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DSCS 2025 NAPOLI

New trends on design, fabrication, and materials for construction: **CARBCOMN, an EIC Pathfinder Challenge project**

Marco PEPE – TESIS srl (Italy)

Tesis s.r.l. Tecnologie Emergenti a Servizio dell'Ingegneria Strutturale

European Innovation Council

Funded by the European Union

CARBCOMN – HORIZON-EIC-101161535

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*Developing a **carbon-negative concrete mixture,** suitable for processing through additive manufacturing, producing **discrete blocks** out of it and employing them in an innovative structural system consisting of **compression dominant members.***

CARBon-negative COMpression-dominant structures for decarbonized and deconstructable CONcrete buildings

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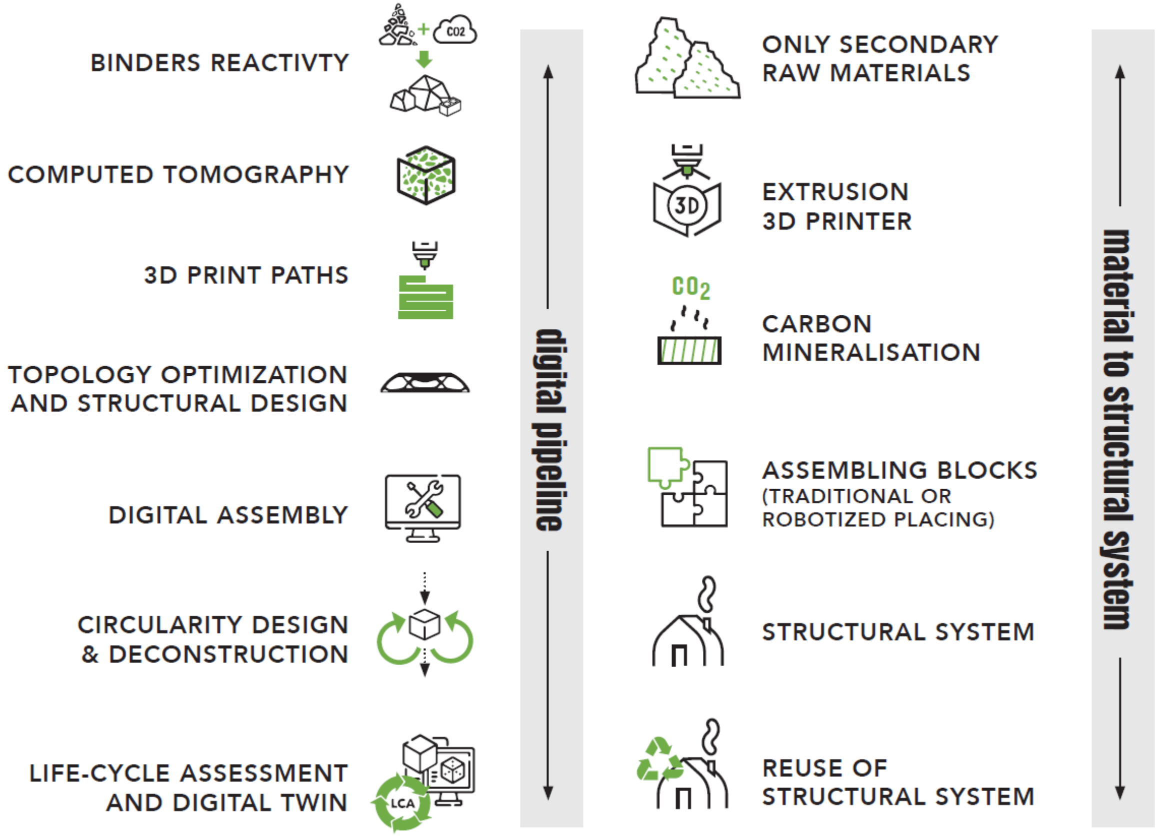
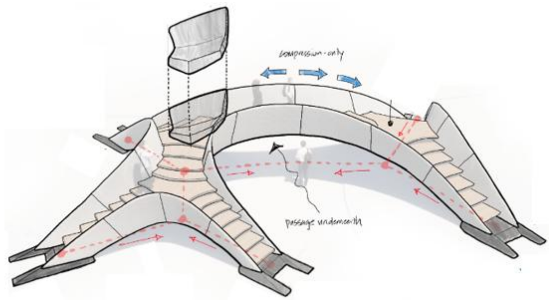
Aim

To **create a decarbonised construction system for load-bearing concrete** buildings and infrastructure.

Envisioning decarbonized and deconstructable compression dominant structures through robust design-to-fabrication digital pipeline (left); scale model and funicular floor system examples (right)





