30. SLOVENSKI KOLOKVIJ O BETONIH

VEČKOMPONENTNI DROBNOZRNATI BETONI IN MALTE

30.th SLOVENIAN COLLOQUIUM ON CONCRETE

MULTI-COMPONENT FINE-GRAINED CONCRETES AND MORTARS

irma inštitut za raziskavo materialov in aplikacije d.o.o.

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Sciences Appliquées

New developments in the recycling of Construction and Demolition Wastes for the concrete industry

L. Courard, S. Grigoletto, Y. Muy, F. Michel, A. Fanara, J. Hubert

Ljubljana, 30. Slovenski Kolokvij o Betonih
November 7, 2023

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Global context

What to do?

Global context

- Transforming wastes …

Global context

- … into secondary ressources

Global context

- 3R: Reduce, Reuse and Recycle
- 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)

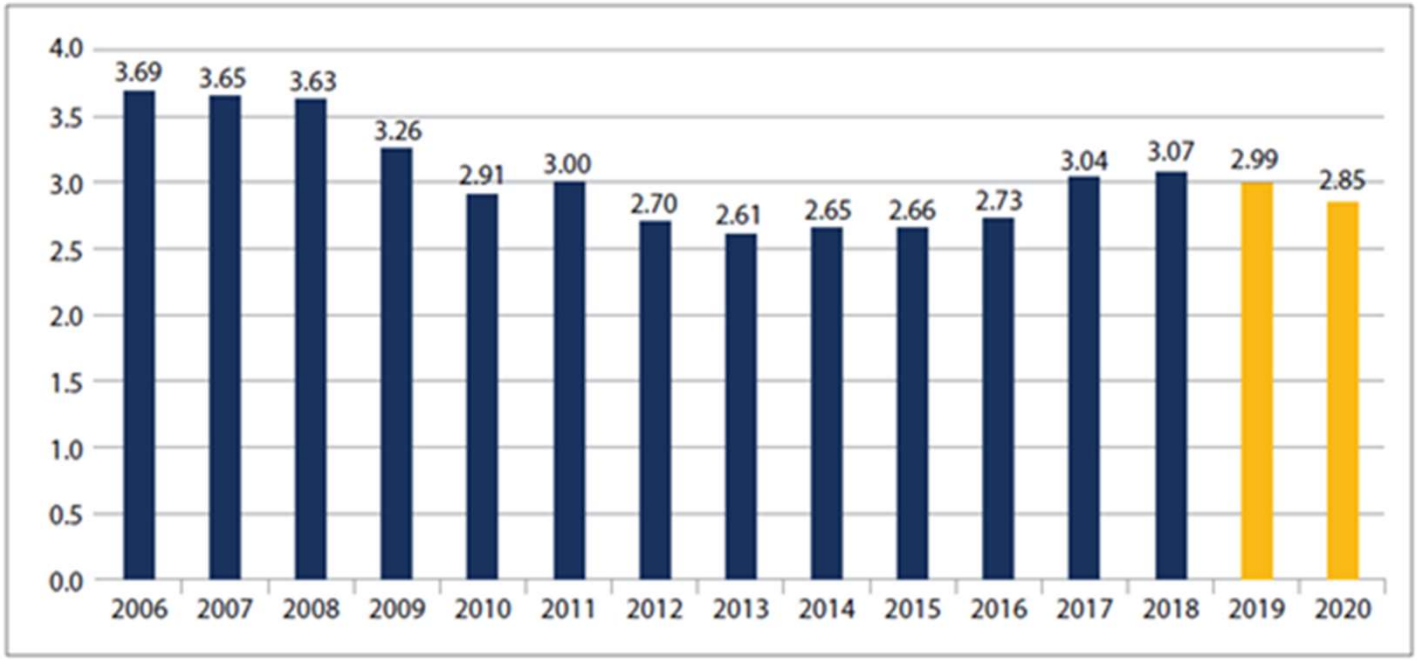
Global context

- 3R: Reduce, Reuse and Recycle
  - Mean recycling of C&DW in EU27 is 87% (7% backfilling and 80% recycling) + 7% landfilling and 6% energy recovery
  - 25 (out of 27) member states comply with the target!
  - In 7 (out of 25 states complying), compliance is only with backfilling
- Using CD&W as sub-base and base material in road construction ("less noble") → upcycling ("upscaling")

Use of recycled aggregates in concrete – opportunities for upscaling in Europe. J. N. Pacheco, J. de Brito, M. L. Tornaghi, 2023 (JRC Science for policy report (ISSN 1831-9424)

