Sustainable, Innovative and Energy-Efficient Concrete, based on the Integration of All-Waste Materials

Alessandro Largo, CETMA

December 3rd 2015, Brindisi

Outline of presentation

- The SUS-CON Project
- **Fully eco-sustainable concretes (up to 100% secondary raw materials)**
- Prototypes and real case demonstrators
- Achievements

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aim

Develop new concepts and technology routes to integrate secondary materials in the production cycle of concrete…

…resulting in an innovative, eco-compatible and cost-effective construction materials for **ready-mixed** and **pre-cast** applications, characterized by:

- **light-weight**
- **low embodied energy**
- **low CO_2 footprint**
- **improved insulation performances**

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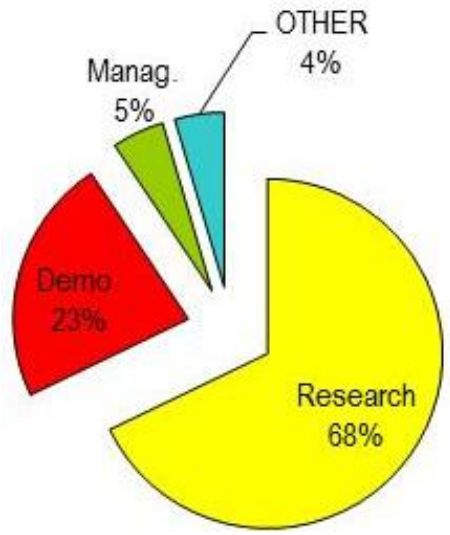
general info

- **Total cost**: 7.200.000 €
- **EU funding**: 4.500.000 €
- **Cost per activity type** →
- **Start date**: 01/01/2012
- **Duration**: 4 years
- **Coordinator**: CETMA (IT)



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the team

16 partners from 10 countries

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coordinator: CETMA

CETMA is a RTO founded in 1994 by ENEA with the aim of developing the Innovation System of Southern Italy

90 employees

researcher, engineers, designers & innovation managers

Departments

- Materials and Structures engineering
- Computer science and engineering
- Industrial design

Laboratories

- materials & technologies
- NDT & SHM
- virtual reality
- prototyping

one of 50 (out 5100) research organizations with more than 50 employees in Italy
one of the biggest research center not linked to a Large Enterprise

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the idea

Secondary Raw Materials (SRM)

- novel binders
- novel aggregates

Development of new technologies

SRM lightweight concrete

- sustainable
- energy-efficient

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challenges: impact & sustainability

50% reduction of embodied energy

most notably for the binder productions

Improvement of insulation properties

use of lightweight aggregates with insulation performances

50% reduction of CO2 emissions

use of secondary raw materials (SRM)

Costs reduction

use of secondary raw materials (SRM)

Eco-Sustainable concrete

100% secondary raw materials (SRM)

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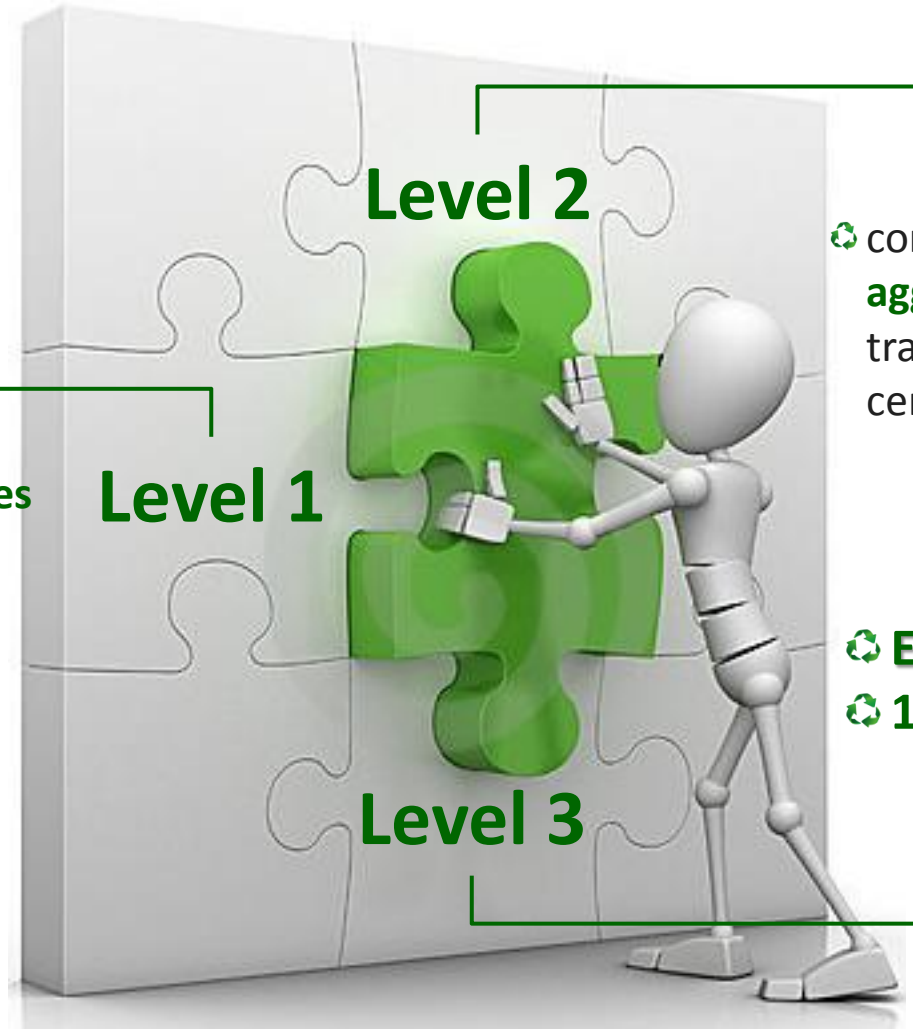
the structure