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Facts and figures

48 months
01/10/2024
30/09/2028

11 partners
- 7 beneficiaries
- 4 ass. partners

10
work packages

41
deliverables

10
milestones

3
reporting periods

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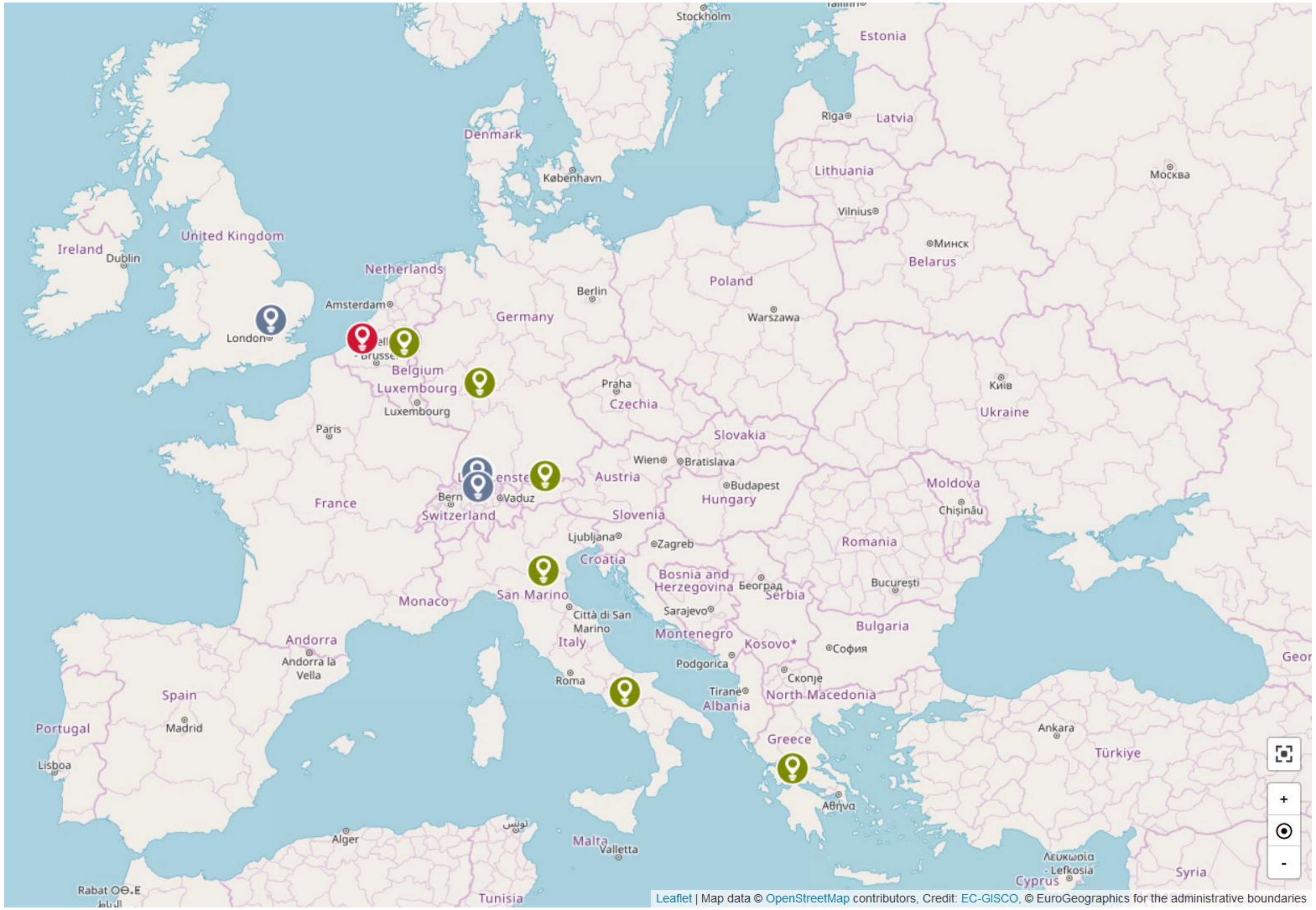
Consortium

5 research institutions
+
6 industry partners



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Main objectives (OB 1-7)

- **OB1.** Realising the ***LCA-based*** CO2 sequestration capability of a ***carbon-negative concrete***, manufactured with carbonatable by-products and recycled/secondary concrete aggregates.
- **OB2.** Discovering the ***reactivity-based mix design and pore structure*** of carbon-negative concrete that allows manufacturing complex forms by extrusion-based 3D printing while remaining suited for carbon mineralisation.
- **OB3.** Establishing ***advanced computational structural design methods*** for discrete structural geometries, custom-made for the aforementioned materials and applications.
- **OB4.** Exploiting digital design and fabrication methodology to realise discrete blocks based on OB1-2, with the aim of assembling structures designed as in OB3, establishing a ***robust and replicable computational pipeline from design-to-fabrication***.

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Main objectives (OB 1-7) (cont.)

- **OB5.** Reaching satisfactory ***structural safety*** under static and seismic actions of the CARBCOMN load-bearing carbon-neutral concrete structures and understanding how ***self-prestressing with shape memory alloy*** (SMA) can enhance the capacity.
- **OB6.** Detailing the ***new design paradigm*** (that follows from OB1 to 5) and defining scenarios and use cases for the proof-of-concept of the CARBCOMN technological solution.
- **OB7.** Exploring the ***future exploitation potential*** of the results in collaboration with other portfolio projects and disseminate information on the project result.

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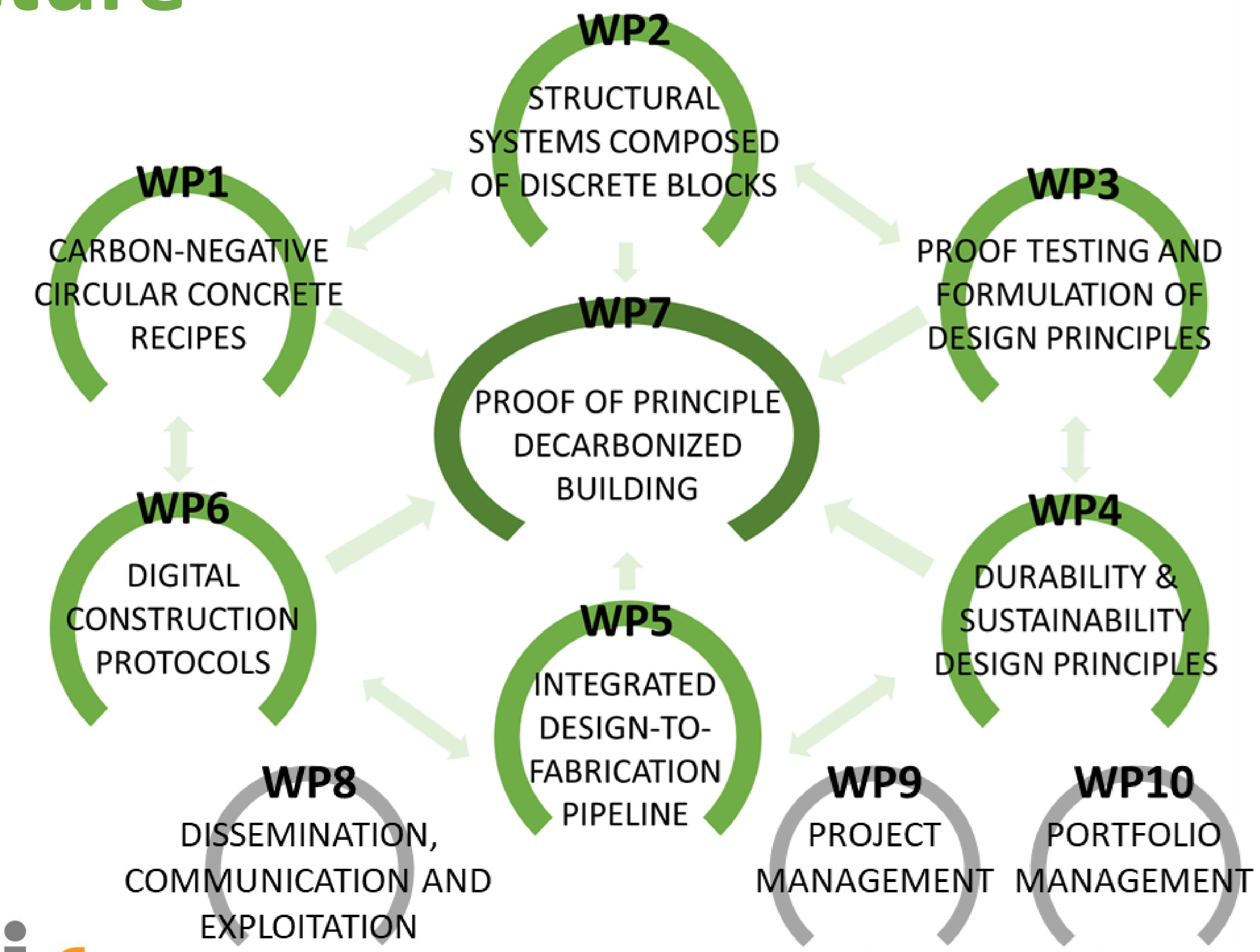
WP structure