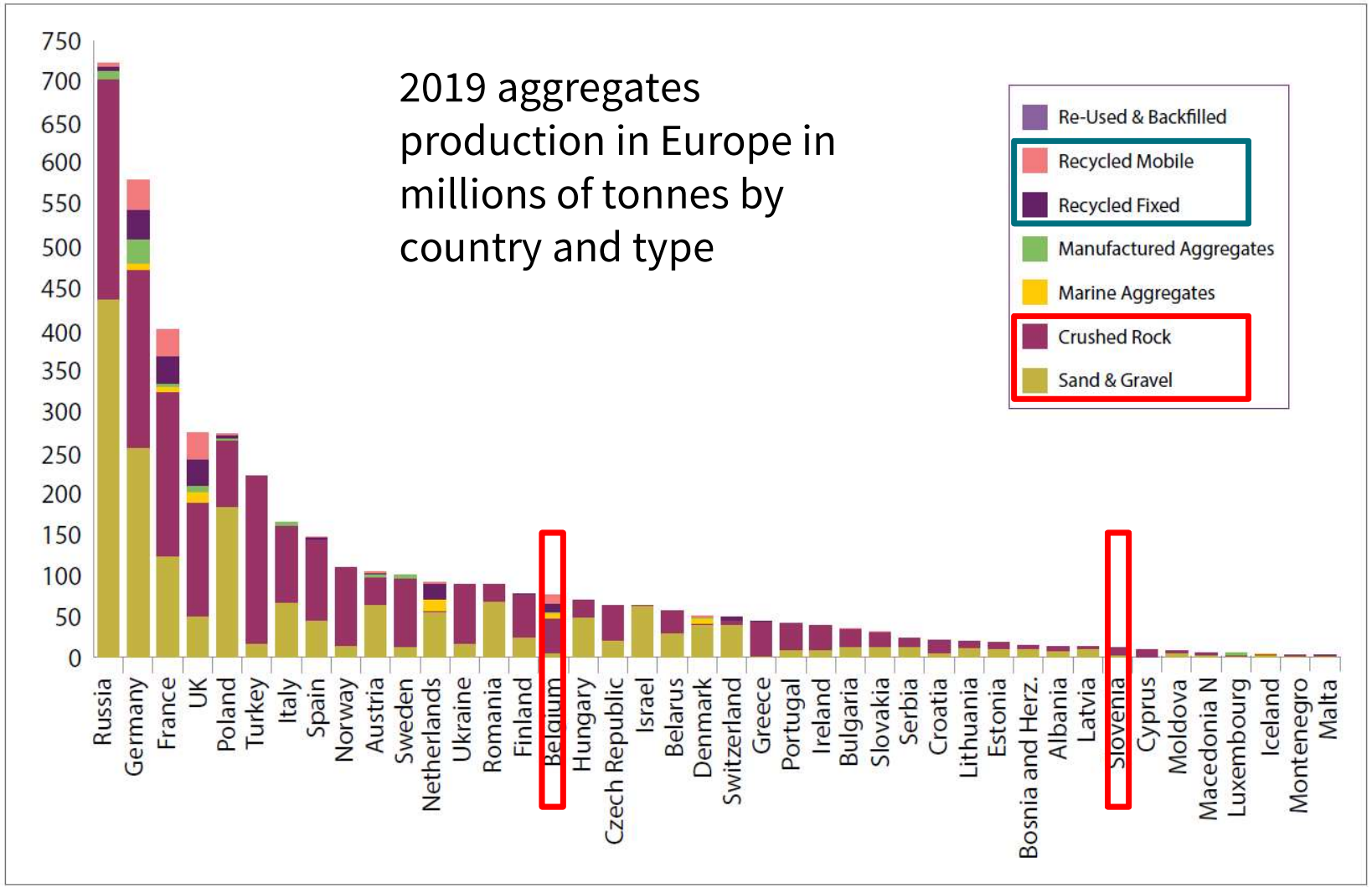
Global context

- We produce wastes
  - Annual production of recycled aggregates accounted for 278 million tons in 2019 (EU27+UK+EFTA)
- Market for aggregates/sand



UEPG, 2021. European Aggregates Association – Annual Review 2020-2021, Brussels, 30 p.

Global context



UEPG, 2021. European Aggregates Association – Annual Review 2020-2021, Brussels, 30 p.

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Global context

- 3 billion tons produced in EU27+UK+EFTA in 2019 (UEPG 2021)

Virgin Aggregates

46.9% crushed rock

39.7% sand & gravel

Recycled Aggregates

Construction & demolition wastes (CDW)

9.3% recycled (278 million tonnes)

