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Needs and availability of secondary resources in the construction industry: scientific challenges

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Tongji University – online course
April 6th, 2023

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Urban & Environmental Engineering

University of Liège in Belgium

Birthplace of Charlemagne

Witness of a millenary principality

Economic capital of Wallonia

University of Liège in Belgium

Coal mining,
steelmaking,
weaponry

Aerospace, logistics,
mechanics,…

Exceptional post-industrial and
natural environments

University of Liège in Belgium

A widespread campus in the heart of nature

26.863 students among which 22% foreigners

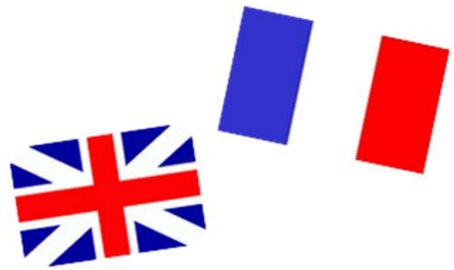
11 faculties (Science, Applied Science, Medicine,…)

Department/research unit

Urban and Environmental Engineering research Unit (UEE) Architectu
re, Geology, Environment and Construction Department (ArGEnCo)

- 200 professors, researchers, technicians
- 11 laboratories
- 3 masters (civil, architectural and geological engineering)
- 316 students (Bachelor and Master degrees)
- 18.10^6 euros cash flow (March 2023)
- 89 PhD students (2023)
- 103 on-going research projects

Master programs



Accredited at European level EUR-ACE Label & CTI

3 civil engineer master degrees

Geology and Mining Engineering

Civil Engineering

Architectural Engineering

2 specialized master's degrees

Urban and regional planning

Transportation management

Continuing education programs

Auscultation et réparation des ouvrages e

BIM

MOCC ConstruiREcycler

International cooperation

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Construction industry context

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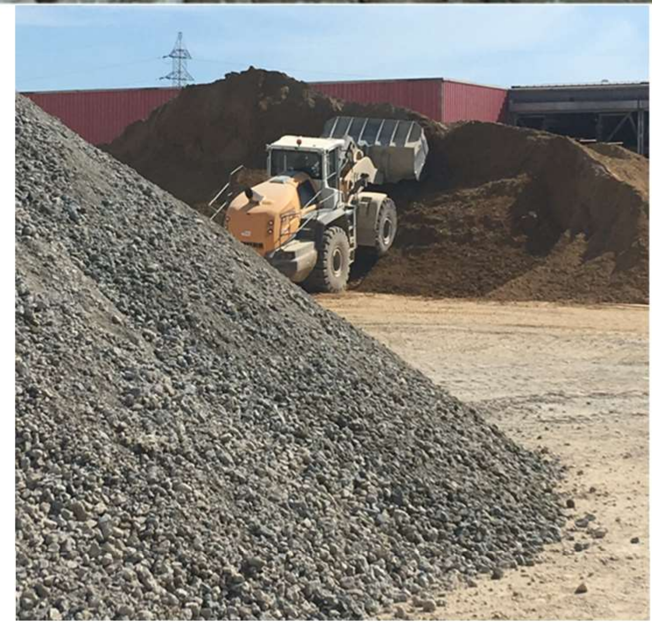
Global context

What to do?



Global context

- We are living in a limited world
  - Energy
  - Raw materials
  - Space
  - Maximum capacity of resilience of nature
- Ascertainment → behaviour
- **Deposit ↔ market ?**

Global context

- We produce wastes
  - Between **3.4 to 4 billions tons/year** or from 80 to 126 tons/second!
  - Each day, human activity is contributing for more than 10 billions kg wastes
  - Annual production of recycled aggregates accounted for 202 million tons in 2015
  - *Construction area is producing more or less than 40% of* CO_2

UEPG. 2018. http://www.uepg.eu/statistics/estimates-of-production-data/data-2015

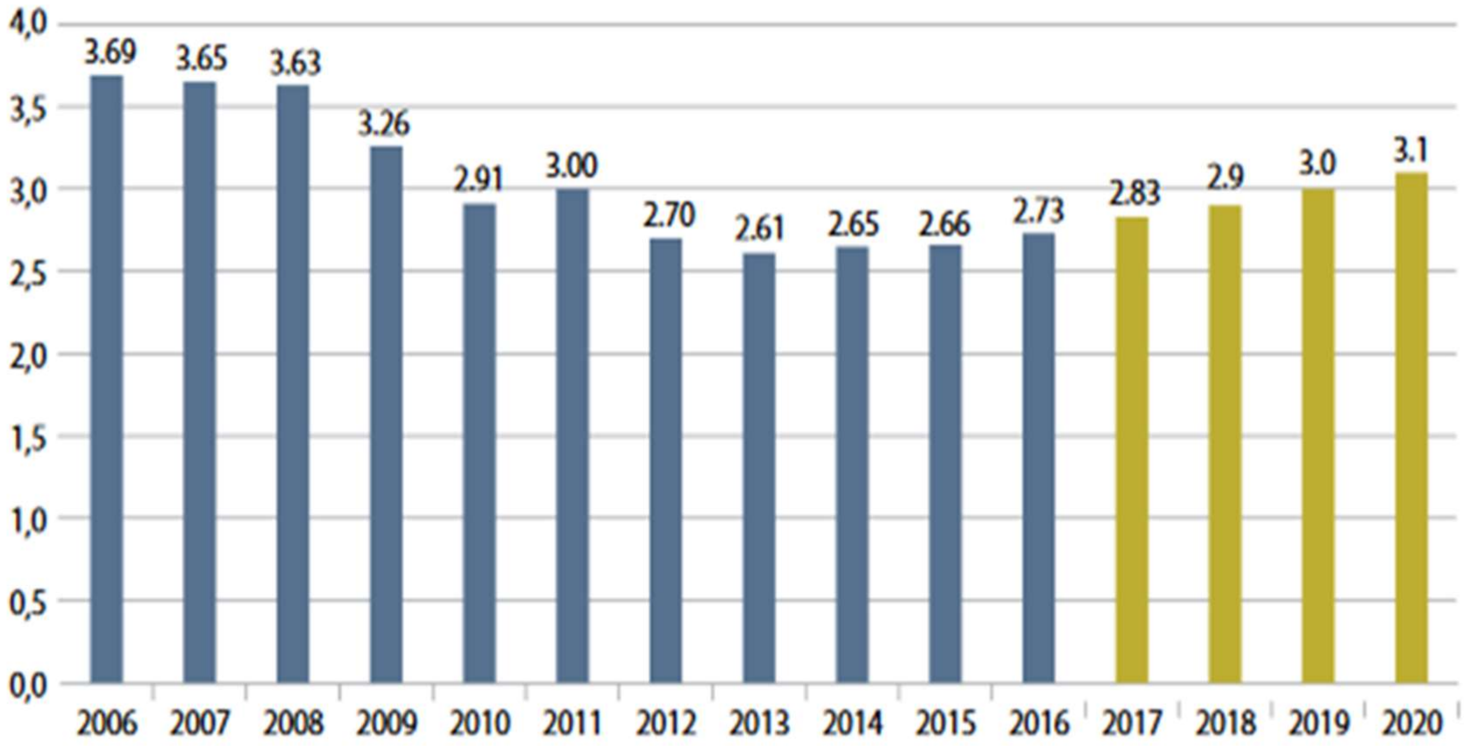
Global context

- We need construction materials
  - Cement: 4 billions tons/year (56% from China)
  - Concrete: 10 billions tons/year
  - Consumption of cement in kg/inh (2018)
    - China: 1704 kg/inh
    - EU: 309 kg/inh
    - USA: 287 kg/inh
    - BE: 550 kg/inh
    - AR: 270 kg/inh
  - Emission of CO_2 (2018): 5-8% world production

Global context

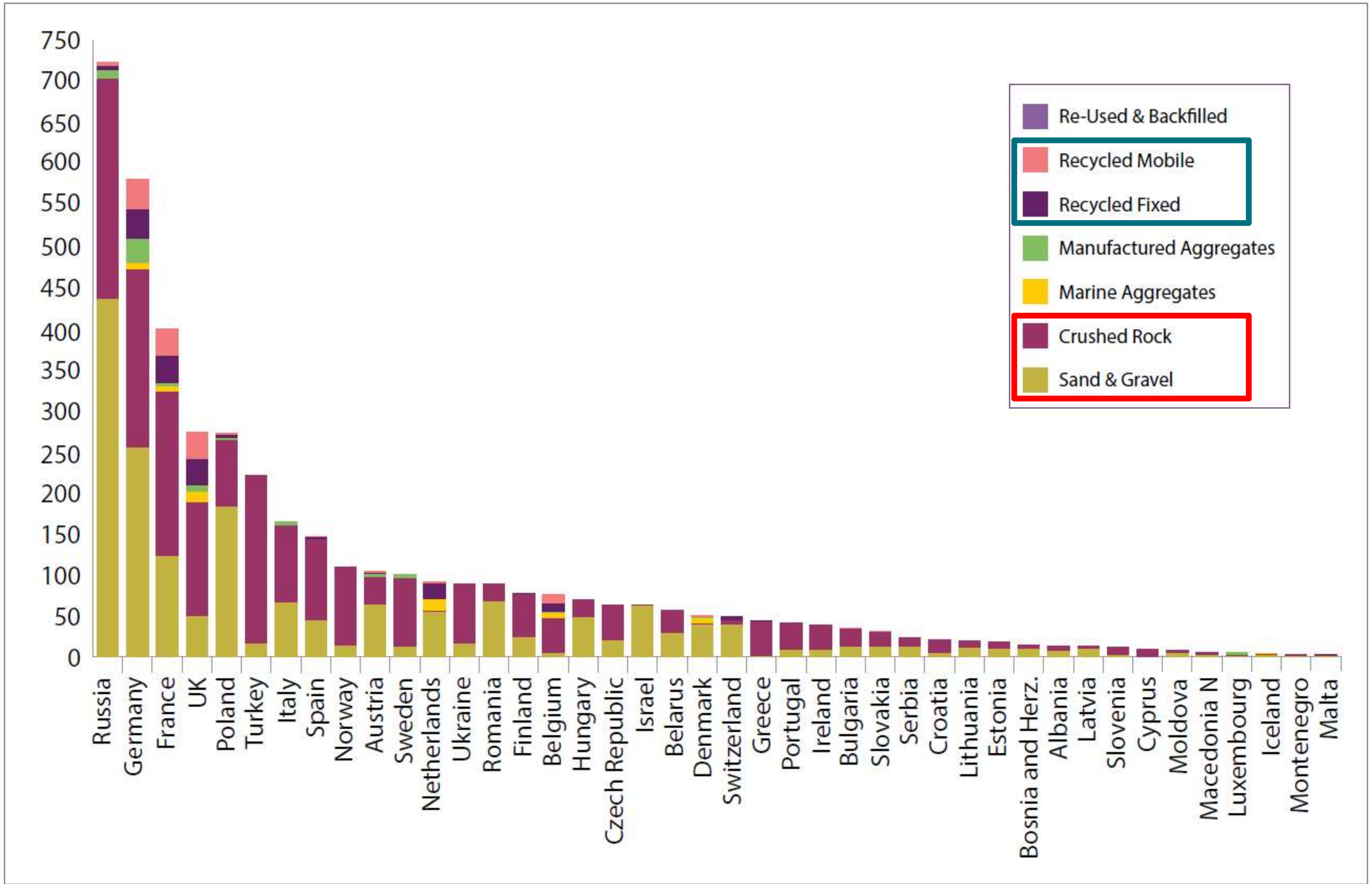
- We need construction materials
  - For the EU28 plus EFTA countries, the total 2019 **aggregates production** is estimated just on **3,00 billion tons**. The primary materials came from 26,000 quarries and pits, operated by 15,000 companies (UEPG, 2018, http://www.uepg.eu/statistics/current-trends)

Global context



Trend in total EU + EFTA Tonnages (in billions of tonnes) for the production of aggregates

Global context



2019 aggregates production in Europe in millions of tonnes by country and type

Objectives

- 3R: Reduce, Reuse and Recycle
- Using CD&W as sub-base and base material in road construction ("less noble")
- Meeting Sustainable Development Goals: recovery targets to 70% of construction and demolition wastes (CD&W) by 2020 in European Union (**Directive 2008/98/EC**)
- Reducing use of natural aggregates (preservation of natural resources)

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Conditions for recycling: requirements, barriers, applications

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Conditions for recycling

- Possible restrictions
  - Transport
    - Transport price = f(quantity, distance)
    - Independent of the quality
    - Interesting recycling if
      - Landfill far away
      - High dumping charge
      - Expensive raw materials and difficult supply
  - Standards
    - *a material has not specification because it is new and not used*
    - *a material is a few used because it is uncovered by specifications*

Conditions for recycling

- Possible applications
  - *Filling materials*: low requirements, consumed in large quantities, for embankments but transportable over short distances due to costs;
  - *Aggregates*: high quality requirements to lead to finished products of quality identical to that of traditional materials;
  - *Binders*: very precise specifications, properties must remain constant over time;
  - *Activators*: small quantities, which can cause problems of collection, storage, distribution and regularity.

Conditions for recycling

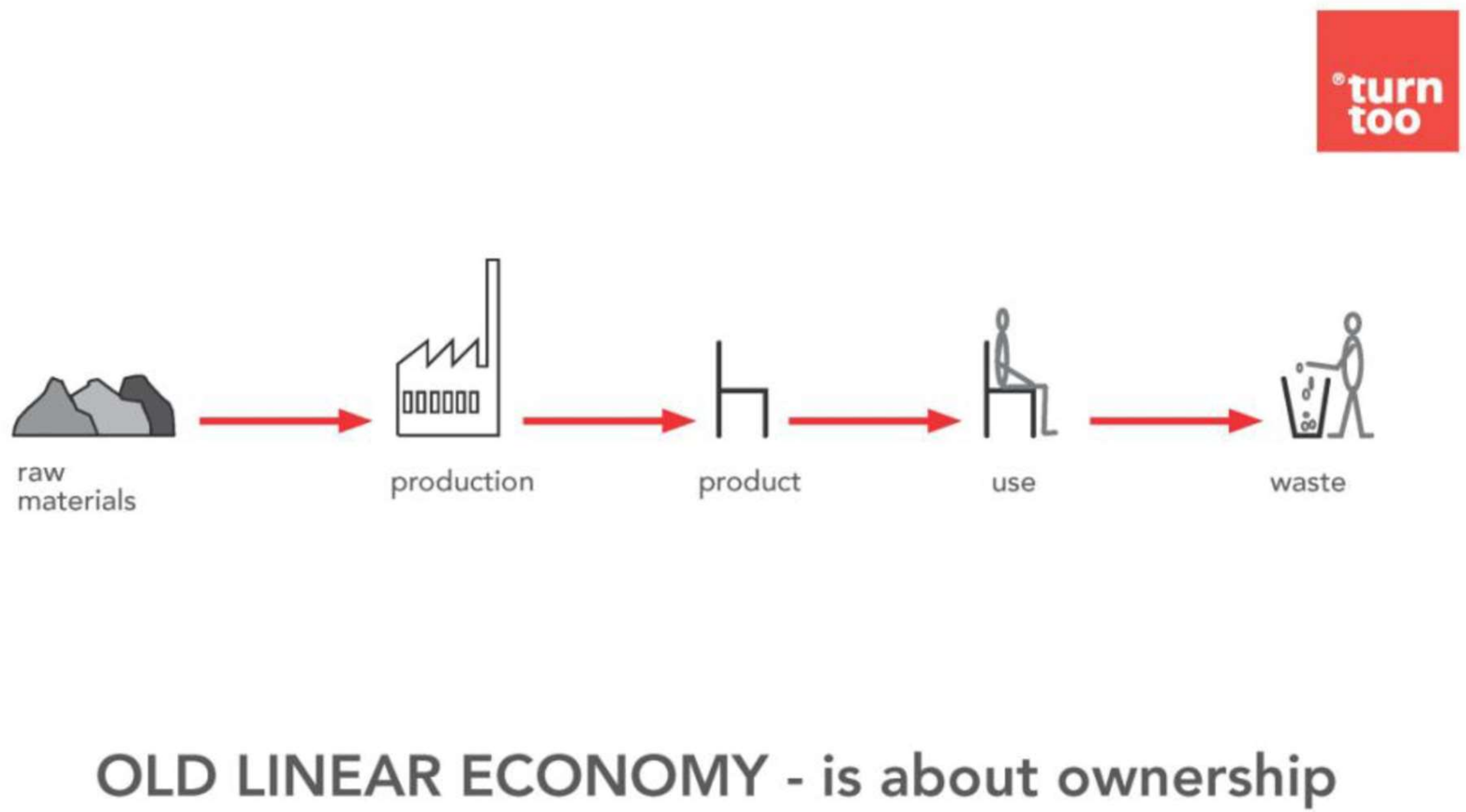
- Evaluation of the opportunity of recycling
  - Technique
    - Waste characterization
    - Durability
    - Consistency of the properties
  - Logistic et economic
    - Deposit and transport
    - Consistency of the production
    - Conditioning
    - Localisation

Conditions for recycling

- Evaluation of the opportunity of recycling
  - Environmental et economic
    - Decrease of the quantities in landfill
    - Regulatory obligation to eliminate
    - Taxation

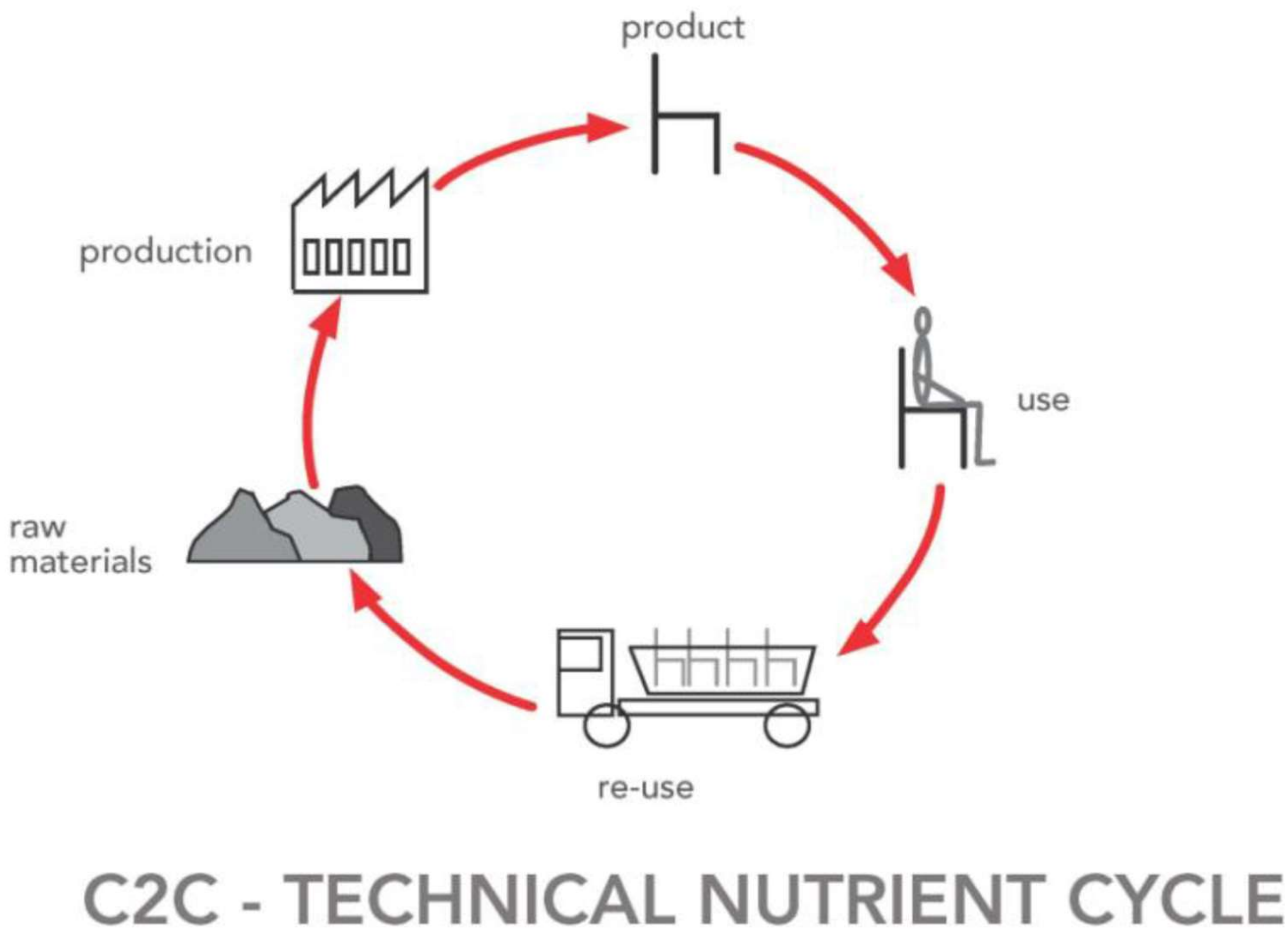
We don't recycle …
anything,
anyhow,
at any price.