- **innovative aggregates** from SRM
- **innovative binders** from SRM

- combination of **innovative aggregates** and **binders** with traditional materials (Portland cement, natural aggregates)

- **Eco-Sustainable concretes**
- **100% SRM**

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the structure

level 1

novel eco aggregates and binders from SRM

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level 1: novel eco aggregates from SRM

… from *secondary raw materials*

Plastic from WEEE

Mixed plastic from MSW

Rigid PU foams

Rubber tyres

… to *novel lightweight eco aggregates*

- lightness
- thermal insulation

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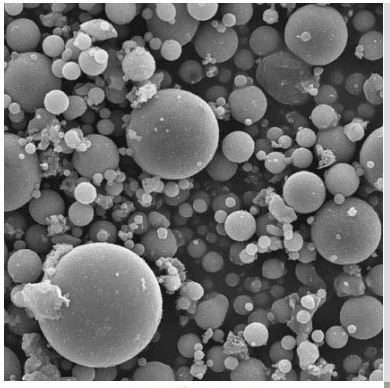
level 1: novel binders from SRM

… from ***secondary raw materials***

- **PFA** (pulverized fly ash) a *by-product* from power plants
- **GGBS** (ground granulated blast furnace) a *by-product* from steel industries
- **Perlite (cyclones) tailings** a *by-product* from mining activities

… to ***novel eco binders (geo – polymer)***



- OPC replacment
- cost effectiveness
- low energy consuption
- reduced CO_2 emissions

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what is a geo-polymer?

Alkali activated material (AAM)

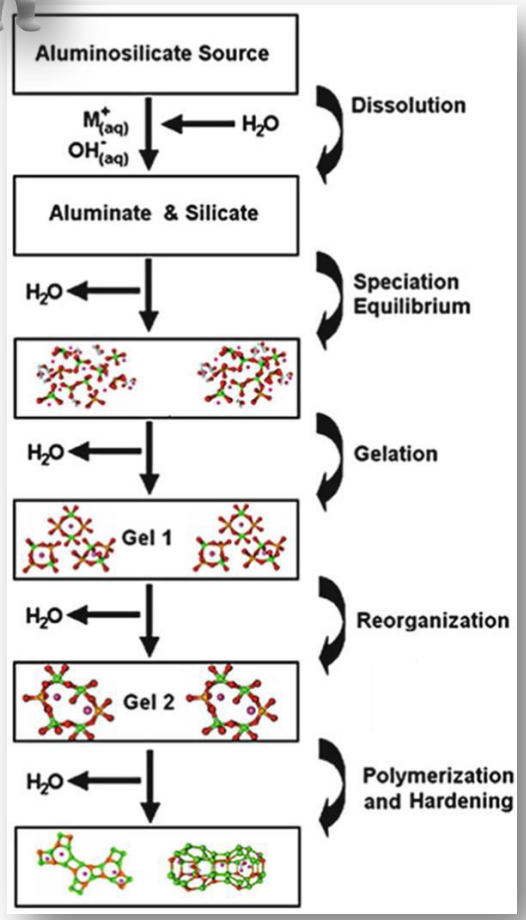
Any binder system derived by the reaction of an alkali metal source (solid or dissolved, i.e. *activator*) with a solid silicate powder (i.e. *precursor*)