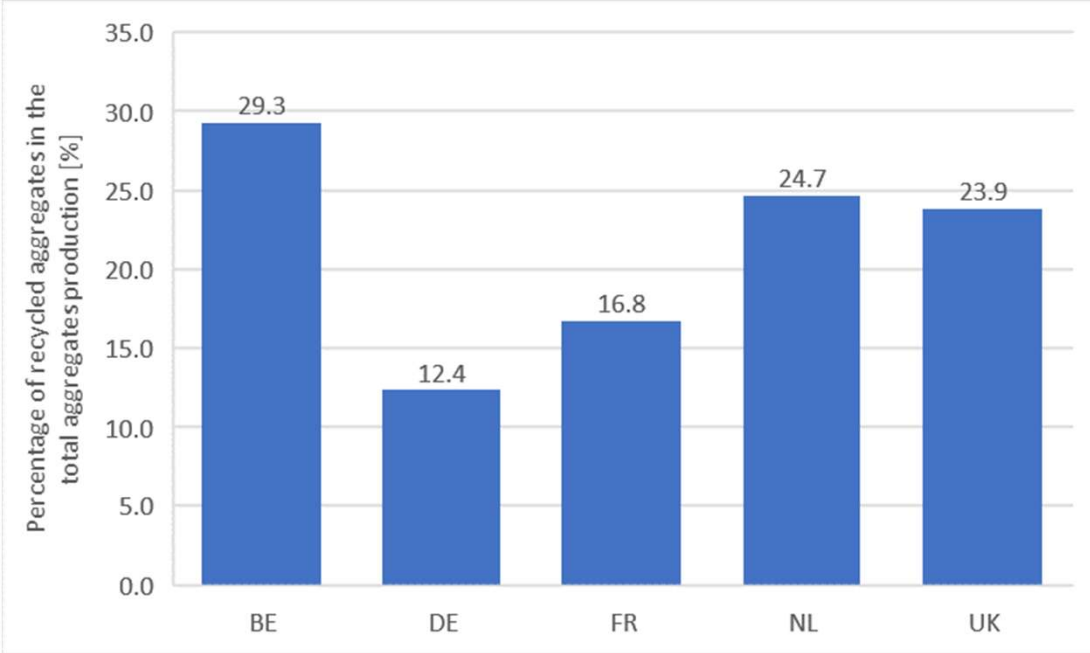
Concrete

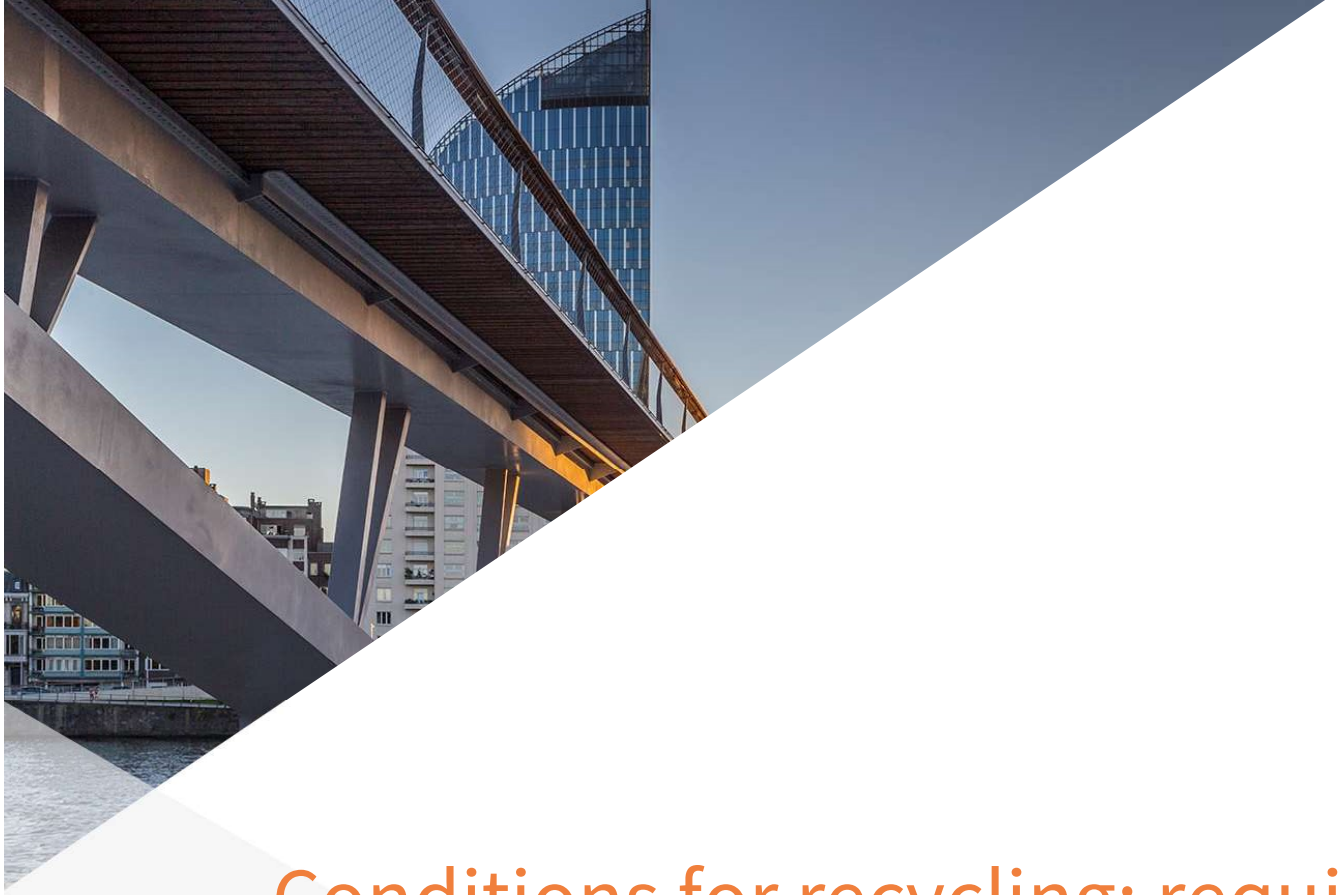
Mixed

Global context

- NWE countries (BE, DE, FR, NL, UK) are responsible for:
  - 47% of the virgin aggregates production (1417 Mtons)
  - 89% of the recycled aggregates production (248 Mtons)

Recycled aggregates/natural aggregates





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Conditions for recycling: requirements, barriers, applications

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Conditions for recycling

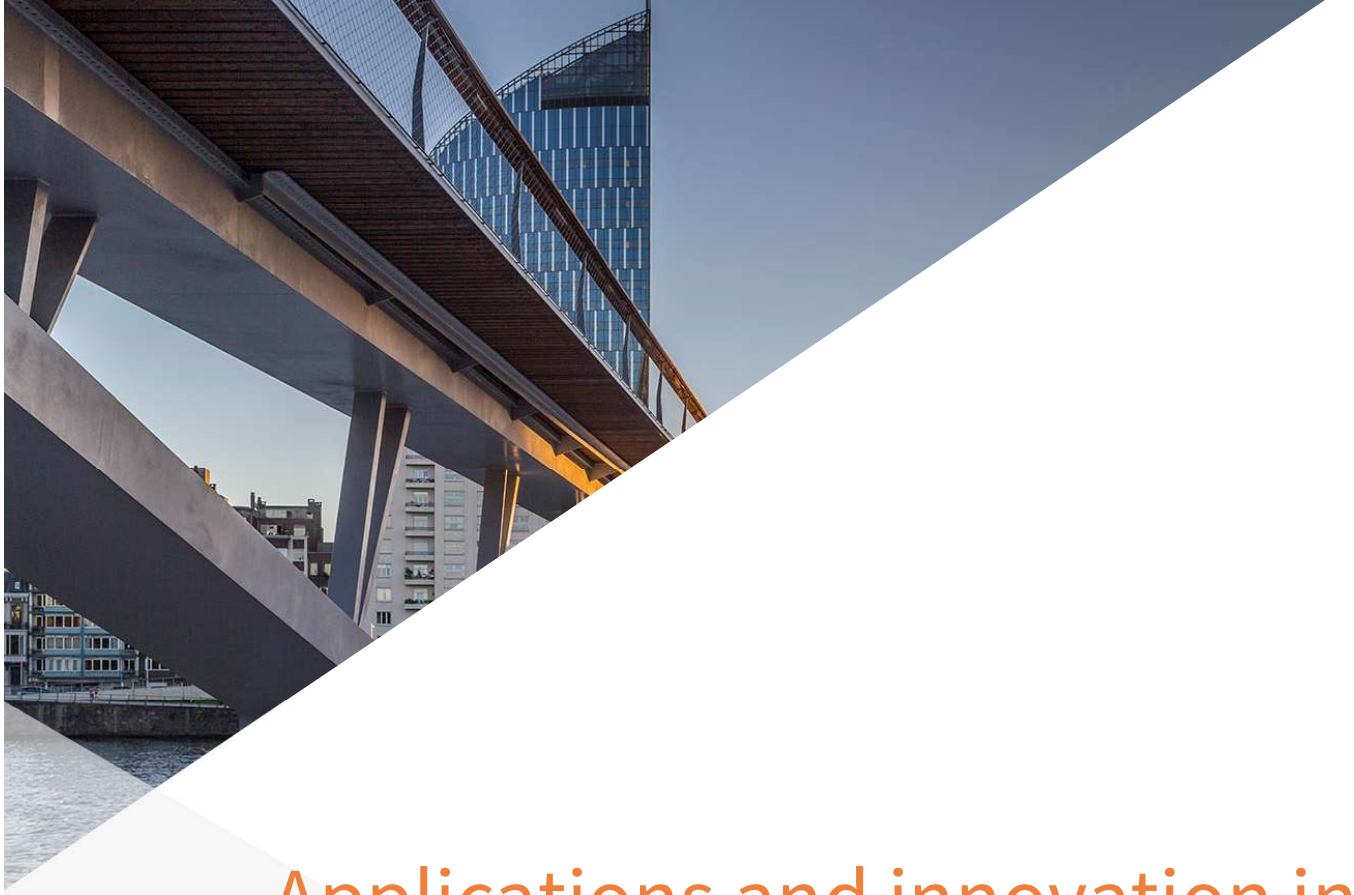
- Possible applications
  - *(Back)Filling materials*: low requirements, consumed in large quantities, for embankments but transportable over short distances due to costs;
  - *Aggregates*: high quality requirements to lead to finished products of quality identical to that of traditional materials;
