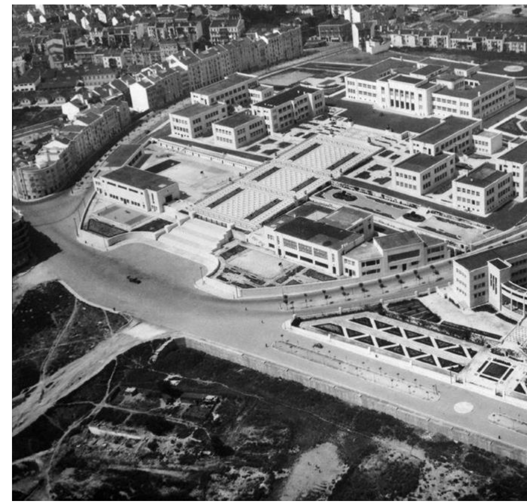
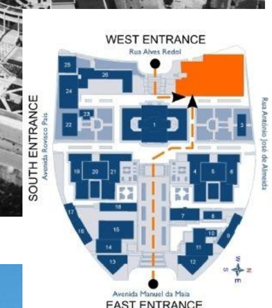
1. OVERVIEW OF TÉCNICO AND CERIS

University of Lisbon /IST/ DECivil

IST was established in 1911 and became the School of Engineering, Science and Technology of UTL (1927) and ULisboa (2013)





University of Lisbon 50.000 students

Instituto Superior Técnico 11.611 students
1200 faculty

DECivil 1600 MSc students; 229 PhD students; 134 faculty members.

CIVIL ENGINEERING (IST/ULisboa)	1st in Portugal	1
SHANGHAI RANKING (ARWU, 2017)	7th in Europe 43rd in the World	7/43
NATIONAL TAIWAN UNIVERSITY (NTU, 2017)	8th in Europe 29th in the World	8/29

CERIS research unit

- **MISSION** - Research and dissemination of scientific knowledge and innovation in the Built and Natural Environmental sector.

4 Thematic Lines **6 Research Groups** **8 Laboratories** **184 PHD Researchers**

CERIS thematic strands (4)

TS1 **Product Development in Civil Engineering Industries**

TS2 **Risk and Safety in Built and Natural Environments**

TS3 **Rehabilitation of Built and Natural Environments**

TS4 **Response to Natural and Social Changes**

CERIS research groups (6)

RG1 Hydraulics

RG2 Environment and Water Resources

RG3 Systems and Management

RG4 Transportation Systems

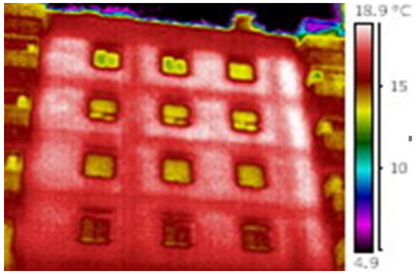
RG5 Studies in Construction

RG6 Structures and Geotechnics

Large unit: stability / flexibility

DECivil laboratories

- Architecture
- Construction
- Geotechnics
- Hydraulics, environment and water resources
- Mining and geo-resources
- Structural mechanics and structures
- Urban and regional systems



Innovative and sustainable solutions - Research area

Incorporation (aggregates, fibres or additions) in partial/total replacement of sand or binder: Nanomaterials; Recycled materials; Waste (e.g. plastic); Bio-based and by-products (e.g. rice husk; fibres).

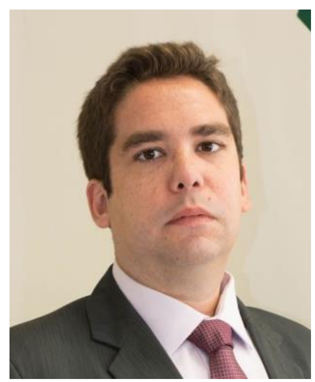
Researchers in RA

Giovanni Borsoi; Maria Paula Mendes; Marco Pedroso: Also, other CERIS researchers: Rui Silva, João Firmo and João Pacheco.

IST PhD students in RA

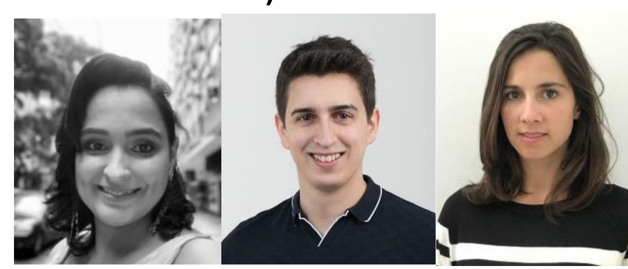
Ana Raimundo; João Parracha; Poliana Bellei; Rita Santos; Maria Júlio

Research fellow



Rafael Travincas

PhD students in RA (other universities)



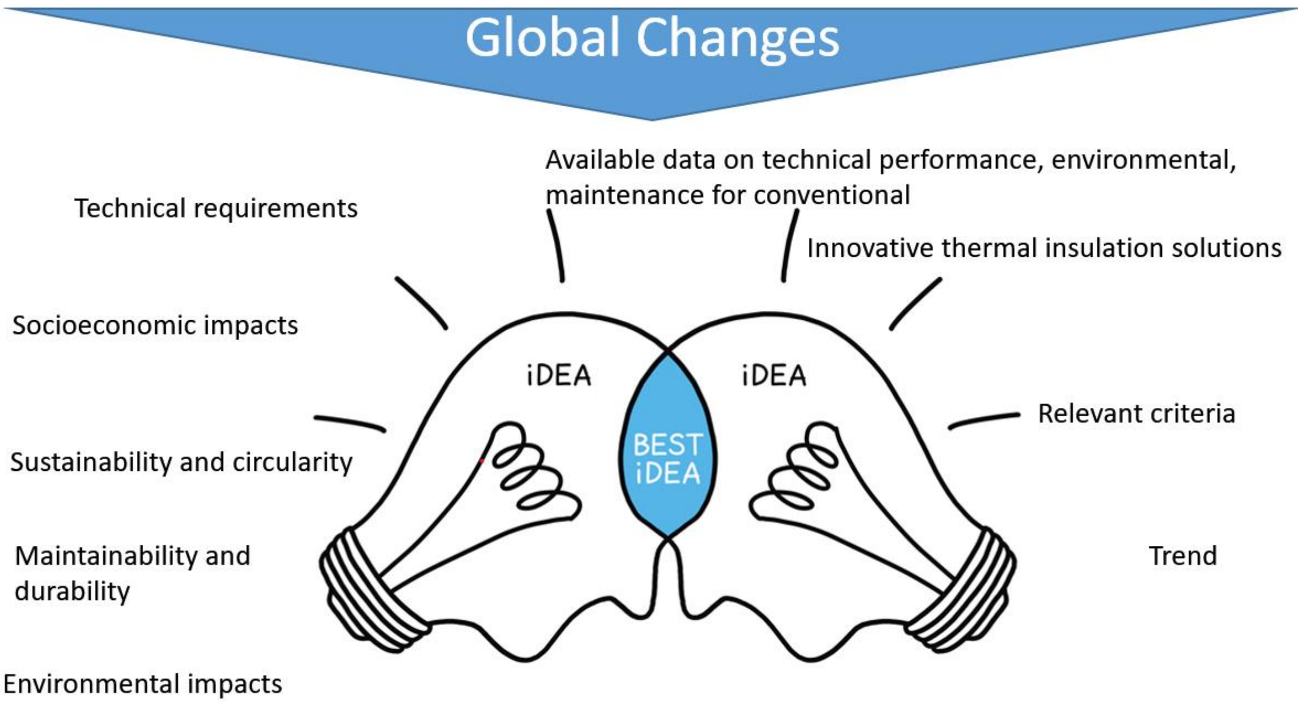
Andréa Souza; Márcio Gonçalves; Catarina Ribeiro

Plus: visiting researchers

2 - PERFORMANCE PERSPECTIVES

PERFORMANCE

EFFICACY (Energy eFFiciency buIlding and CirculAR eConomY for thermal insulating solutions) project, which intends to develop guidelines to systematize relevant criteria for thermal insulation solutions on existing buildings retrofitting and/or for new constructions.

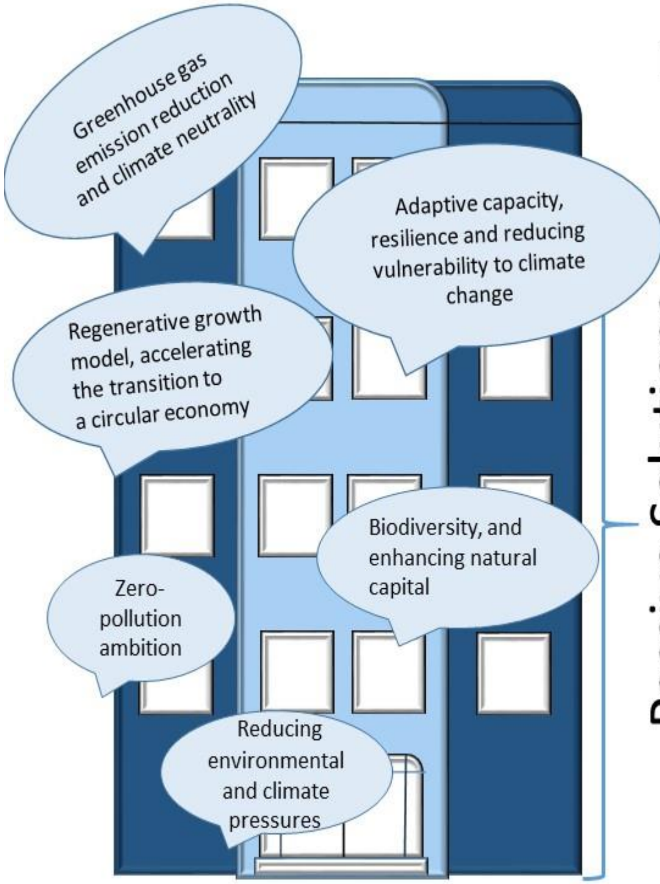


NTNU
Norwegian University of Science and Technology

Iceland Liechtenstein Norway grants

Ongoing (started in September 2021)

PERFORMANCE



Passive Solutions

New buildings & "Renovation Wave" initiative

Technical requirements
- Mechanical
- hygothermal
- water resistance
- biosusceptibility
- constructive restraints

Environmental impacts
- Green gas emissions:
  - CO_2 emissions
  - Embodied energy
  - Deforestation
- Environment and health
  - Toxicity
  - Water footprint and water pollution

Sustainability and circularity
- Life Cycle Assessment (LCA)

Maintainability and durability

Socioeconomic impacts
- Climate-proof building sector
- Competiveness in the construction industry

The **climate change scenarios** and weather extreme events are crucial to consider in the selection of the previous criteria due to the **hazards and risks associated**. Several options for insulating materials solutions can improve the climate proofing of buildings.

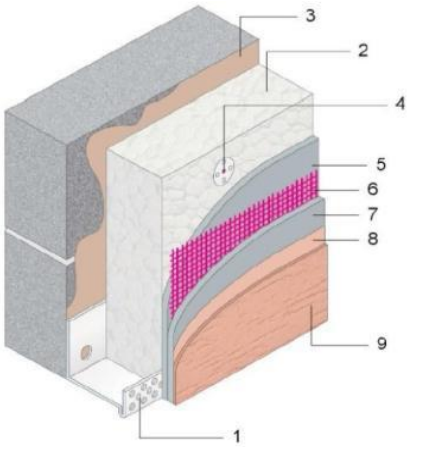
3 - PERFORMANCE OVERTIME (DURABILITY)

WGB Shield project

Evaluation of protection degrees on ETICS surfaces in terms of their resistance to water, graffiti and biocolonization

The purpose of this project is to develop **ETICS with greater durability in the urban environment**, ensuring the aesthetic quality of the facades, without negative repercussions on the buildings' energy efficiency and toxicity.

i) integrated analysis of the performance, durability, maintenance and ecotoxicity of surfaces, considering the combined action of urban agents and the creation of sustainable rehabilitation solutions;
ii) a **new set of performance and ageing tests simulating real urban conditions**;
iii) definition of **integrated protective-repair solutions** that combine advanced and ecoefficient materials.