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Portifolio activities

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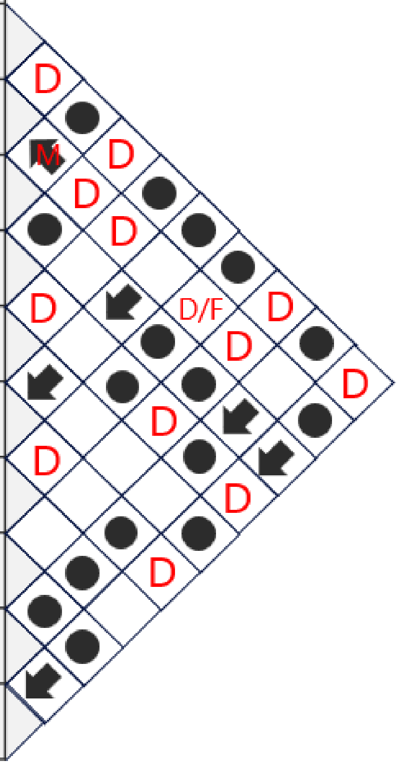
Synapsis	D	F	M	Consortium
Computation and 3D fabric weaving for minimal material no formwork fabric-cement composites	★	★	★	FLEXIFORM
Computational design and freeform hot blade cutting of foam for low waste optimal formwork	★	★		STACK
Resource model enabling use of waste-sourced and fast-growing materials in AEC	★	★	★	RAW
Computational design and robotized fabrication of parametric multi-story timber building system	★	★	★	UniversalTimberSlab
Construction system using carbon mineralisation materials and compression dominant structures	★	★	★	CARBCOMN
Computational design and fabrication of fabric-loam composites for buildings	★	★	★	ALGOLOAM
Computational design and additive fabrication of bio-foam for load bearing structures in AEC	★	★	★	ARCHIBIOFOAM
Additive to predictive manufacturing for multistorey construction using learning by printing and networked robotics	★	★	★	AM2PM
Multi-scale bio-waste derived meta-materials design for meta-structures for AEC	★	★	★	PANTAREI
Developing digital twin and intuitive design tools for accurate AM using extrudable low-carbon Aluminium fibre reinforced materials	★	★	★	SCENE-B



D Complementary on Design M Complementary on Materials F Complementary on Fabrication ● Strong mutual benefit on D, F, M Directional benefit

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Project background- TESIS srl

The **major expected impacts** of the project are the **improvement of the market uptake and industrial recovery of CDW as *fRA*.**

The impact of the proposed innovation considers the whole life cycle of the produced 3D printed concretes incorporating *fRA* (3D-RAC).

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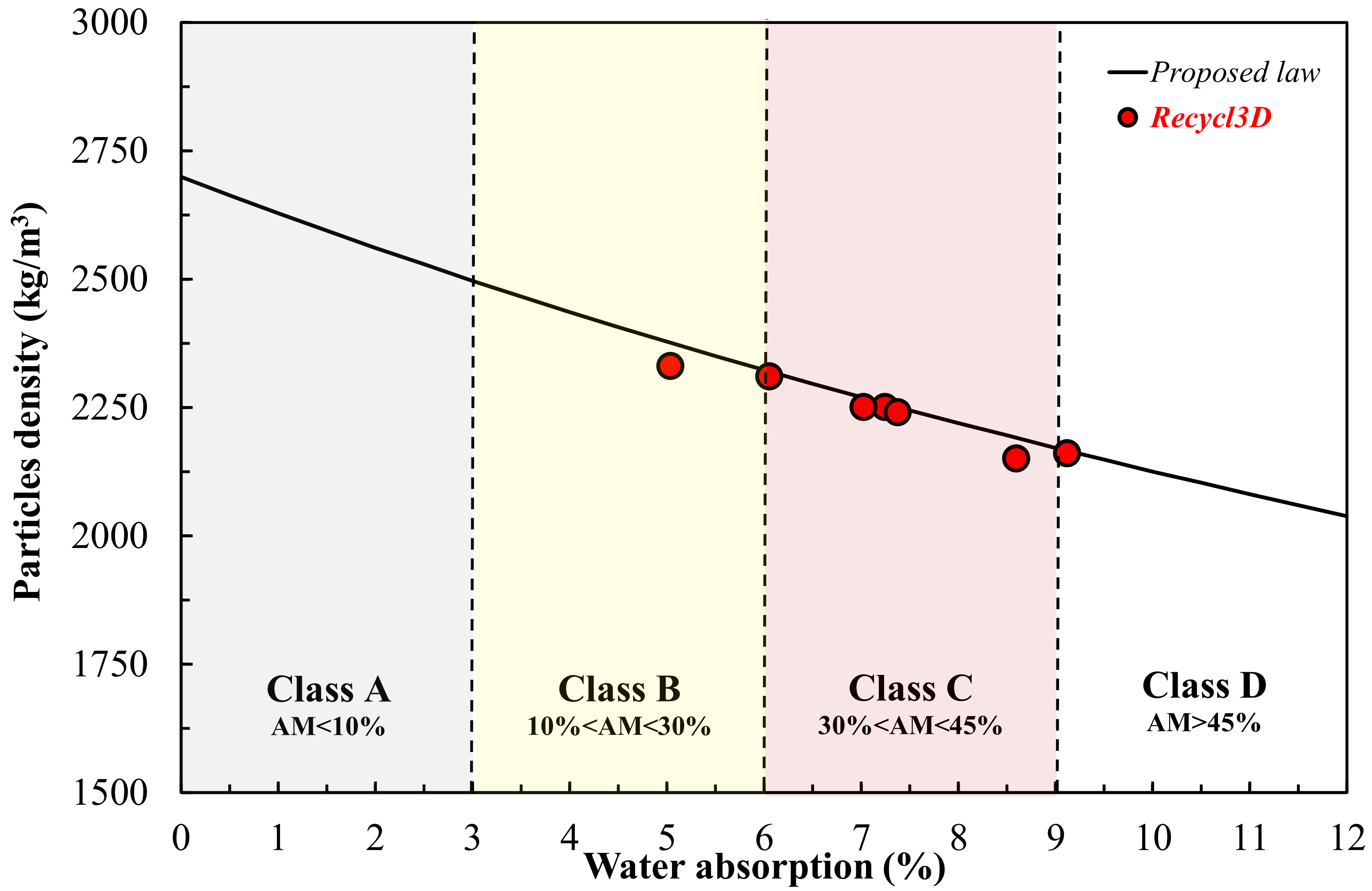
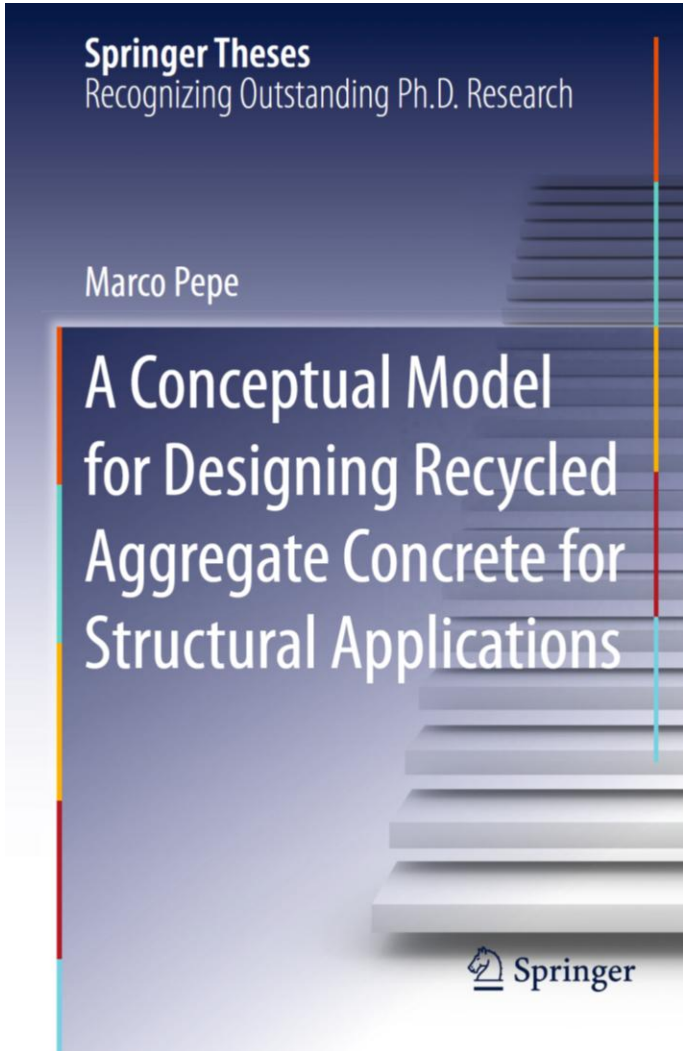
Project background- TESIS srl