Geopolymers

A subset of AAMs, where the **binding phase** is almost exclusively **aluminosilicate** with low calcium content. The **activator** will usually be an **alkali metal hydroxide** or **silicate**

Low-calcium fly ashes and calcined clays are the most prevalent precursors used in geopolymer synthesis

Definitions from State-of-the-Art Report, RILEM TC 224-AAM)



Duxson et al. (2006)

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the structure

level 1

novel eco aggregates and binders from SRM

level 2

combination of novel aggregates with OPC

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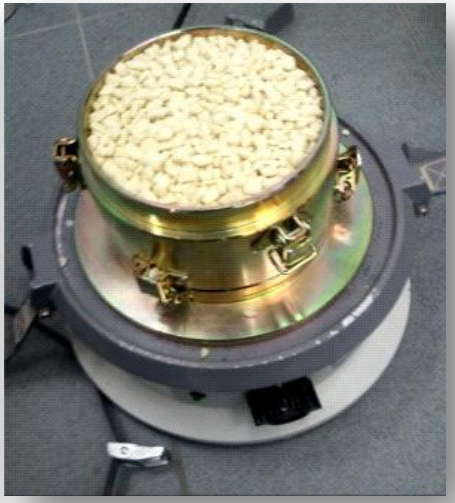
level 2: characterization of novel SRM aggregates

Testing of novel aggregates to assess their **suitability for LW concrete production**

- *grading curves - sieving method (EN 933-1)*
- *loose bulk density (EN 1097-3)*
- *particle density and water absorption - pyconometric method (EN 1097-6, App C)*
- *crushing resistance (EN 13055-1, App A)*
- *chemical tests - water-soluble chloride salts, total sulfur content, acid soluble sulphates and organic compounds - (EN 1744-1)*
- ***HSE assessments***



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level 2: characterization of novel SRM aggregates

Aggregate typology/size		Physical properties		Mechanical properties		Chemical properties			
		Loose bulk density [kg/m³]	Particle density [kg/m³]	Water Absorption [%]	Crushing Resistance [N/mm²]	Acid soluble sulphates [%]	Water soluble chloride salts [%]	Total sulphur content [%]	Organic impurities
Polyuretane (PU)	0-4 mm	256	-	-	-	0.177	0.031	0.134	acceptable
	4-8 mm	336	330	10	1,35				
	8-16 mm	164	300	11	1,60				
Remix (RX)	Remix HD (0-2 mm)	-	-	-	-	-	-	-	-
	Remix HD (1-4 mm)	290	810	10	2,50	0.011	0.125	0.030	-
	Remix LD (8-12.5 mm)	359	660	22	2,15	0.152	0.022	1.063	absent
Tyre rubber (TR)	0-0.6 mm	764	-	-	-	0.084	0.019	0.274	acceptable
	0.6-2 mm	403	-	-	-				
	2-4 mm	422	-	-	-				
	3-7 mm	459	970	6	0,20				
	8-16 mm	419	1090	5	0,18				

- **Lightweight aggregates** (EN 206-1: loose bulk density < 1200 kg/m³ ; particle density < 2000 kg/m³)
- Good particle size distribution
- All the aggregates are in **compliance** with the **chemical requirements**
- **Not hazardous materials** according to HSE evaluations

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level 2: LW concrete (OPC & SRM aggregates)

Mix design, testing and **lab** optimization of **LW concrete** with traditional **OPC** and **SRM aggregates**

Testing

- *workability by slump test (EN 12350-2)*
- *air content (EN 12350-7)*
- *fresh density (EN 12350-6)*
- *compressive strength (EN 12390-3)*
- *tensile splitting tests (EN 12390-6)*
- *thermal conductivity (EN 12664)*
- *UPV tests (EN 12504-4)*

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level 2: LW concrete (OPC & SRM aggregates)

Industrial up-scaling of **LW concrete** with traditional **OPC** and **SRM aggregates** for **ready mixed** and **pre-casted** applications

Aggregate	Target application	Target properties		
		R_{ck} [MPa]	Density [kg/m³]	Workability
Polyurethane (PU)	*Blocks*	3-20	700-1500	S1 - SCC
Remix (RX)	*Panels for facades*	5-24	350-1700	S4 - SCC
Tyre rubber (TR)	*Floor screed*	3-10	700-1200	S4 - SCC
	Floor screed underlay	1-6	500-800	S1 - SCC



- **Parametric study** (optimization of cement content, natural aggregate content, water/cement, additive, aggregates proportioning)

SCALING UP

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level 2: LW concrete (OPC & SRM aggregates)