  - *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

- Possible restrictions
  - Transport
    - Transport price = f(quantity, distance)
    - Independent of the quality
    - Interesting recycling if
      - Landfill far away (*if landfilling is accepted*)
      - 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 little used because it is uncovered by specifications*

Conditions for recycling

- Possible restrictions
  - Technique
    - Constant properties - Material quality
  - Logistic et economic
    - Constant production
  - Environmental impact
    - LCA



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Applications and innovation in recycling C&DW

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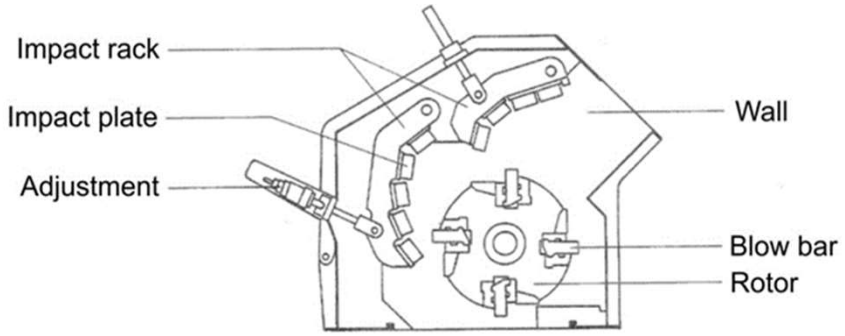
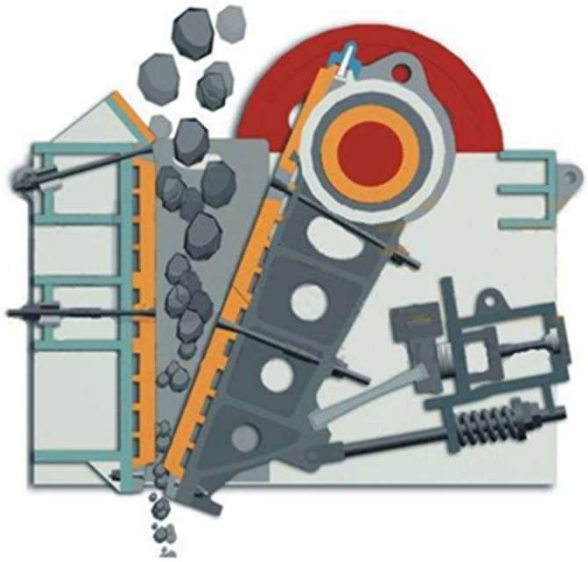
Research and innovation