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Project background- TESIS srl

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CONCRETE

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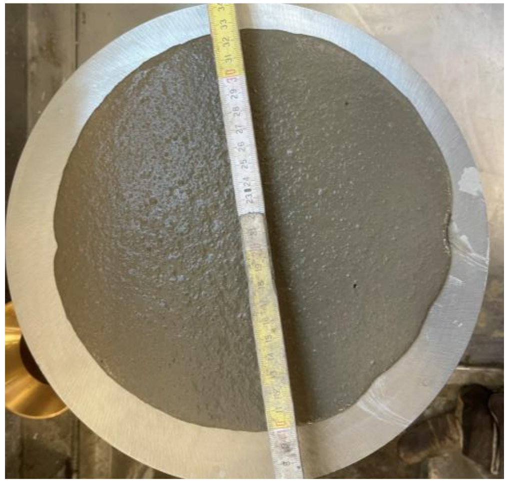
Table 1. Mixture proportioning for printable mixtures

Mix	Cement [kg]	Total water [kg]	SP [kg]	Natural sand [kg]	*fRA* sand [kg]
REF	800	298	2.50	1136	0
RMA50	800	400	5.00	568	425
RMA100	800	390	5.00	0	850

REF – 150mm

RMA50 – 180mm



RMA100 – 240mm

Flow table test results for printed concrete mixtures

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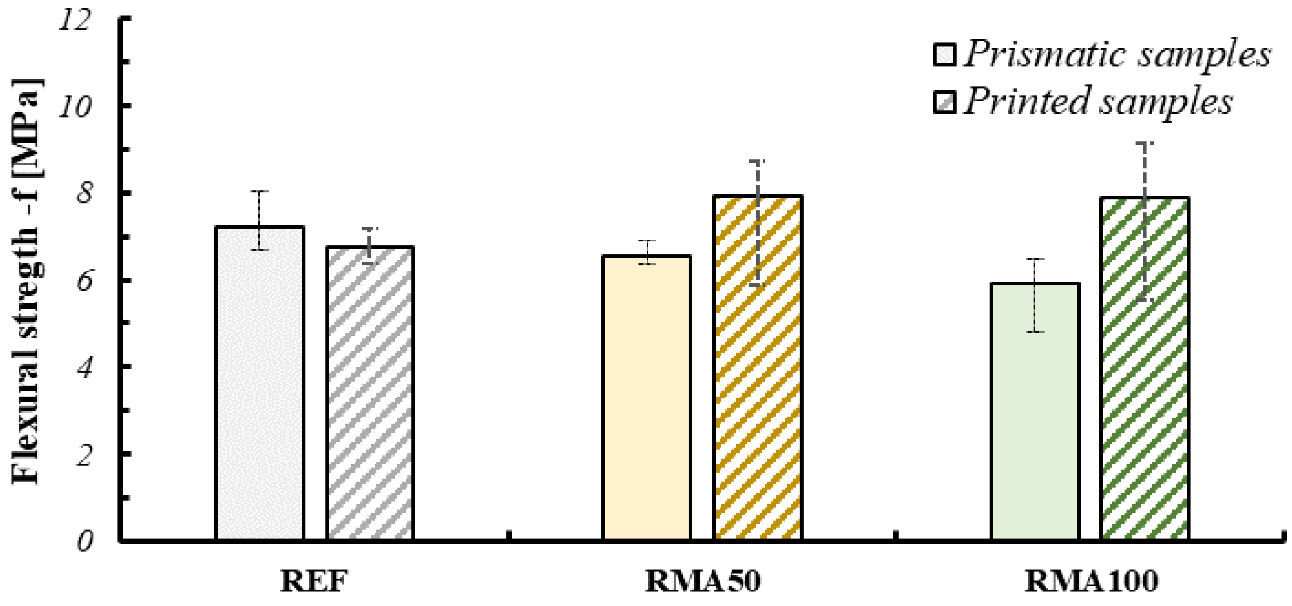
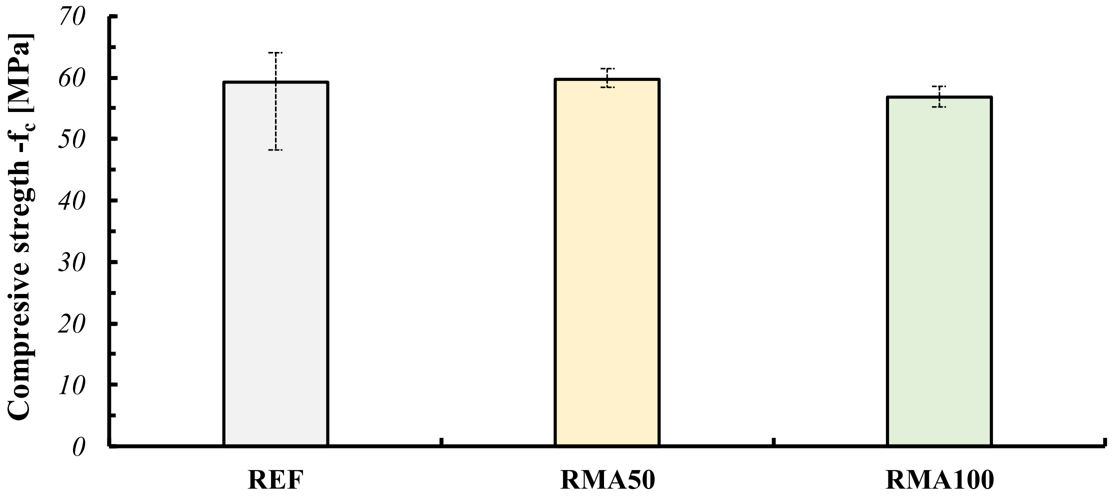
Project background- TESIS srl