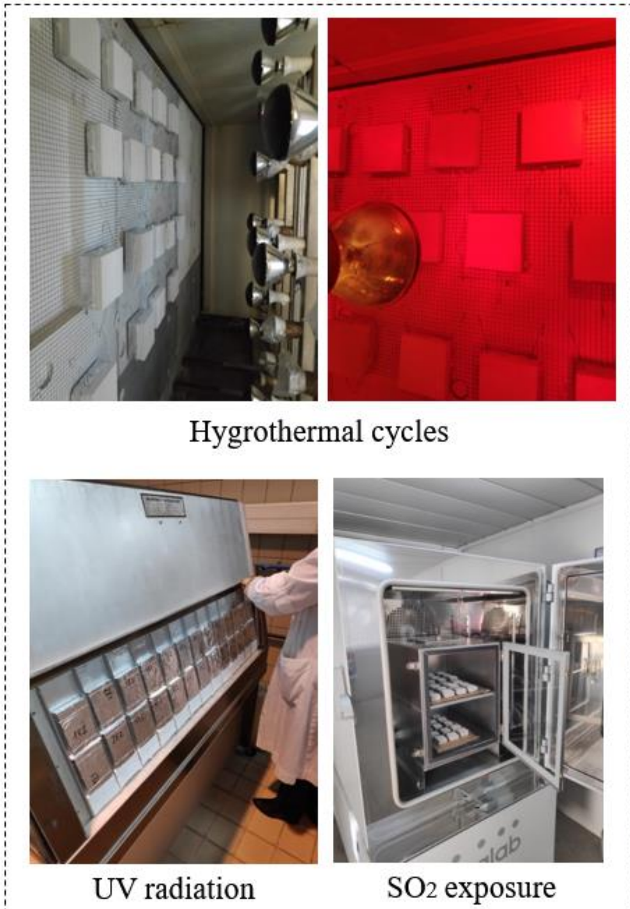


Ongoing

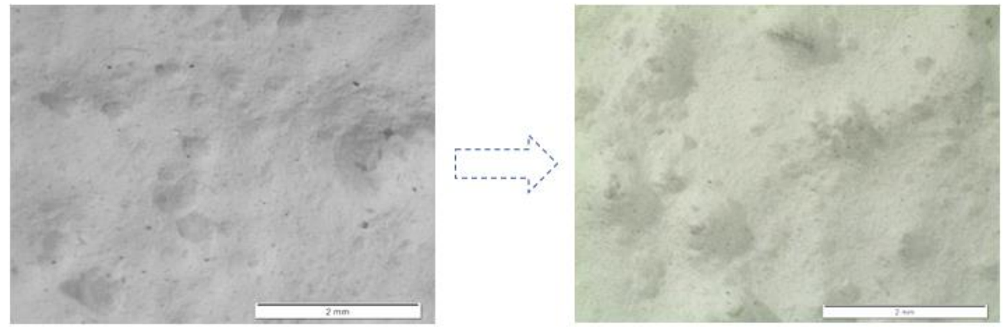
WGB - DURABILITY

ETICS

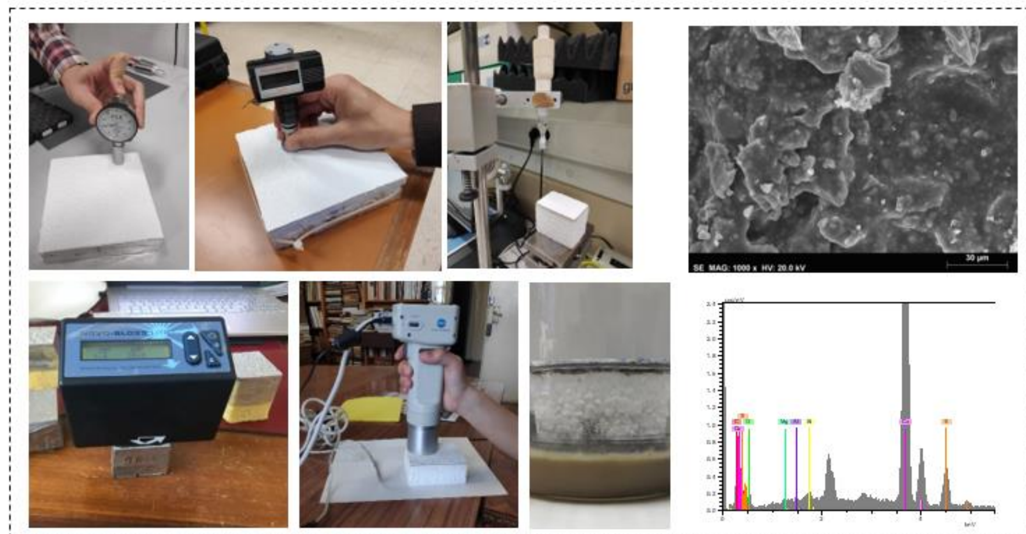
Accelerated ageing tests



BEFORE *AFTER*



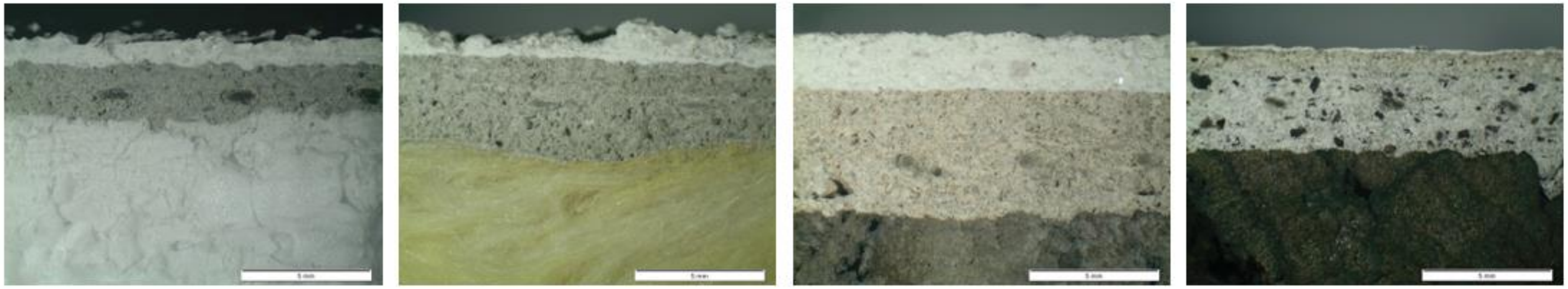
Durability assessment



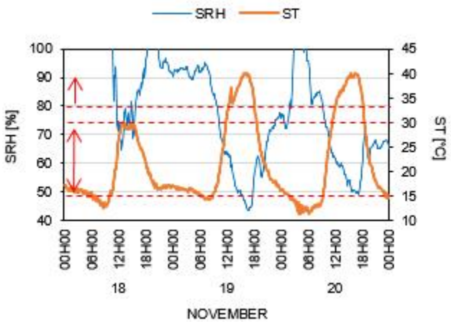
Ongoing

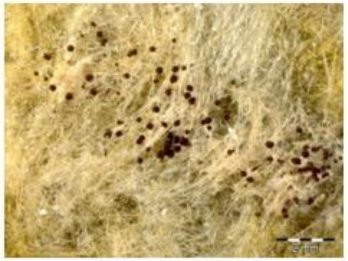
WGB AND Bi-THERM projects - DURABILITY

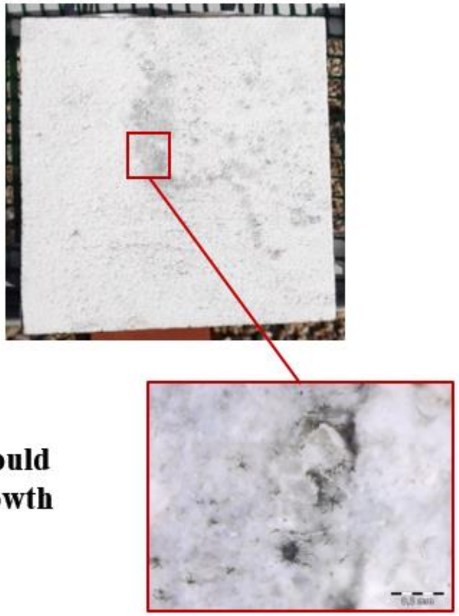
ETICS



Monitoring and *in situ* observations



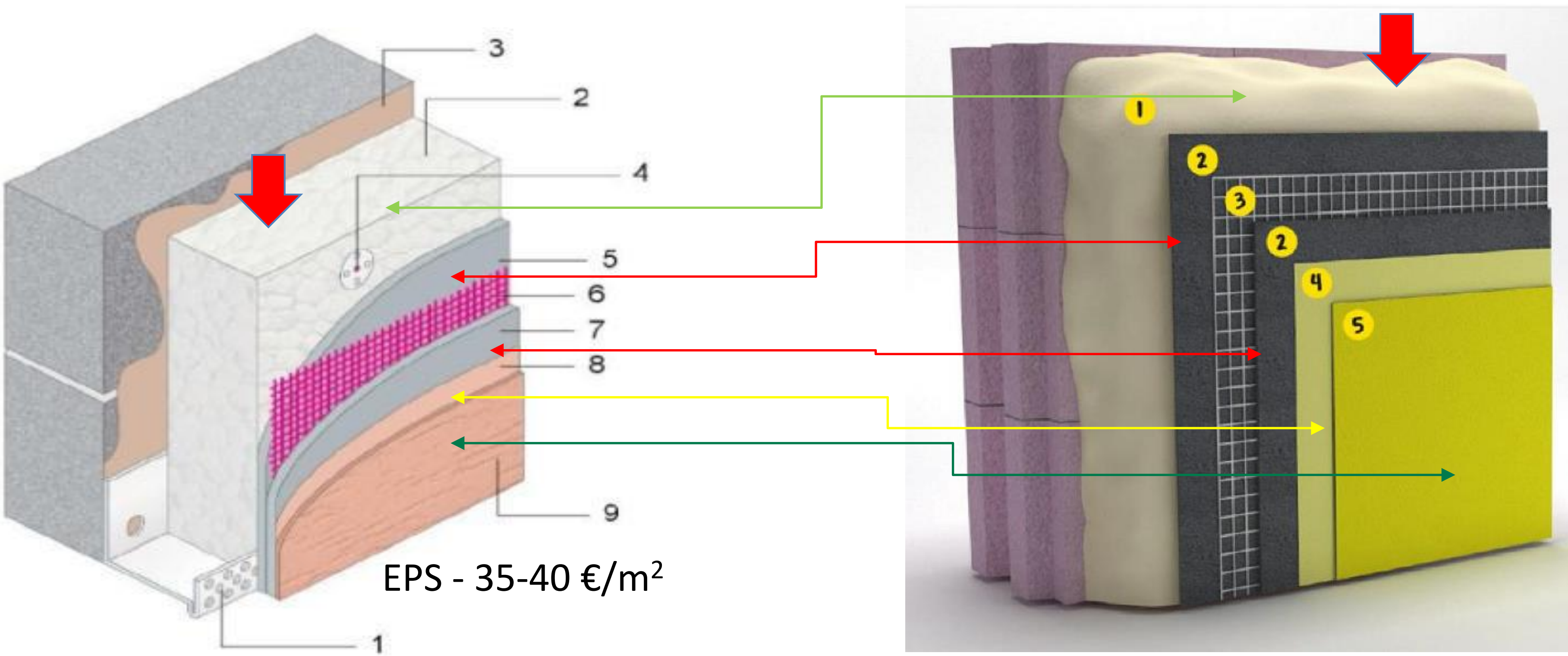




Mould growth

ETICS *VS* THERMAL MORTARS

50-55€/m²



EPS - 35-40 €/m²

DURABILITY

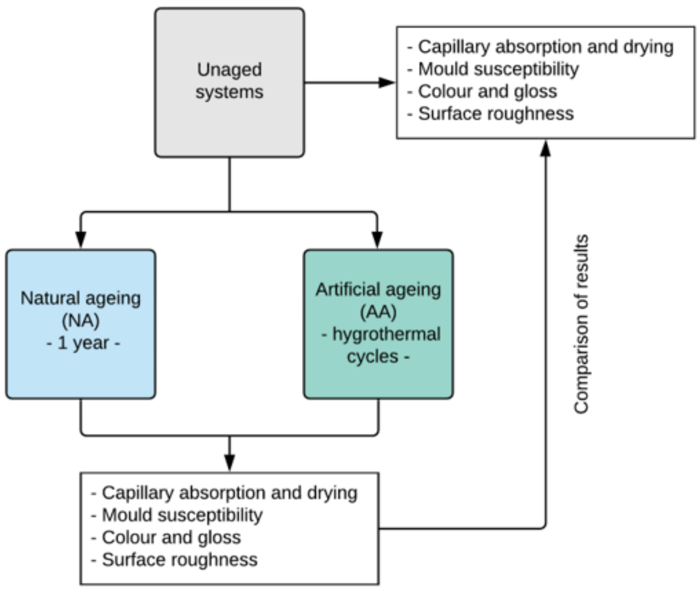
Thermal mortars (ongoing PhD work with the objective of assessing the durability of these systems)

Ongoing

DURABILITY

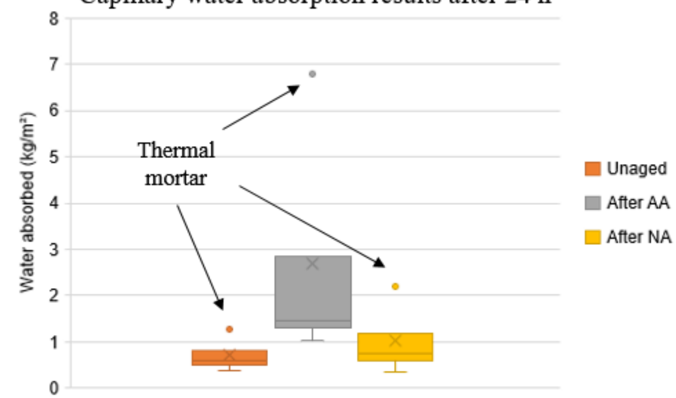
Mortar with acrylic protective coating

Some preliminary results

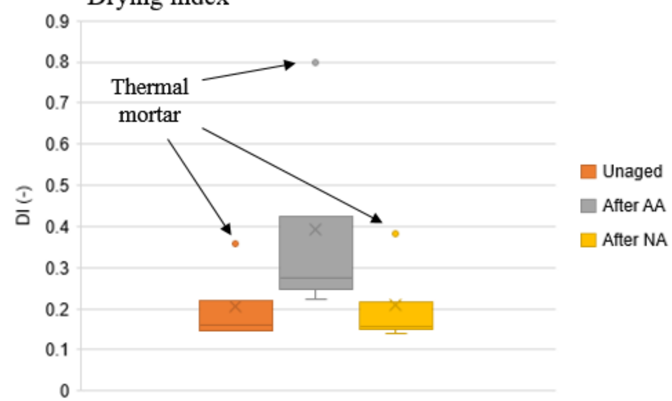


Scheme of the experimental programme

Capillary water absorption results after 24 h



Drying index



Experimental and Numerical Analysis of Interface mortar-support

This project intends to analyse the **influence of the characteristics of several substrate**s on the characteristics of several mortars.