Conditions for recycling



SOURCE: S. BECKERS (d'après M. BRAUNGART –EPEA, Cradle to Cradle)

Conditions for recycling

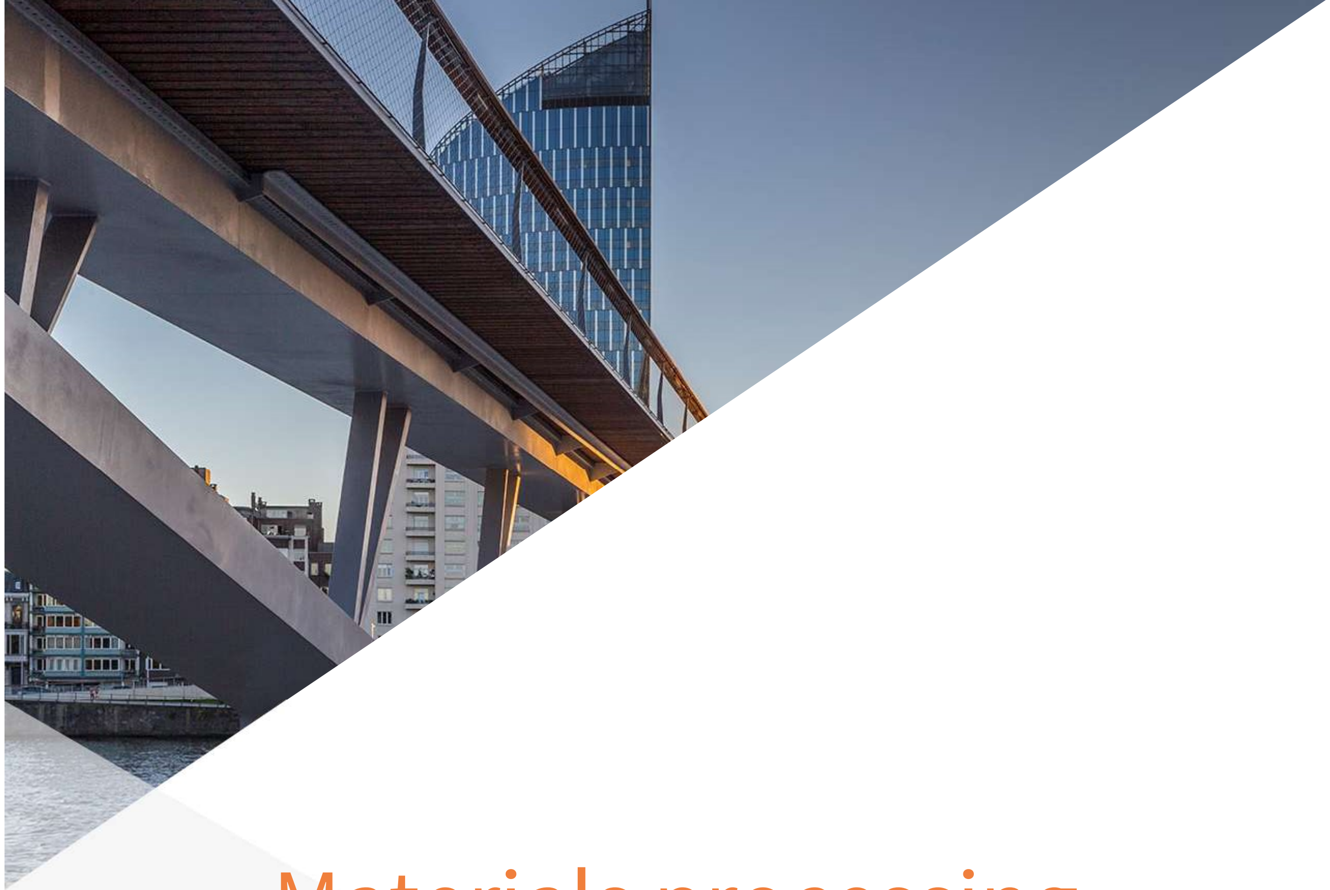


SOURCE: S. BECKERS (d’après M. BRAUNGART –EPEA, Cradle to Cradle)

Most significative challenges

- the lack of incentive to design for the end-of-life issues for construction products
- the low value of products at end-of-life (economic challenge)
- the construction industry's structure (fragmented supply chain)

- *a better recovery of material by means of viable take-back schemes*
- *higher value markets*
- *assurance schemes for reused materials*



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Materials processing

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C&DW recycling

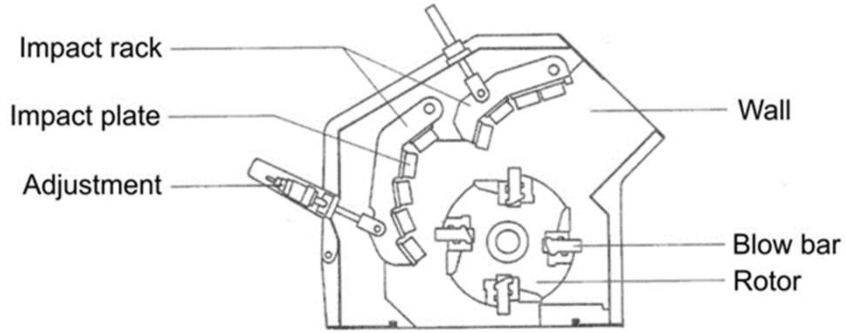
- Transforming wastes …

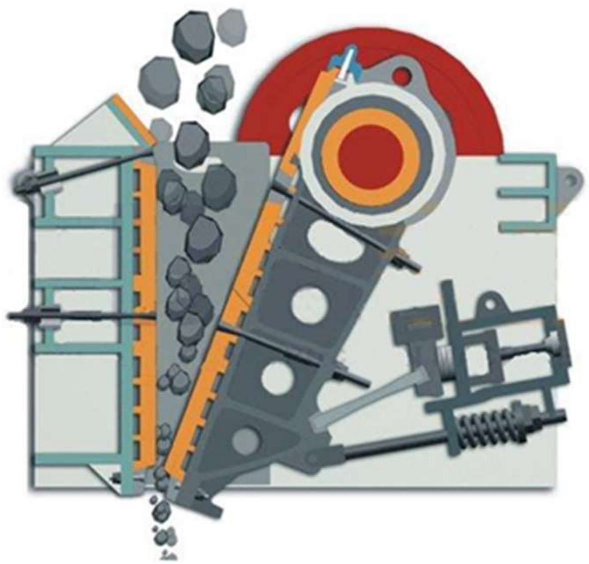
C&DW recycling

- … into secondary ressources

Material processing

- Impact crusher
  - allows producing very fine fractions
  - induces the biggest wear
  - limited by the primary size of waste to be treated
- Jaw crusher
  - to treat bulky waste like concrete slabs
  - does not allow to produce very fine particles
  - generally requires a secondary crushing





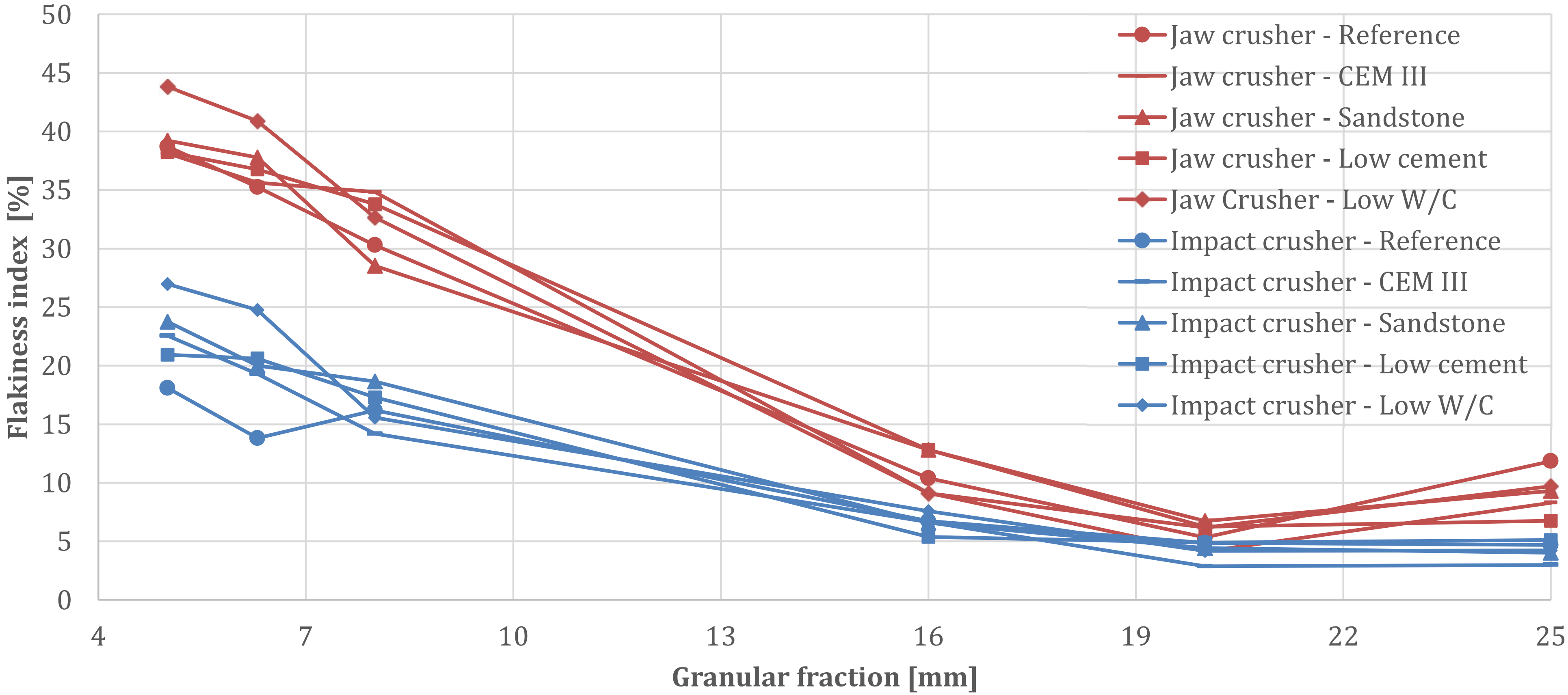
Material processing

- Experimental mixes

Name	Reference	CEM III	Sandstone	Low cement	Low W/C
Aggregates nature	Limestone	Limestone	**Sandstone**	Limestone	Limestone
Aggregates 2/7 mm (kg/m³)	368.8	368.8	368.8	405.1	367.1
Aggregates 7/14 mm (kg/m³)	345	345	345	379	343.4
Aggregates 14/20 mm (kg/m³)	433.5	433.5	433.5	476.2	431.5
Sand 0/4 mm (kg/m³)	604.9	604.9	604.9	664.4	602.1
Cement type	CEM I 52.5	**CEM III 52.5**	CEM I 52.5	CEM I 52.5	CEM I 52.5
Cement quantity (kg/m³)	400	400	400	**320**	452
Cement paste volume (dm³/m³)	351	358	351	282	351
Efficient water (kg)	224.2	224.2	224.2	180.6	207.1
W/C ratio	0.56	0.56	0.56	0.56	**0.46**
Superplasticizer (g/kg cement)	0	0	0	6.8	3.3

Material processing

- The flakiness index decreases with increasing granular fraction and the jaw crusher produces flakier aggregates
- No influence of the concrete composition



Effect of washing

Expectations of washing aggregates:

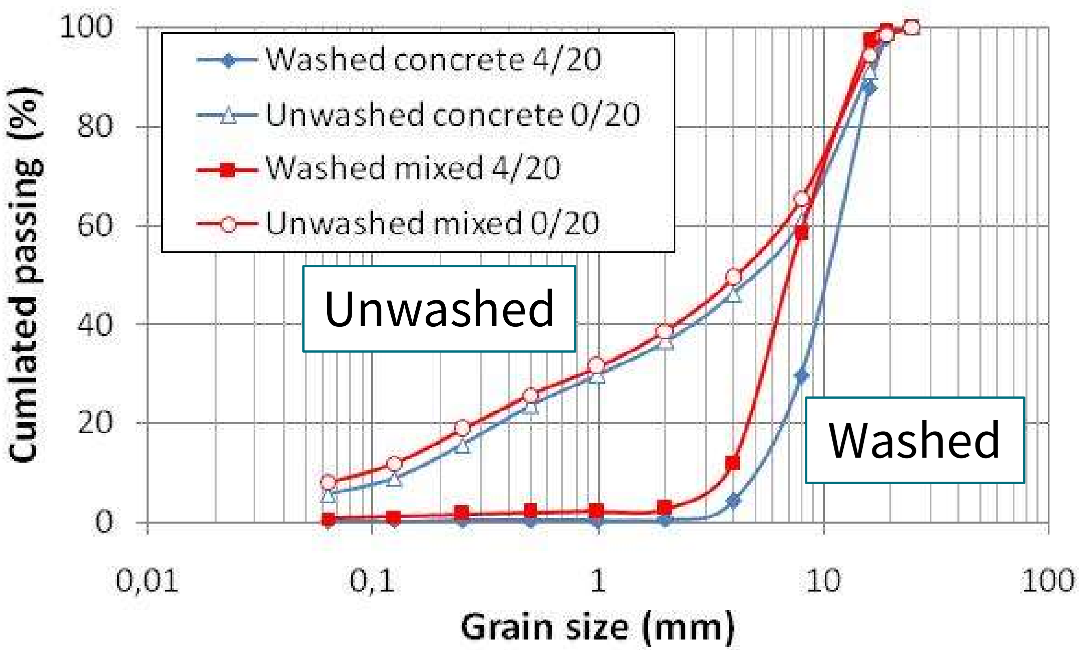
- Constrain grain size distribution
- Decrease fine content
- Decrease the quantity of unwished components (floating, clay, plaster...)
- Increase resistance to fragmentation

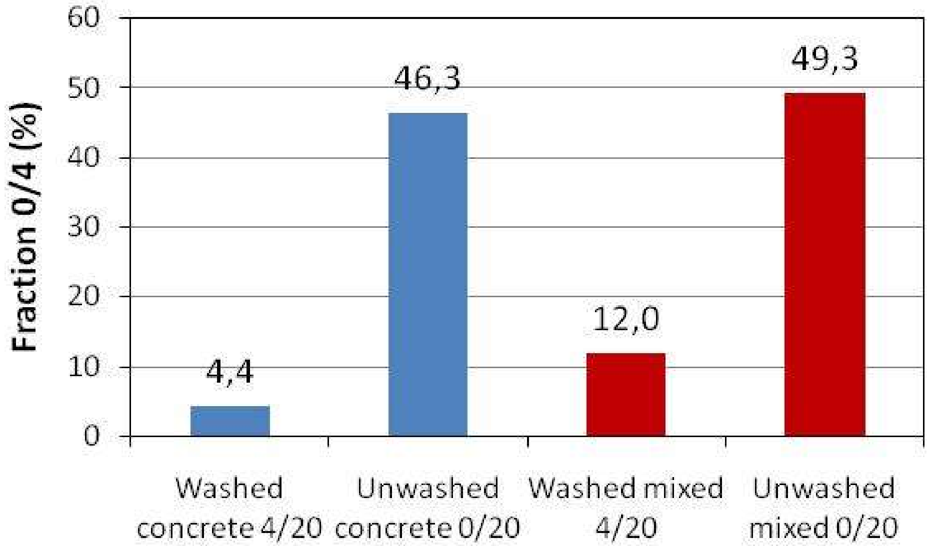
Methodology

Unwashed		Washed
Concrete aggregate 0/20	↔	Concrete aggregate 4/20
Mixed aggregate 0/20	↔	Mixed aggregate 4/20