Industrial up-scaling of **LW concrete** with traditional **OPC** and **SRM aggregates** for **ready mixed** and **pre-casted** applications

Aggregates	Binder	Workability	Density [kg/m³]	Compr. strength [MPa]	λ [W/mK]	UPV [m/s]	Application
Polyurethane (PU); Natural aggregate	OPC	S1	1200	9.3	0.33	3310	blocks
Remix (RX); Natural aggregate	OPC	S4	1080	8.3	0.25	2730	panels
Tyre rubber (TR)	OPC	S2	1200	2.6	0.20	2210	insulating components

- **Successful** scaling-up from the lab to the industrial level
- Concretes suitable for **blocks**, **panels** and **insulating components**
- Reduced **thermal conductivity**

Conclusion

SCALING UP

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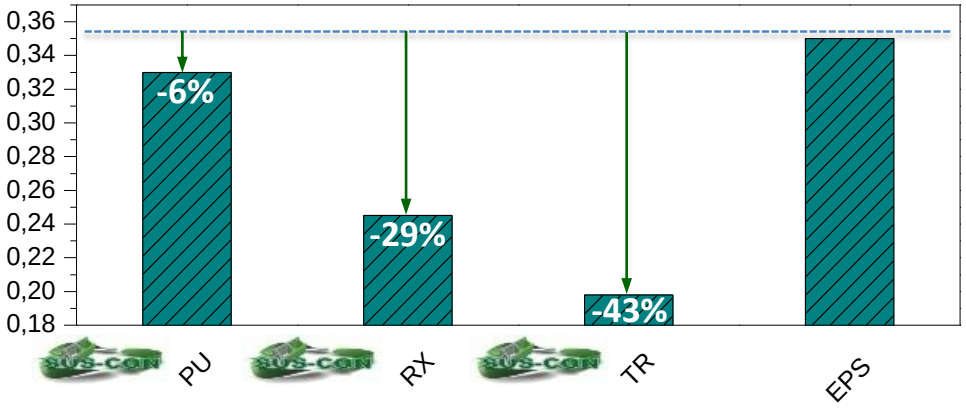
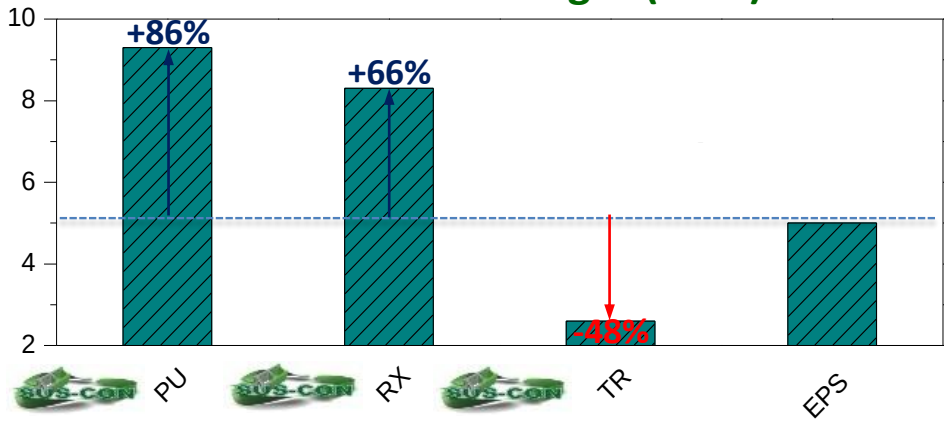
level 2: LW concrete (OPC & SRM aggregates)

Performance comparison with traditional LW concrete based on expanded polystyrene **(EPS)** – *λ=0.35 W/mK (d=1000 kg/m³) and R_{ck} 5 MPa*

Thermal conductivity (W/mK)



Mechanical strength (MPa)



Conclusion

- **higher thermal insulation** performance for SUS-CON concretes
- **higher mechanical performance** for PU and RX-based concretes
- TR-based concretes have the lowest thermal conductivity (insulating components)

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the structure

level 1

novel eco aggregates and binders from SRM

level 2

combination of novel aggregates with OPC

level 2

combination of novel binders with natural aggregates

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lev. 2: LW concrete (SRM binder & natural aggregate)

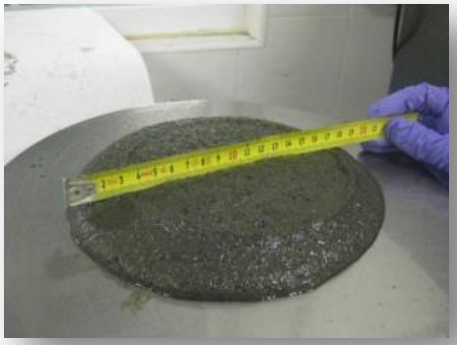
Physical and chemical **characterizations** of **binders** and investigation of **potential for geopolymerization** *(identification of key parameters – chemical dosages, water content, curing temperature)*