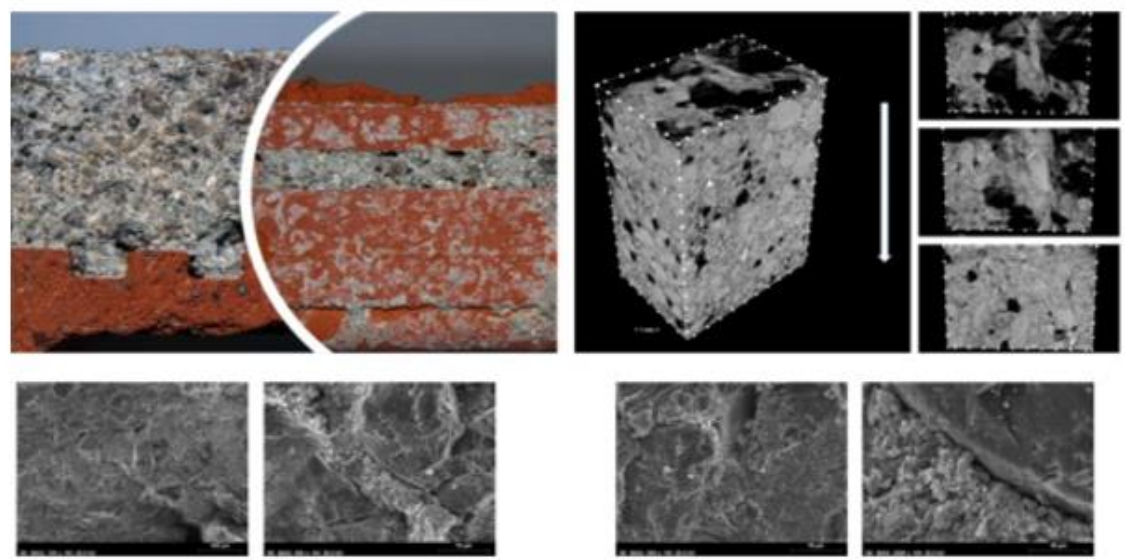
- **What are the parameters that will influence the mortar behavior over time?**
- Will the characteristics of the mortars have more influence than the characteristics of the support?
- How will these characteristics influence the behaviour of mortars?
- Will the conditions of application and cure have any influence?
- **Will the characteristics of the applied mortars change over time differently depending on the type of support?**

Ongoing

X-ray microtomography applied to mortar

Sample acquisition

General macroscopic, tomographic and SEM aspects of the Ceramic brick/cement mortar interface



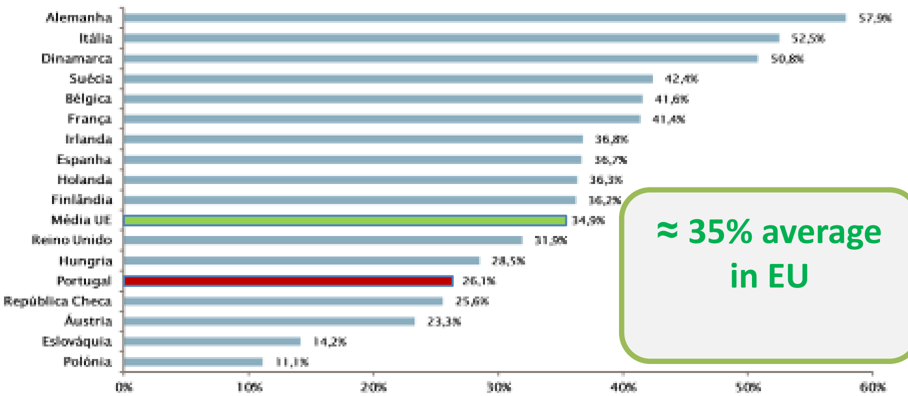
Machine learning applied to mortar

4 - INOVATIVE SOLUTIONS
(Thermal mortars - aerogel)

Motivation for innovative insulating materials

The problem:

- Demanding energy and environmental directives (2002/91/CE, 2010/UE, 2012/27/UE);
- **Multifunctional and innovative solutions for energy efficient buildings** (NZEB buildings);
- **Rehabilitation of existent housing stock** with minimum cost/optimal performance, lesser environmental impacts and higher durability.



≈ 35% average in EU

≈ 26% rehabilitation of construction sector in Portugal

Market opportunity:

- 35% of the EU's buildings are over 50 years old;
- Only in Portugal there are about 3 million buildings with traditional renders; **2.5 million built before 1990** (the first thermal code - RCCTE);
- Energy rehabilitation projects and funding programs (e.g. H2020).

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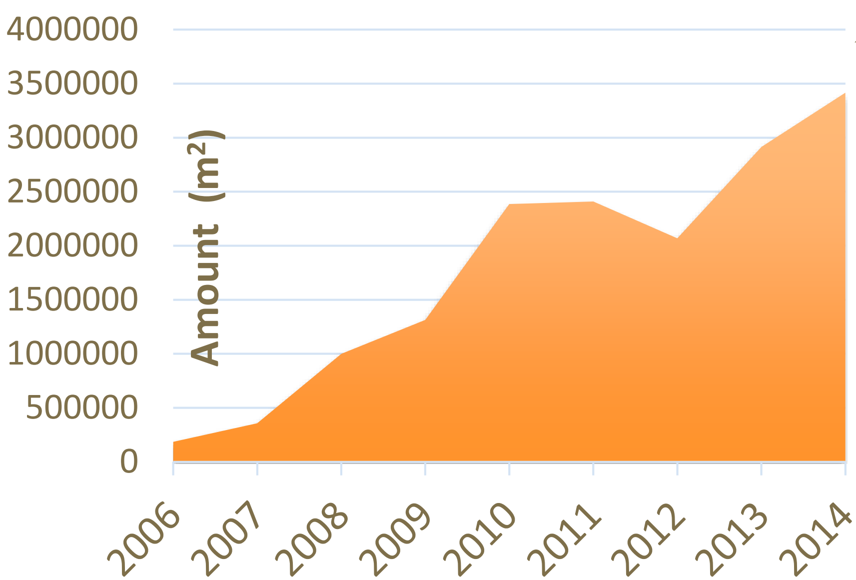
Motivation for innovative insulating materials

ETICS application in **Portugal**



Thermal insulation materials; EPS ≈0.034 W/(mK)

Increase of buildings energy requirements

Increase of insulation thickness

Architectural problems

Thermal renders ≈0.05 W/(mK)

- **Thermal rehabilitation of curved surfaces or complex architecture features**
- **Thermal rehabilitation of old buildings walls**

CONVENTIONAL THERMAL MORTARS

EN 998; T1 OU T2

BINDER + **AGGREGATE** + WATER + ADMIXTURES/ADITIONS

BINDER → Cement, Lime, Resin

AGGREGATE → Sand

Replacement of sand

Lightweight aggregate- Expanded polystyrene (EPS)

- Expanded cork

Higher % of incorporation

(λ < 0.1 ou < 0.2 W.m^{-1}.K^{-1})

INDUSTRIAL MORTARS WITH LIME AND EPS:

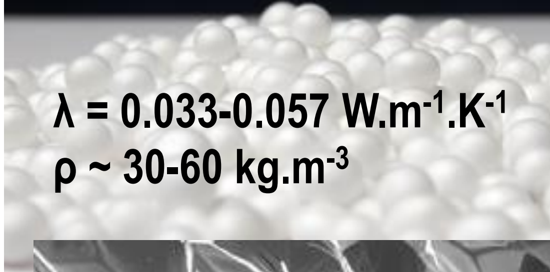
$\lambda \approx 0.05$ W.m^{-1}.K^{-1}

Bulk density ~ 250 kg/m^3

THERMAL INSULATING AGGREGATES

Light and insulating materials used as aggregates in thermal renders:

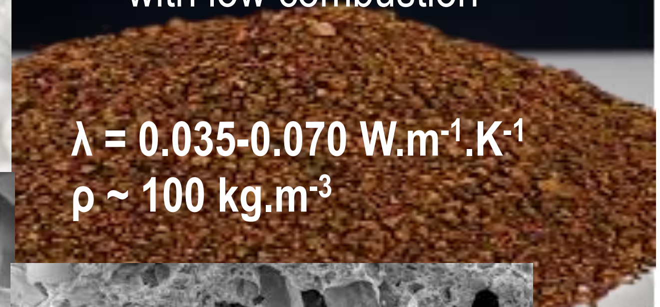
EXPANDED POLYSTYRENE



thermoplastic polymer, rigid and flammable

λ = 0.033-0.057 W.m^{-1}.K^{-1}
ρ ~ 30-60 kg.m^{-3}

CORK

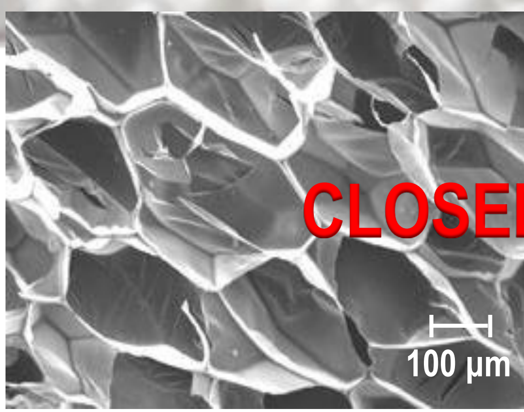


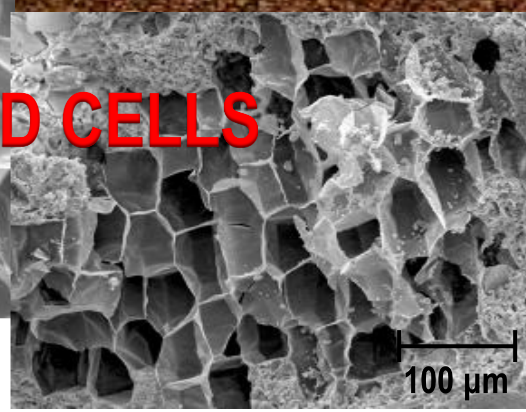
cellular, natural, renewable with low combustion

λ = 0.035-0.070 W.m^{-1}.K^{-1}
ρ ~ 100 kg.m^{-3}

INSULATING MATERIALS

λ ~ 0.030-0.040 W.m^{-1}.K^{-1}





CLOSED CELLS

(SEM)

Thermal conductivity **(λ)** of a porous material does not only depend on its **density** (related with porosity) but also on its **pore size** and **structure**.

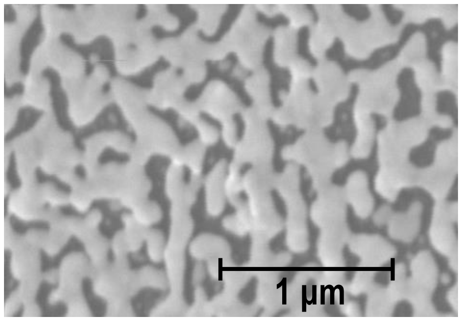
- **Closed pore** system: Negligible convective transport by the pore medium: **low thermal conductivity**

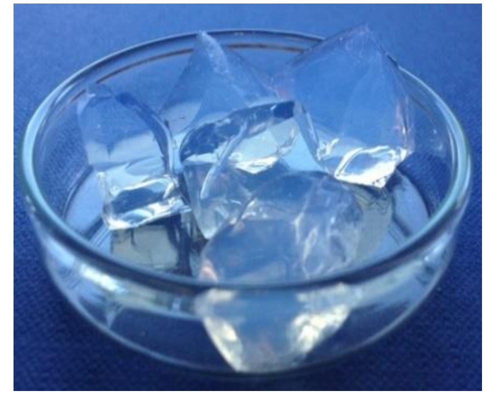
THERMAL INSULATING AGGREGATES

- **Interconnected pore** system:

SILICA AEROGELS

(SEM)





IUPAC:
Mesopores (2< Φ<50 nm)

- **Highly porous** solid materials: **pore volume** up to **99%**
- **Extremely light:** envelope density between **400** and **100 kg.m^{-3}**
- High specific surface areas: **S_{BET} ~ 1000 m^{2}.g^{-1}** (**mesoporous structure**)
- Acoustic insulators, fire resistant
- Thermal insulators:

Very low densities → **Conduction** greatly diminished

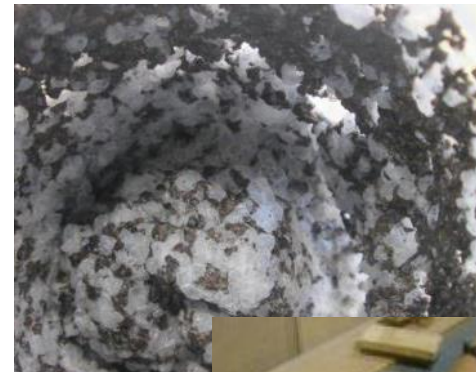
Very small pore size (Φ < 50 nm) → **Convection** eliminated

SUPERINSULATING MATERIALS

λ < 0.020 W.m^{-1}.K^{-1}

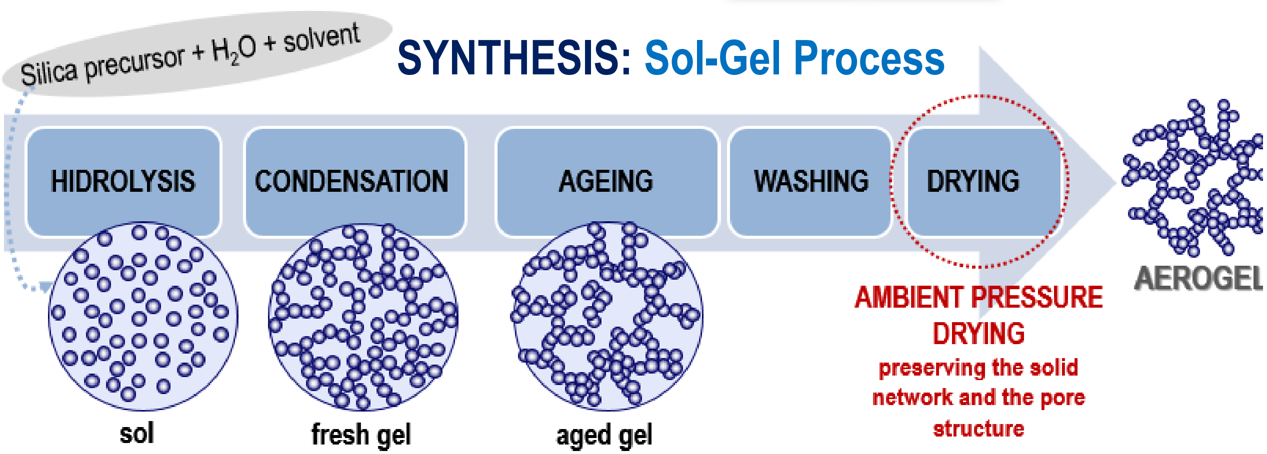
AEROGEL BASED RENDERS

NANORENDER PROJECT (2015)



Made with Portland cement, fly ash, and/or lime, silica-based subcritical hybrid aerogel, natural lightweight co-aggregates of expanded cork and expanded clay, lightweight fillers and admixtures.

Key value: innovative aggregate produced by a sol gel process with ambient pressure drying (grain size control and hydrophobicity).