Grain size distribution - aggregates

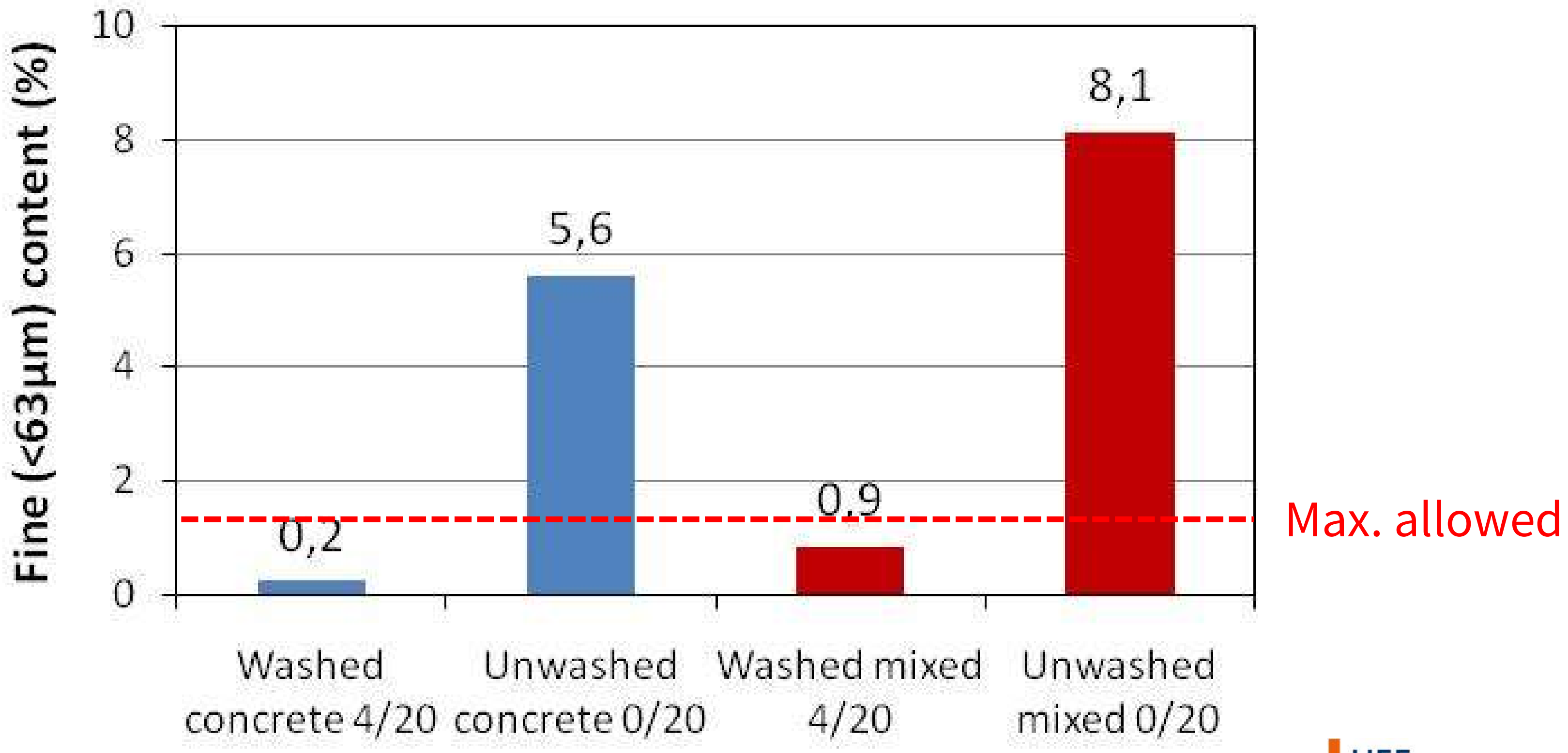
- 0/4 fraction comprises nearly 50% of the unwashed aggregates composition
- 0/4 fraction a bit higher in mixed aggregates
- Washing significantly reduces the sand fraction of the aggregates





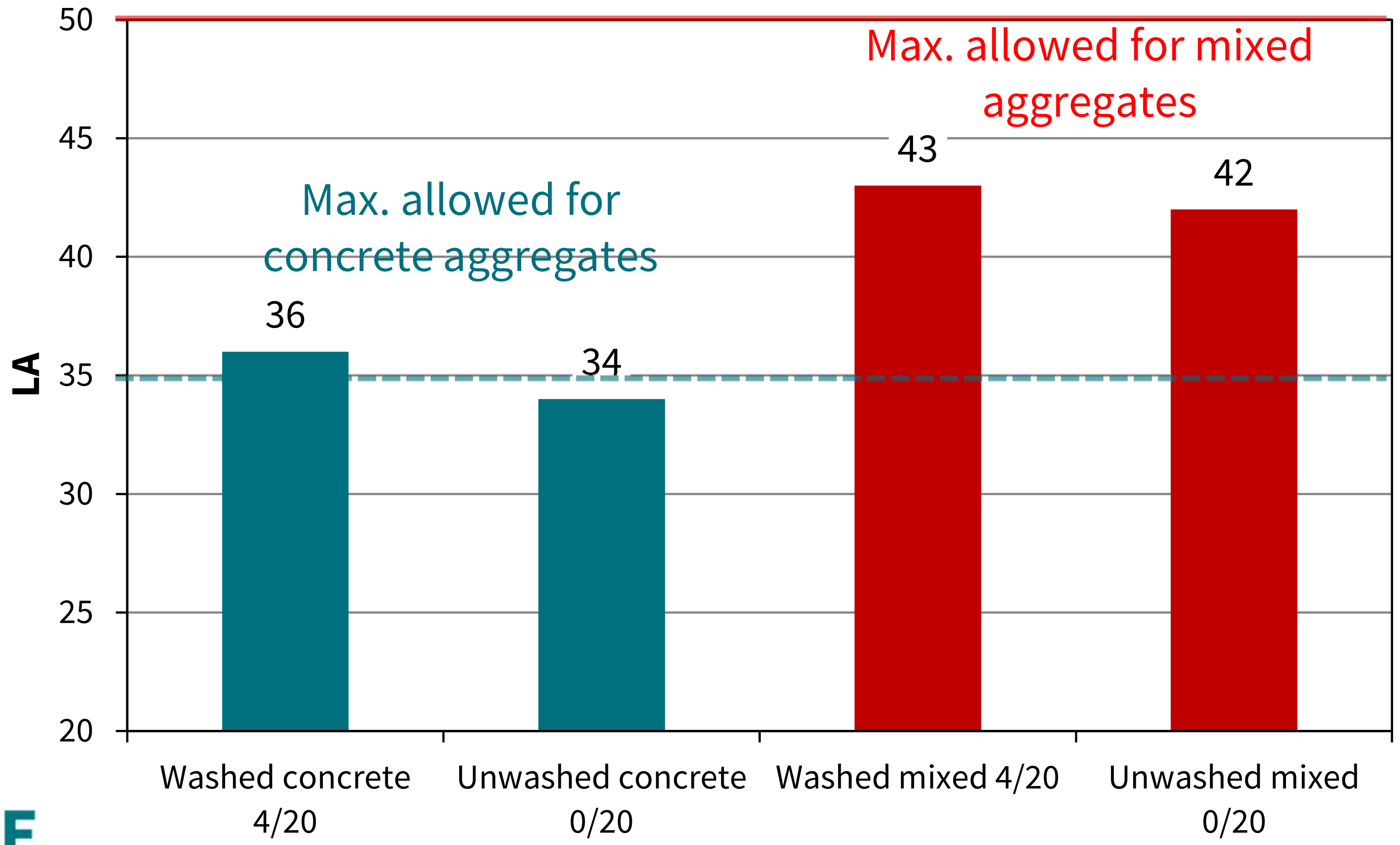
Grain size distribution - aggregates

- Fine content (< 63µm) higher in mixed aggregates and significantly reduced by washing
- Fine fraction higher in mixed aggregates
- Washed aggregates respect regulations in all considered countries



Resistance to fragmentation

- Concrete recycled aggregates have better resistance to fragmentation than mixed aggregates
- No effect of washing



Conclusions

Expectations of washing aggregates:

- Constrain grain size distribution ✓
- Decrease fine content ✓
- Decrease the quantity of unwished components (floating, clay, plaster…) ✓
- Increase resistance to fragmentation ✗

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Characterization of Recycled Concrete Aggregates

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Flow sheet for material processing

Flow sheet for material processing

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Standardization

Standards NBN EN 206 and NBN B 15-001

- Annex E (NBN EN 206) gives recommendations for using recycled aggregates
- Two types of aggregates are defined (d > 4mm) :

Type A : concrete aggregates

Type B : mix aggregates

Belgian context

Belgian norm NBN B 15-001 defines criterions A+ recycled aggregates :

- $d \geq 4$ mm et $D \geq 10$ mm;
- Composition
  - Rc_{90}, Rcu_{95}, Ra_{1-}, $XRg_{0.5-}$, FL_{2-}
- Physical and chemical properties
  - FI_{20}, $f_{1.5}$, LA_{35}, $SS_{0.2}$, A_{40}
- Minimum density : 2200 kg/m^3;
- Maximum water absorption : 10% $\pm$ 2%.

Categories based on NBN 12620 :

Rc : concrete
Ru : natural stone
Ra : bitumineous material
XRg : glass
FL : floating materials

FI : flakiness index
f : fine content
LA : Los Angeles coefficient
SS : soluble sulfate
A : setting time modification

Can be used in concrete with a resistance class of up to $\leq$ C30/37

Belgian context

Belgian norm NBN B 15-001 defines criterions B+ recycled aggregates :

- d ≥ 4 mm et D ≥ 10 mm;
- Composition
    - $\mathrm{Rc}_{50}, \mathrm{Rcu}_{70}, \mathrm{Ra}_{5}, \mathrm{R}b_{30-}, \mathrm{XRg}_{0.5-}, \mathrm{FL}_{2-}$
- Physical and chemical properties
    - $FI_{50}, \mathrm{LA}_{50}, SS_{0.2}, A_{40}$
- Minimum density : 1700 kg/m^3;
- Maximum water absorption : 15% ± 2%.

Categories based on NBN 12620 :

Rc : concrete
Ru : natural stone
Ra : bitumineous material
XRg : glass
FL : floating materials

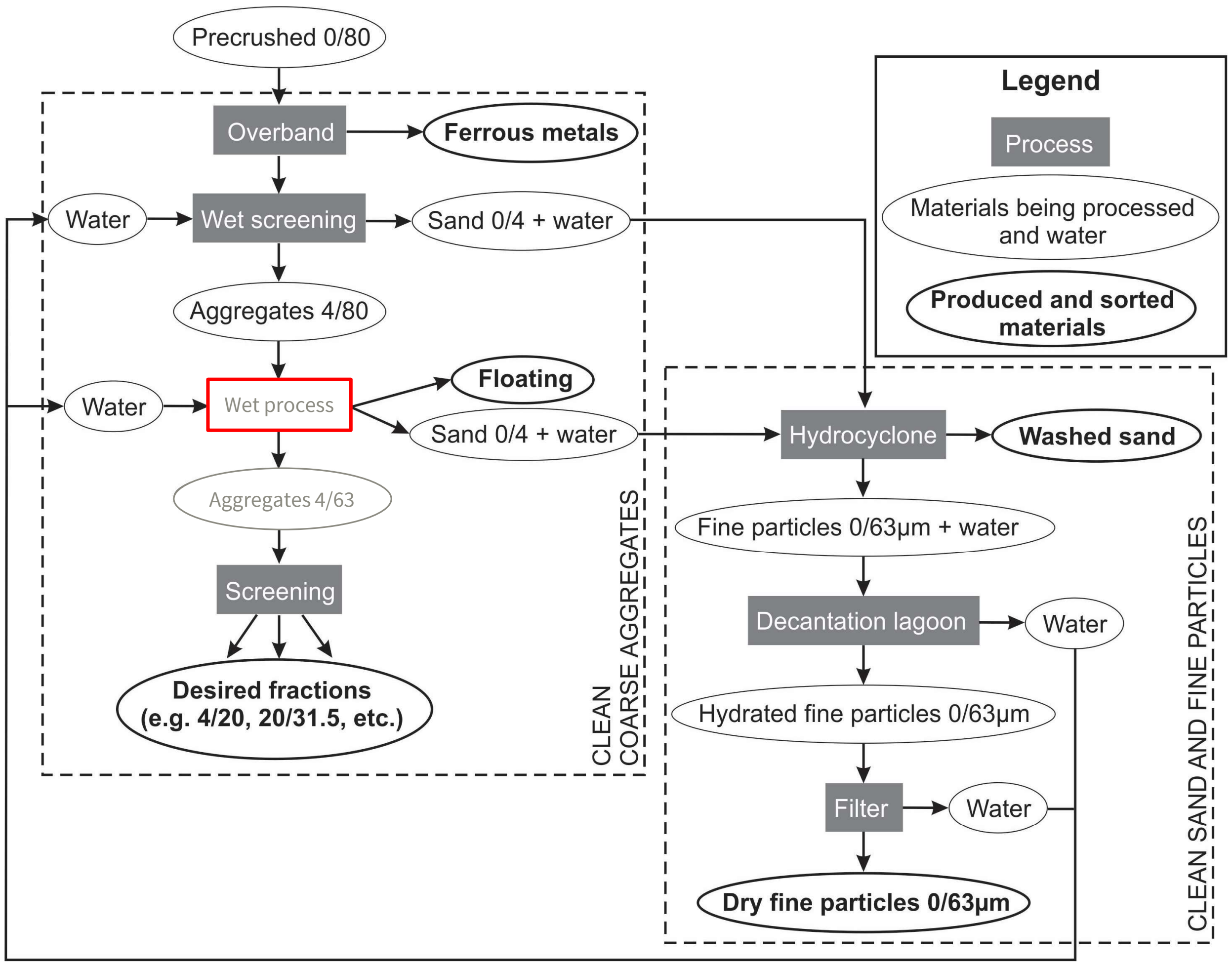
FI : flakiness index
f : fine content
LA : Los Angeles coefficient
SS : soluble sulphate
A : setting time modification

Can be used in concrete with a resistance class of up to ≤ C25/30

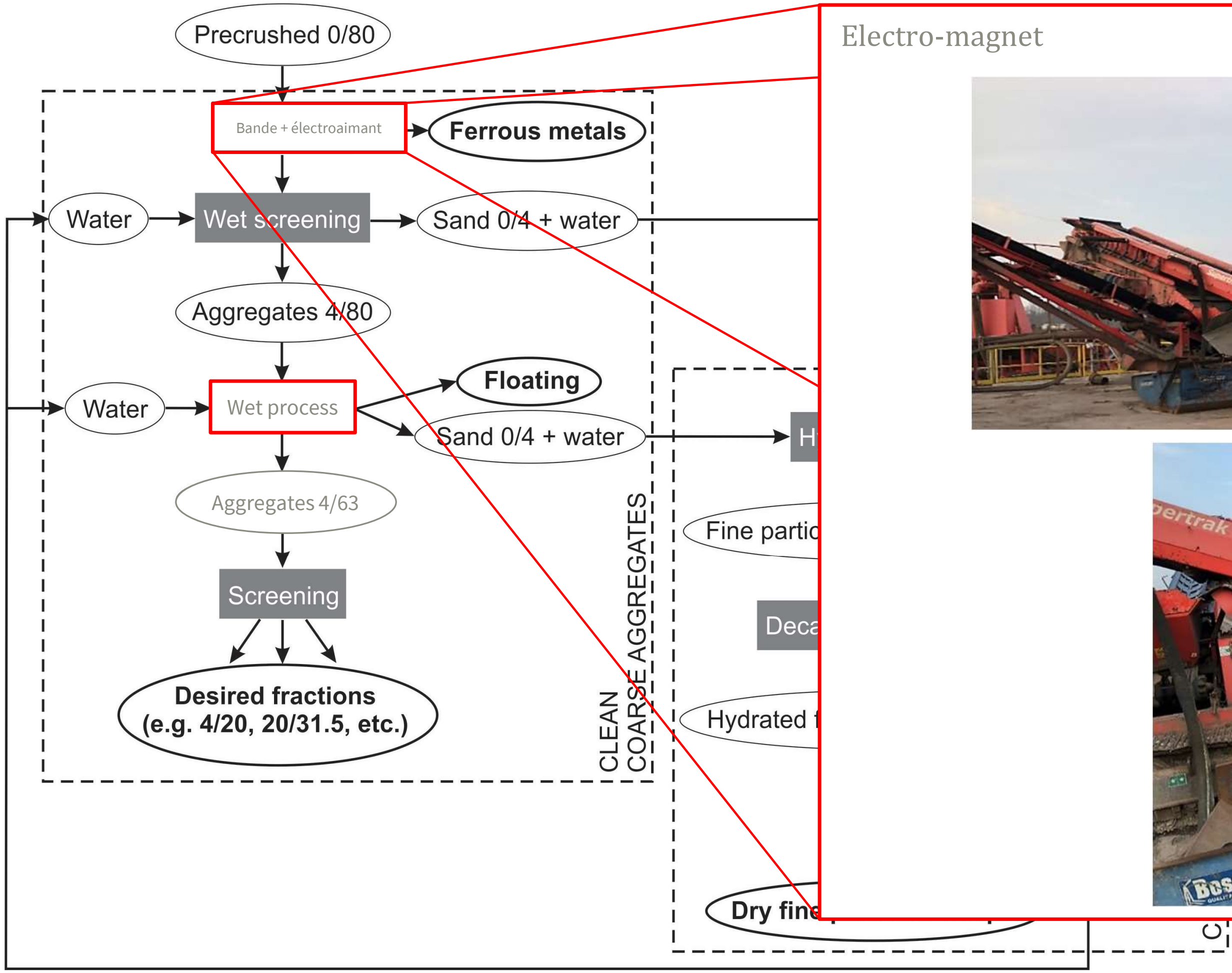
Production of recycled aggregates

“SeRaMCo recycling plant” (Tradecowall)