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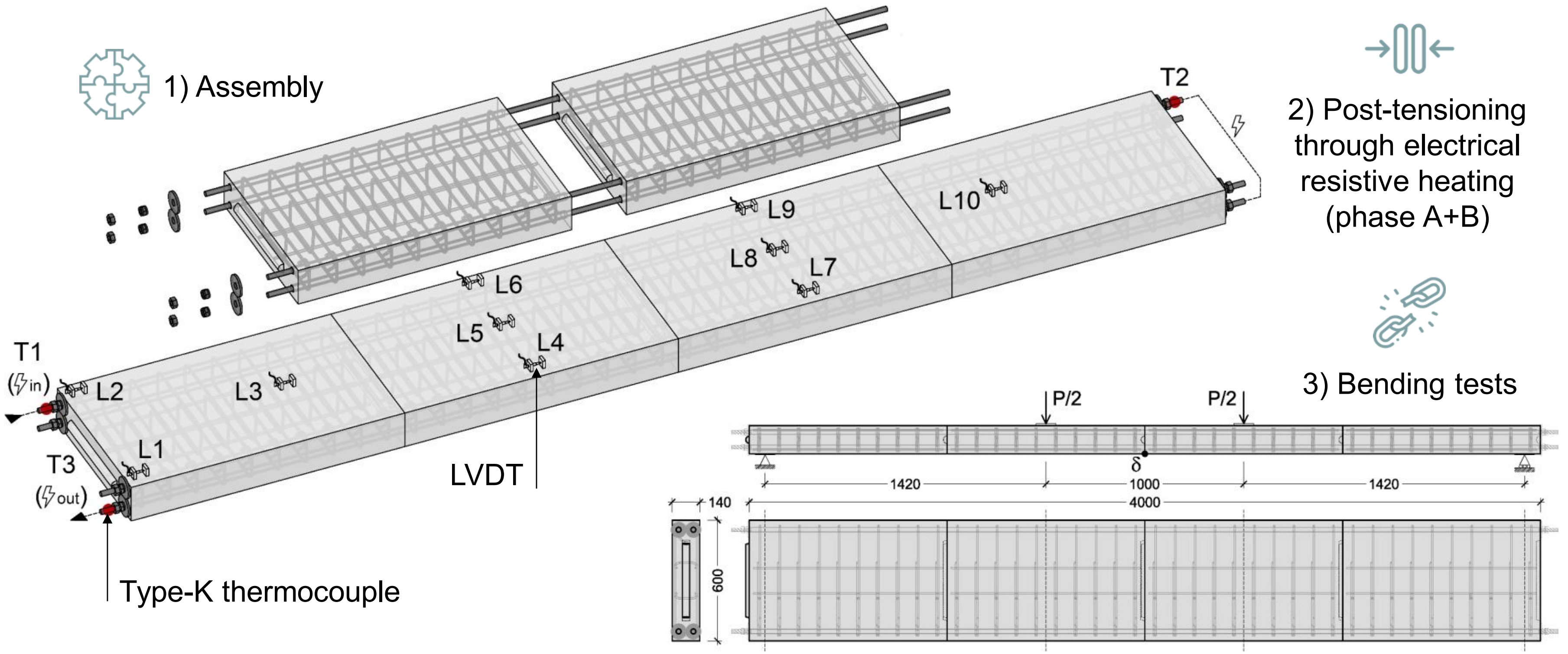
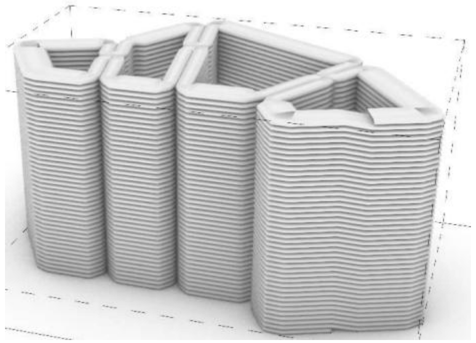


Towards next-generation **De**constructable **Con**crete **St**ructures made of **R**ecycled **A**ggregates from **C**onstruction & demoli**tion** waste