Motivation for innovative insulating materials

According to the **current legislation, it is important to comply the thermal requirements**:

REH **I3 – Bragança, Portugal**

<u>**U ≤ 0,35 W/m².ºC**</u>

30 x 20 x 22 cm

Thickness ≥ 12 cm
$\lambda_{10ºC,dry}$ > **0.054** W/m.K
Medium fire reaction

Thickness ≥ 9 cm
$\lambda_{10ºC,dry}$ > 0.039 W/m.K
Low fire reaction

Thickness ≥ 8 cm
$\lambda_{10ºC,dry}$ > 0.034 W/m.K
High fire reaction

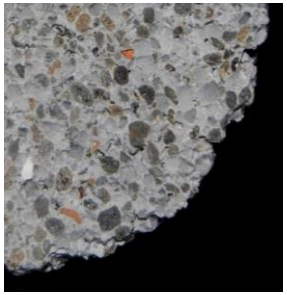
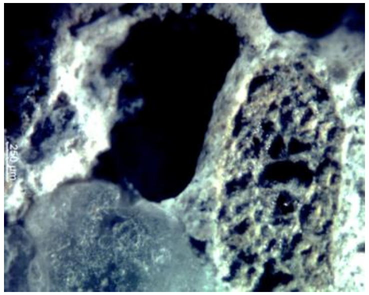
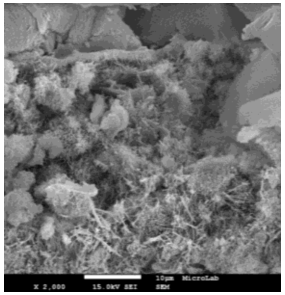
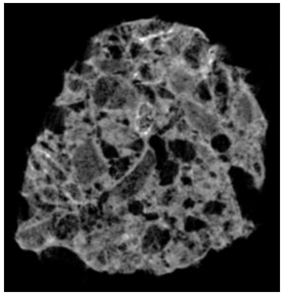
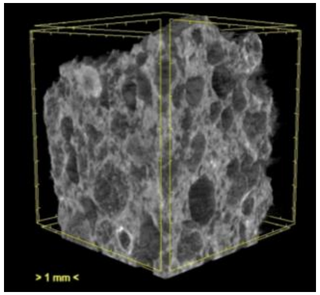
Thickness ≥ 6 cm
$\lambda_{10ºC,dry}$ > **0.030** W/m.K
Low fire reaction

MICROSTRUCTURE

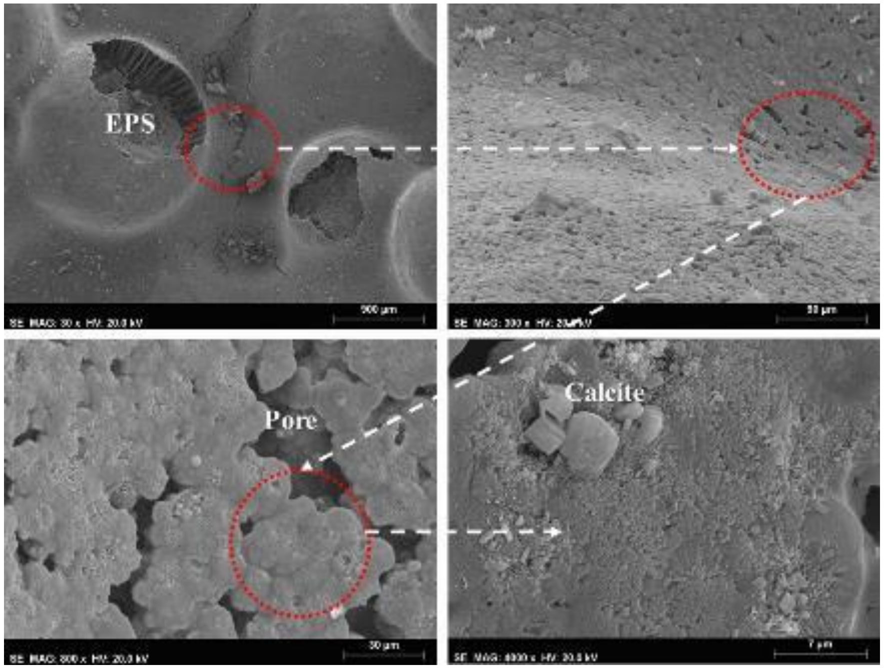
To study the solid and porous structure of the mortars (aggregates, binder paste, aggregate interface / binder and porous space).

Component	Macrostructure		Microstructure				
	Photographic record	Stereo microscope	DRX	FTIR	SEM	MicroCT	Stereo microscope
Aggregate	X	X	-	-	X	X	X
Binder	X	X	X	X	X	X	X
Binder/aggregate interface	-	X	-	-	X	X	X
Porous structure	X	X	-	-	X	X	X

Caption: DRX – x-ray diffraction; FTIR – infrared spectroscopy with Fourier transform; SEM – Scanning electronic miscroscope; MicroCT – computerized x-ray microtomography.
(X) refers to a utilized method and (-) to a non-applicable method.

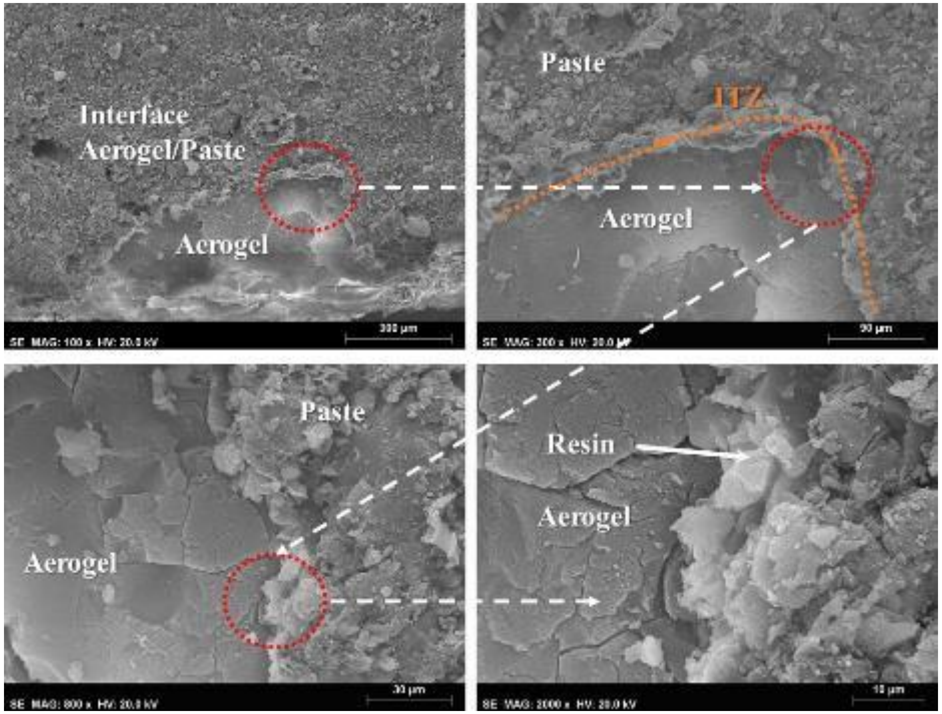






SEM images (EPS vs Aerogel)



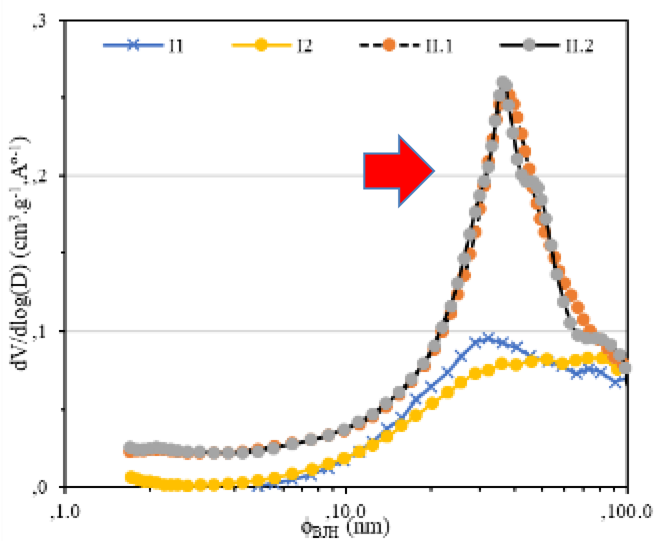
SEM images of EPS-based mortar

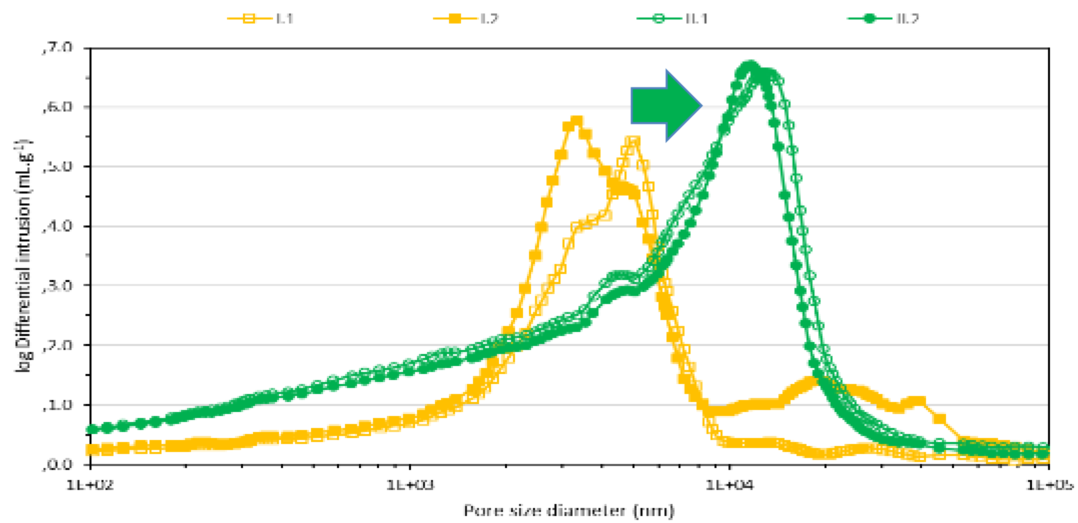
EPS and aerogel particles are well blended in the paste



SEM images of aerogel-based mortar

THERMAL MORTARS (EPS vs Aerogel)





Mesopore size distribution for the N_2 adsorption branch (left) and pores distribution by MIP for both mortars

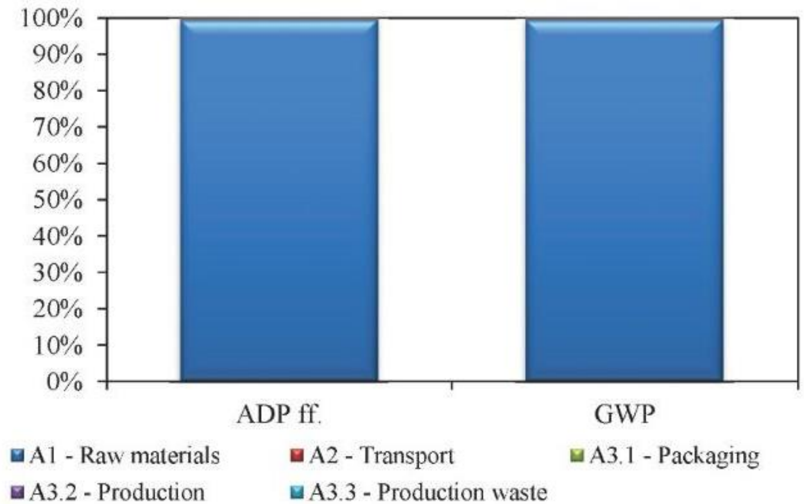
The aerogel-based mortar has a high number of mesopores (< a 50 nm) and macropores (10000 nm): low compressive strength (0.23 MPa); high water absorption (1 kg/($m^2min^{0.5}$); excellent thermal conductivity λ = 0.0293 $W.m^{-1}.K^{-1}$ (dry state at 10 ºC).

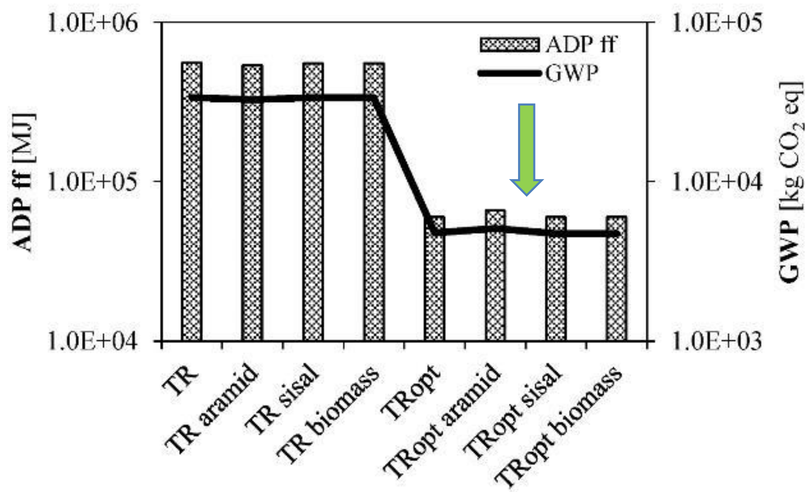
The EPS-based mortar has a high number of pores at 4000 nm (macropores): better compressive strength (0.35 MPa); lower water absorption (0.3 kg/($m^2min^{0.5}$); higher thermal conductivity λ = 0.0514 $W.m^{-1}.K^{-1}$ (at dry state and 10 ºC).