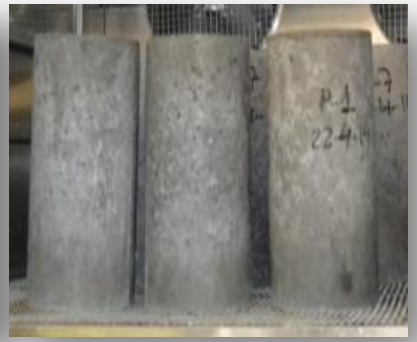
Binder	Activator	Aggregate	Curing	Mortar compressive strength [MPa]
PFA	NaOH + waterglass	Traditional	oven curing	30
PFA/GGBS	NaOH + waterglass	Traditional	room temp	55
cyclones/µ-silica alkalis	NaOH	Traditional	oven curing	20
cyclones/µ-silica waterglass	NaOH + waterglass	Traditional	oven curing	22

Development of **geopolymeric concrete** with natural aggregates

Testing

- *workability by slump test (EN 12350-2)*
- *fresh density (EN 12350-6)*
- *compressive strength (EN 12390-3)*
- *UPV tests (EN 12504-4)*
- *durability*





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lev. 2: LW concrete (SRM binder & natural aggregate)

Manufacturing of **concrete products** by **substitution** of **OPC binder** with **GP binder** from SRM

- *façade panels*
- *building blocks*
- *aerated autoclave concrete (AAC)*

The replicated concrete products (**substitution of OPC with geopolymers**) are **fully conform to existing technical prescriptions**

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the structure

level 1

novel eco aggregates and binders from SRM

level 2

combination of novel aggregates with OPC
combination of novel binders with natural aggregates

level 3

eco-sustainable concretes – 100% SRM

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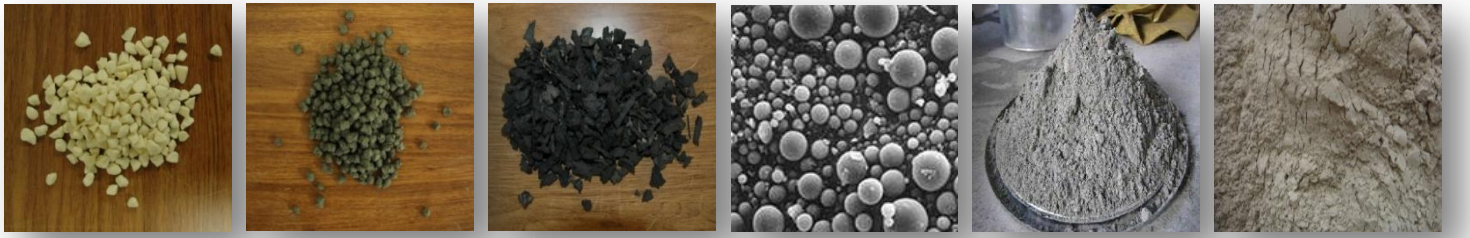
level 3: eco-sustainable concretes – 100% SRM

Mix design, testing and **lab** optimization of **SUS-CON LW concrete** with aggregates and binders from SRM (PU, plastics, tyres, PFA, GGBS, perlite)



Application	Workability [cm]	Density [kg/m^3]	Compressive strength [MPa]
Screeds	20-22	1100	3-6
Blocks	0-5	1400	5-20
Panels	9-20	1100	5-20

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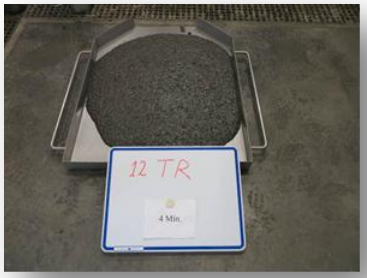
level 3: eco-sustainable concretes – 100% SRM

Testing of the SUS-CON concretes performances

- **Fresh state** (workability, density)
- **Hardened state**
  - *Mechanical (compressive strength, Young's modulus, Poisson's ratio, flexural strength)*
  - *Thermal (thermal conductivity, thermal expansion coefficients, heat capacity)*
  - *UPV (qualitatively evaluations of acoustic insulation)*
  - *Durability (carbonation tests, freeze-thaw, resistivity)*
- **HSE evaluations** (raw materials and production steps)



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level 3: eco-sustainable concretes – 100% SRM