Production of recycled aggregates

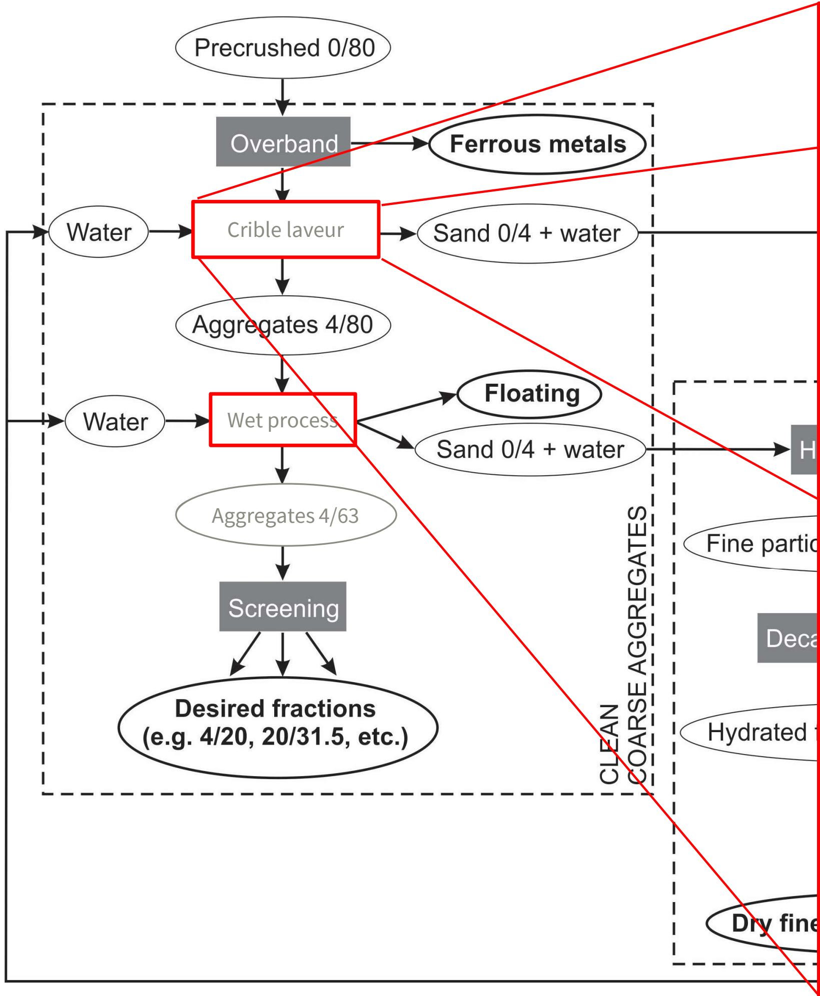


Production of recycled aggregates



Electro-magnet

Production of recycled aggregates



3 steps washing

1. Sieve washer

1st washing → 63+ mm → rejected

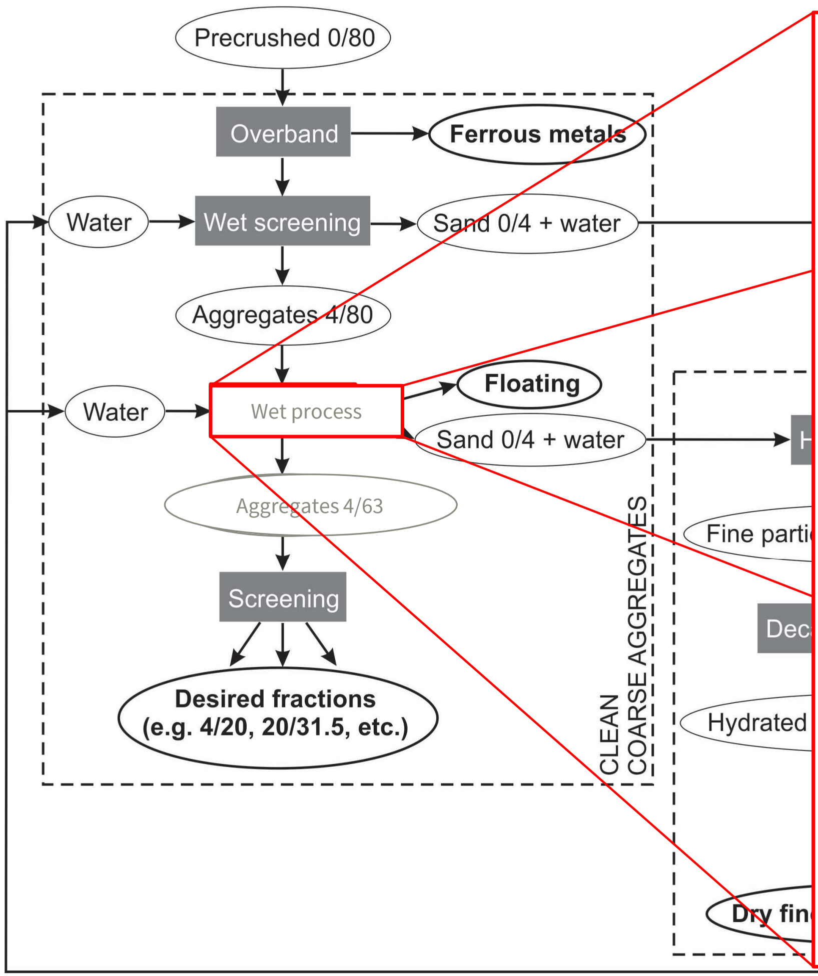
1st washing → 0/63mm

0/63mm → 2nd washing

2nd washing → 0/4 mm → hydrocyclones

2nd washing → 4/63 mm → Sludge trap

Production of recycled aggregates



3 steps washing:

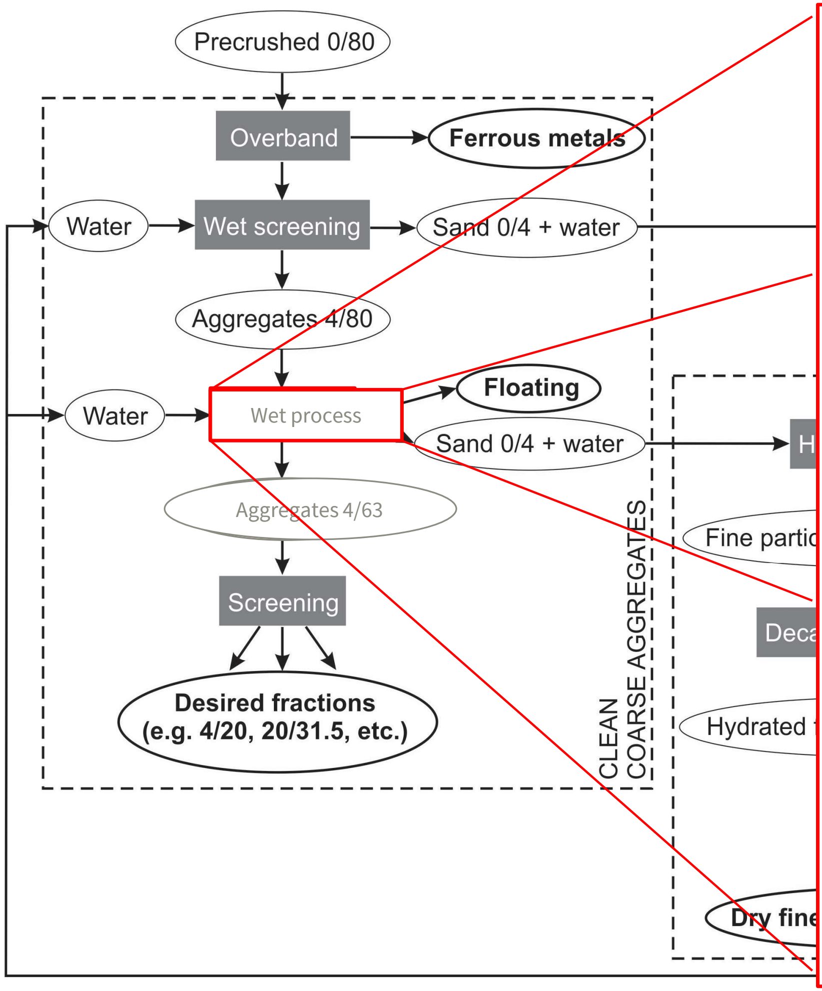
2. Paddle de-sludger

3rd washing

Wash water with fine particles → hydrocyclone

4/63mm

Production of recycled aggregates



3 steps washing:

3. Mogensen screen flusher

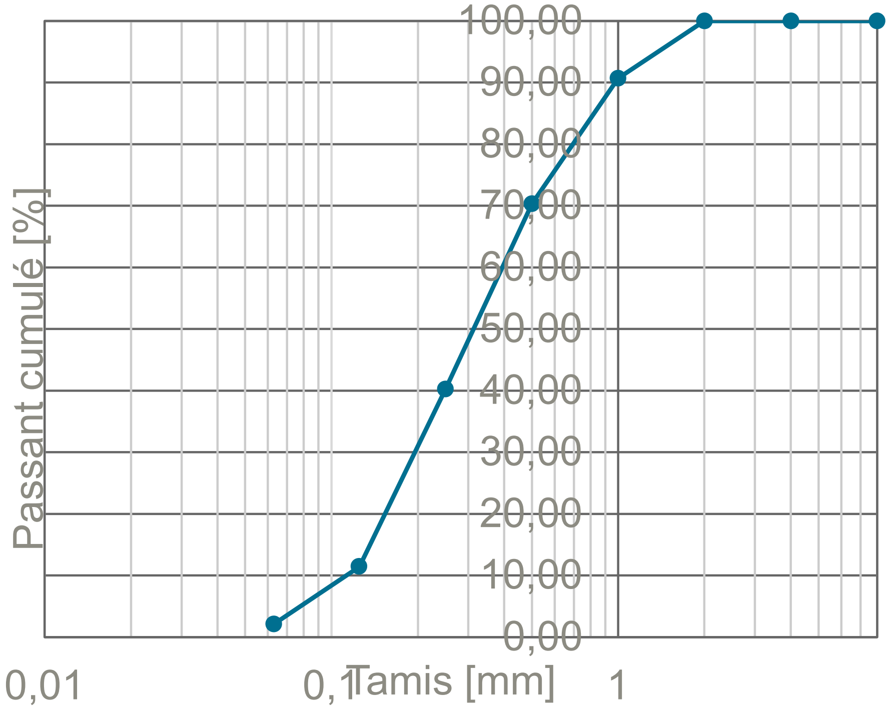
4th washing

- 0/4mm → hydrocyclone
- 4/63mm

Production of recycled aggregates

Recycled concrete fine washed sand 0/4 (semi industrial screening process 0/2)

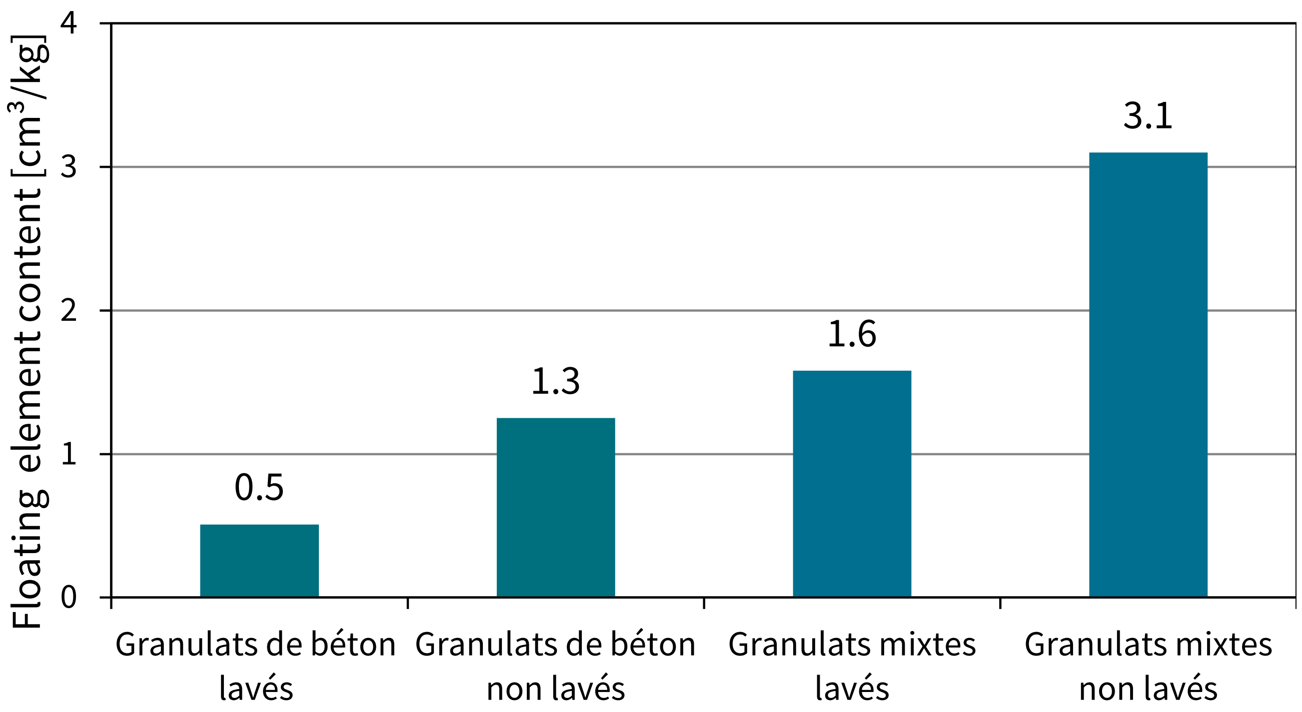
- Sieving curve ⟶ 2.5 % fines



Production of recycled aggregates

Recycled concrete fine washed sand 0/4 (semi industrial screening process 0/2)

- Floating particles → 50 % reduction



Production of recycled aggregates

Recycled concrete fine washed sand 0/4 (semi industrial screening process 0/2)

- Other properties

	Water absorption [%]	Density [kg/m³]	Cement paste content [%]
Recycled sand 0/2	4.65	2230	2.83

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Properties of concrete blocks made with recycled concrete aggregates: from block wastes to new blocks

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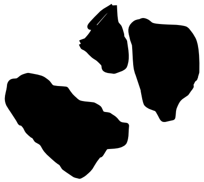
Materials

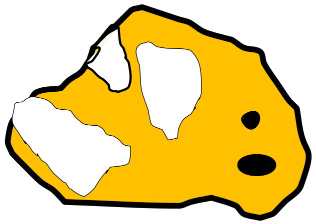
- ▶ RCA manufactured in laboratory
  - Old concrete from block wastes (C8/10 from Prefer Company)
  - Crushing (jaw crusher in laboratory, opening ≈10mm)
  - Separation of RCA by sieving (0/20mm)
    - ➢ Four granular classes: 0/2 - 2/6.3 - 6.3/14 - 14/20

Properties of RCA

- Hardened Cement Paste Content (CPC) of RCA
  - Principal soluble and insoluble phases in salicylic acid and methanol dissolution *(Zhao et al., 2013. Journal of Sustainable Cement-Based Materials* ***2****,186-203)*



Quartz, Dolomite, Calcite
Insoluble in salicylic acid

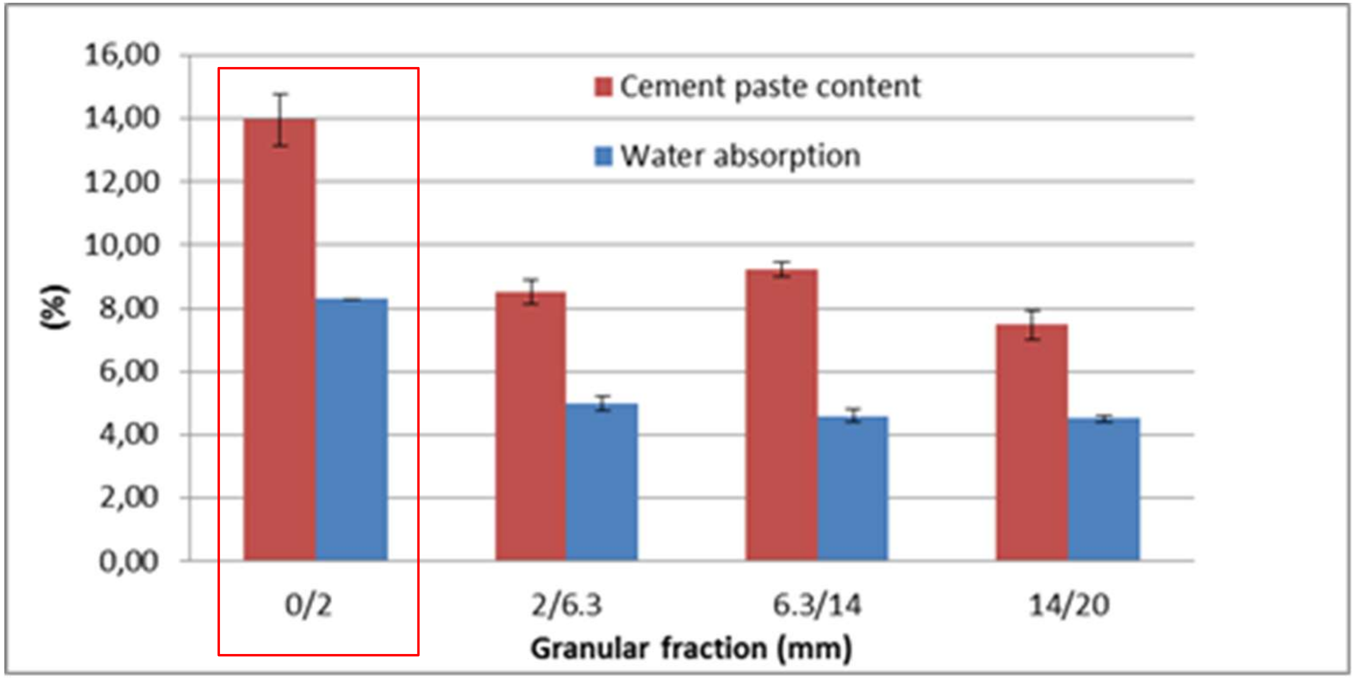


C_2S, C_3S, $Ca(OH)_2$, C-S-H, Ettringite
Soluble in salicylic acid

Insoluble in salicylic acid
C_4AF, AFm → CEM I
Calcite, Slag… → CEM II, III

Properties of RCA

- Water absorption W_A (EN 1097-6)



- CPC and W_A of 0/2mm fraction larger than three coarse fractions
- Recycled sand presents higher CPC and W_A than CRCA

Materials

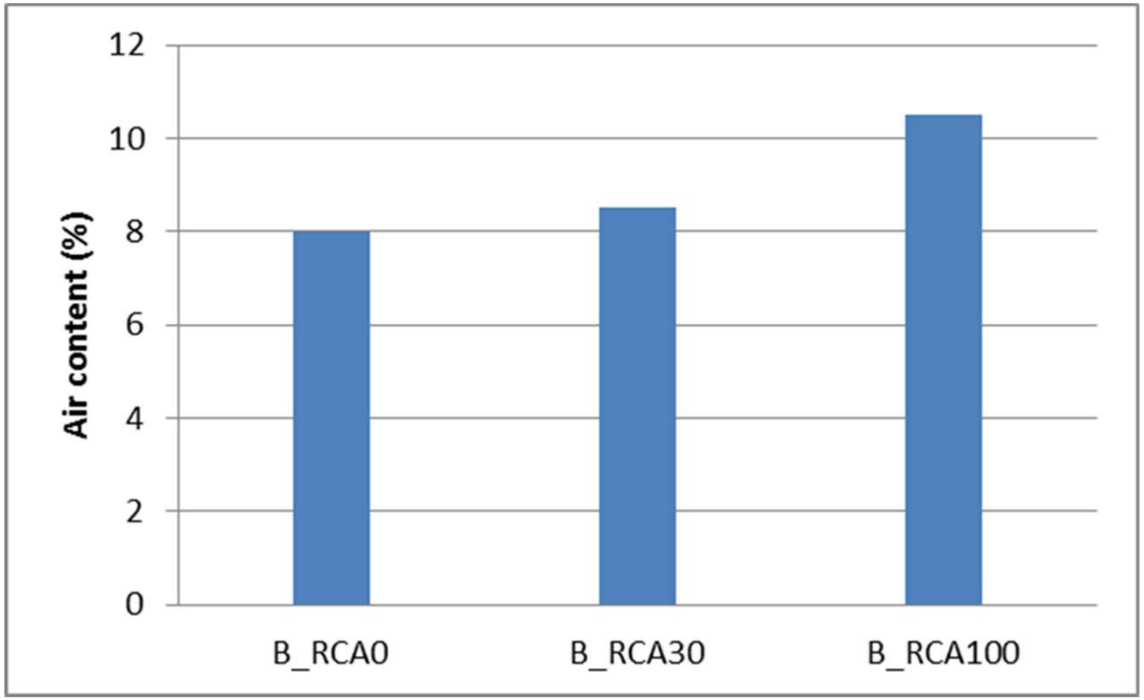
- Mix design

	B_RCA0	*B_RCA30*	*B_RCA100*
NA 2/7 (kg)	1080	754	0
RCA 2/6.3 (kg)	0	302	1008
NS 0/2 (kg)	825	825	825
Cement (kg)	150	150	150
Efficient water (kg)	105	105	105
Absorbed water (kg)	13.12	26.00	56.20
W_{eff}/C	0.70	0.70	0.70

