Seminario "Nuovi sviluppi sui materiali per l'edilizia", *Lecce 01/07/2015*

The SUS-CON project: transforming waste to "green", sustainable and energy efficient lightweight concrete

ing. Alessandro Largo

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Outline of presentation

- The SUS-CON Project
- Novel recycled aggregates and binders
- Integration of novel recycled aggregate in OPC
- Combination of alternative binders with traditional aggregates
- **Fully eco-sustainable concretes (100% waste)**
- LCA
- Real case demo
- Conclusions

CETMA

Engineering, Design & Materials Tech Center

CETMA is a RTO organized under the national law of private consortia
It is a non-profit organization and all its profits are reinvested in R&D

CETMA SHAREHOLDERS

PUBLIC SHAREHOLDERS

• ENEA	51%
• University of Salento	5%

PRIVATE SHAREHOLDERS

• D'Appolonia SpA (Genova)	9%
• RINA Services SpA (Roma)	4%
• Telcom SpA (Ostuni)	11%
• Digimat (Matera)	7%
• Marlanvil SpA (Bergamo)	7%
• Sysman srl (Mesagne)	2%
• Veneto Nanotech	4%

CETMA

Engineering, Design & Materials Tech Center

CETMA was founded in 1994 by ENEA with the aim of developing the Innovation System of Southern Italy

90 employees:

Researcher, engineers, designers & innovation managers

SKILLS

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

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

CETMA

Engineering, Design & Materials Tech Center

CETMA is located in the area of "*Cittadella della Ricerca*" close to Brindisi

Laboratories and offices take up about 5.000 m²

- **A well equipped laboratory of advanced materials tecnologies**
- **One of the biggest Virtual Reality Center in Europe**
- **A prototyping laboratory**

The SUS-CON Project

Challenges

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

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

- **Energy efficient building materials:** **concrete producers** need new, eco-compatible and cost-effective materials for energy efficient building components

- **Efficient waste management:** waste management is an increasingly complex and challenging task for both local authorities and **waste recycler companies**

The SUS-CON Project

Project idea

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

Wastes

- Novel Binders
- Novel Aggregates

Development of new technologies

All-waste lightweight concrete

- sustainable
- energy-efficient

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complementary among partecipants

Waste recycling and processing

Aggregates from waste

Binders from waste

Nano-additives and surface treatments

Concrete design and process

LCA/LCC/HSE/Certification

Industrial end-users

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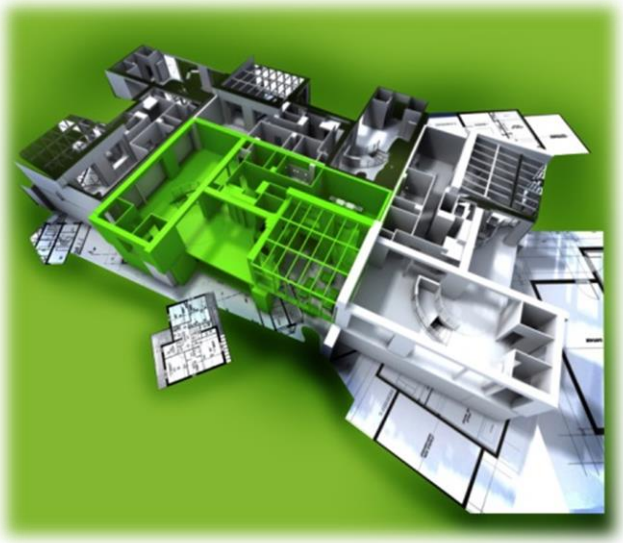
Project aims

- Decrease of the **embodied energy**, especially by the substitution of the cement
- Decrease of the **CO_2 footprint** by the reduction of raw materials processing
- Improvement of the **insulation properties** (novel aggregates)
- Increase of **cost effectiveness** (lower costs of the raw materials)



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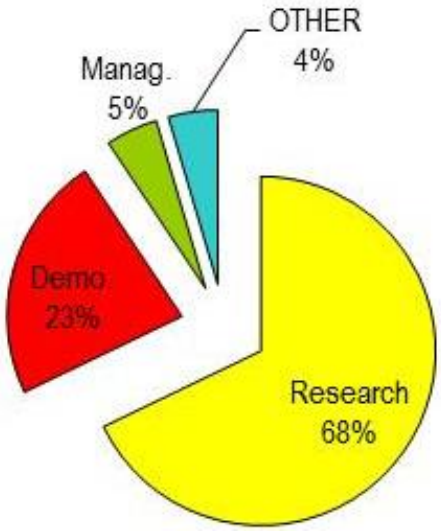
Project aims