LIFE CYCLE ASSESSMENT

Subcritical drying (80% energy savings when compared to supercritical drying)

Mortars





Raw materials

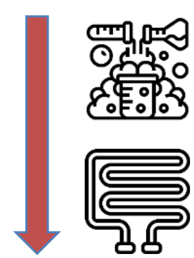
TEOS

Isopropanol

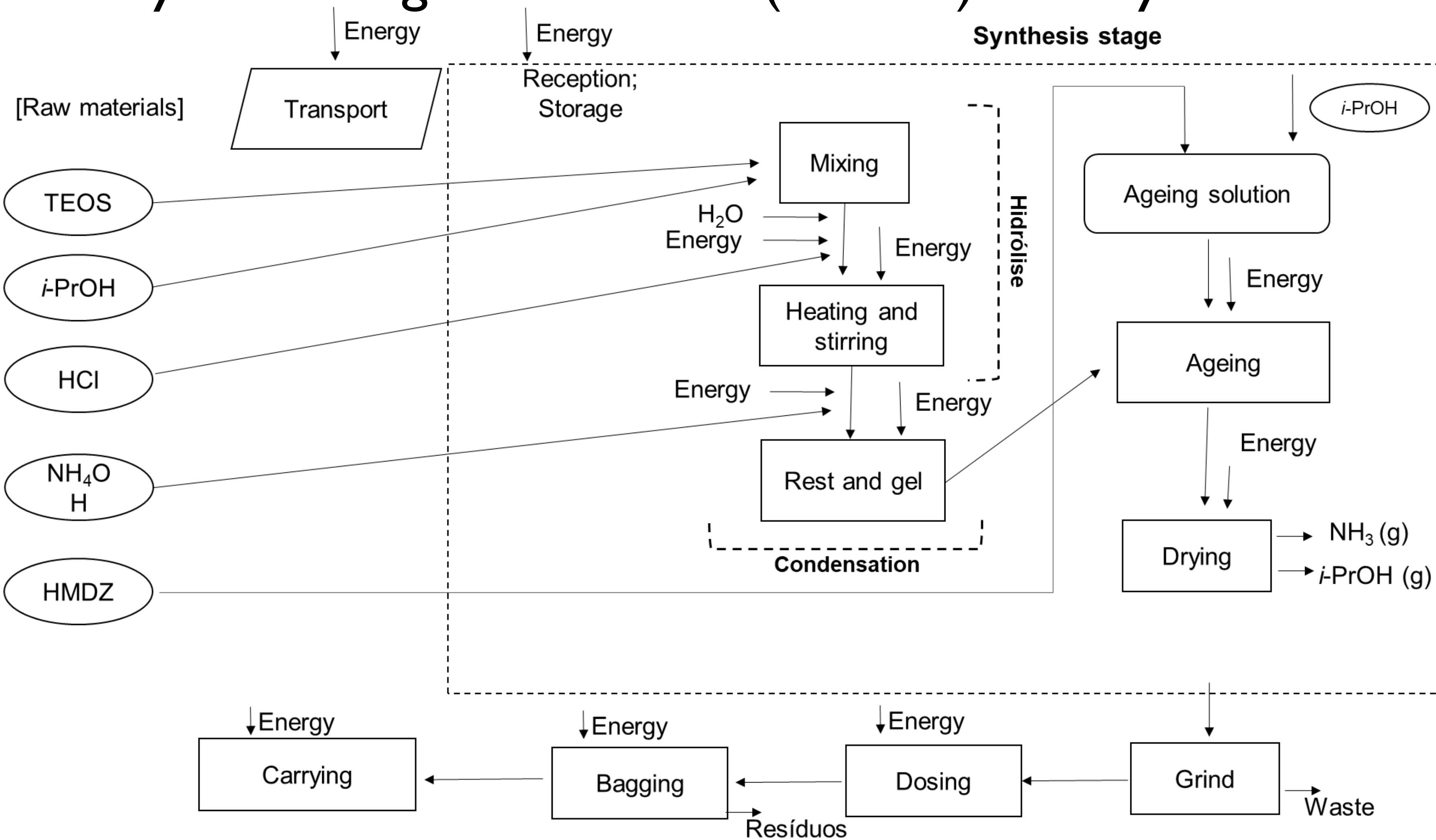
HMDZ

Energy

Reusing reactants and reduction of drying energy



Hybrid aerogel monolithic (HYB-C) Life Cycle



TAILORED AEROGEL

Ongoing PhD (co-supervision):

Renders with thermal conductivity **as low as possible**

Acceptable mechanical and physical properties

Yield **NEW FUNCTIONALITIES TO THE RENDERS**:
- Low density,
- Fire resistance,
- Durability,
- Controlled Hidrophobicity/Lipophilicity,
- Application versatility.

CQFM Centro de Química-Física Molecular

IN Institute of Nanoscience and Nanotechnology

Maria de Fátima Júlio
PhD student in Materials Engineering

HOW TO OBTAIN STABLE AEROGELS BY SAFER AND MORE ECONOMICAL METHODS?

- Using **specific precursors**, organically modified: **CO-PRECURSOR METHOD**
- Using a **silylating agent DURING AGEING or as POST-SYNTHESIS MODIFIER**

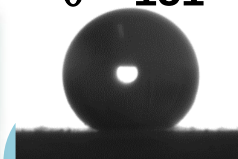
Ongoing

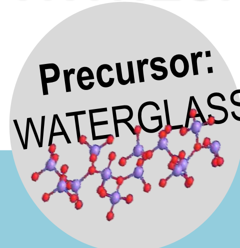
TAILORED AEROGEL

HYBRID AEROGELS SYNTHESIS WITH HEXAMETHYLDISILAZANE (HMDZ)


Superhydropobic powders:

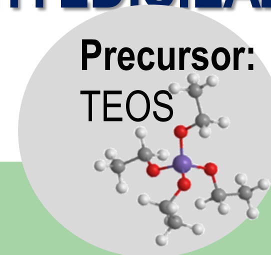
θ = 151°





CO-PRECURSOR METHOD

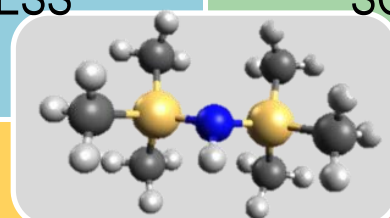
ONE-STEP
SOL-GEL PROCESS



CO-PRECURSOR METHOD

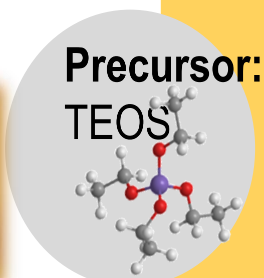
TWO-STEP
SOL-GEL PROCESS

Vitreous monoliths

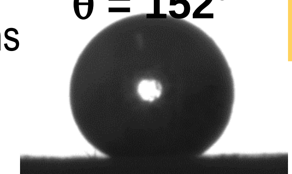


Particles

Opaque monoliths



θ = 152°

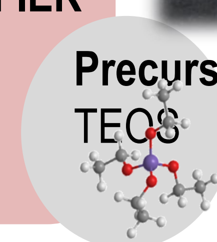


POST-SYNTHESIS MODIFIER

TWO-STEP
SOL-GEL PROCESS

CO-PRECURSOR AND **POST-SYNTHESIS MODIFIER**

TWO-STEP
SOL-GEL PROCESS



SYNTHESIS CAN BE ADJUSTED DEPENDING ON THE PURPOSE!

ENERGY EFFICIENT WALL PLUS (PEP) PROJECT

P2020 project: *Parede Eficiente Plus* (2017-2019) - development of a super insulating render

Cofinanciado por:

COMPETE 2020 | PORTUGAL 2020 | UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional

weber SAINT-GOBAIN | institutodaconstrução | CERIS Investigação e Inovação em Engenharia Civil para a Sustentabilidade

A new thermal mortar formulation with **improved insulating properties.**

PEP (Efficient Wall Plus) Project

Innovative rendering mortar: SIM[1]

SIM

Aerogel

Hardened SIM

[1] *Super Insulating Mortar*

Tests *@ hardened state*	**Procedure**	**Results** *average*
Density	*EN1015-10*	**0.160** g/cm^3
Compressive strength	*EN1015-11*	**0.23** MPa
Thermal conductivity, 10ºC and dry state	*EN1745*	**0.029** W/m.K
Water vapour permeability coefficient	*EN1015-19*	**14.8**
Liquid water permeability	*LNEC FEPa39.1*	**4.19** kg/m^2
Water absorption coefficient due to capillary action	*EN1015-18*	**1.0** kg/m^2.min$^{0.5}$
Adhesive strength	*EN1015-12*	**0.06** MPa **C**

This innovative mortar formulation is composed, mainly, by: mineral binders, resins, hydrophobic agents and light aggregates. The silica aerogel represents 37% (m/m) and the perlite 26% (m/m).

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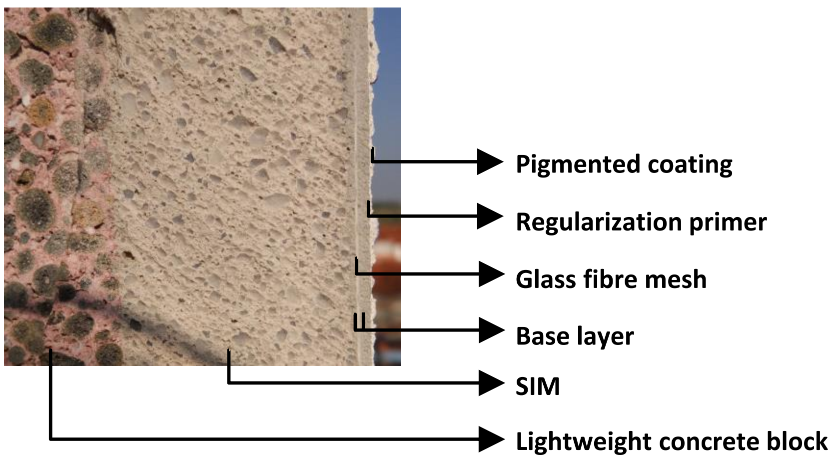
PEP (Efficient Wall Plus) Project

ETICS[1] incorporating **SIM**



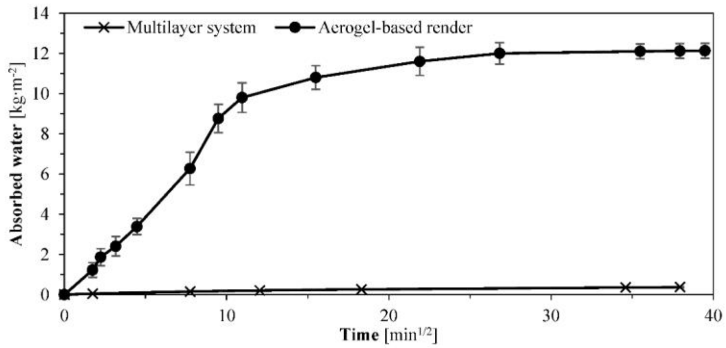
Tests *@ hardened state*	**Procedure**	**Results** *average*
Water vapour permeability coefficient	*EN1015-19* *ETAG 004*	24h: **25.1** 168h: **34.8**
Resistance to water vapour diffusion (air thickness equiv.)	*EN1015-19* *ETAG 004*	24h: **0.63** m 168h: **0.90** m
Water absorption due to capillary action	*ETAG 004*	1h: **0.11** kg/m^2 24h: **0.30** kg/m^2
Adhesive strength (SIM / base layer)	*ETAG 004*	**0.07** MPa, **C**
Impact resistance	*ETAG 004*	Category **II**

[1] *External Thermal Insulation Composite System*

Currently, and for the tests made according to ETAG 004 (now EAD), the full system (ETICS) incorporating SIM has a performance that meets the requirements, although it needs further tests to fully comply with the ETAG 004.

PEP (Efficient Wall Plus) Project

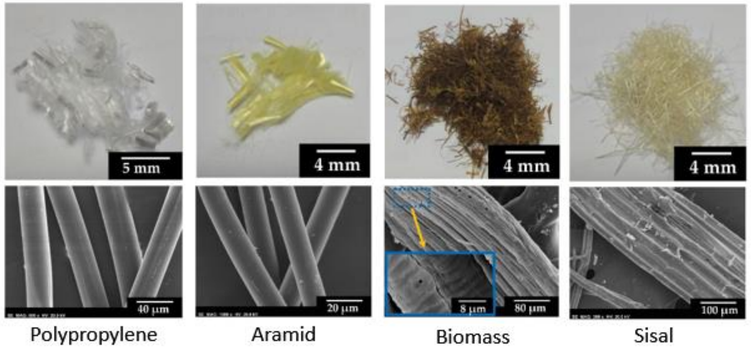
Parameter	Standard	Render | Multilayer Avg (* ETAG 004)	EN 998-1 requirement
Bulk density fresh-state	EN 1015-6	295.0 | similar kg m^{-3}	Declare
Air content	EN 1015-7	22.0 | similar %	Declare
Bulk density hard-state	EN 1015-10	165.0 | similar kg m^{-3}	Declare
Compressive strength	EN 1015-11	≈ 0.20 | similar Mpa	≥ 0.40 MPa (CS I)
Adhesion	EN 1015-12	0.06 MPa : B | similar	Declare
Capillary water absorption	EN 1015-18	1.0 | 0.16 @60* min kg m^{-2} $min^{-1/2}$	≤ 0.4 kg m^{-2} $min^{-1/2}$ (W1)
Water vapour permeability	EN 1015-19	≈ 8 | ≈ 35	≤ 15
Thermal conductivity at 10 ºC and dry state	EN 1745	0.0293 | similar W m^{-1} K^{-1}	≤ 0.100 W m^{-1} K^{-1} (T1)
Impact 3J diameter	LNEC Fe Pa 25	30.3 with 4 cracks in 5 impacts 20.2 with 0 cracks in 5 impacts	None (* ETAG 004 related)



PEP MORTAR WITH FIBRES

Multifunctional and eco-efficient thermal renders based on silica aerogel and natural fibres

Aerogel-based fibre enhanced thermal renders



Used fibres

λ_{fibres} ~ *0.040 to 0.060 W m^{-1} K^{-1}*

Aramid: *Good research results at the University of Bath*
Polypropylene: *One of the synthetic fibres with widest use*
Sisal: *same origin as biomass (leaves) more widespread use*
Biomass: *innovative fibres obtained from patented procedures*

PEP MORTAR WITH FIBRES

Aerogel-based fibre enhanced thermal renders: *analysis*

Main objective: Study how the **incorporation of fibres** (natural and synthetic) **influenced** the **aerogel-based thermal render physical**, **mechanical** and **microstructural** characteristics

Preliminary campaign

Total of **21** distinct formulations
- **Aerogel-based thermal render formulation**
- **4 fibres (2 synthetic** – aramid and polypropylene; **2 natural** – biomass and sisal)
- **1 length** (manually cut avg. 4.4 mm)
- **5 volume fractions** (0.10, 0.25, 0.50, 1.00 and 2.00%) plus **reference** (0.0%)

Analysed parameters

- Water : powder ratio fixed (1.30)
- **Workability**
- Consistency
- Bulk density fresh and hardened state
- Visually observed cracking
- Dynamic modulus elasticity
- **Compressive strength**
- **Thermal conductivity**