- Different substitution rates of NA 2/7 by the same volume RCA 2/6.3 (0, 30, 100%)
- Same W_{eff}/C ratio - cement CEM III/A 42.5
- Pre-saturation of aggregates in the mixer **5 min** before the addition of cement by half of total water

Properties

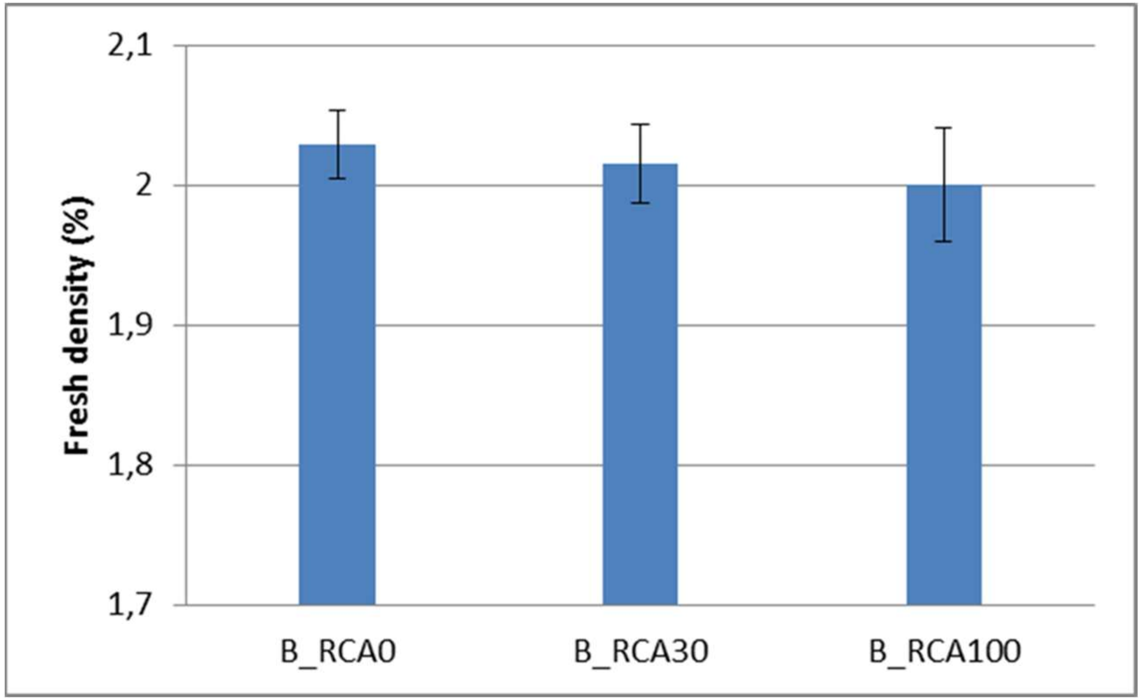
- Fresh properties of concrete (zero slump)



  - The air content of concrete increases when the substitution of recycled aggregates increases

Properties

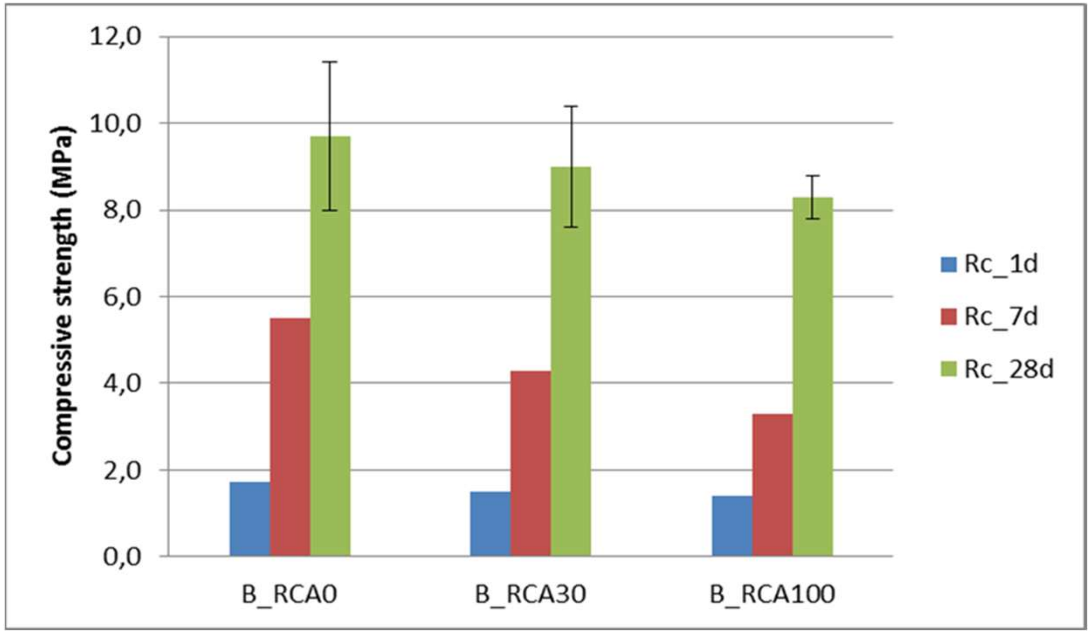
- ▶ Density of fresh concrete



  - The density of fresh concrete slightly decreases when the substitution of RCA increases

Properties

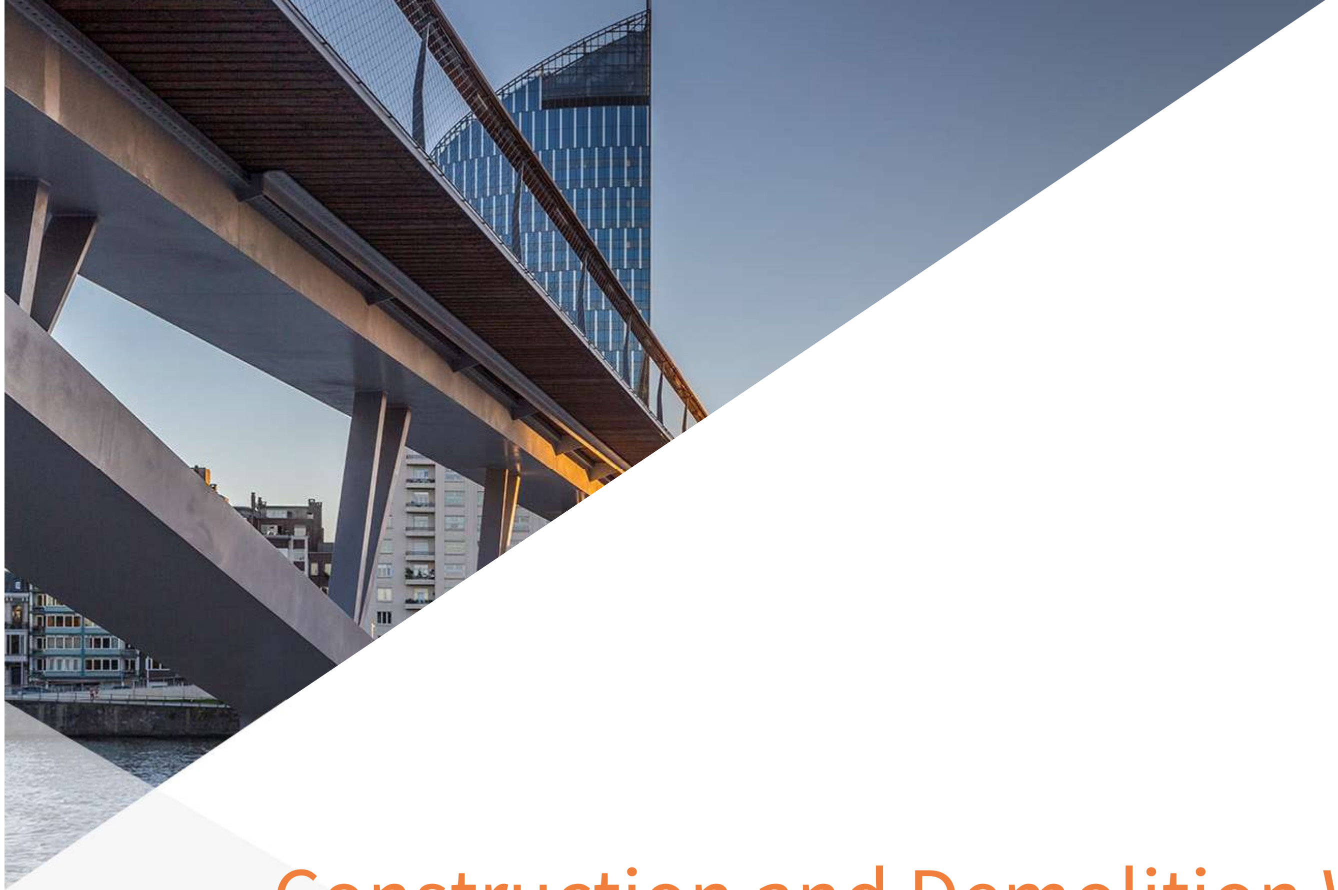
- Compressive strength



  - Compressive strengths of concretes with RCA are slightly lower than those of concrete with natural aggregate
  - Compressive strength of concrete made with 100% RCA at 28 days is 8 MPa (14.4% decrease)

Conclusions

- Feasibility of using RCA obtained from old concrete block wastes in the new concrete blocks
  - Recycled sand possesses significantly higher cement paste content and higher water absorption than coarse RCA
  - Compressive strength of concrete blocks slightly decreases as the substitution of RCA increases;
  - Rc of B_RCA100 could reach 8 MPa after 28 days without increasing the cement content of the concrete mix



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Construction and Demolition Waste: SeRaMCo project

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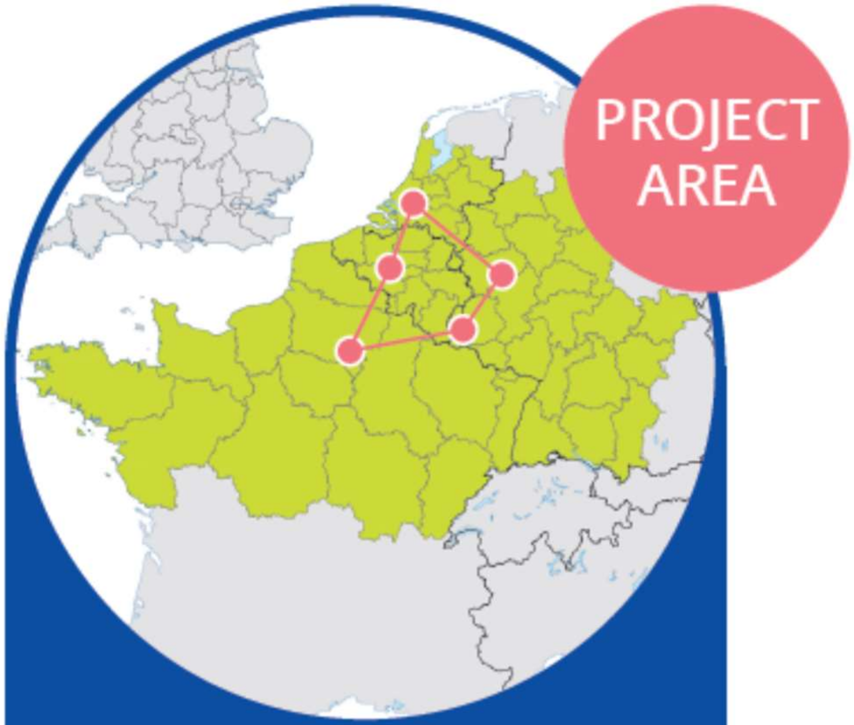
Interreg
EUROPEAN UNION
North-West Europe
SeRaMCo
European Regional Development Fund



Duration
March 2017 - September 2020

Budget
Total: € 7.28 million
EU funding: € 4.37 million

Partnership:
11 Partners
3 Sub-Partners
3 Associated Partners

17 Partners from 5 EU countries (Germany, France, Netherlands, Belgium, Luxemburg)

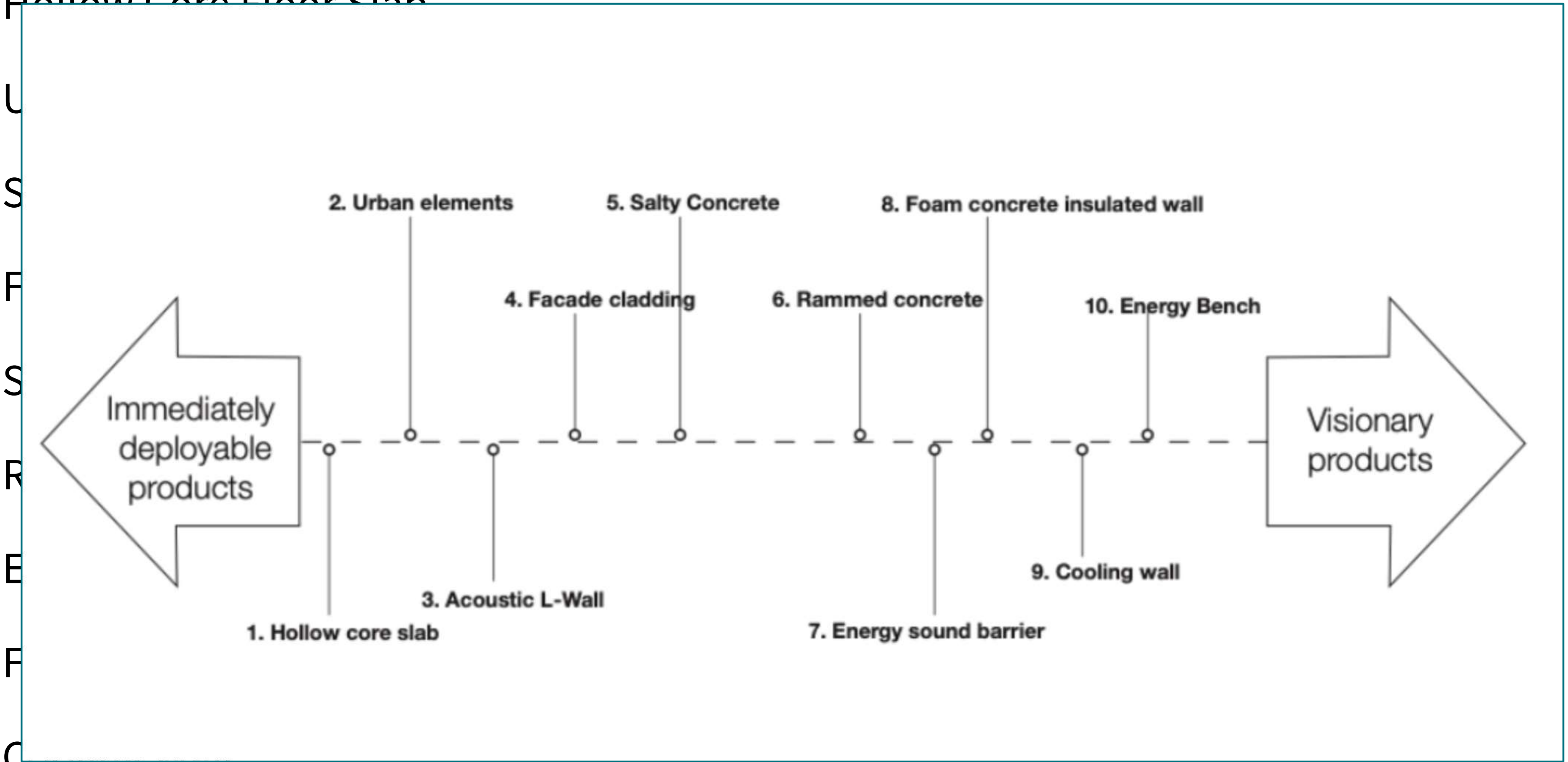
Objective: prefabricated concrete elements with recycled concrete aggregates

10 Product designs

1. Hollow Core Floor Slab
2. Urban SeRaMCo Elements
3. Sound Absorbing L-Wall
4. Façade Cladding
5. Salty Concrete
6. Rammed Concrete
7. Energy Sound Barrier
8. Foam Concrete Insulated Wall
9. Cooling Wall
10. Energy Bench

10 Product designs

1. Hollow Core Floor Slab
2. U
3. S
4. F
5. S
6. R
7. E
8. F
9. Cooling Wall
10. Energy Bench



10 Product designs

1. **Hollow Core Floor Slab**
2. **Urban SeRaMCo Elements**
3. **Sound Absorbing L-Wall**
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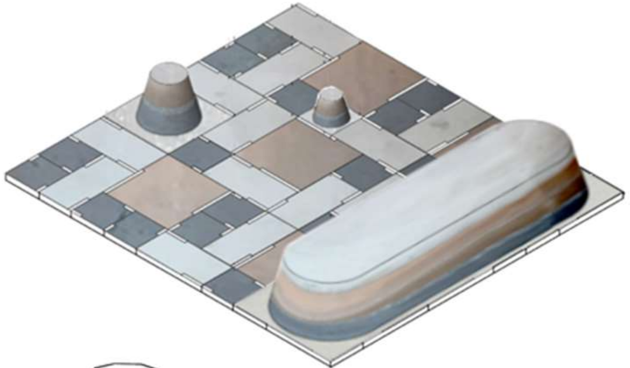