- Research and innovation in improved methods for reuse and recycling
  - Preparation of recycled concrete aggregates: materials processing
  - Recycling production waste for concrete blocks
  - RA for prefab elements
  - Valorization of fine bricks
  - Use of recycled sand for 3D printing
  - Rammed concrete

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





Effects of crushing method on the properties of produced recycled concrete aggregates. J. Hubert, Z. Zhao, F. Michel, L. Courard. Buildings 2023, 13, 2217 (https://doi.org//10.3390/buildings13092217)

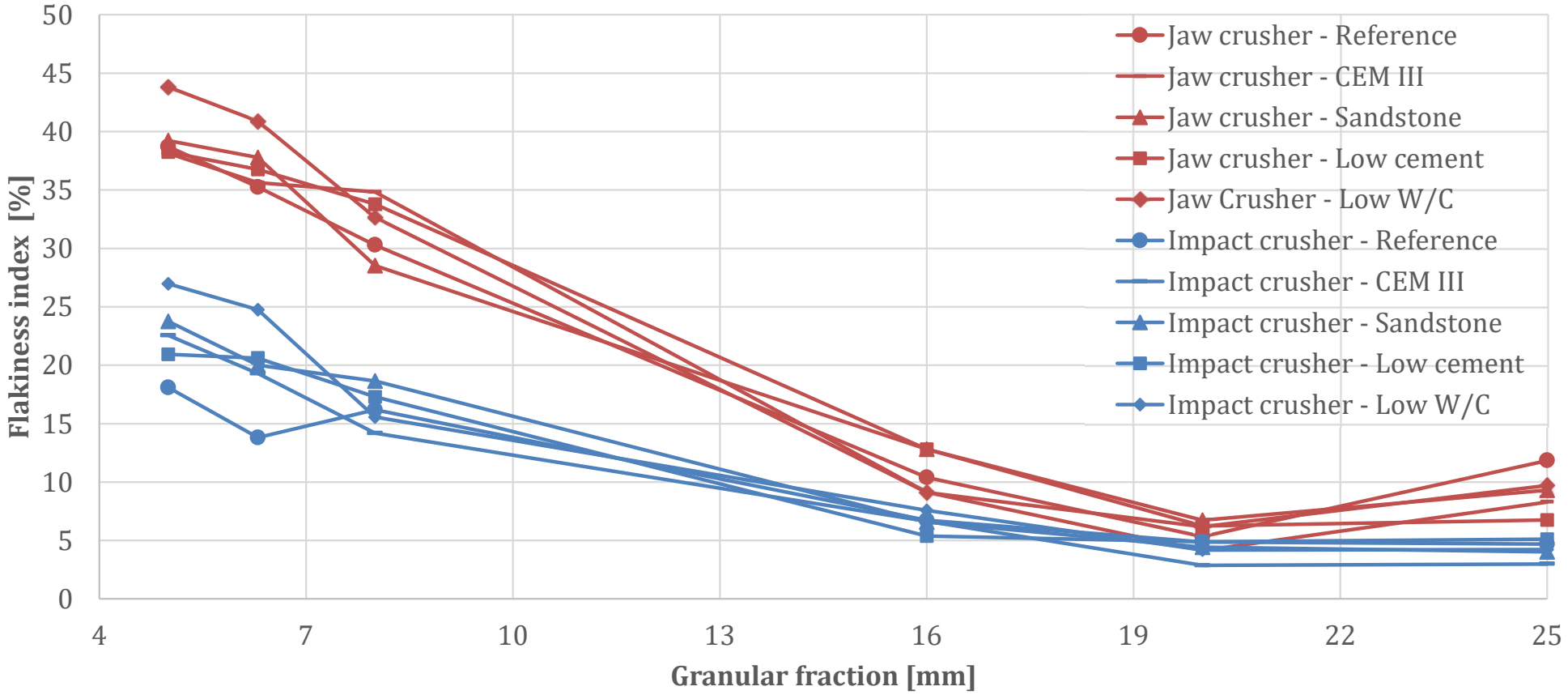
Material processing

- 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

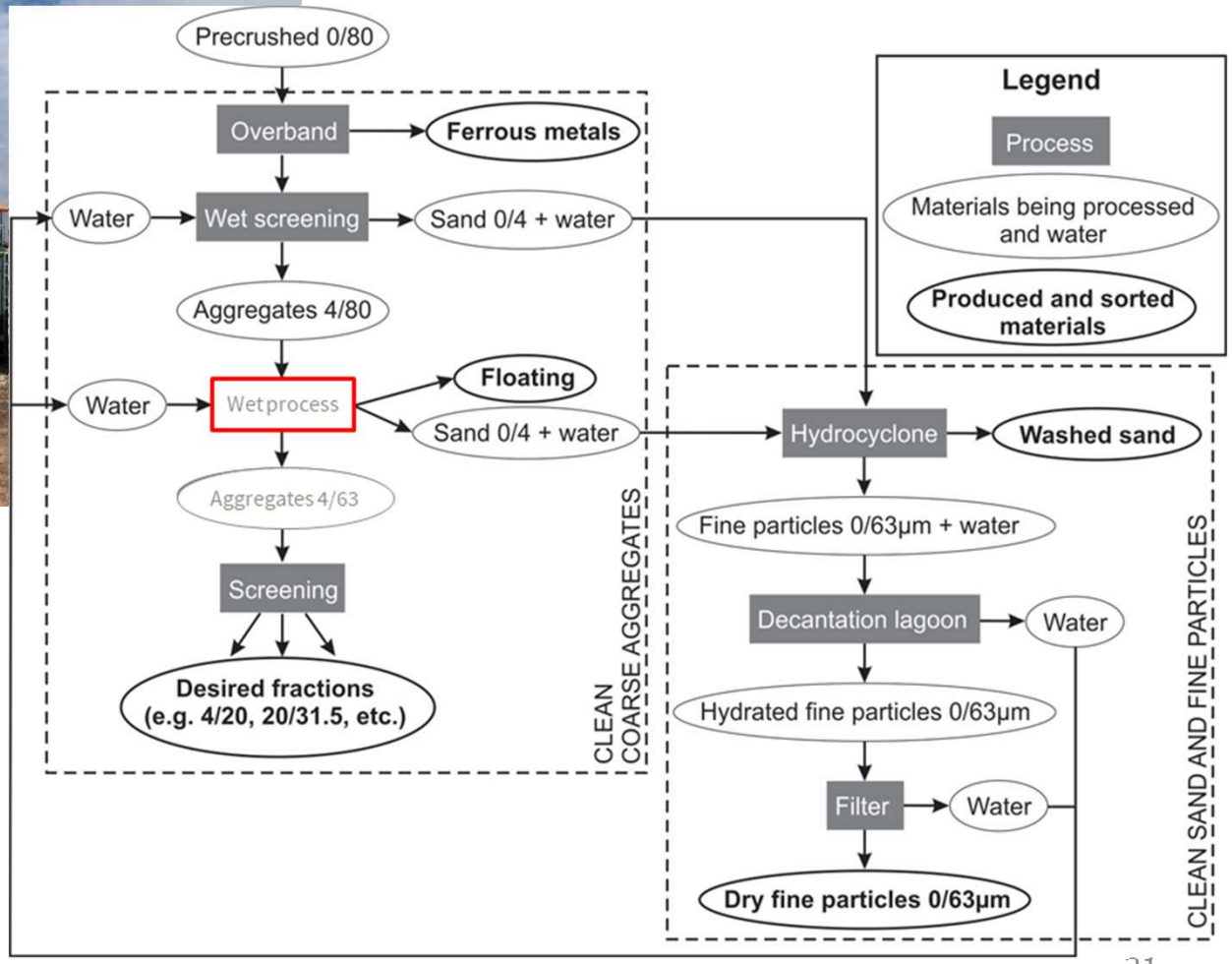
Material processing

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



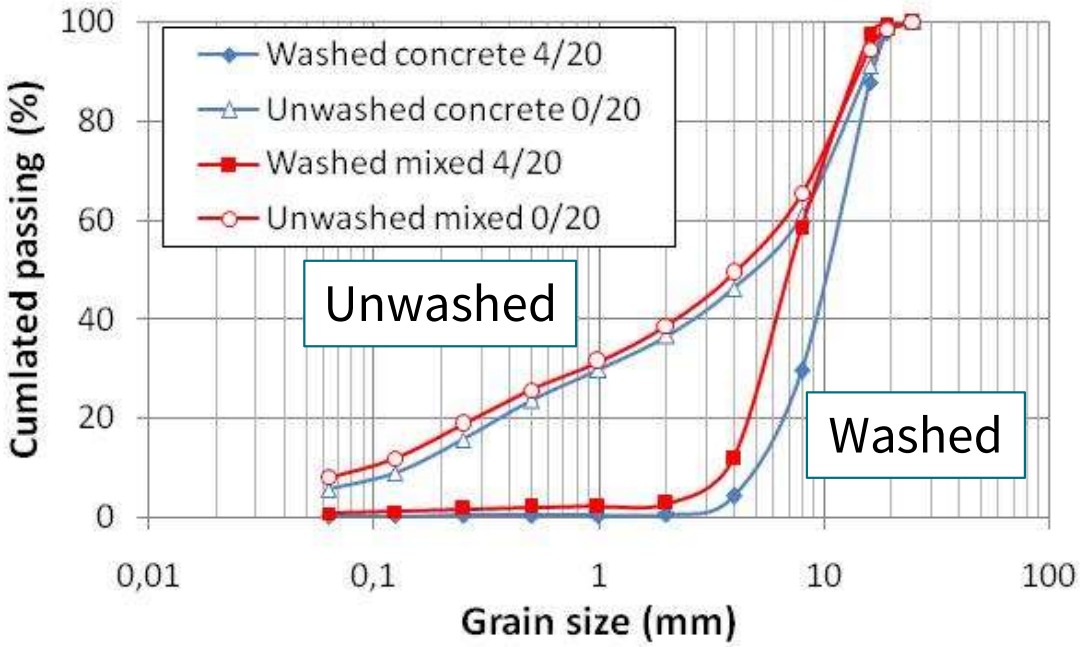
Materials processing: washing

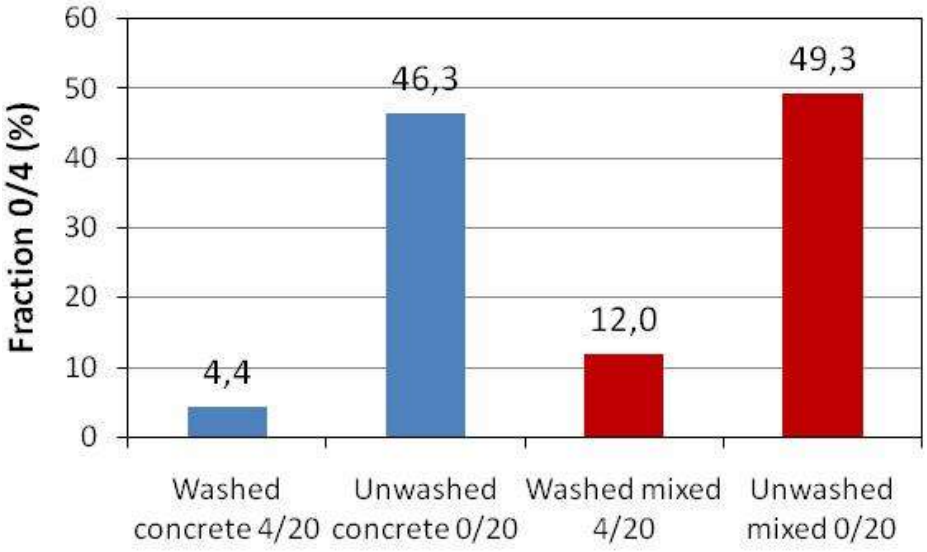
SeRaMCo recycling plant (Tradecowall)