Most promising formulations

1) **0.5% aramid – TR aramid**
2) **0.10% sisal – TR sisal**
3) **0.10% biomass – TR biomass**
4) **Reference (0.0%) – TR reference**

Further analysis

- **Physical**
- **Mechanical**
- **Microstructural**

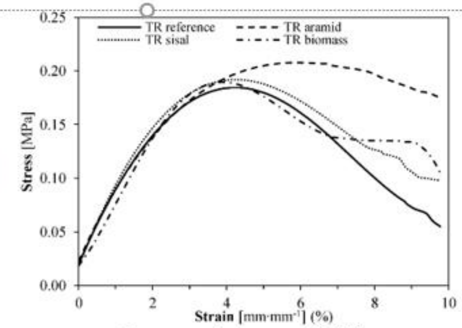
PEP MORTAR WITH FIBRES

Aerogel-based fibre enhanced thermal renders: *analysis*

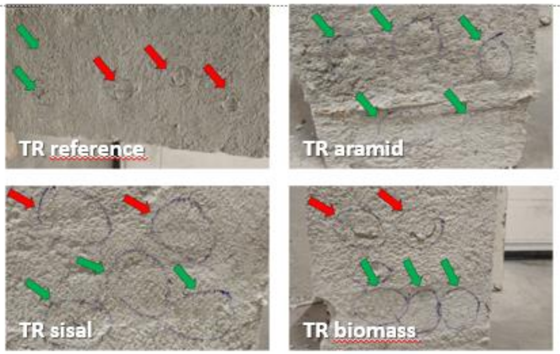
Evaluation	Parameter	Formulation: TR reference	TR aramid	TR sisal	TR biomass
Fresh state	Water powder ratio	1.3	1.3	1.3	1.3
	Workability	Excellent	Good	Excellent	Excellent
	Cons [mm]	143.5	121.1	139.7	139.1
	ρ_{fresh} [kg m^{-3}]	293	310	297	299
	Air content [%]	21.5	19.5	22.0	22.5
Mechanical	ρ_{hard} [kg m^{-3}]	0.159	0.165	0.16	0.162
	$f_{c,peak}$ [MPa]	0.185	0.208	0.193	0.190
	$f_{t,peak}$ [MPa]	0.092	0.165	0.093	0.092
	Cracks during curing (visual evaluation)	No	No	No	No
	E_d [MPa]	51.3	77.4	49.2	48.3
Impact	f_u [MPa]	0.066 B	0.075 B	0.067 B	0.066 B
	$f_{u,basecoat}$ [MPa]	0.065 B	0.073 B	0.065 B	0.066 B
	Imp 3J ϕ [mm]	31.5	29.9	31.0	31.2
	Cracks (Impacts with cracks in 5 impacts)	3 in 5	0 in 5	1 in 5	2 in 5
	Scl	59.3	62.4	59.5	59.4
Physical	$\lambda_{10°C,dry}$ [W m^{-1} K^{-1}]	0.029	0.032	0.030	0.031
	A_W [kg m^{-2} s$^{-1/2}$]	0.109	0.0286	0.0325	0.031
	C [kg m^{-2} min$^{-1/2}$]	0.90	0.34	0.40	0.35
	D1 phase [kg m^{-2} h^{-1}]	0.172	0.147	0.159	0.162
	D2 phase [kg m^{-2} h$^{-1/2}$]	1.483	1.485	1.514	1.522
	DI	0.20	0.19	0.18	0.18
	μ	13.7	13.3	12.7	12.4
	P_0 [%]	86.3	85.1	86.9	87.0

Legend:

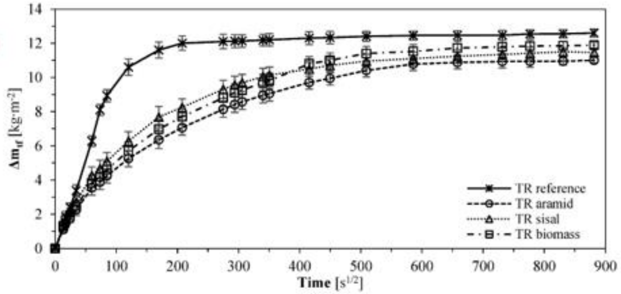
- Improved over reference (green)
- Similar or non-significant
- Worsen over reference (orange)



Compressive strength (f_c)



Impact 3J



Capillary water absorption (A_w)

Example of fibres' distribution – TR aramid

Aerogel-based fibre enhanced thermal renders: *analysis*

Parameter	EN 998-1 [95] requirements	Formulation			
		TR reference	TR aramid	TR sisal	TR biomass
ρ_{fresh} [kg m^{-3}]	Declare	293	310	297	299
Air content [%]	Declare	21.5	19.5	22.0	22.5
ρ_{hard} [kg m^{-3}]	Declare	0.159	0.165	0.16	0.162
$f_{c,peak}$ [MPa]	≥ 0.40 MPa (CS [illegible]	0.185	0.208	0.193	0.190
f_u [MPa] and fracture pattern	Declare	0.066 B	0.075 B	0.067 B	0.066 B
C [kg m^{-2} min$^{-1/2}$]	≤ 0.40 (W1)	0.90	0.34	0.40	0.35
μ	≤ 15	13.7	13.3	12.7	12.4
$\lambda_{10°C,dry}$ [W m^{-1} K^{-1}]	≤ 0.100 (T1)	0.029	0.032	0.030	0.031

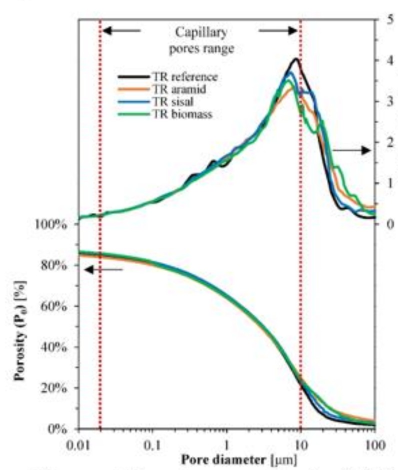
Legend:

Fulfils
Non-significant
Not fulfils

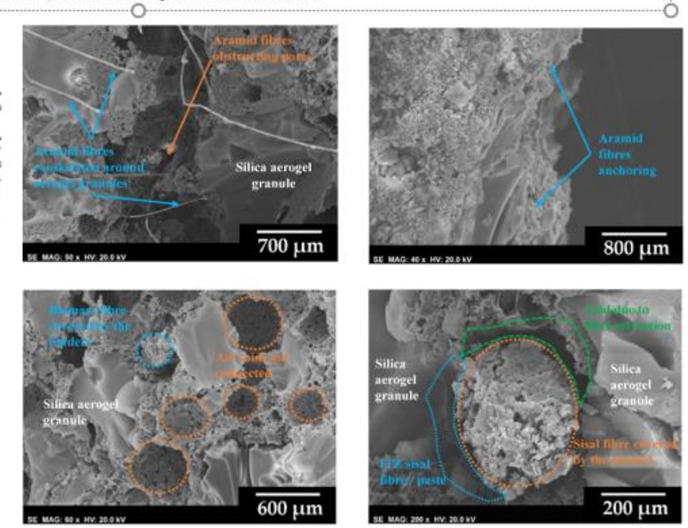
+ 12%

- 50%

Microstructural analysis main results



Mercury intrusion porosimeter (MIP)



SEM images

- **Fibres' incorporation solved** the **non-compliance** of the **EN 998-1 capillary water absorption** (**↓ + 50%**: ≤ 0.40 kg m^{-2} min$^{-1/2}$); **thermal conductivity** was **kept low** (≈ 0.030 W m^{-1} K^{-1}); **mechanical impact resistance** was **improved**; however, **compressive strength** is **lower** than the **requirements** (0.20 *vs* 0.40 MPa)

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NANOFIRE PROJECT – seed project from CERIS

NanoFire intends to **compare fire reaction** of 3 mortars: lime, thermal mortar with EPS and with Aerogel.

The lime one is used as a reference since it has the higher possible fire reaction class - A1. **To compare the improvements of using Aerogel (an innovative material) as an aggregate instead of EPS.**

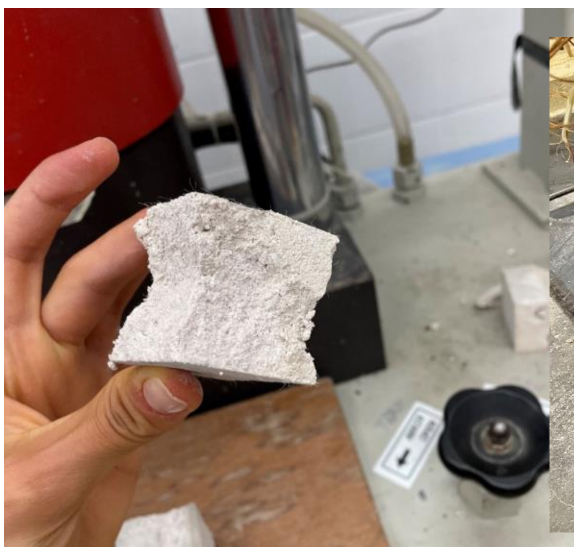
The aim is also to determine **thermophysical properties as a function of temperature** as well as to perform a **microstructural analysis**.

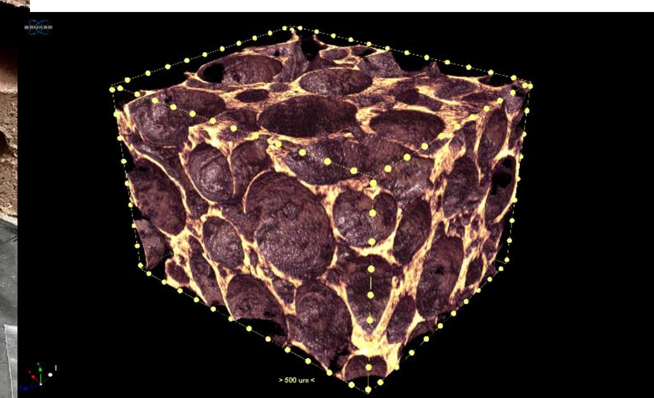
The results will be used to propose a **matrix with the risk assessment** comparing the 3 types of mortars.

Ongoing

NANOFIRE PROJECT – seed project from CERIS

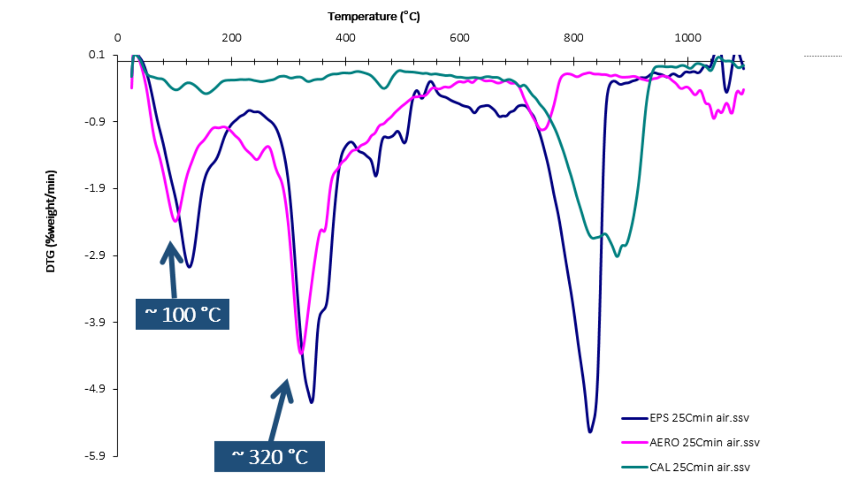




NANOFIRE PROJECT – seed project from CERIS

Curve ISO - 834



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5 - INCORPORATION OF WASTE

RICE HUSK+ PROJECT

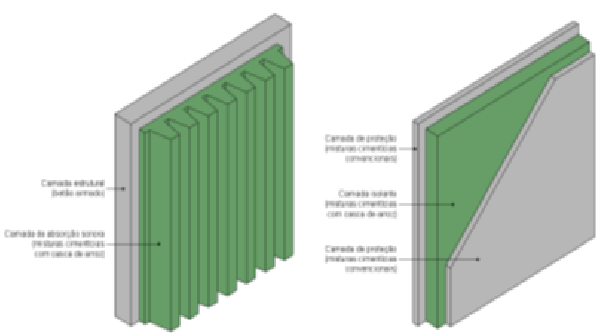
RiceHUSK+

Rice husk cementitious composites for prefabricated multilayer panels and acoustic barriers solutions

POCI-01-0247-FEDER-039577 / LISBOA-01-0247-FEDER-39577

R&TD Project

01/08/2019 - 31/07/2022



FARCIMAR Soluções em Pré-Fabricados de Betão S.A.

TÉCNICO LISBOA

itecons

Cofinanciado por: Lisb@20[20] COMPETE 2020 PORTUGAL 2020 UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional

Ongoing

RICE HUSK+ PROJECT

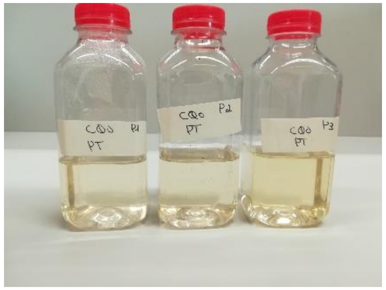
- ✓ Waste recovery and product disposal

- ✓ 37 000 tons/year - Portugal;
- ✓ Low comercial value;
- ✓ Low nutritional value;
- ✓ Incinerated or landfilled;

- ✓ Thermal insulation;
- ✓ Acoustic insulation;

RICE HUSK+ PROJECT

- ✓ Studies on the characterization of rice husk and its compatibility with the cement matrix of the composite system
- ✓ Formulation and optimization of cementitious composites
- ✓ LCA



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INCORPORATION OF GYPSUM WASTE

Influence of gypsum wastes on the workability, mechanical and thermal behaviour of plasters: Heating process, microstructural and environmental analysis

- Two different types of gypsum: gypsum **waste from industrial plasterboard production** (GPW) and Flue Gas Desulphurization gypsum (FGD Gypsum) from a thermal central plant.
- amounts of waste (25, 50, 75 and 100 wt.%) and different heating temperatures (100 ºC and 150 ºC)
- a microstructure analysis using XRD and SEM techniques was conducted.
- an environmental analysis was carried out using the LCA methodology.