Preliminary results



3D-printed concrete blocks

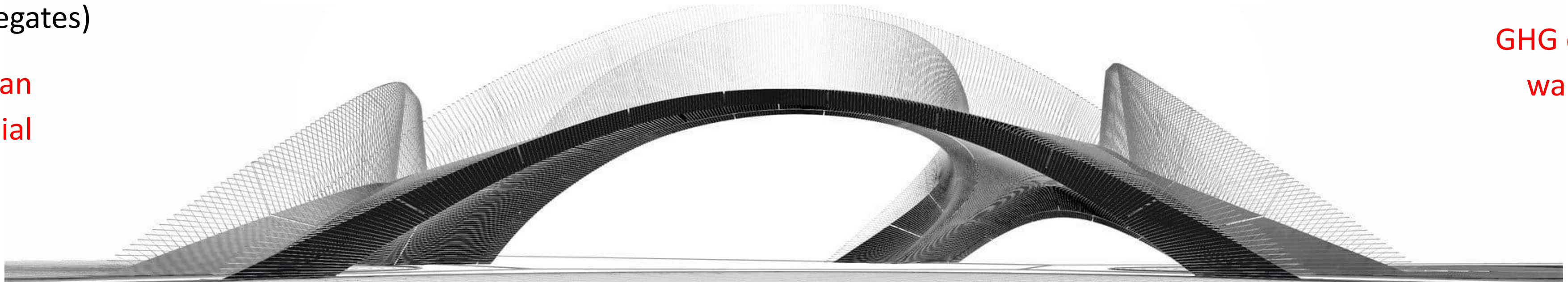
Long construction duration, labor shortage, material wastage, need for formwork

Metal Oxide-rich byproduct (binder & aggregates)

Dumping-human toxicity potential

Captured CO_2

GHG emission - Global warming potential

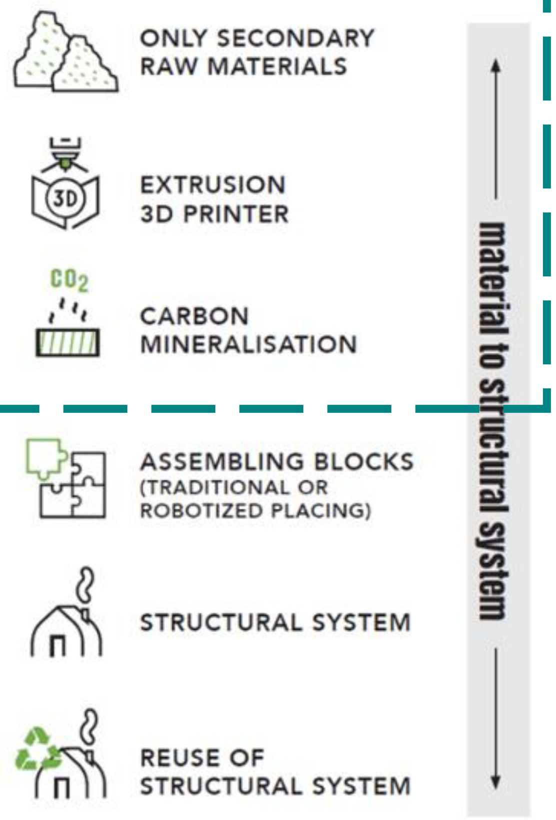


Compression-dominant structural logic

(A. Dell'Endice et. Al, 2023)

Preliminary results

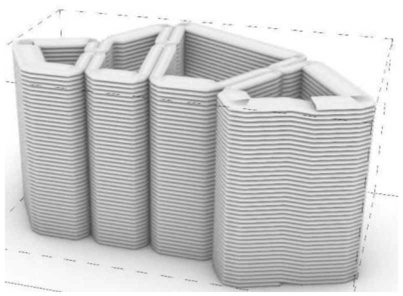
Material system



Process

- Optimization of formulations
- Flow assessment
- Yield stress evolution
- Extrudability assessment and small-scale specimen fabrication
- Carbon-curing of specimens
- Mechanical performance assessment
- 3D-print trial
- Carbon-curing of blocks
- Mechanical performance assessment of carbon-cured block

Short-term go



First 3D-printed carbon-cured block

Towards the first 3D-printed carbon-cured block

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Preliminary results

Materials

Binder - Carbinox

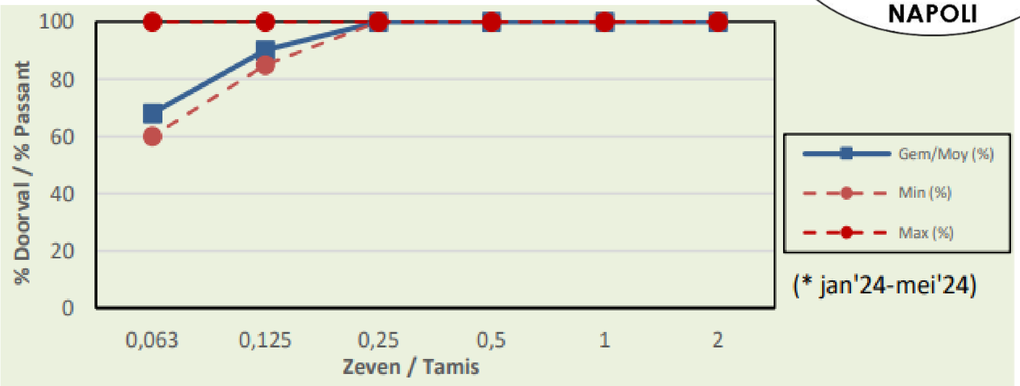
Fine stainless-steel slag fraction
Particle size: 0.25 mm max.
Bulk density: 1,000 kg/m^3
Apparent particle density: 2,527 kg/m^3

Aggregates - Stinox

Coarser blended slag fraction
Particle size: 2 mm max.
Bulk density: 1,586 kg/m^3
Apparent particle density: 1,775 kg/m^3
Water absorption capacity: 3.1 %

- Water - Potable
- VMA: HMC, Tylose (ShinEtsu)
- Superplasticizer: PCE MasterGlanium 51 (BASF)