- Integration of **waste materials** in the production cycle of concrete
- Development of **innovative**, **sustainable** and **cost-effective** construction materials
- **Novel** ready-mixed and pre-casted **solutions** for the building sector

MATERIAL RESEARCH PHASE → ***INDUSTRIAL IMPLEMENTION PHASE*** → ***INDUSTRIAL UPTAKE PHASE***

The SUS-CON Project
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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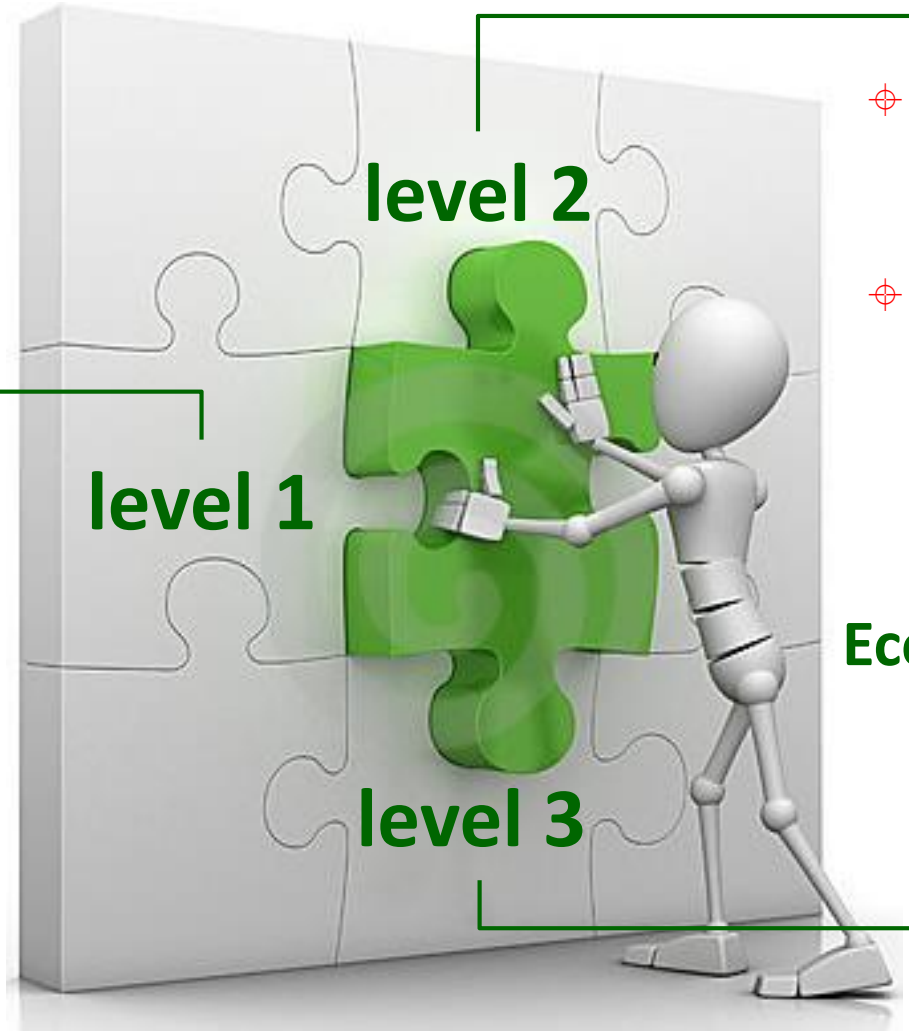
Project structure



- Combination of **novel aggregates** with traditional binder (**Portland** cement)
- Combination of **novel binders** with **traditional aggregates**

- **Novel Aggregates** from waste
- **Novel Binders** from waste

Eco-sustainable 100% waste concretes

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level 1: novel recycled aggregates

… from *wastes materials*

… to *Novel lightweight Aggregates*

- Cost effectiveness
- Lightness
- Thermal insulation

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level 1: novel recycled binders

... from *wastes materials* ... to *Novel geopolymeric binders*

ALUMINIUM-SILICATE PRECURSORS
(energy industry wastes, metallurgical slag and mining industry wastes)