MANUEL ALEJANDRO PEDREÑO ROJAS
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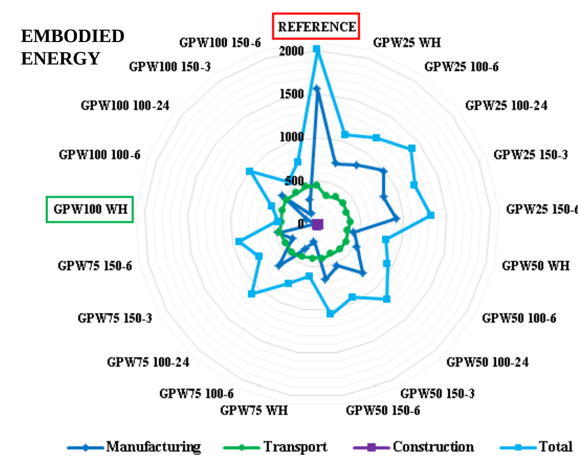
Departamento de Construcciones Arquitectónicas I
mpedreno@us.es

It was possible to **substitute 100% of commercial gypsum with GPW without any heating treatment.** With this action, apart from the benefits in terms of environmental impacts, **a slight improvement in density (27%), mechanical properties (17%) and thermal conductivity (18.8%) of the plaster was obtained.**



INCORPORATION OF PLASTIC WASTE

E.T.S. of Architecture, University of Seville

PhD student: Mª Isabel Romero Gómez

GYPSUM COMPOSITES CONTAINING PLASTIC WASTE

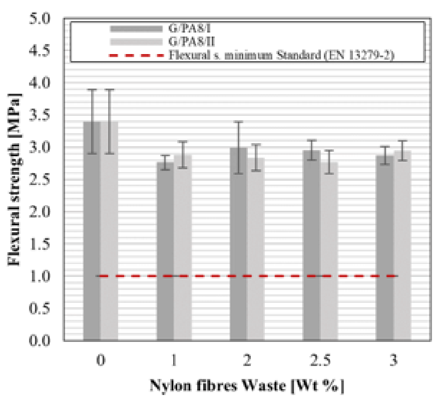
BINDER MATRIX	Gypsum B1 with controlled setting time	
WATER	Regular tap water in accordance with Council Directiva 98/83/EC	
PLASTIC WASTE	Polypropylene (PP)	Particles >2mm
	Nylon (PA 8)	Fibres $Ø_{1-2}$=200 µm; L_1= 20-25mm; L_2=10-12,5 mm
	Cellulose acetate (CA)	Fibre Ø=39±2µm; L=< 1mm

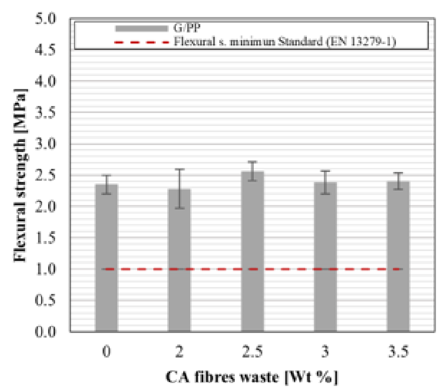
REPLACEMENT LEVELS (wt %)	W/G RATE
2.5 – 5 – 7.5 – 10 %	0.55
1 – 2 – 2.5 – 3 %	0.55
2 – 2.5 – 3 – 3.5 %	0.60

UNIVERSIDAD D SEVILLA 1505

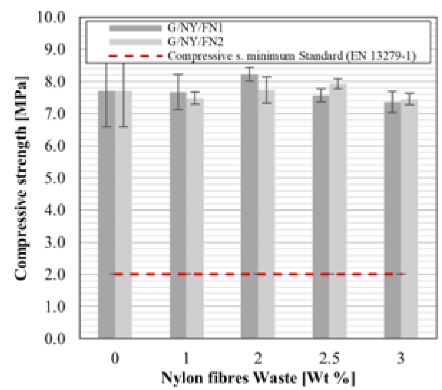
1. MECHANICAL STRENGHT PERFORMANCE (Most interesting results)

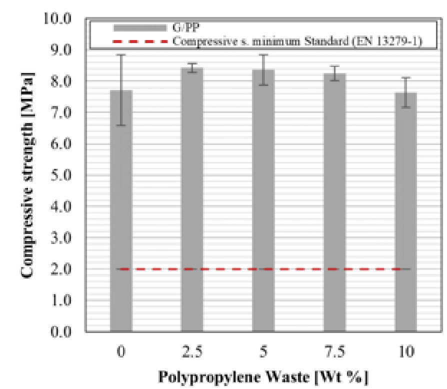
Flexural strength





Compressive strength





Ongoing

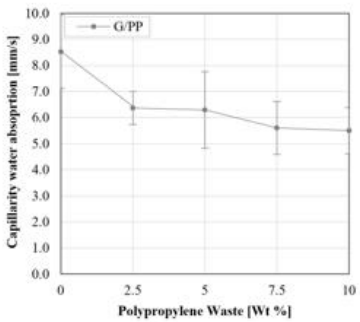
INCORPORATION OF PLASTIC WASTE

E.T.S. of Architecture, University of Seville

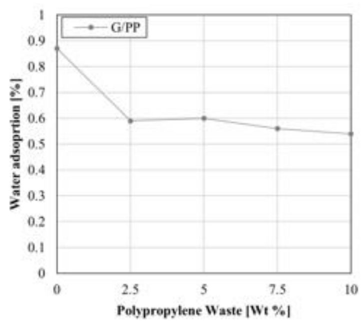
PhD student: Mª Isabel Romero Gómez

2. WATER RESISTANCE PERFORMANCE (Most interesting results)

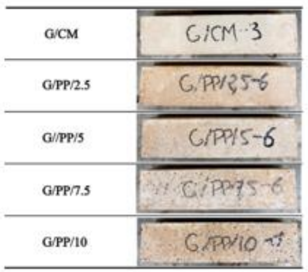
Water absorption by capillary (-36% with 10% PP content)



Hygroscopicity range 72%RH (-38% with 10% PP content)



Deterioration from wetting-drying cycles

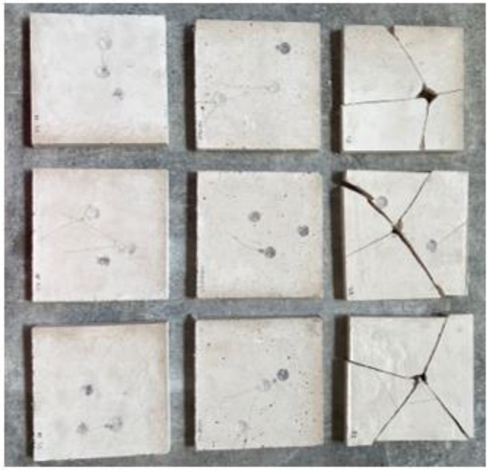


(Water absoprtion -13% with 10% PP content)

Optimal replacement levels

Gypsum + PP : 7.5%
Gypsum + PA8/I: 2,5%
Gypsum + CA: 2,5%

PRODUCT PROPOSAL



IMPROVEMENT RESPECT REF. SAMPLE:

- -Total water absorption: 5.5% with PP
- Superficial water absoprtion: 5% with PP
- Impact resistance (footprint): 20% with 2.5% PA8

INCORPORATION OF RECYCLED AGGREGATES

Use of recycled aggregates in concrete and other building materials

To produce aggregates for the manufacture of mortars and concrete, with partial recycling of materials, optimizing logistical operations, in order to reduce economic and environmental impacts and to contribute for a circular economy in the construction sector.

This study would consider both the use of carbonated and non-carbonated recycled aggregates and performance comparisons when used in concrete.

Ongoing

C5Lab | Sustainable Construction Materials Association

INCORPORATION OF WASTE - PHD

- Compositions:

- Cement, Natural Hydraulic Lime, Gypsum;
- Sand (0/2 mm);
- Water.

❑ Mortar with replacement of natural aggregate by recycled aggregate: 50 % and 100 %.

❑ Mortar with replacement of binder/aggregate by mask waste (PP).

Ongoing

INCORPORATION OF WASTE

Aggregate 1

Aggregate 2

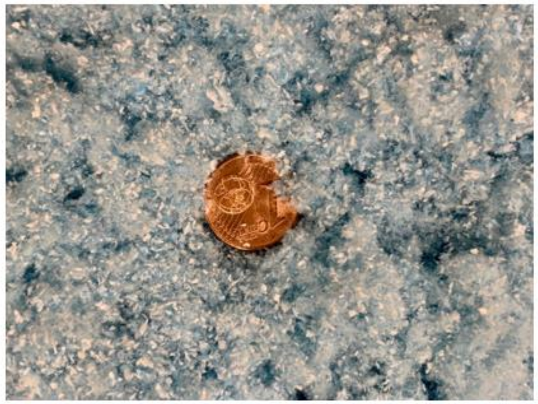
Particle density and water absorption test

Particle size test

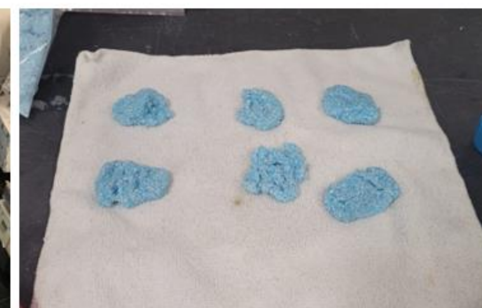
Bulk density test

REDUCE PROJECT

Mask waste PP



Bulk density test



Particle density and water absorption test

Ongoing (started in September 2021)

6 - CONCLUSIONS

CONCLUSIONS

- Performance and durability of **innovative and sustainable solutions** should include a **multidisciplinary approach and different perspectives of performance** (technical, environmental, economical);
- **International collaborations** are crucial to boost the knowledge of these solutions and established **harmonized criteria of perf**ormance;
- **Performance over time** monitoring is crucial to develop **more resilient** solutions;
- This session was mainly applied on **non-structural applications** (e.g. coating systems to protect walls) but can be adapted to structural components of construction.
- The incorporation of **nanomaterials or waste** on mortars/coating solutions could improve the performance (e.g. thermal behaviour, mechanical and water resistance).

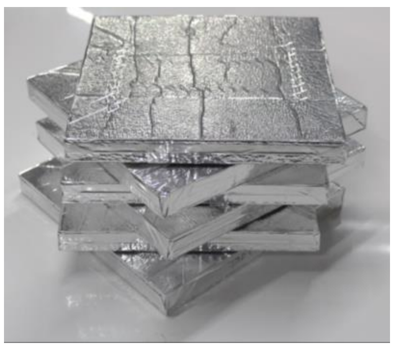
7 - OTHER STUDIES
(Further information)

Performance evaluation of External Vacuum Insulation Finishing System

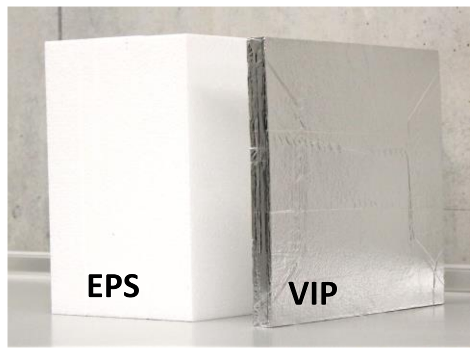
ITeCons

Ongoing

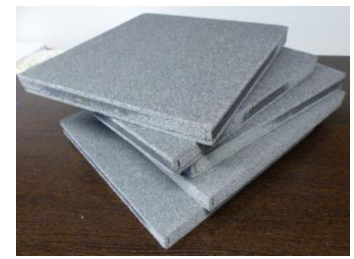
- Supervisors: Nuno Simões and Inês Flores-Colen



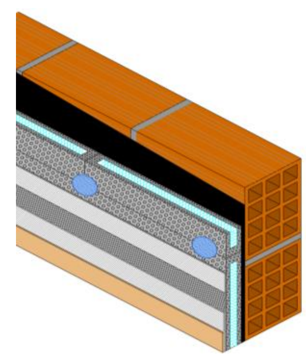
Vacuum insulation panels (VIP)



Thermal insulation products with the same thermal resistance: **17 cm** thick EPS and **2 cm** thick VIP.



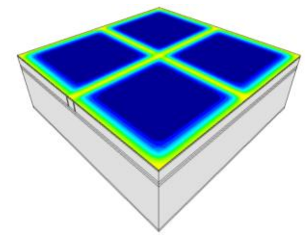
Encapsulated VIP



External Vacuum Insulation Finishing System

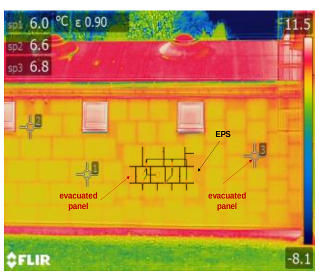
Are **VIPs** suitable for use in **ETICS**?

Performance evaluation of External Vacuum Insulation Finishing System

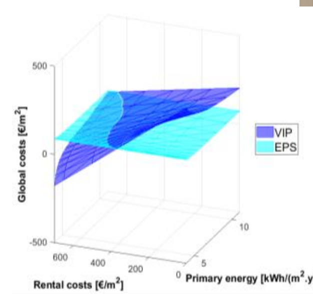


- **Studying in detail the edge thermal bridging effects of VIP**
- **Performing experimental ageing test campaign** of the **ETICS kit,** assessing the **long-term performance of VIP** and their compatibility with **rendering systems**

- Developing **new test methods** adequate for VIP based ETICS solutions, including **solar radiation simulation**



- **Onsite monitoring** of real VIP based ETICS walls
- **Life cycle costing** of VIPs



Performance evaluation of External Vacuum Insulation Finishing System

- The **thermal bridging effect** have a **significant impact** on the **overall thermal performance** of the walls;
- After **more than 24 months** of onsite monitoring the **VIP based ETICS solution did not reveal remarkable anomalies;**
- **Higher surface temperature amplitudes** were found in the VIP solutions, increasing the **cracking risk** of the rendering system. The **condensation risk** was found to **be slightly higher** compared EPS ETICS, leading to **higher biological risk** on VIP based ETICS façades;
- **Ageing cycles** showed that **VIP joints** and the connection with other insulation materials are the **critical issue** of the solution;
- The **LCC results** showed that at the current price, **VIPs are only cost-effective** in cities where the **economic benefit of saving space** is decisive;
- **VIP can be successfully used in ETICS.** Nevertheless, such integration needs to be meticulously performed, since there are additional concerns regarding the VIP installation which need to be looked at.