Materials processing: washing

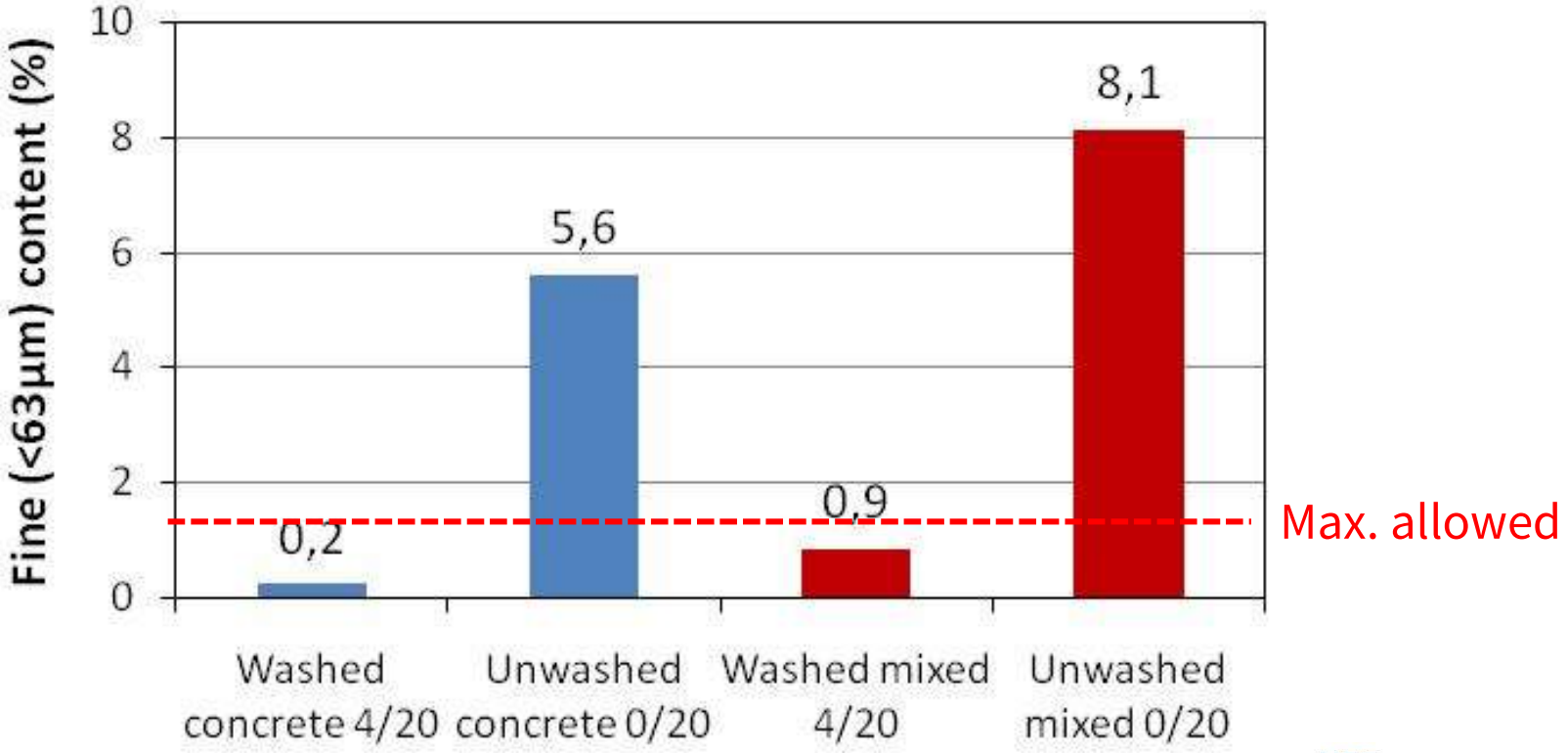
- 0/4 fraction comprises nearly 50% of the unwashed aggregates composition
- 0/4 fraction a bit higher in mixed aggregates
- Washing significantly reduces the sand fraction of the aggregates





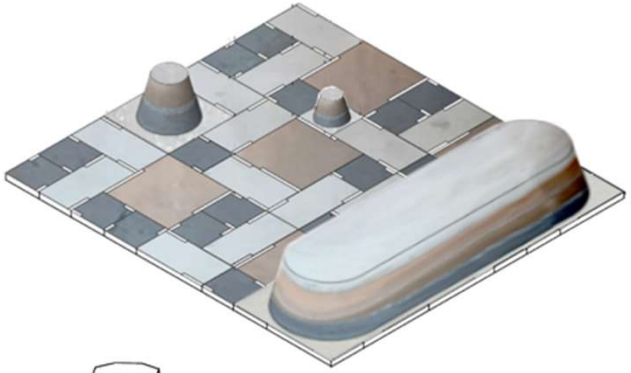
Materials processing: washing

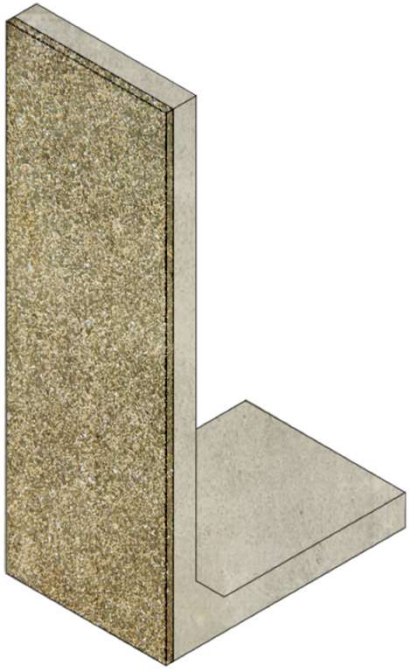
- Fine content (< 63µm) higher in mixed aggregates and significantly reduced by washing
- Fine fraction higher in mixed aggregates
- Washed aggregates respect regulations in all NWE countries (BE, DE, FR, LU, NL

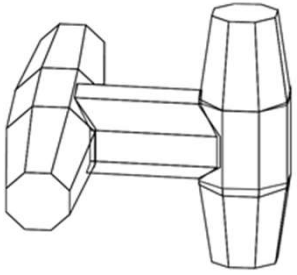


Prefab products

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







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Prefab products

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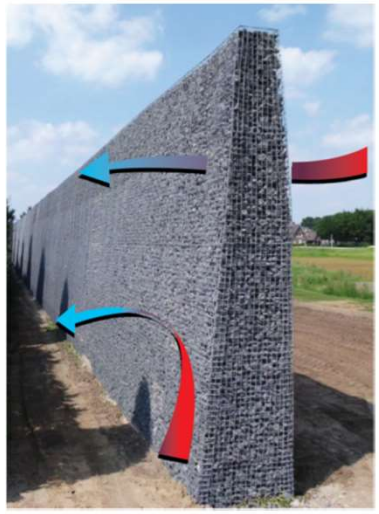
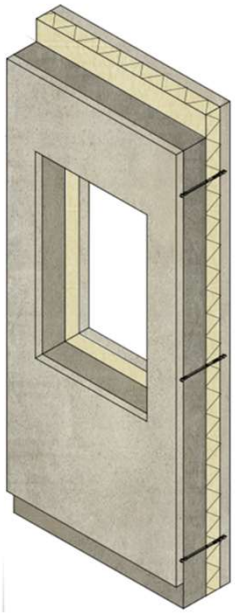
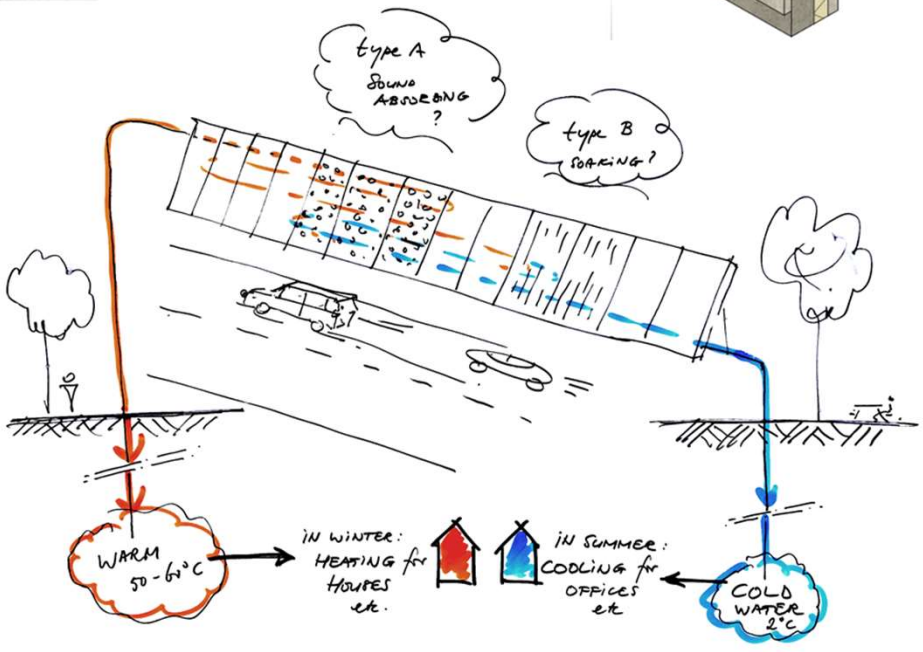