SUS-CON concrete	Aggr.	Binder	Work.	Density [kg/m³]	Compr. Strength [MPa]	Flex. strength [MPa]	λ [W/mK]	UPV [m/s]	SUS-CON product
GEOscreedunderlay_P18	PU	PFA/GGBS	S4	1146	8.4	1.4	0.18	2018	Floor screed ulderlay
GEOpanel_R34	RX	PFA	S5	1440	6.8	1.3	0.34	1613	Panel for facades
GEOpanel_P17	PU	PFA/GGBS	S5	1089	6.6	0.9	0.17	1596	Panel for facades
GEOblock_R27	RX	PFA/GGBS	S1	1475	18.2	2.3	0.27	2668	Block
GEOblock_P31	PU	PFA	S1	1255	8.3	2.0	0.31	1760	Block
GEOblock_P32	TR	PFA	S5	1501	4.2	0.9	0.32	1595	Block
GEOblock_P21	PU	PFA/GGBS	S4	1184	15.1	2.1	0.21	2632	Block
GEOblock_P16	PU	PFA	S4	942	5.6	1.2	0.16	1344	Block

- **Innovative concretes** based on **100% SRM** aggregates (PU, RX and TR) and binders (PFA and PFA/GGBS) successfully optimized for ready-mix and pre-cast applications
- **Improved insulating performances**
- **Not hazardous (HSE analysis of raw materials and production processes)**

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SUS-CON prototypes production & demonstration

Production of **SUS-CON prototypes** and **testing** of the performances (i.e. mechanical tests, thermal and acoustic insulation and fire resistance)

- SUS-CON products **highly compatible with the existing** concrete **production processes** (minimized equipment costs)

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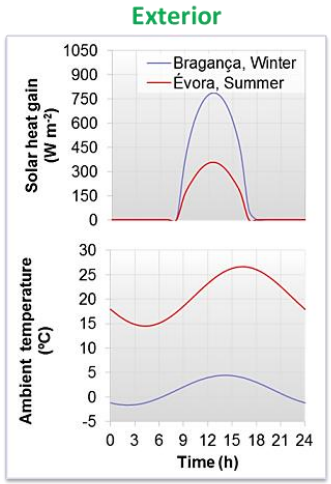
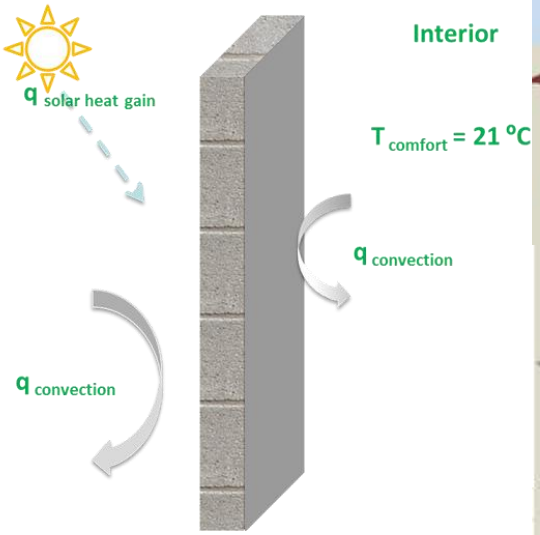
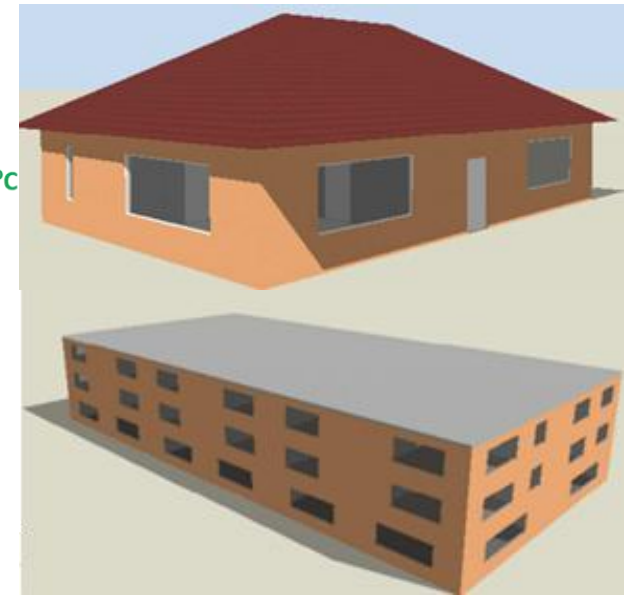
SUS-CON prototypes modelling

Numerical simulation of SUS-CON prototypes exposed to realistic environmental conditions (thermal, mechanical and acoustic behaviour)