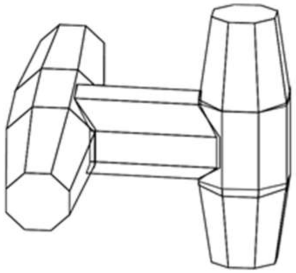

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10 Product designs

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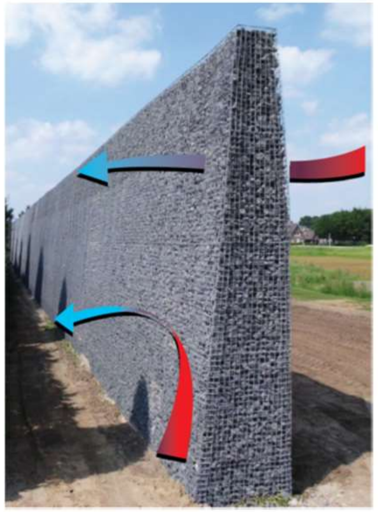
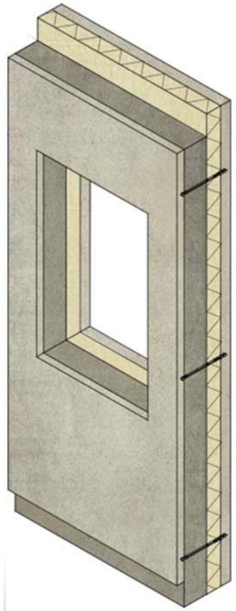
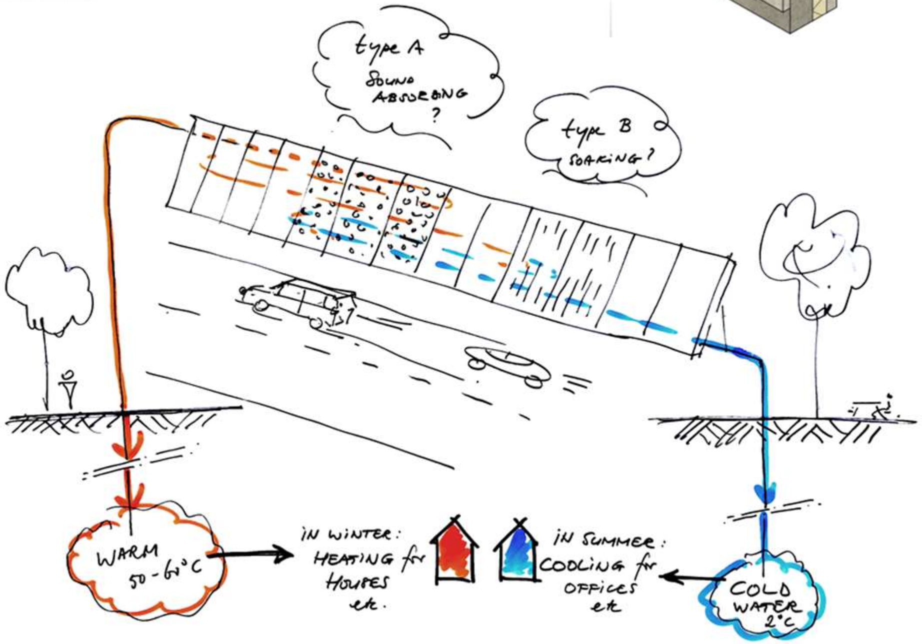
10. **Energy Bench**



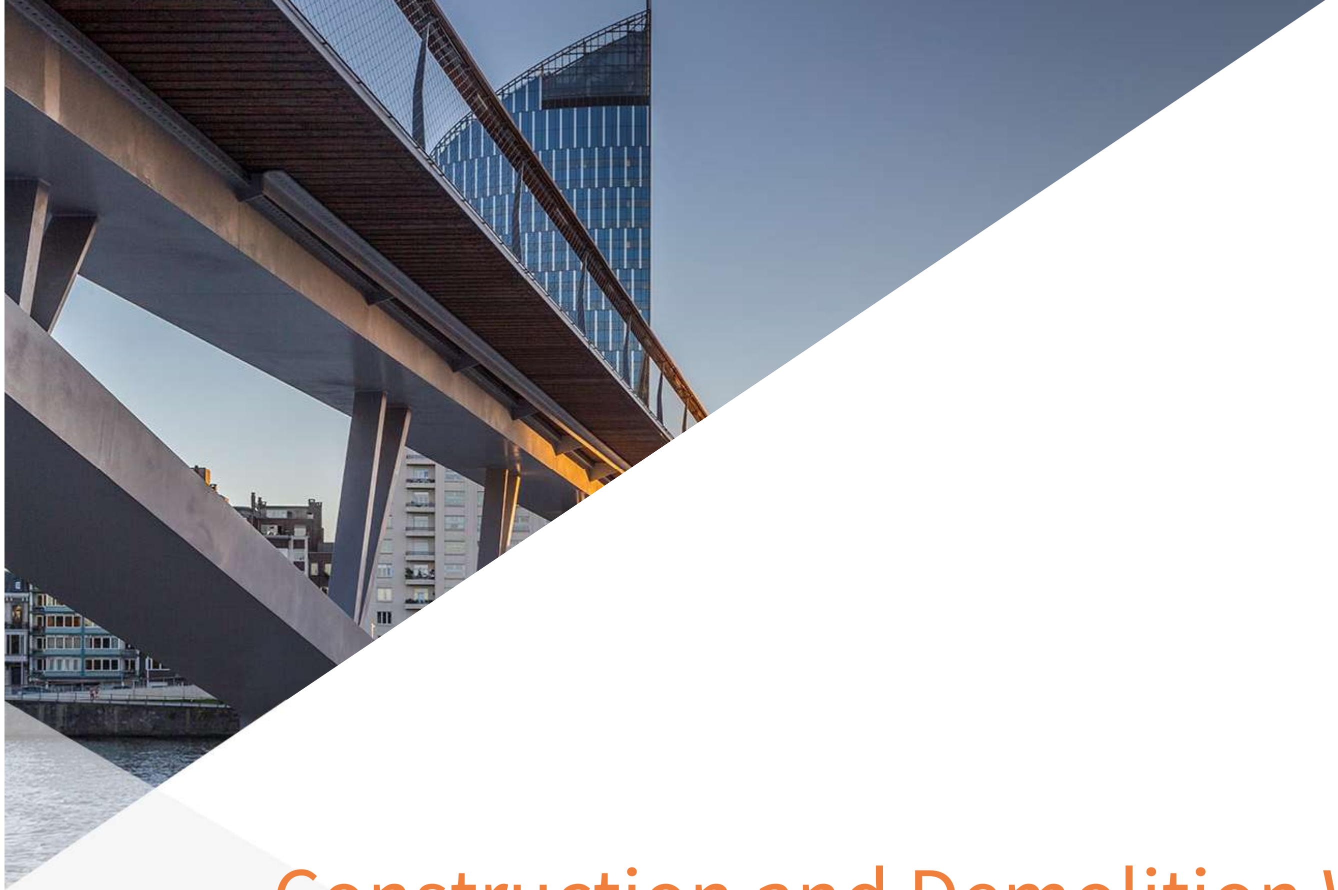




Parkour Park

Parkour Park

LIÈGE université
Sciences Appliquées



Construction and Demolition Waste: CiRMAP project

UEE
Urban & Environmental Engineering

CiRMAP project

Objective:
Circular economy via customisable furniture with Recycled MAterials for public Places

Partnership:

17 partners and sub-partners from 5 European countries :

- Germany
- Belgium
- France
- Netherlands
- United Kingdom

Interreg NWE

Durée : 2020-2023

Budget : 4.22 M€ ERDF
7.03 M€ total

CIRMAP project : challenges

3D printing:

(+) Design opportunities

(−) Environmental impact

→ Binder

Granular skeleton

Siam Research and Innovation Company - Triple S (2017)

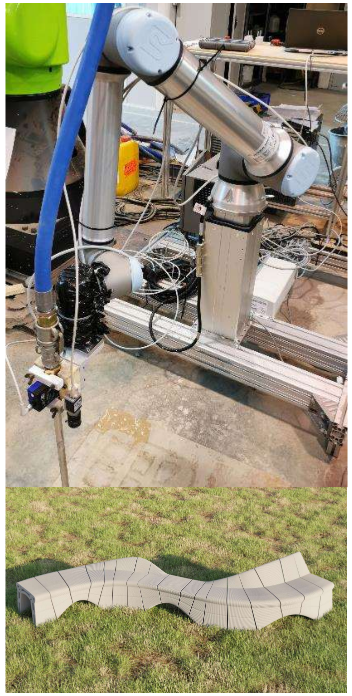
CIRMAP project: objectives

Design and production of 3D printed urban furnitures with recycled fine aggregates

THEMATIC PRIORITY

RESOURCE AND MATERIALS EFFICIENCY

CIRMAP project: organization

WP T1	WP T2	WP T3
Material flow, market and life cycle analyses	Development of methodologies and process for the 3DP of mortars containing RFA	Industrial feasibility
		

Material used for the study

Granular materials :

Natural sand:
- St Bonnet quarry natural sand (France)
- Crushed limestone sand
- Screened at 2 mm

Recycled Fine Aggregates (RFA):
- Tradecowall RFA – RECYMEX recycling plant at St-Ghislain (Belgium)
- Washed recycled concrete sand (95%+ concrete)
- Screened semi-industrially at 0/2 by the CTP

Hydraulic binders :

Cement:
- Vicat cement: Performat®, CEM I 52.5 N

Admixtures :

Liquid superplasticizer (SP):
- Chryso®Fluid Optima 100

Viscosity modifying admixture (VMA):
- Chryso Belitex® Addichap

Mortar Formulations

RFA mortar formulation : developed and tested with IMT Nord Europe using the extrusion pistol method. This formulation had been successfully printed at the lab scale multiple times (see pictures below).

RFA 0/2 Tradecowall [kg/m³]	Vicat cement Performat CEM I 52.5N [kg/m³]	E_{eff}/C	SP [% SP/C]	VMA [% VMA/C]
995.6	905	0.29	2.50	0.2

Mortar Formulations

Reference mortar formulation : developed to present similar rheology to the RFA (Tradecowall) mortar. The rheology was evaluated using the flow table test and slump test

The mortar is poured inside the conical mold. The mold is and the height of the mortar is measured using a caliper (slump test). The mortar is then subjected to 10, 15 and 25 jolts with the flow table (to a maximum of 25 jolts). After each sequence, the mortar's spread is measured using a caliper (2 perpendicular measurements are taken)

	Sand	Comment	Mean height after mold removal [mm]	Mean diameter after 10 jolts [mm]	Mean diameter after 15 jolts [mm]	Mean diameter after 25 jolts [mm]
#1	Natural crushed limestone sand	St-Bonnet Quarry 3 mixes tested	45.4	118.6	124.8	134.1
#2	Natural silica river sand	Rhine sand 1 mix tested	40.2	116.8	122.8	131.7
#3	Tradecowall RFA	Washed concrete RFA 3 mixes tested	43.4	120.8	128.0	139.1

The mortar mixed with the St-Bonnet crushed limestone sand presents closer rheological properties and has been chosen as reference mortar with the following formulation (same composition with less WAI24 water) :

Natural 0/2 crushed limestone sand [kg/m³]	Vicat cement Performat CEM I 52.5N [kg/m³]	E_{eff}/C	SP [% SP/C]	VMA [% VMA/C]
995.6	905	0.29	2.50	0.2

Experimental program

Three points bending tests and compressive strength:

- NBN EN 196-1 :
- Tests at 2, 7, 28, 56 and 91 days
- 3 samples (4x4x16 cm) for each test
- Casted samples with 20°C and 95±5% relative humidity curing/water curing
- Casted samples with 20°C and 60±5% relative humidity curing
- Printed samples with 20°C and 95±5% relative humidity curing
- Reference mortar and Tradecowall RFA mortar

Capillary absorption tests :

- NBN EN 13057
  - Samples were cured in water at T=20 ± 3°C for 28 days, dried in an oven at 40°C for 7 days, and stored in a controlled environment at T=20 ± 3°C and RH=60 ± 10% for 7 days.
- NBN EN 480-5
  - Two sets of samples were stored directly in a controlled environment at T=20 ± 3°C and RH=60 ± 10%, one set is for testing at 7 days old, and another set is for testing at 90 days old.
- Reference mortar and Tradecowall RFA mortar
- Casted and printed samples

Experimental program

Porosity tests :

- NF P18-459
- Tests at 2, 7, 28, 56 and 91 days
- 3 samples (4x4x4 cm) for each test
- Casted samples with 20°C and 95±5% relative humidity curing/water curing
- Casted samples with 20°C and 60±5% relative humidity curing
- Printed samples with 20°C and 95±5% relative humidity curing
- Reference mortar and Tradecowall RFA mortar

Drying Shrinkage:

- NF P18-427
- Tests measurement is frequent after demolding (every 2h) on the 2nd day, followed by the everyday measurement for 2 weeks.
- 3 samples (4x4x16 cm) for each test
- Casted samples with 20°C and 60±5% relative humidity curing
- Storing ambient is 20°C and 60±5% relative humidity
- Reference mortar and Tradecowall RFA mortar

Experimental program

Direct tensile tests :

- NBN EN 1542
- Tests at 2, 7, 28, 56 and 91 days
- 3 samples (d=50 mm and h= 50mm) cores drilled for each test
- Only for the printed samples with 20°C and 95±5% relative humidity curing
- Only for Tradecowall RFA mortar

Mortar preparation

Blending sequence (total duration: 15 min – Mixing paddle: Hook) :

No pre-saturation of the RFA

33% (W_{eff} + W_{abs}) + 33% cement + 33% RFA

Blending

33% (W_{eff} + W_{abs}) + 33% cement + VMA + SP + 33% RFA

Blending

33% (W_{eff} + W_{abs}) + 33% cement + 33% RFA

Blending

Casted samples (4x4x16 cm prismatic samples are casted)

Printed samples (4x4x16 cm prismatic samples are extracted from S shaped printed éléments)

Mortar preparation

Samples casting (according to a method derived from standard NBN EN 196-1)
Metallic molds are used, each mold presenting 3 prismatic indents
Each prismatic indent is half-filled with the mortar
The mold is fixed to a jolting table and the first mortar layer is compacted by applying 60 jolts
The other half is slightly over filled and 60 jolts are applied
The excess mortar is removed using a metal spatula

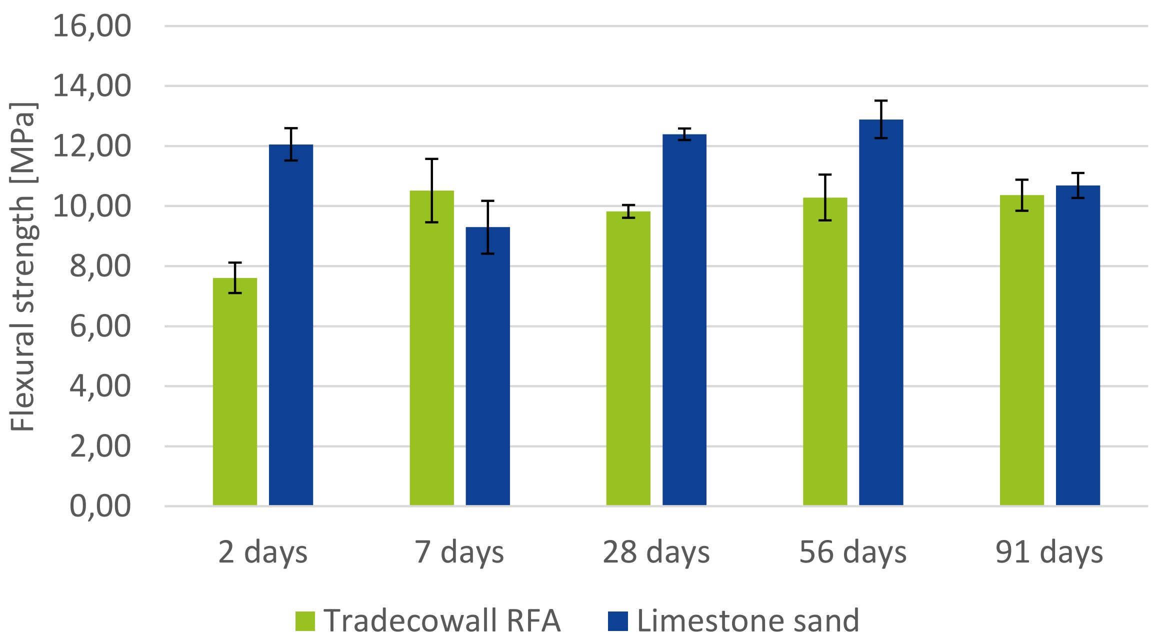
Samples conservation and curing
Right after casting, the filled molds are stored at 20°C and 95±5% relative humidity. After 24 hours, the samples are demolded to recover the 4 x 4 x 16 cm prismatic specimens.
A set of prismatic specimens are stored at 20°C and 95±5% relative humidity and another set are stored directly in a room with 20°C and 60±5% relative humidity curing. They are kept in these conditions for the required duration before testing (2, 7, 28, etc. days).

Printed samples
S shaped elements are printed at the IMT Nord Europe in Douai. The printed layer is around 6 cm wide and 1 cm thick. 6 layers are printed.
Two hours after printing, roughly 20 cm long segments are cut using a sharp metallic object (knife, ruler or trowel). They are covered with a plastic sheet and left to cure for the night.
They are then transported to Liège in closed bags or covered with plastic sheets and stored at 20°C and 95±5% relative humidity. They are kept in these conditions for the required duration before testing (2, 7, 28, etc. days).