- **Pulverised Fuel ash (PFA):** a by-product from the combustion of pulverised fuel (coal) in power plants
- **Ground-granulated blast-furnace slag (GGBS or GGBFS):** obtained by molten iron slag
- **Perlite tailings (cyclones):** a by-product from perlite industry

- cost effectiveness
- low energy consumption
- reduced CO_2 emissions

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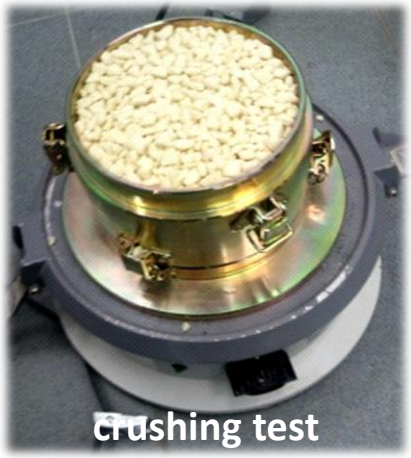
level 2: novel recycled aggregate testing

- Testing of aggregates to assess their **suitability for concrete preparation**
  - loose bulk density (EN 1097-3)
  - grading curves - sieving method (EN 933-1)
  - 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**

sieving machine

pycnometer tests


crushing test

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level 2: integration of novel recycled aggregate in OPC

Lab optimization

- Several concretes designed by the volumetric method
- Concretes optimization monitoring different parameters (i.e. w/c, aggregates % or aggregates/binder ratio)
- **Testing of concretes**
  - workability by slump test (EN 12350-2)
  - air content (EN 12350-7)
  - fresh density (EN 12350-6)
  - return (fresh state density/density from mix design)
  - compressive strength (EN 12390-3)
  - tensile splitting tests (EN 12390-6)
  - thermal conductivity (EN 12664)
  - UPV tests (EN 12504-4)

Eco-sustainable concretes
(recycled aggreates & Portland cement)

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level 2: integration of novel recycled aggregate in OPC

Industrial upscale

- Concretes optimization for different **end products** and **target performance** for each application

Responsible Partner	Aggregate to be used	Target application	Target properties		
			R_{ck} [MPa]	Density [kg/m³]	Workability
iridex group construcții	Polyurethane (PU)	*Blocks*	3-20	700-1500	S1 - SCC
Magnetti Building Soluzioni per costruire	Remix (RX)	*Panels for facades (or part of it)*	5-24	350-1700	S4 - SCC
acciona Infraestructuras	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)
- **Concretes performance evaluation** (i.e. workability, density, return, compressive and tensile splitting resistance, thermal conductivity, qualitative acoustic behavior)

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level 2: integration of novel recycled aggregate in OPC

Industrial upscale

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***

Conclusion

Traditional concrete (d=1800 kg/m³) has λ=1.6 W/mK and UPV values 3000-5000 m/s

The use of ***waste plastic aggregates*** resulted in:

- **lightweight** concretes
- **strength** suitable for the target applications
- reduced **thermal conductivity**
- low tendency to transmit ultrasonic pulses (**acoustic insulation**)