Prefab products: Parkour Park

Cement produced with recycled fines

Recycled concrete aggregates

Natural sand

Rc : 50-55 MPa
W/C <= 0.45
Cement >= 340 kg/m³
WAI <= 6.5%

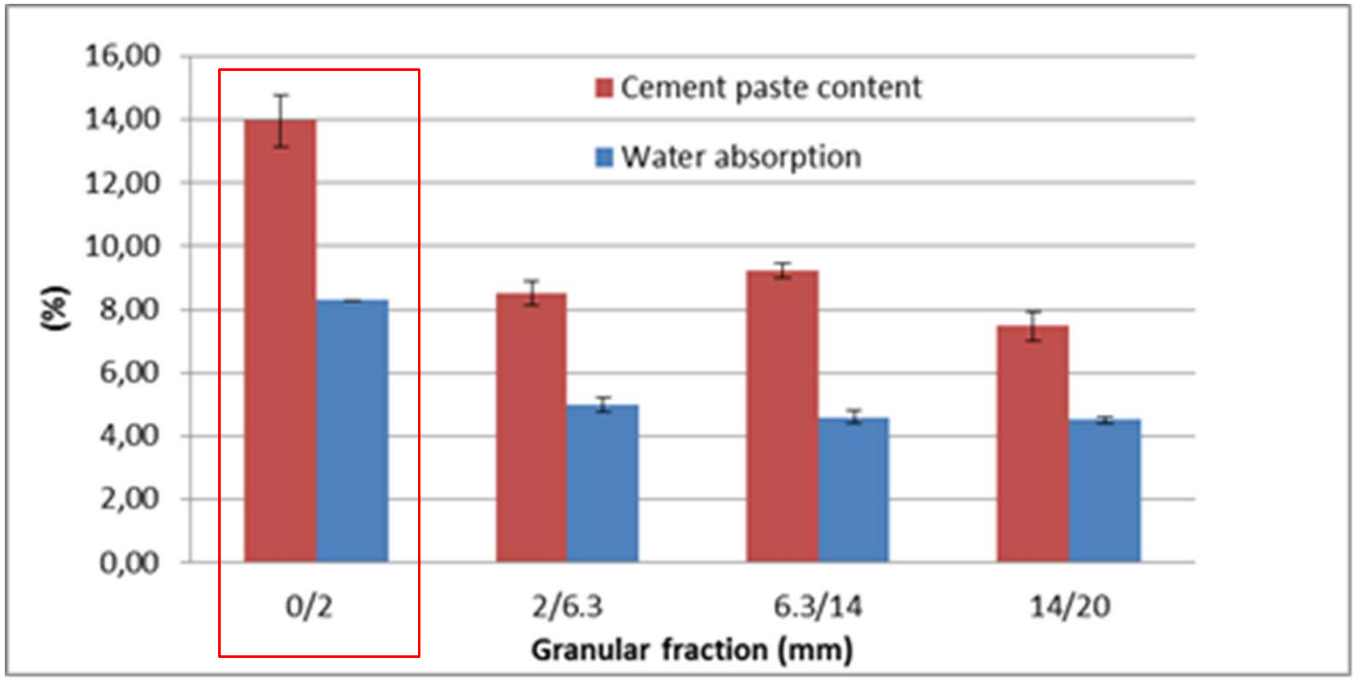
Production wastes

- RCA manufactured in laboratory
  - Old concrete from block wastes (C8/10 concrete)
  - 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

Use of RCA from precast blocks for the production of new concrete building blocks: an industrial scale study. Z. Zhao, L. Courard, S. Groslambert, Th. Jehin, A. Léonard, J. Xiao. Resources, Conservation & Recycling 157 (2020) 1-13 (https://authors.elsevier.com/a/1ahbs3HVLKiAuJ)(http://hdl.handle.net/2268/246444)

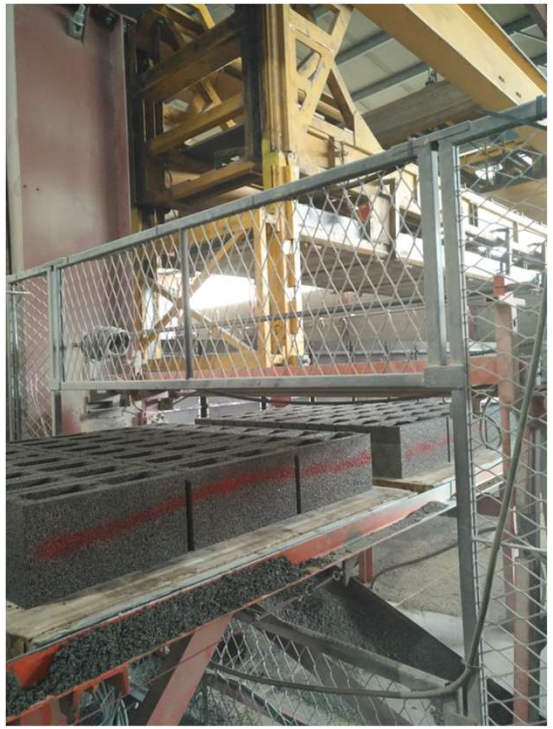
Production wastes

- Water absorption W_A (EN 1097-6)