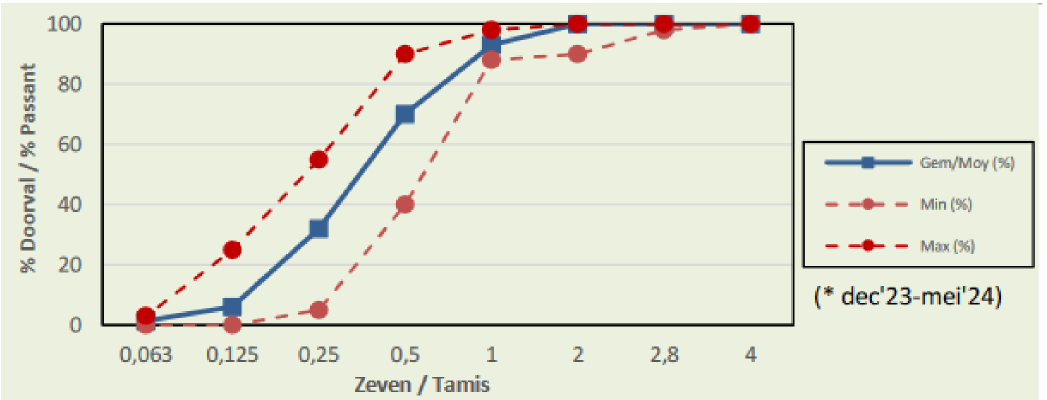
Printability optimization



Binder Gradation Curve - Orbix

Mineral Oxide	CaO	SiO_2	MgO	Al_2O_3	Mn_2O_3	Cr_2O_3	Fe_2O_3	TiO_2
% by mass	51.0	25.3	10.5	5.9	1.2	2.9	1.1	1.0

Chemical composition of binder- Orbix



Aggregates Gradation Curve - Orbix

Materials supplied by Orbix, Belgium

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Preliminary results

Methods

Optimized formulations

mix	A/B ratio	W/B ratio	SP/B ratio (%)	VMA/B ratio (%)	D1 (mm)	D2 (mm)	Davg. (mm)
M-0.5_0.25	**0.5**	**0.25**	**0.80**	**0.056**	**165**	**165**	**165**
M-0.5_0.30	0.5	0.30	0.25	0.056	155	160	158
M-0.5_0.35	0.5	0.35	0.00	0.075	170	165	168
M-0.7_0.25	0.7	0.25	1.00	0.080	155	150	153
M-0.7_0.30	0.7	0.30	0.50	0.080	165	160	163
M-0.7_0.35	0.7	0.35	0.00	0.045	155	155	155
M-1.0_0.25	1.0	0.25	1.75	0.090	150	150	150
M-1.0_0.30	1.0	0.30	1.00	0.090	150	155	153
M-1.0_0.35	1.0	0.35	0.50	0.090	160	160	160

Flow dia. 150 – 170mm

A/B - Aggregate-to-binder ratio
W/B - Water-to-binder ratio
SP/B - Superplasticizer-to-binder ratio
VMA/B - VMA-to-binder ratio
D1, D2 - Spread diameter in perpendicular directions
Davg. - Average of D1 & D2 (ASTM 1437-20)

Mixing time, 2.5 min rotary mixer

Mix M-0.5_0.25 considered reference mix for the first 3D-print test, its performance reported here as key result.

Flow optimization (ASTM 1437-20)

Before 25 drops

After 25 drops

Slow penetration tests

Anton-Paar MCR 102 Rheometer

Speed: 5 µm/s
Time: 600 s

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Preliminary results

Methods

Specimen extrusion

Extruded layered specimen

- Printing speed 40 mm/s
- Layer dimensions approx. 45 mm width & 15 mm height
- 2D Mortar gun
- Transferred to chamber 30 – 45 min after printing

Carbonatation

3% CO_2 20˚C Temp, 60% RH

Mechanical properties

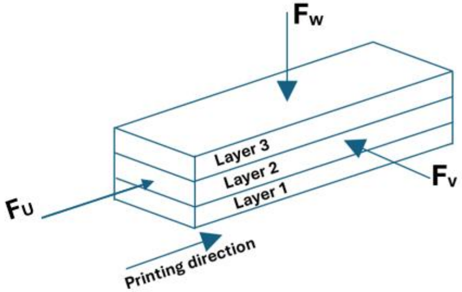
Flexural test (3-point bending)
EN 12390-5

Compression test
EN 12390-3

Carbonation depth

Uncarbonated

Fully carbonated (7 days)



Loading sign convention

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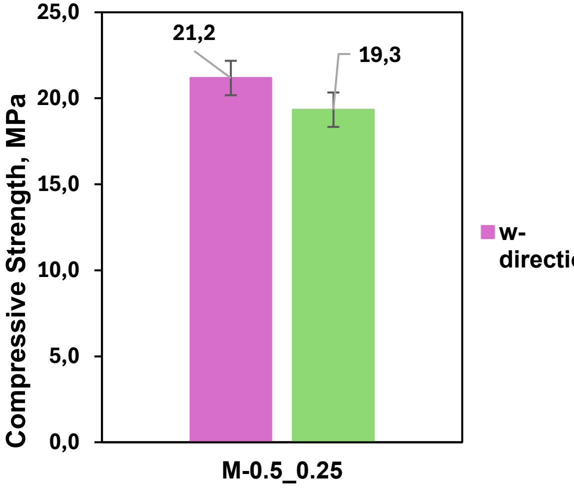
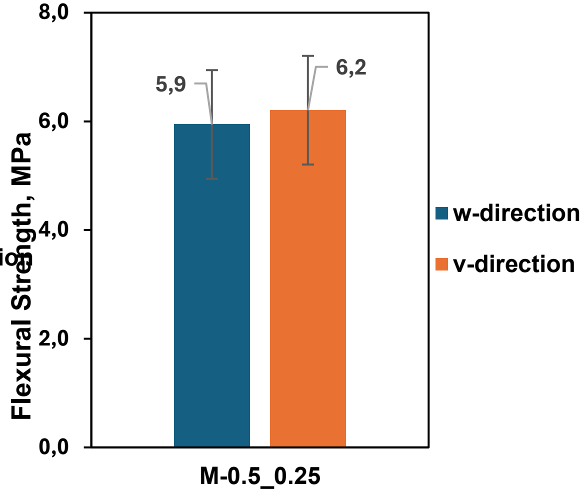
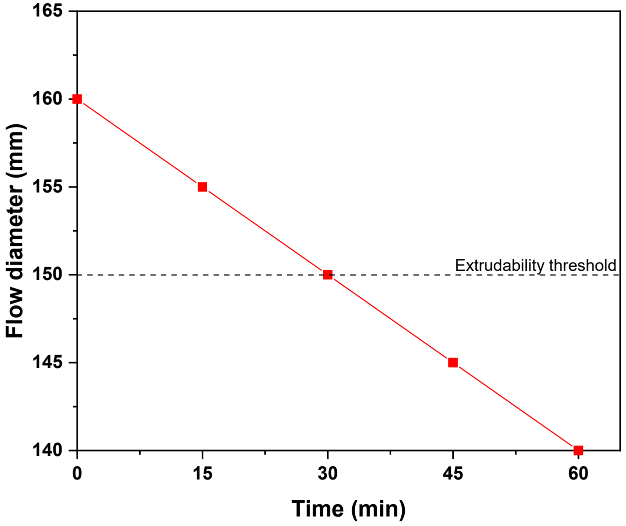
Preliminary results