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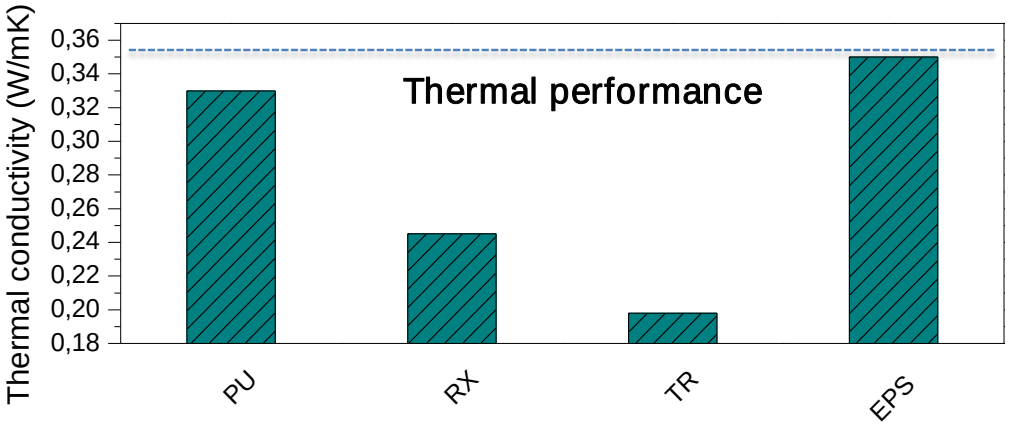
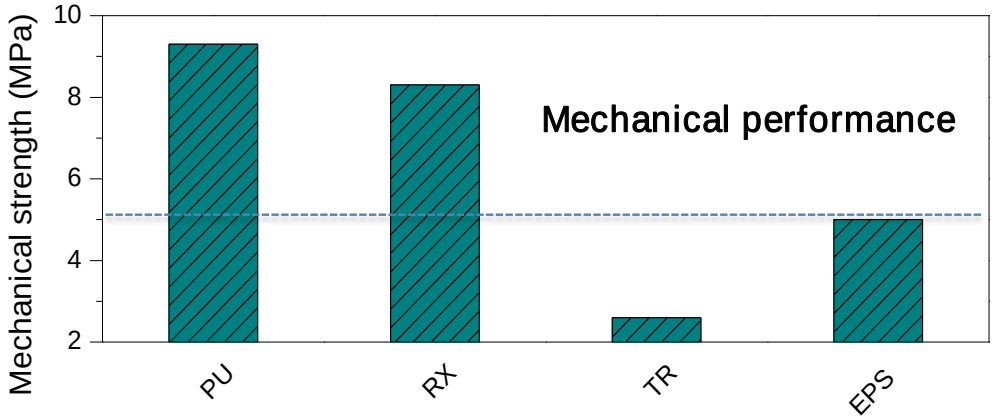
level 2: performance comparison

- **Traditional lightweight concrete**: concrete based of **expanded polystyrene (EPS)** has λ=0.35 W/mK (d=1000 kg/m^3) and compressive strength 5 MPa





Conclusion

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

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level 2: novel recycled binder testing (geopolymers)

- Physical and chemical **characterizations** of the binders ad investigation of their **potential for geopolymerization**
- Identification of key parameters for the **geopolymerization process** (chemical dosages, water content, curing temperature)

Binder	Activator	Aggregates	Curing	Mortar compressive strength [MPa]
PFA	NaOH + waterglass	Traditional	room temp	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** recipes with traditional aggregates
- **Geopolymer concretes testing** (workability, strength, ultrasonic wave transmission, elastic modulus)

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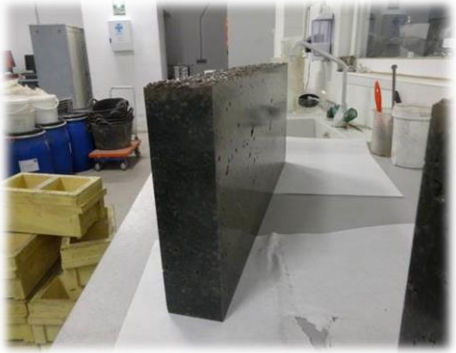
level 2: novel recycled binder testing (geopolymers)

- Some **concrete products** have been targeted for investigating the possibility of replicating them with **substitution of OPC binder with geopolymer binders**
  - Lightweight GP concrete (mechanical and durability characterisation)
  - Façade panels
  - Geopolymer building blocks
  - Aerated autoclave concrete (AAC)
  - Specimens with conventional aggregates (silicates and lightweight expanded perlite)

- The **substitution of OPC with geopolymer** binders proved to be **successful** in all but one case (AAC), being the replicated concrete products **fully conform to existing technical prescriptions**



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level 3: 100% waste concrete (aggregate & binder)

TARGET APPLICATIONS

Ready-mixed products
- Floor screed
- Floor screed underlay

Pre-casted products
- Panels for facades
- Blocks

TARGET REQUIREMENTS

Application	Workability [cm]	Density [kg/m³]	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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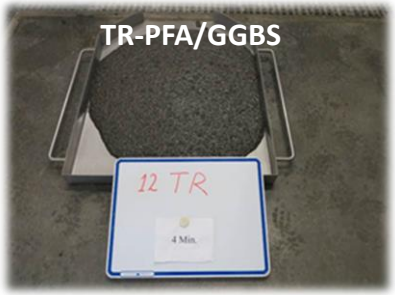
level 3: 100% waste concrete (aggregate & binder)