- SUS-CON prototypes allow a **thickness reduction** (up to 88% with the same thermal insulation) and **lower consumption** (up to 10% by HVAC) compared to NC

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demonstration: application on real buildings

- **3 European demo sites** (Spain, Romania, Turkey)

Mock-ups with SUS-CON prototypes

- **Pre-casted** components (GEOpanels, GEOblocks)
- **Ready-mixed** concretes (GEOscreeds)

Magnetti Building

ISTON

The SUS-CON Project

demonstration: application on real buildings

Installation of SUS-CON GEOcomponents (panels, blocks) on real buildings

Mockups with SUS-CON (front) & traditional panels (back)

Mockups with SUS-CON (right) & traditional (left) blocks

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demonstration: application on real buildings

Mock-ups monitoring

- energy efficiency (temperature, heat flux)
- acoustic insulation performance
- thermographic survey

Tests on SUS-CON prototypes

- mechanical tests
- thermal insulation performance
- fire behavior

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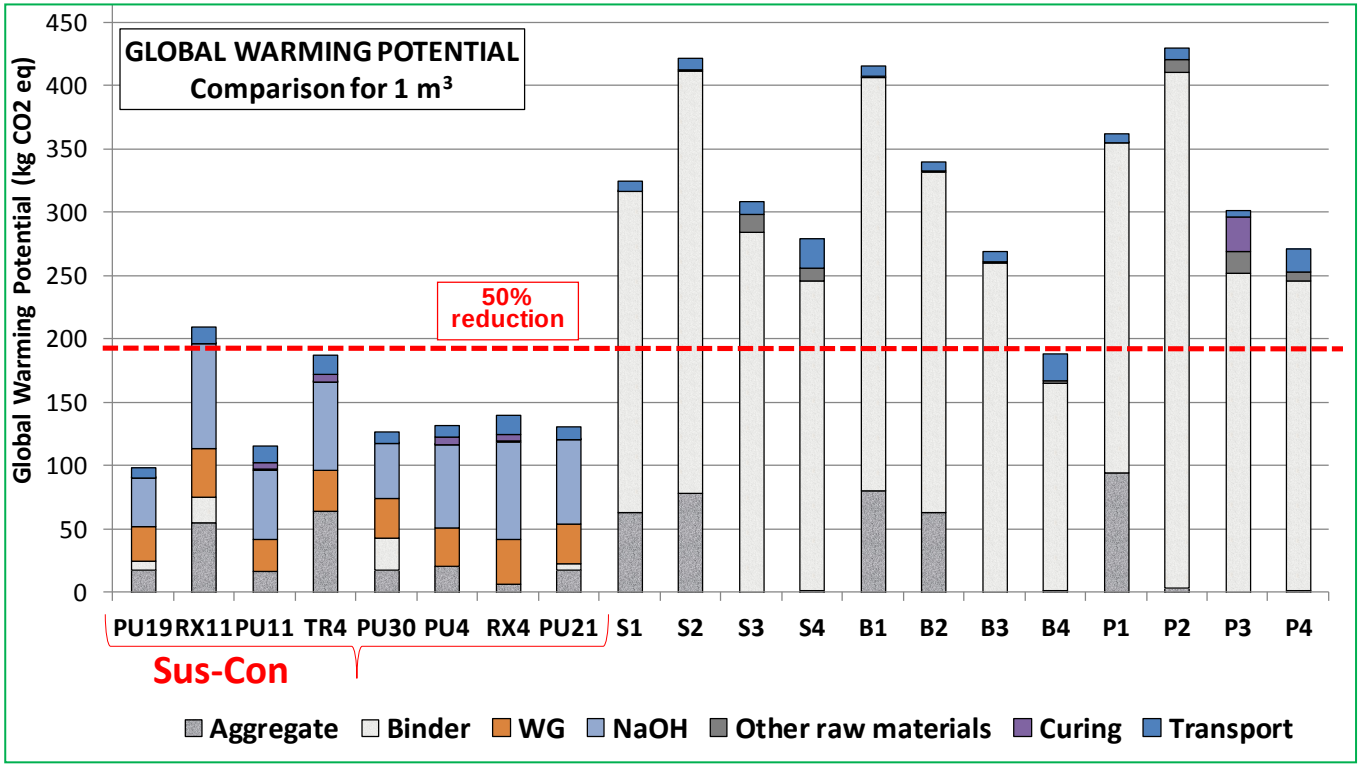
impact & sustainability: LCA