Performance of Reflective Multi-layered Finishing System:
Durability and Thermal Behaviour of Facades

Andrea Resende Souza

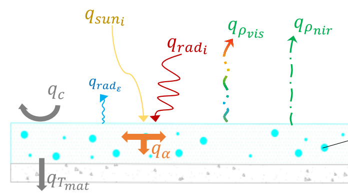
Supervisors:
Nuno M. M. Ramos
Inês Flores-Colen

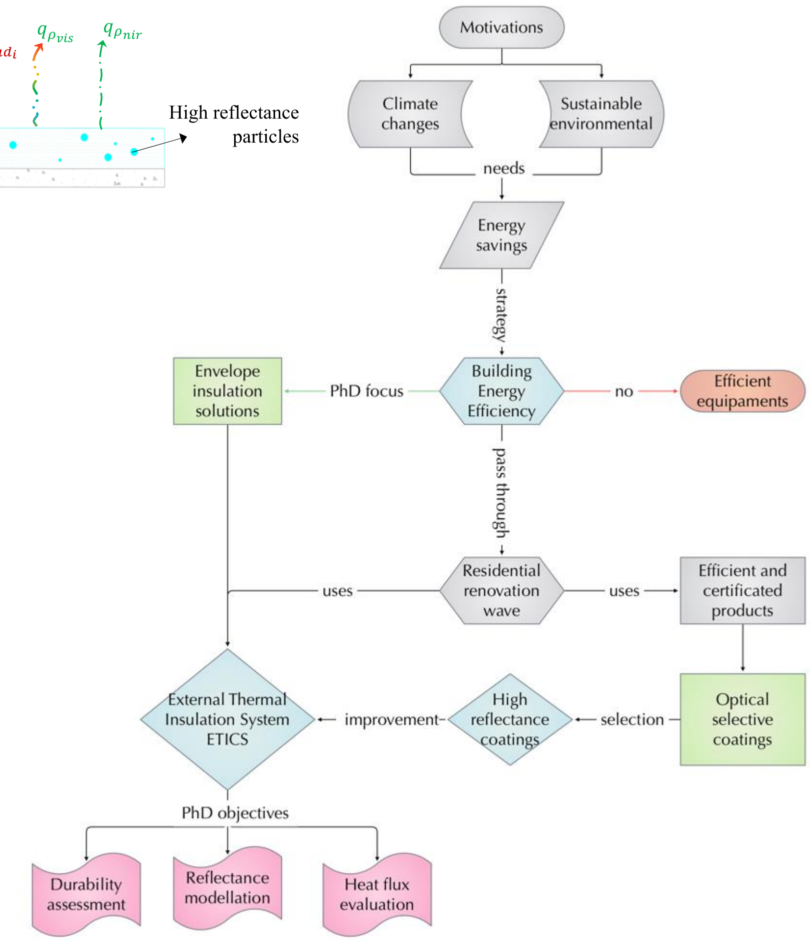
Ongoing

U.PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Motivation


1828

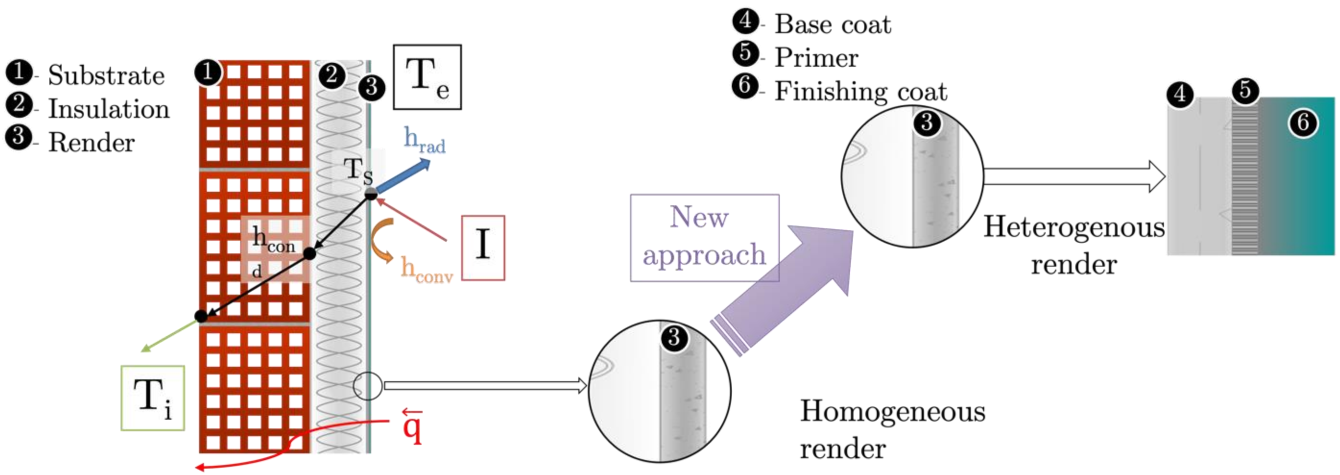

q_{sun_i}
q_{rad_i}
$q_{\rho_{vis}}$
$q_{\rho_{nir}}$
q_c
q_{rad_e}
q_α
$q_{T_{mat}}$
High reflectance particles


Motivations
Climate changes
Sustainable environmental
needs
Energy savings
strategy
Building Energy Efficiency
PhD focus
Envelope insulation solutions
no
Efficient equipaments
pass through
Residential renovation wave
uses
uses
Efficient and certificated products
Optical selective coatings
selection
High reflectance coatings
improvement
External Thermal Insulation System ETICS
PhD objectives
Durability assessment
Reflectance modellation
Heat flux evaluation

Research Problem

Considering the aesthetic characteristics and improvement of the thermal behaviour regarding the technological challenge of incorporating near-infrared reflective or highly reflective coats.

Is it possible to improve the thermal performance and assess the durability of facades by incorporating a **reflective multilayer finishing system?**



Survey and Design methodology for an accurate Eco-construction and rehabilitation of the building envelope

Ongoing

Catarina Sofia Freitas Teixeira Ribeiro

Faculdade de Engenharia da Universidade do Porto
Eco-Construction and Rehabilitation

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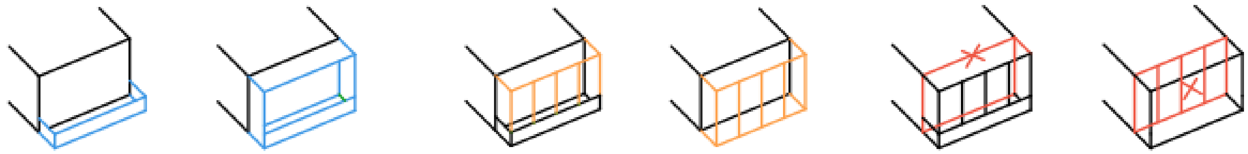
context spaces in-between on housing buildings



open spaces in-between · closed spaces in-between · integrated spaces in-between

The main objective is to develop a project support methodology to evaluate the impacts of morphological transformations of the space in-between on the indoor environmental quality and energy efficiency.

test of solution improvement

morphological transformation design → **survey with laser scanning and in-situ tests** → **impact evaluation of design solution**

creation, alteration or elimination of spaces in-between

set of in-service techniques that allow the mechanical, physical, chemical and hydrothermal assessment of inside environmental quality and energy eficiency

impact prediction of air quality, acoustic comfort, illumination comfort, thermal comfort and energy efficiency

satisfactory performance → **optimisation of projected solutions** / **mitigation of identified problems**

unsatisfactory performance

sustainable design soluction

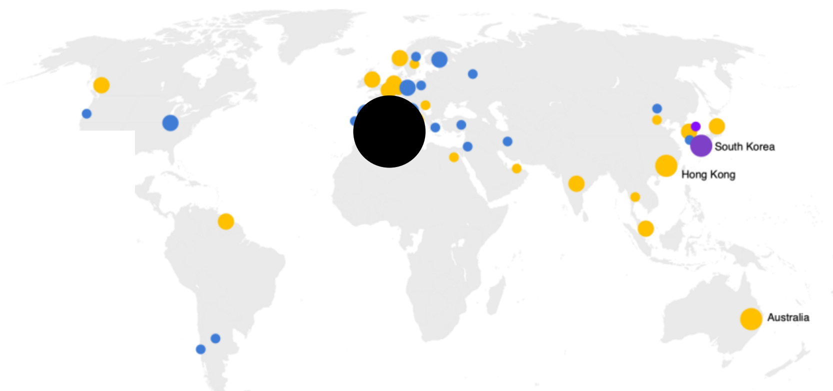
indoor environmental quality improvement
energy efficiency improvement
valid architectural desing for other generations

morphological transformation design re-evaluation

Catarina Ribeiro
FEUP - ECOCORE

The battle of Balconies: inhabitants' preferences and indoor impacts of an archetype for housing building

How can the element balcony contribute to provide healthier, affordable and sustainable dwellings?



EB: eliminated balcony
GB: glazed balcony
OB: open balcony

The studies on balconies demonstrate the lack of holistic study that embraces the physical and the social aspects

case study: a balcony in Porto

10 variation in study:
4 open balconies
4 glazed balconies
2 eliminated balconies

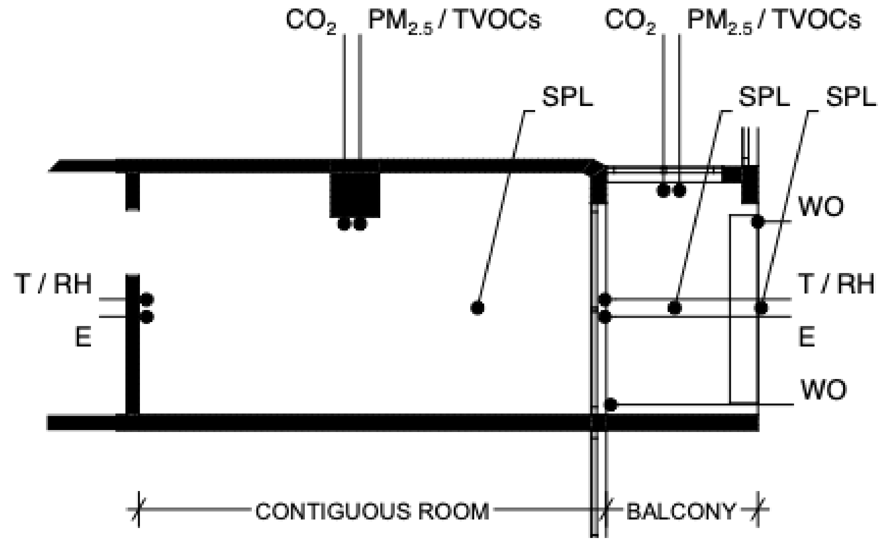
methodology:

quantitative AND qualitative approaches

qualitative approach: inhabitant's perception

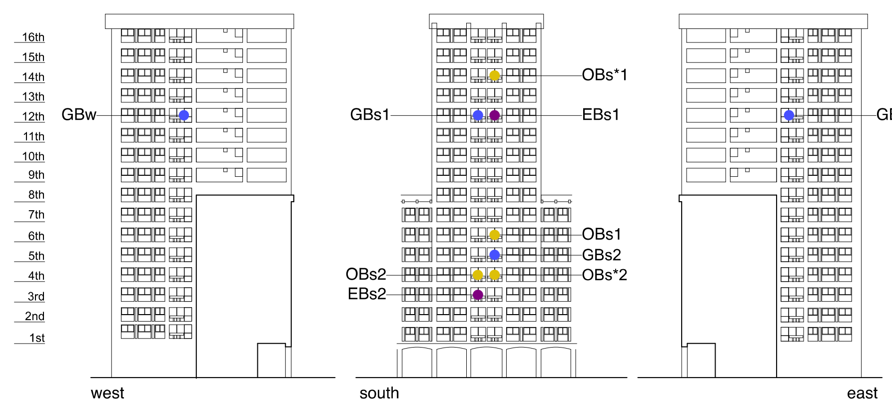
quantitative approach: balcony impacts

2 monitorisations campaigns –
1 month summer and 1 month winter



Indoor environmental quality (IEQ)

thermal comfort	Ta; RH
indoor air quality	CO_2, TVOCs $PM_{2.5}$
acoustic comfort	SPL
visual comfort	E



Eco-design for thermal rehabilitation of buildings envelope based on energy, economic and environmental life cycle assessment

Rita Andrade Santos
andrade.santos@tecnico.ulisboa.pt

Supervisor: Inês Flores-Colen (IST)
Co-Supervisors: Nuno Albino Vieira Simões (UC) / José Dinis Silvestre (IST)

EcoCoRe Doctoral Programme
FCT scholarship PD/BD/135215/2017

BUILDING SECTOR
Production and construction
Use stage
End-of-life

CO_2 emissions
EU: 36% B.S.

CLIMATE CHANGE
Global Warming

EPBD aim:
Building Sector Decarbonization

Residential
BUILDING RETROFITTING

STATIC BUILDING ENVELOPE
Winter optimization
Exclusive approach
design strategy (Super insulation / Air-tightness)

Dwelling
OVERHEATING RISK

Increasing Cooling Needs

Ongoing

ADAPTIVE BUILDING ENVELOPE
Auto-reactive Strategies

SOLUTION?

"A climate adaptive building shell has the ability to repeatedly and reversibly change some of its functions, features or behaviour over time in response to changing performance requirements and variable boundary conditions, and does this with the aim of improving overall building performance." (Loonen et al., 2013)

Research objectives:
to contribute to the building sector decarbonization, through the systematization of **rehabilitation strategies** for residential buildings, considering: **climate change; overheating risk; adaptability to different season; embodied energy**.

Research questions:
Switching the paradigm from static to **adaptive building envelope** reduces:
the overheating risk? the building sector contribution for Climate change?
Is it possible at acceptable cost?

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CERIS Civil Engineering Research and Innovation for Sustainability | TÉCNICO LISBOA | DECIVIL DEPARTAMENTO DE ENGENHARIA CIVIL, ARQUITECTURA E GEORRECURSOS

Thank you!

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