- Several combinations of **SUS-CON aggregates/binders** tested targeting specific applications
- **Optmized SUS-CON concretes for target aplications**

Mix ID	Aggregates	Binder	Application
PU19	Polyurethane (PU)	PFA/GGBS	Floor screed underlay
RX4	Remix (RX)	PFA	Panel for facades
PU21	Polyurethane (PU)	PFA/GGBS	Panel for facades
RX11	Remix (RX)	PFA/GGBS	Block
PU11	Polyurethane (PU)	PFA	Block
TR4	Tyre rubber (TR)	PFA	Block
PU30	Polyurethane (PU)	PFA/GGBS	Block
PU4	Polyurethane (PU)	PFA	Block



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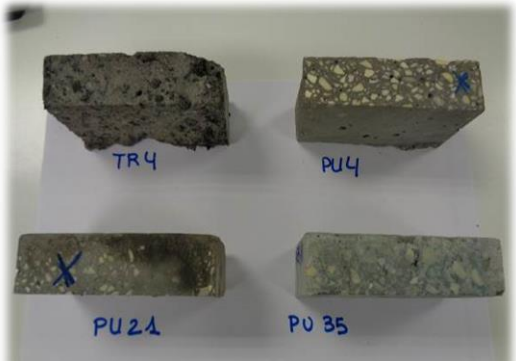
level 3: 100% waste concrete (aggregate & binder)

- **Testing** the SUS-CON concretes performance
  - **Fresh state** (consistency, 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)

FLEXURAL STRENGTH



SPECIMENS FOR λ MEASUREMENT

The SUS-CON products

level 3: 100% waste concrete (aggregate & binder)

Mix ID	Aggr.	Binder	Workability	Density [kg/m³]	Compr. Strength [MPa]	Flex. strength [MPa]	λ [W/mK]	UPV [m/s]	Application
PU19	PU	PFA/GGBS	S4	1146	8.4	1.4	0.18	2018	Floor screed ulderlay
RX4	RX	PFA	S5	1440	6.8	1.3	0.34	1613	Panel for facades
PU21	PU	PFA/GGBS	S5	1089	6.6	0.9	0.17	1596	Panel for facades
RX11	RX	PFA/GGBS	S1	1475	18.2	2.3	0.27	2668	Block
PU11	PU	PFA	S1	1255	8.3	2.0	0.31	1760	Block
TR4	TR	PFA	S5	1501	4.2	0.9	0.32	1595	Block
PU30	PU	PFA/GGBS	S4	1184	15.1	2.1	0.20	2632	Block
PU4	PU	PFA	S4	942	5.6	1.2	0.16	1344	Block

- **Innovative concretes** based on waste aggregates (PU, RX and TR) and waste binders (PFA and PFA/GGBS) successfully optimized
- **Target** requirements (workability, density, mechanical resistance) **fulfilled**
- **Higher thermal insulating performance**
- **100% waste concretes suitable for ready-mixed and pre-casted applications**