♻ **SUS-CON products meet the -50% CO_2 target**

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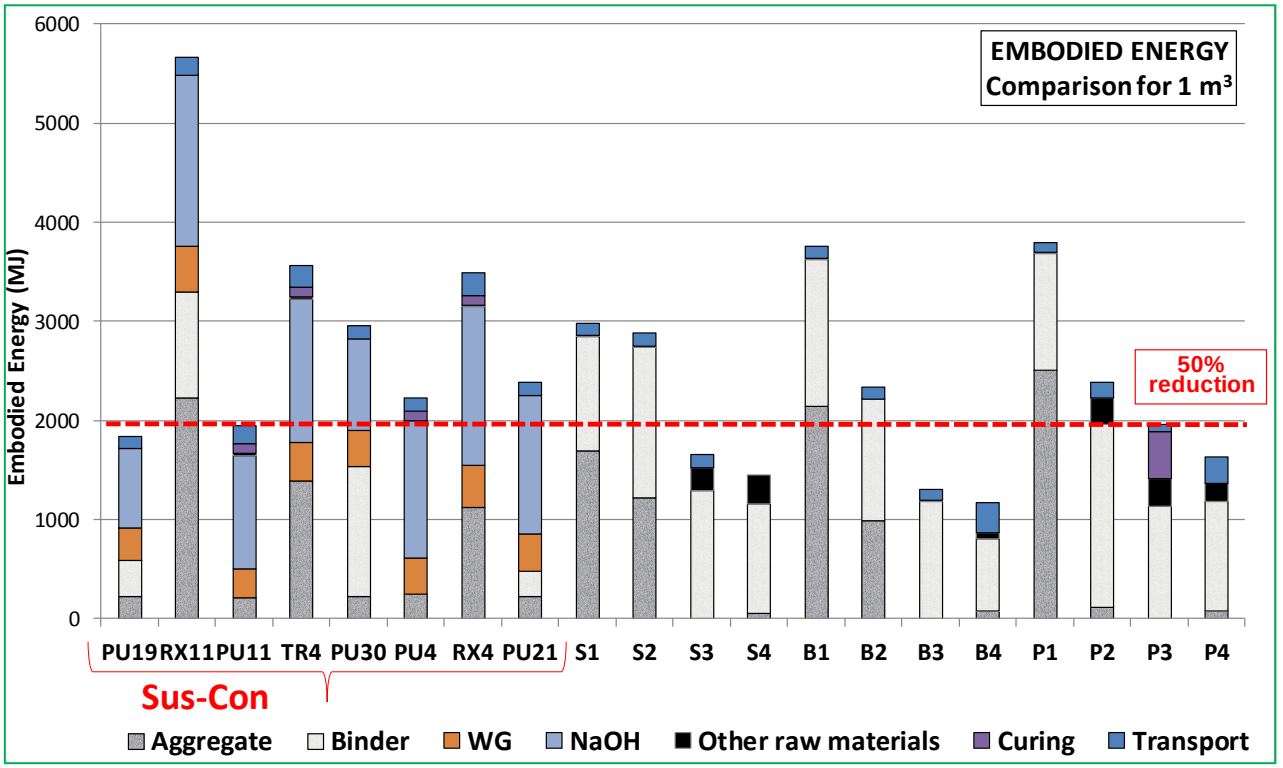
impact & sustainability: LCA



♻ **SUS-CON products meet the -50% EE target**

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SUS-CON tool

- **Information** on secondary raw materials in different EU areas
  - amounts
  - trends
  - regulations
- **Database** with SUS-CON recipes performances
- **MIX – DESIGN** tool for SUS-CON recipes
  - performance based design (density, thermal conductivity and strength)
  - volumetric design

http://www.sus-con.eu/

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conclusions & achievement

- The **construction industry** is **one of the largest consumers of energy and raw materials**, and highest contributor to the emission of greenhouse gases

reduced Embodied Energy

- The main **aim of the SUS-CON project** was to develop **sustainable, innovative and energy-efficient concrete**, using secondary raw materials

improved insulation properties

- SUS-CON **blocks**, **panels** and **concretes** include up to 100% of SRM and have excellent mechanical and thermal performance

reduced CO_2 emissions

- SUS-CON products are **highly compatible** with **existing concrete production processes** (minimized equipment costs)

reduced costs

- SUS-CON products and processes are **not hazardous** (HSE evaluation) and contribute to the **reduction of CO_2, EE** (50%) and **cost** (up to 15%)

eco-sustainable concrete

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The SUS-CON Project

acknowledgments & contacts

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Project Website http://www.sus-con.eu/

Facebook page https://www.facebook.com/pages/Sus-Con-Sustainable-Concrete/

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Thanks for your attention!

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