Mortar characterization

Three points bending and compressive strength :

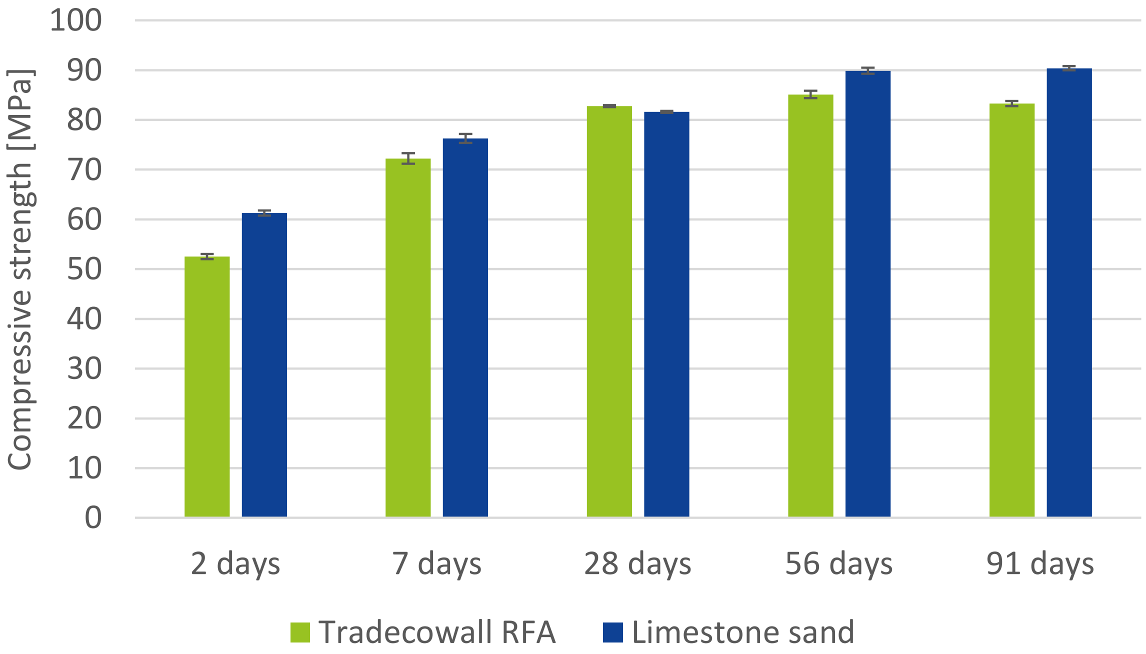
- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Flexural strength
- Water curing (20°C and 95±5% relative humidity)



Mortar characterization

Three points bending and compressive strength :

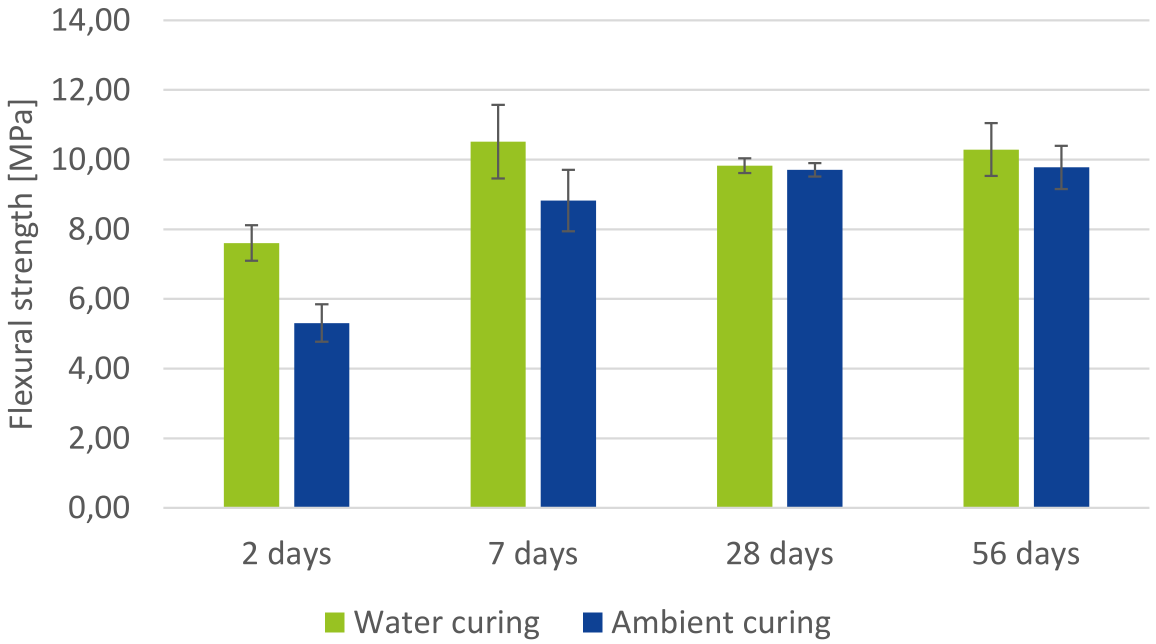
- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Compressive strength
- Water curing (20°C and 95±5% relative humidity)



Mortar characterization

Three points bending and compressive strength :

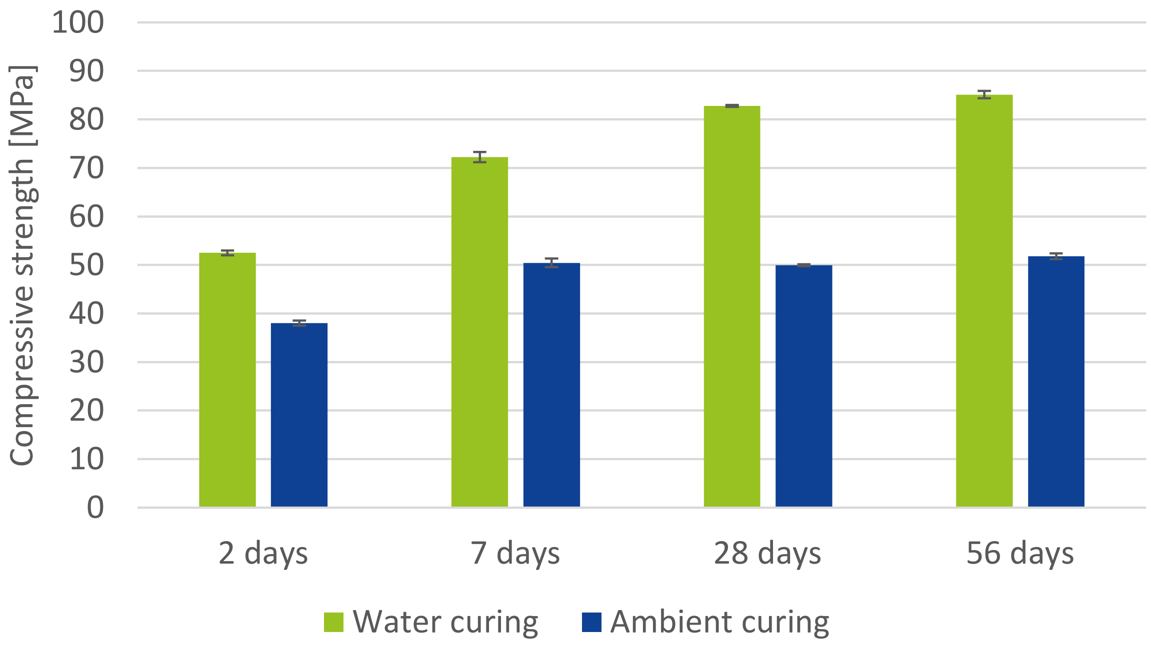
- Influence of the ***curing conditions*** (20°C and 95±5% relative humidity vs 20°C and 60±5% relative humidity)
- Flexural strength



Mortar characterization

Three points bending and compressive strength :

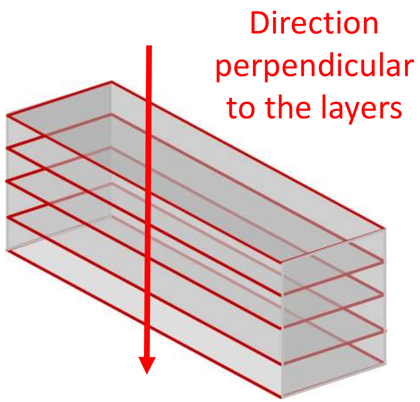
- Influence of the ***curing conditions*** (20°C and 95±5% relative humidity vs 20°C and 60±5% relative humidity)
- Compressive strength

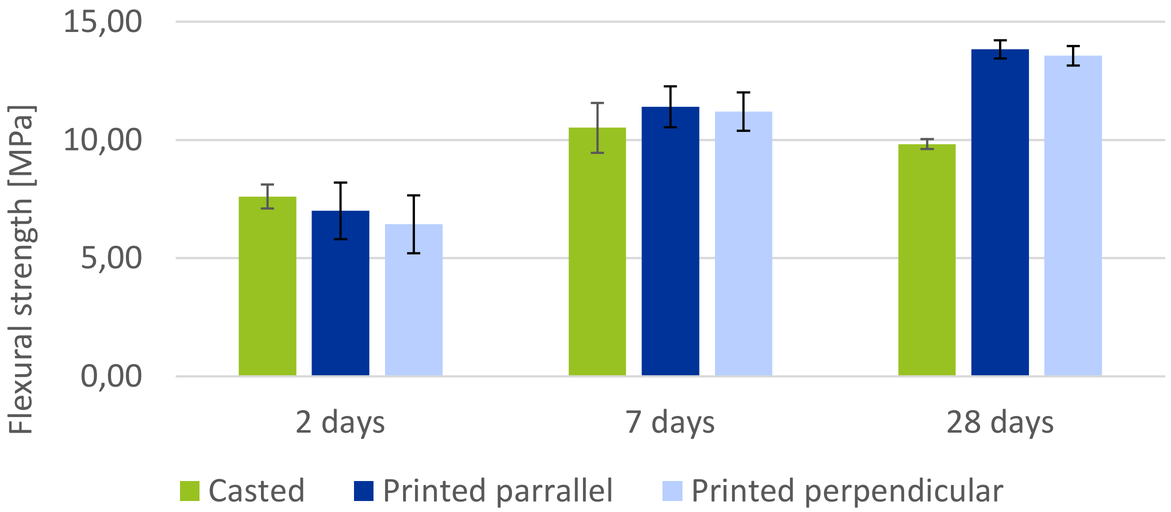


Mortar characterization

Three points bending and compressive strength :

- Influence of the ***printing process*** (casted samples vs printed samples)
- Flexural strength

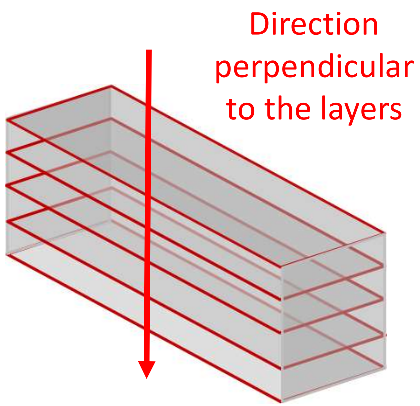


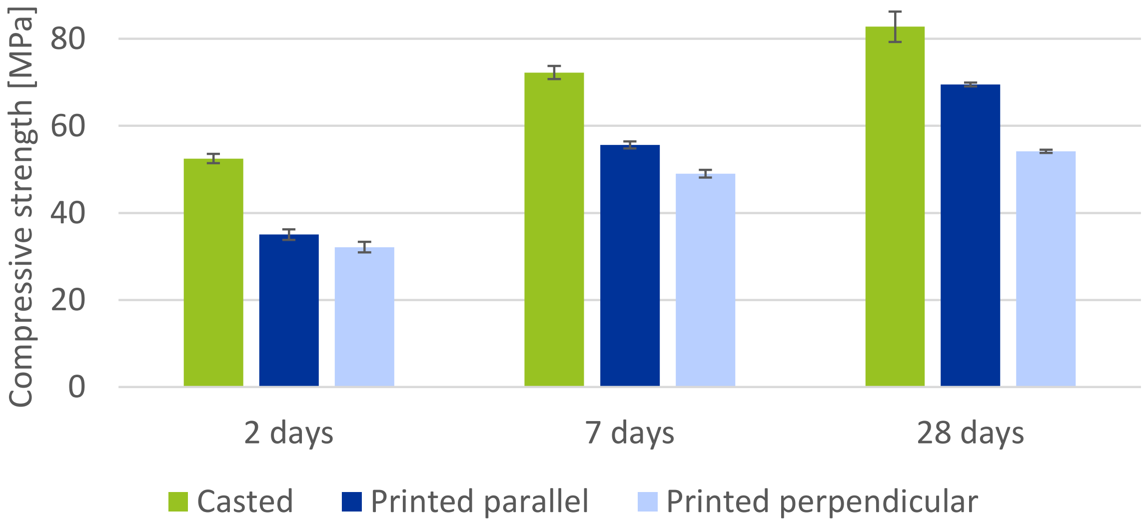


Mortar characterization

Three points bending and compressive strength :

- Influence of the ***printing process*** (casted samples vs printed samples)
- Compression strength

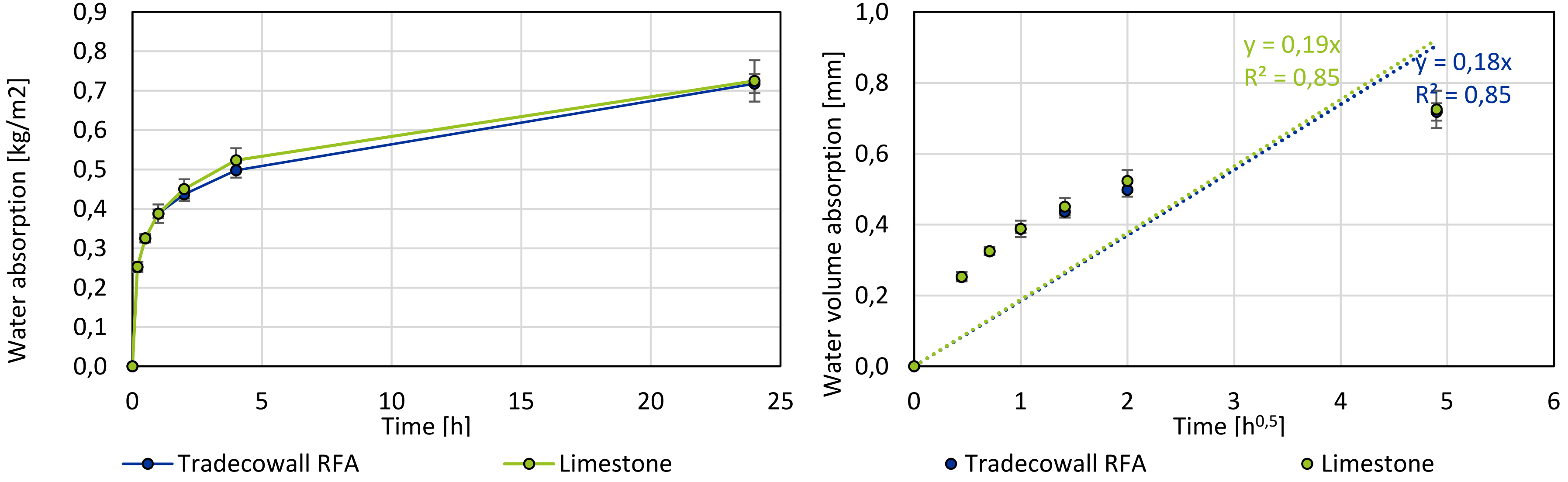




Mortar characterization

Capillary absorption tests NBN EN13057:

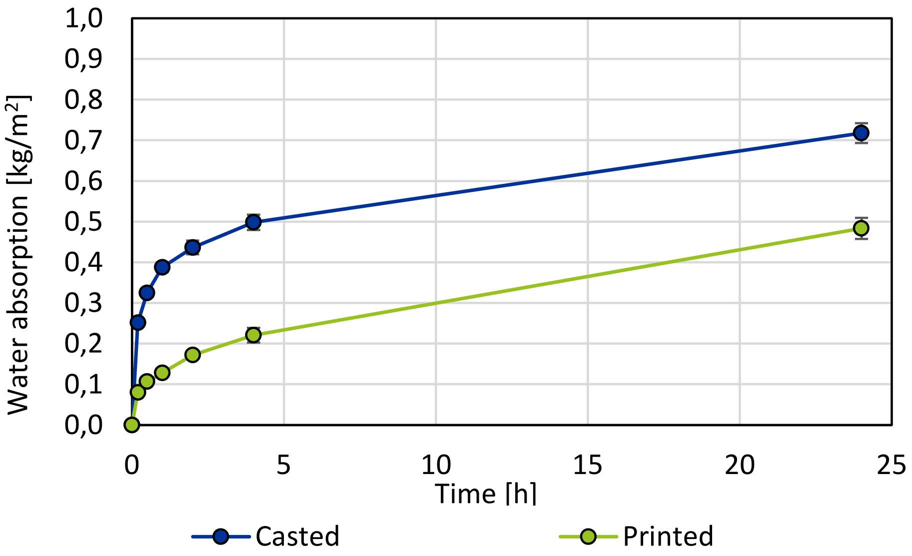
- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Water absorption in [kg/m^2] and absorption coefficient [mm/h^{0,5}]

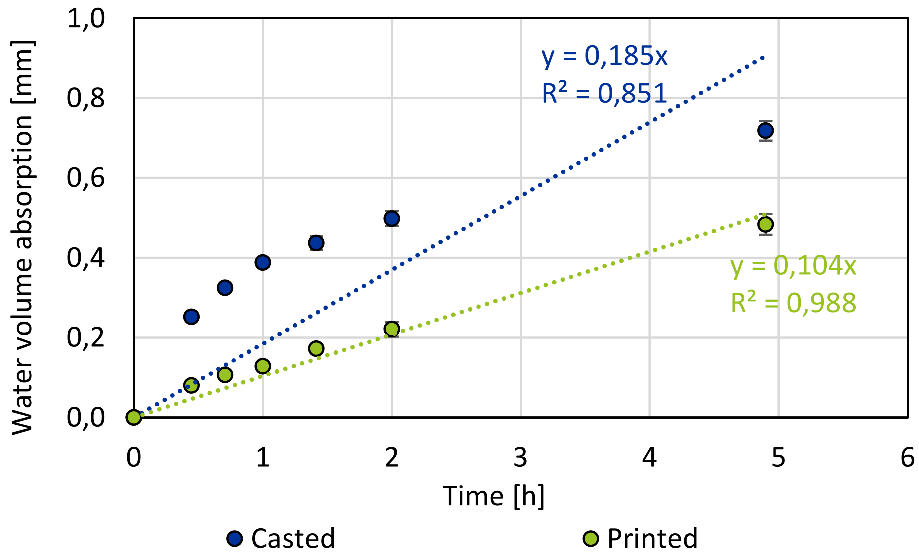


Mortar characterization

Capillary absorption tests NBN EN13057 :

- Influence of the ***printing process*** (casted samples vs printed samples)
- Water absorption [kg/m²] and absorption coefficient [mm/h^{0,5}]

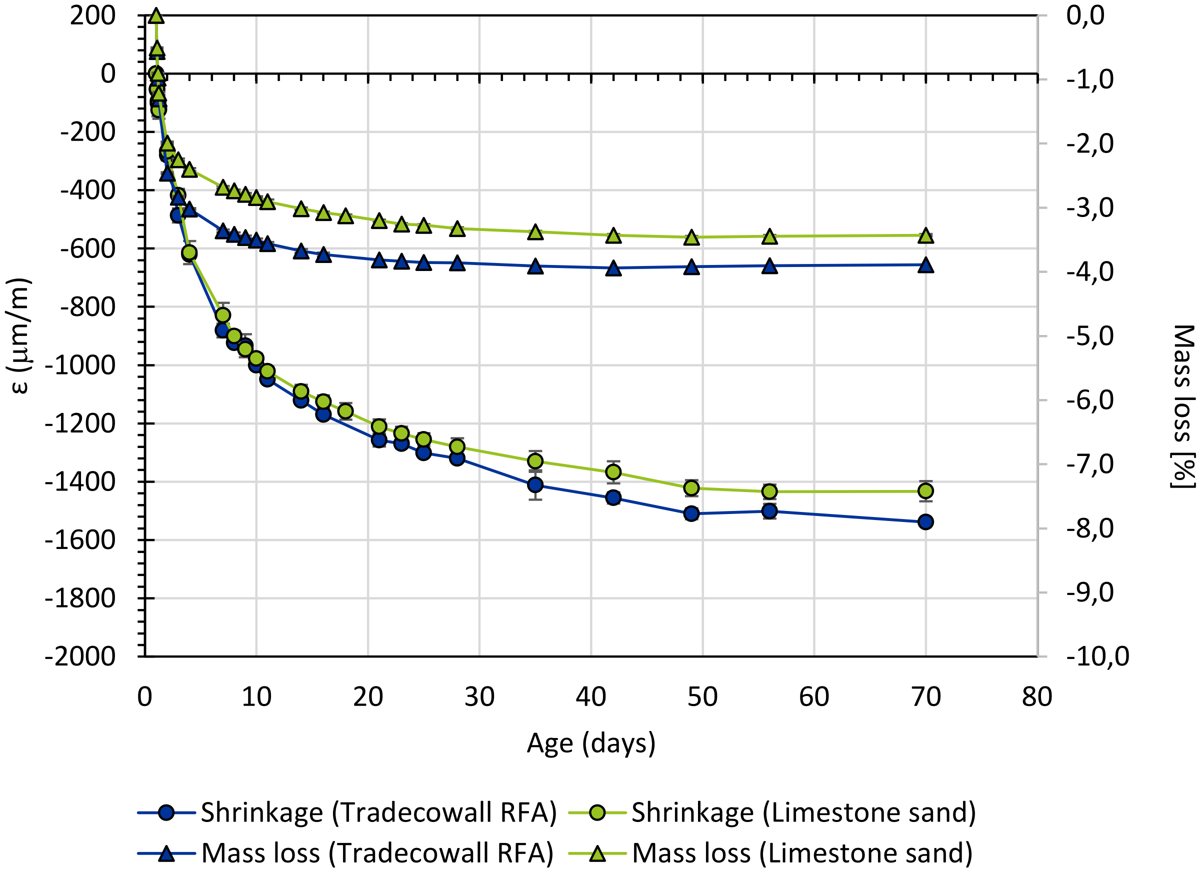




Mortar characterization

Shrinkage measurements :

- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Shrinkage/ longitudinal deformation [μm/m] and mass loss [%]

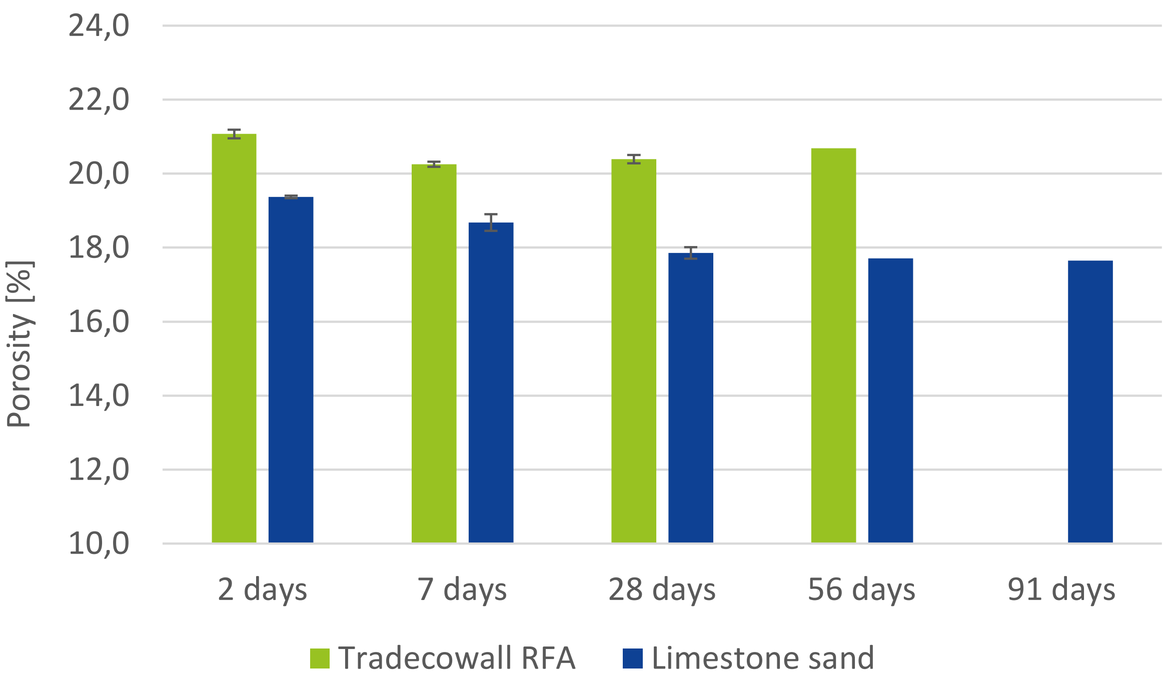


Sand type	Age [days]	ε [μm/m]	Mass loss [%]
Tradecowall	2	-279.8	-2.46
	7	-881.3	-3.36
	28	-1319.8	-3.86
	56	-1501.5	-3.90

Sand type	Age [days]	ε [μm/m]	Mass loss [%]
Limestone	2	-267.3	-1.99
	7	-829.0	-2.68
	28	-1280.1	-3.32
	56	-1434.6	-3.44

Porosity:

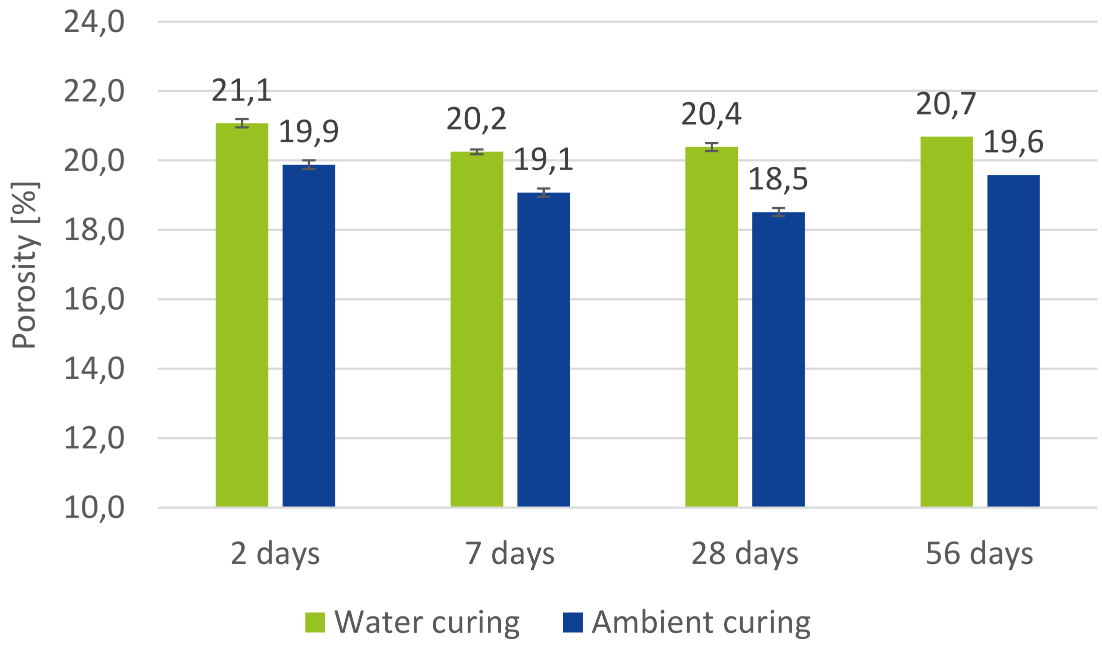
Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)



Mortar characterization

Porosity:

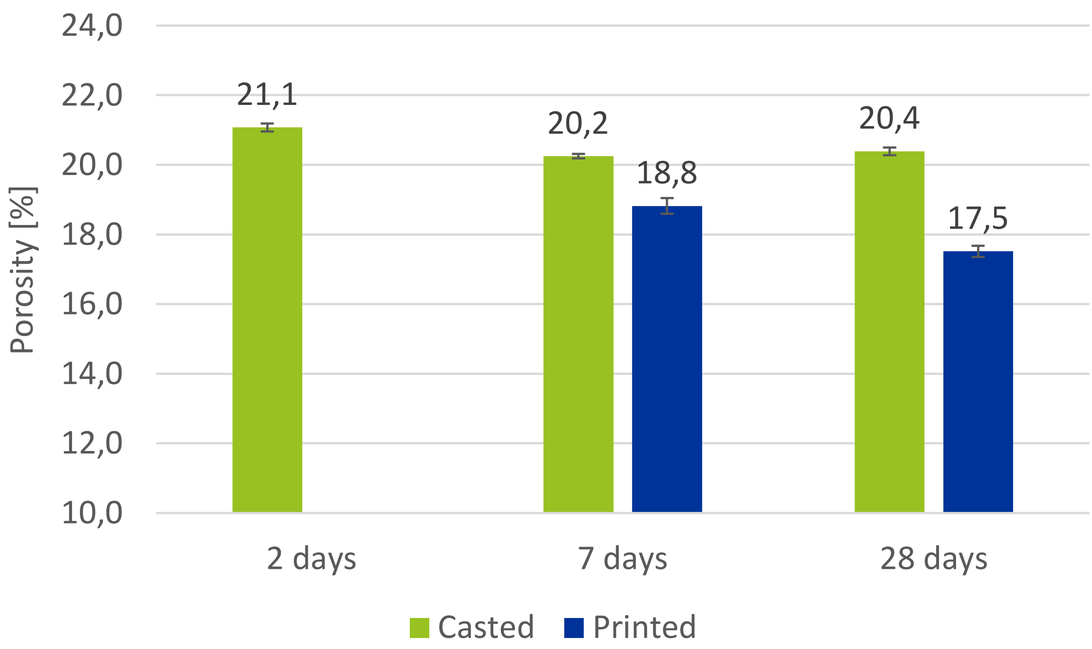
Influence of the ***curing conditions*** (20°C and 95±5% relative humidity vs 20°C and 60±5% relative humidity)



Mortar characterization

Porosity:

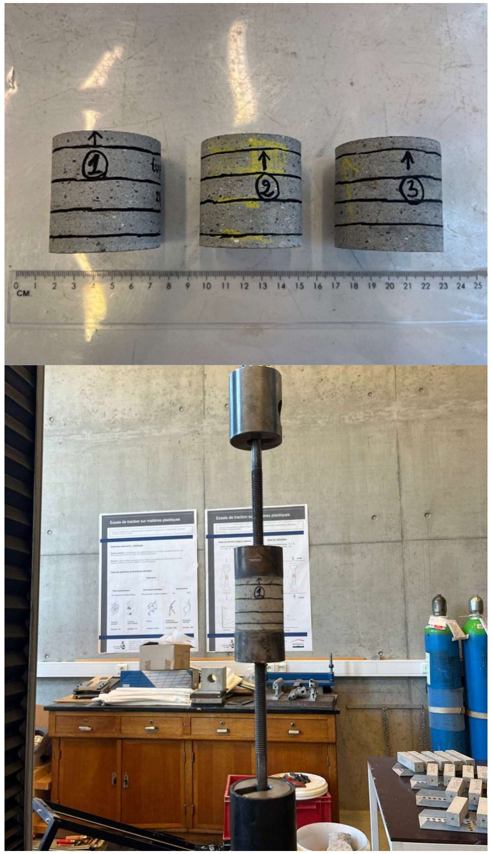
Influence of the ***printing process*** (casted samples vs printed samples)

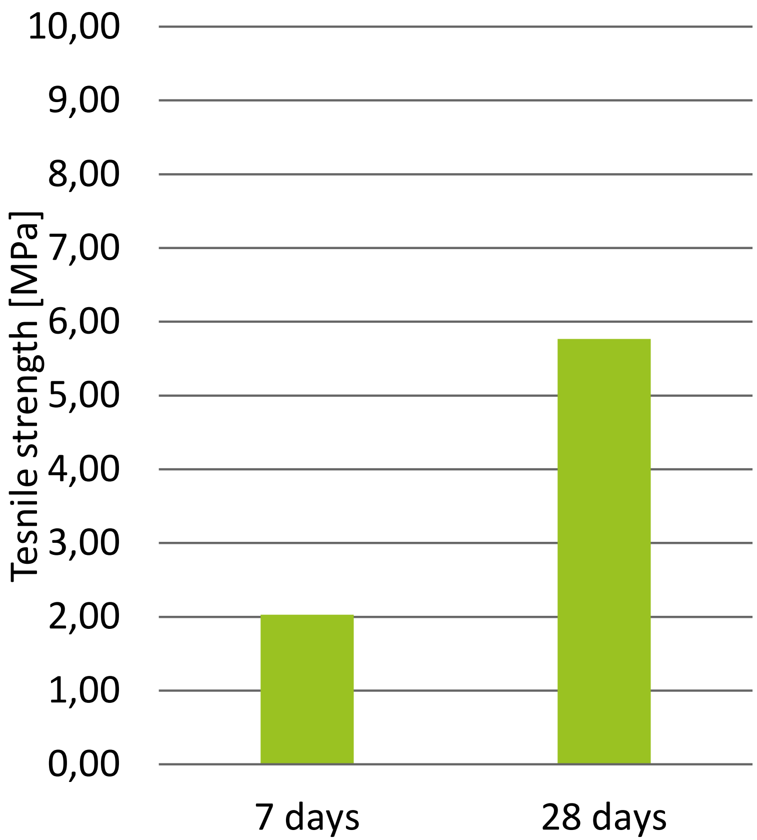


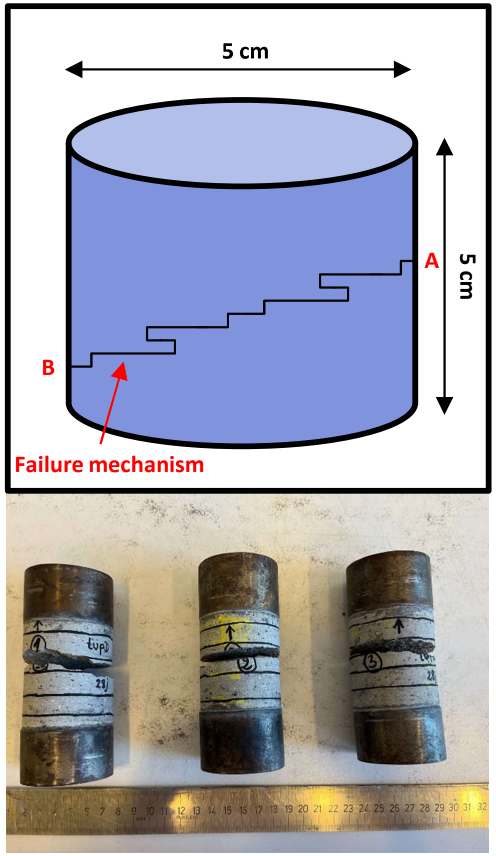
Mortar characterization

Direct tension test :

Layer adherence – potential delamination







Conclusions

Influence of the type of sand

Small decrease of compressive strength (max 8%)

Decrease of flexural strength

Increase of the porosity > durability

} Low impact because of the level of performances

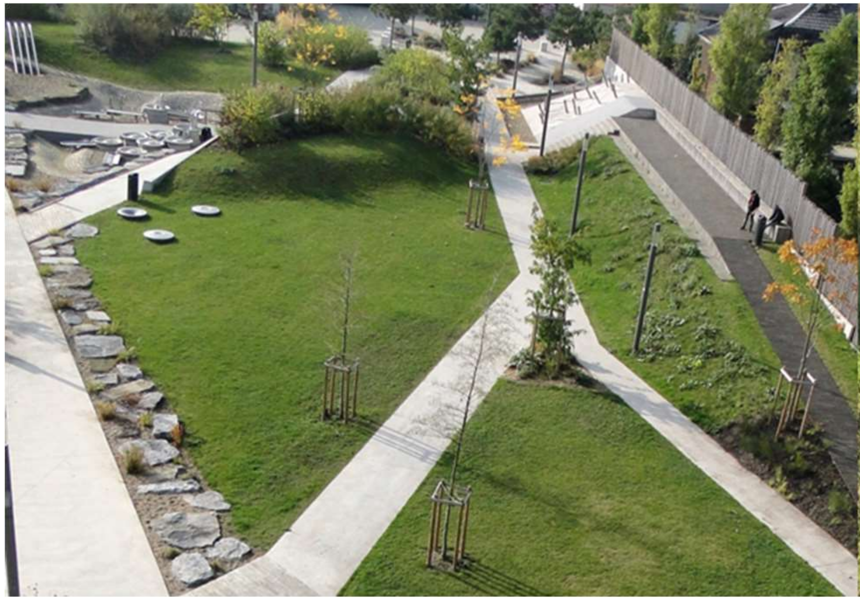
Influence of the *printing process* (casted samples vs printed samples)

Major impact on strength when curing in ambiant conditions due to lower hydration rate

3D printing: very homogenous material (more than expected)

Urban furniture

Bernard Serin park in Seraing



Construction and Demolition Waste: other ongoing projects

Other projects

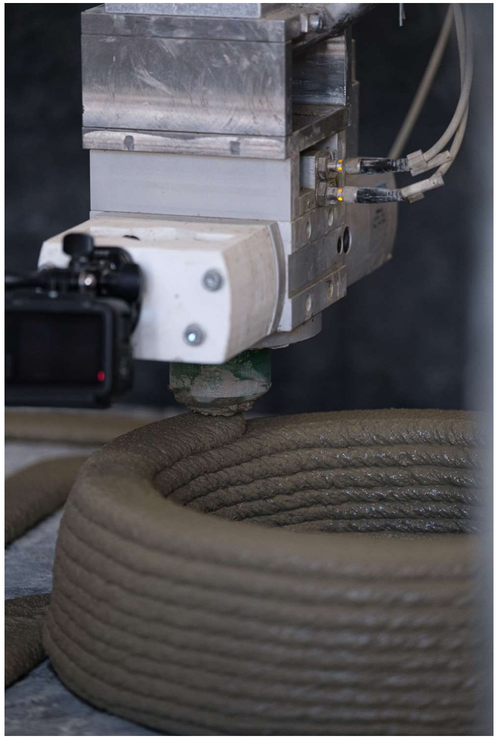
- GreenWin ReMIND CARBOC (2022-2025): accelerated carbonation of municipal solid waste aggregates
- GreenWin ReMIND CIBER (2022-2026): prefabricated structural elements for clading with recycled concrete aggregates
- GreenWin MonoCrete (2021-2024): very thick road concrete road structure with recycled aggregates and alternative binders
- GreenWin Mineral Loop (2021-2024): capture and sequestration of indutrial CO2 by mineral residues carbonation
- SARE4BE (2022-2024): valorization of recycled sands for concrete production
- BeXTRUS (2022-2024): 3D printing for refractory concrete
- Déchets-ressources. Prefabricated rammed concrete
- ARES CCD PRD HaBiMo – Bio-climatic and modular houses with compressed earth bricks in Ouagadougou (Burkina Faso)

Conclusions

Prefabricated concrete

Rammed concrete

Parkour park



3D printing

Concrete blocks

Recommendations

- Enhance public procurement through the introduction of **mandatory percentages** of recycled aggregates in large civil engineering projects;
- Develop reuse/reclaimed products programme of **support and promotion** (e.g. reuse percentage target);
- Introduce end-of-waste criteria for recycled products;
- **Develop standards for recycled materials** for various utilization for waste that did not meet end-of-waste criteria;
- Facilitate material content **traceability**;
- Introduce applications for recycled non-aggregates;
- Encourage the construction products and materials supply chain to have **much greater provision** for taking back and incorporating recycled materials into new products;
- Deploy **financial incentive** to use recycled aggregates.

Acknowledgment (谢谢你)

- Tongji University
- CiRMAP INTERREG NWE project
  - "Circular economy via customisable furniture with Recycled MAterials for public Places" - *https://www.uee.uliege.be/cms/c_4843025/fr/cirmap*
- SeRaMCo INTERREG NWE project
  - "Secondary Raw Materials for Concrete Precast Products (introducing new products, applying the circular economy)" - *http://www.nweurope.eu/seramco*
- Wallonia Brussels International

Interreg EUROPEAN UNION North-West Europe CIRMAP European Regional Development Fund

Interreg EUROPEAN UNION North-West Europe SeRaMCo European Regional Development Fund

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