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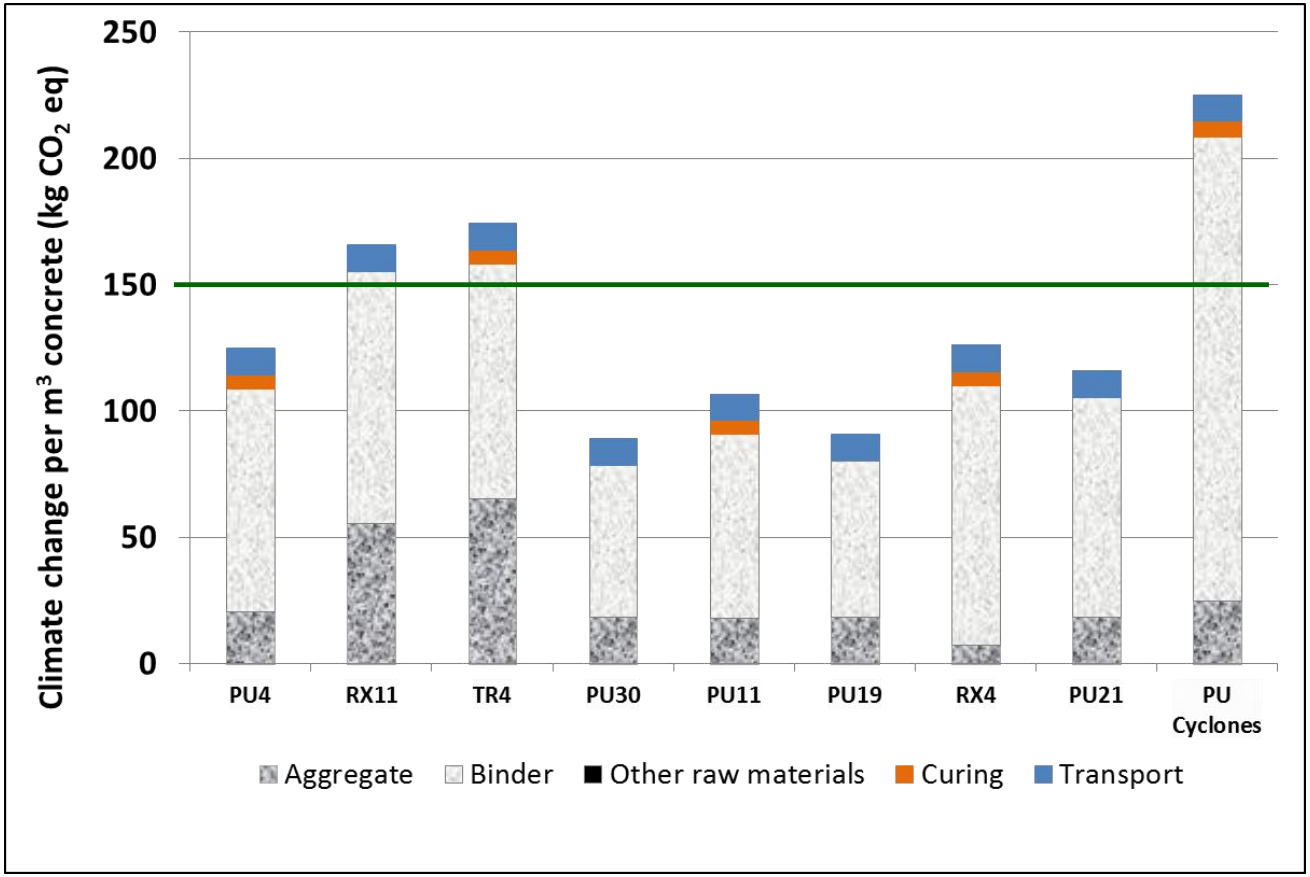
LCA: carbon footprint related to 1 m³ of SUS-CON



- **Traditional LWCs** have around 300 Kg CO_2eq
- One of the target of SUS-CON is to **reduce 50% of the carbon footprint**

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production upscale - demonstration

- Construction of SUS-CON prototypes and monitoring of their performance (i.e. flexure tests up to failure, fire behaviour, thermal and acoustic insulation)

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

The SUS-CON Project
applications on real buidings

- **Three demo sites** selected (Spain, Turkey, Romania)

The SUS-CON Project
applications on real buidings

- **Three demo sites** selected (Spain, Turkey, Romania)
  - **ready mixed** applications
  - **pre-cast** applications

PU blocks
RX panels

- 1 mockup with **blocks** (Spain)
- 1 mockup with **panels** (Spain)

RX, **PU** blocks
PU panels
PU floor screeds

- 1 mockup with **blocks** (Turkey)
- 1 mockup with **blocks** and **panels** (Romania)

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acknowledgements

SUS-CON project *"SUStainable, innovative and energy-efficient CONcrete, based on the integration of all-waste materials"* has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. 285463 (Call FP7-2011-NMP ENV-ENERGY-ICT-EeB)

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

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

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The SUS-CON Project
conclusion

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

- The main **aim of the SUS-CON project** is to develop **sustainable, innovative and energy-efficient concrete**, based on the integration of all-waste materials

- **Novel recycled aggregates** (PU, TR, WEEE, RX) and **binders** (PFA, PFA/GGBS) have been developed

- **Integration** of **novel recycled aggregate** in **OPC** has been assessed
- **Integration** of **novel recycled binders** with **traditional aggregates** has been assessed
- **Integration** of **novel recycled aggregate** with **novel recycled binders** has been assessed

- **100% waste** SUS-CON **blocks** and **panels** has been produced
- SUS-CON products are **highly compatible** with the **existing concrete production processes** (minimized equipment costs)

- Three demo sites for **real case applications** have been selected (Spain, Turkey, Romania) for a complete demonstration

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