Mechanical Performance – reference mix

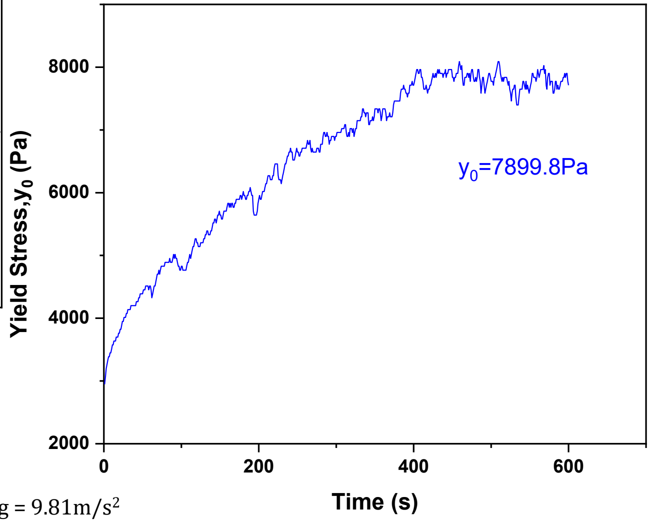




Flow retention



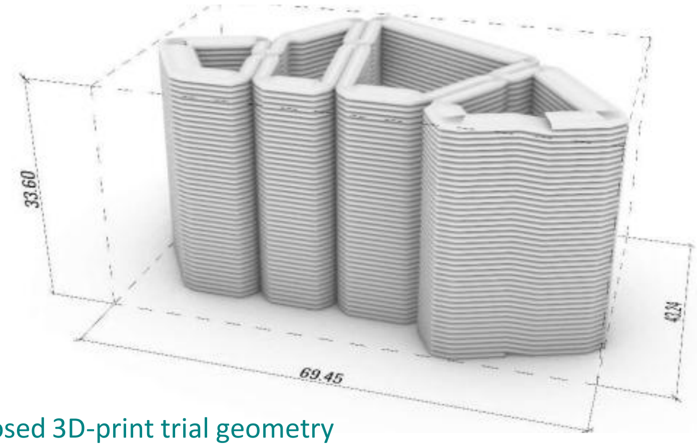
slow penetration test - buildability



$$Printing\ height, H_{cr} = \frac{\sqrt{3} \times y_0}{\rho_m \times g},$$

y_0 = 7,899.8Pa, ρ_m = 1882kg/ m^3, g = 9.81m/s^2

H_{cr} = 740 mm (Higher than proposed block geometry)



Proposed 3D-print trial geometry

3D-printing with 6-axis Robotic arm at UGent

Printed & Carbon-cured geometry

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Preliminary results

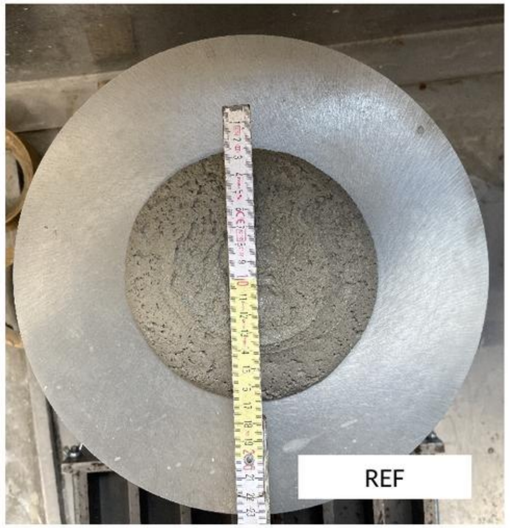
Ongoing

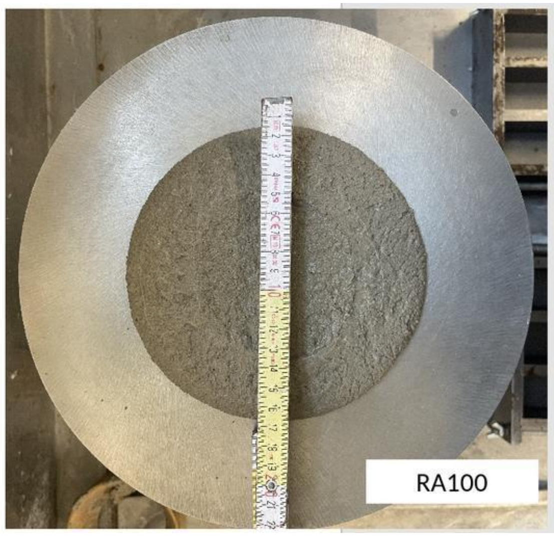
Binder - Carbinox

Recycled Concrete

Mixture materials	UdM	Ref	RA50	RA100
Binder type	-	*Carbinox (0/250 μm)*	*Carbinox (0/250 μm)*	*Carbinox (0/250 μm)*
Binder - B	*kg*	1060.00	1060.00	1060.00
Aggregates type	*kg*	Stinox (0/2 mm)	50% of Stinox (0/2 mm) and 50% 0f RAC	RA
Stinox (0/2 mm)	*kg*	530.00	265.00	0.00
RA	*kg*	0.00	158.83	317.67
Free water	*kg*	402.53	387.75	384.34
Absorbed water - W_{abs}	*kg*	16.43	12.98	9.53
Mixing water - W_{tot}	*kg*	418.96	400.73	393.87

Carbinox BULK density	*kg/m³*	**3060**
Stinox (S) BULK density	*kg/m³*	**3170**
Water absorption capacity of Stinox	*%*	**3.10%**
RA BULK density	*kg/m³*	**1900**
Water absorption capacity of RA	*%*	**3.00%**





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Conclusions

Project overview

- Socio-economic and skills advancement, by introducing digital prefabrication processes not only enhances skills levels within the construction industry but also redefines the role of humans in construction.
- Integration, collaboration and competitiveness, by fostering collaboration, efficiency, and integration, leading to a more competitive and profitable business model;
- Structural paradigms evolution and building codes, by playing a pivotal role in advancing engineering tools and paradigms, with the potential to shape future building codes and industry practices.

Preliminary results

- **Flow optimization** enabled achievement of a printable rheology using **non-activated industrial slags** with additives
- Achieved up to **22 MPa compressive** and **6 MPa flexural strength** after **7 days of carbonation curing** (3% CO_2, 20˚C Temp, 60% RH)
- successful **first 3D-print trial** with **one-component (1k) system / Demonstration of potential for ultra-low-carbon waste-based materials in 3D concrete printing (3DCP)**

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