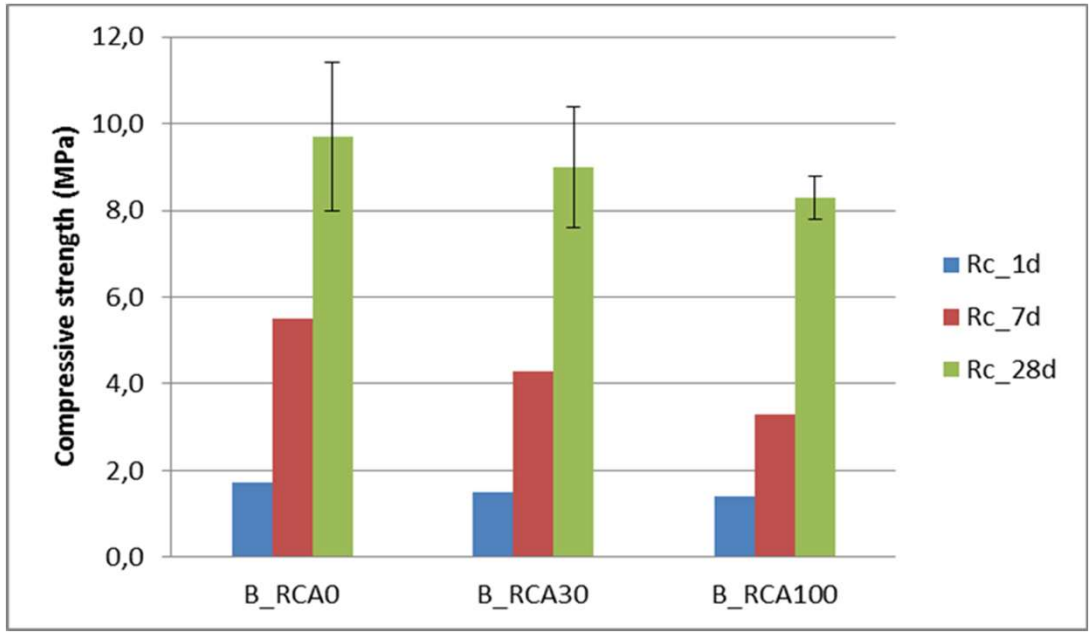


  - Cement Paste Content and W_A of 0/2mm fraction larger than three coarse fractions

Production wastes



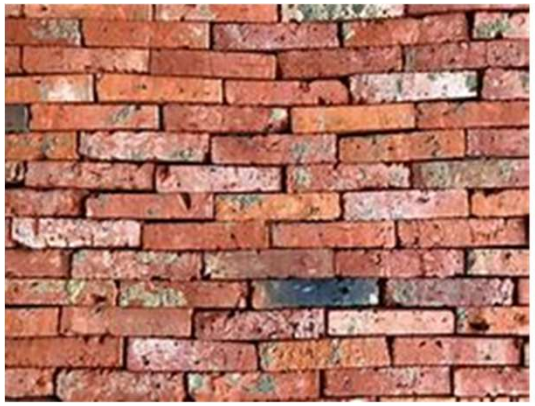
- Compressive strength



  - 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)

Fine bricks

- Flow of brick waste: 1-2% of C&DW in BE/North of France
- Valorization
  - Reuse of bricks
  - Aggregates: landfilling/recycling for backfilling
  - Brick fine particles



Recycled brick fines for new alkali activated binder. A. Grellier, D. Bulteel, L. Courard. 17th International Congress on Polymers in Concrete ICPIC 2023, Sept. 17-20th, Warsaw.

Fine bricks

- Brick fine particles
  - 3 types of granulometry
    - B1: d_{50} = 3.3 µm (with supplementary cyclogrinding)
    - B2: d_{50} = 20 µm
    - B3: d_{50} = 190 µm
- Mineralogy

Oxides (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	MgO	TiO_2	Total
Brick fine	1.7	62.8	10.4	16.3	2.1	0.6	2.2	2.4	99.3
GGBFS	42.9	38	10.8	0.5	0.3	-	6.5	0.7	99.5

Fine bricks

- Alcali Activated Material production

Brick fine particles
B2

GGBFS

Alcali-Activating Solution

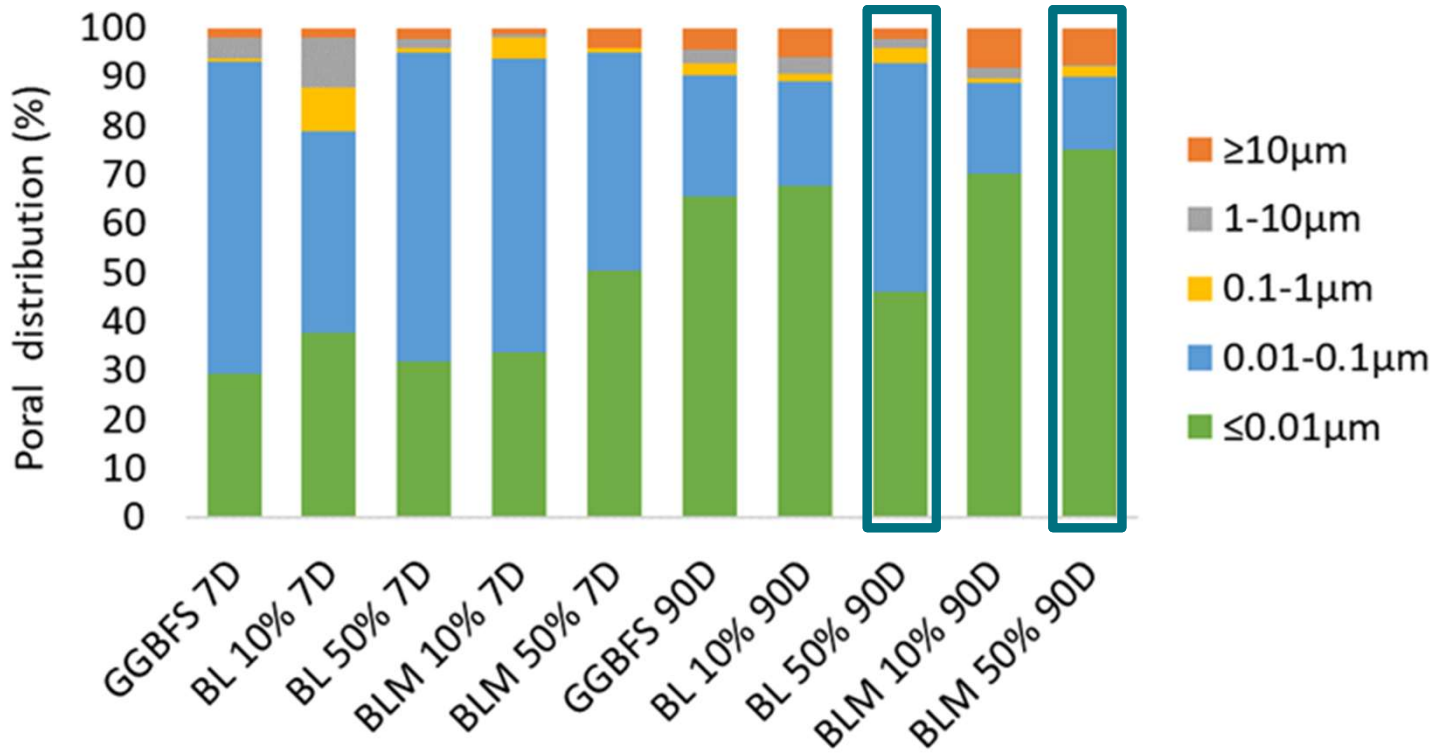
Soda (NaOH)
Sodium Silicates (Na_2SiO_3)
(SiO_2/Na_2O: 1.45)

Substitution
10, 20, 30 and 50 %

Characterization at
7 and 90 days

Fine bricks

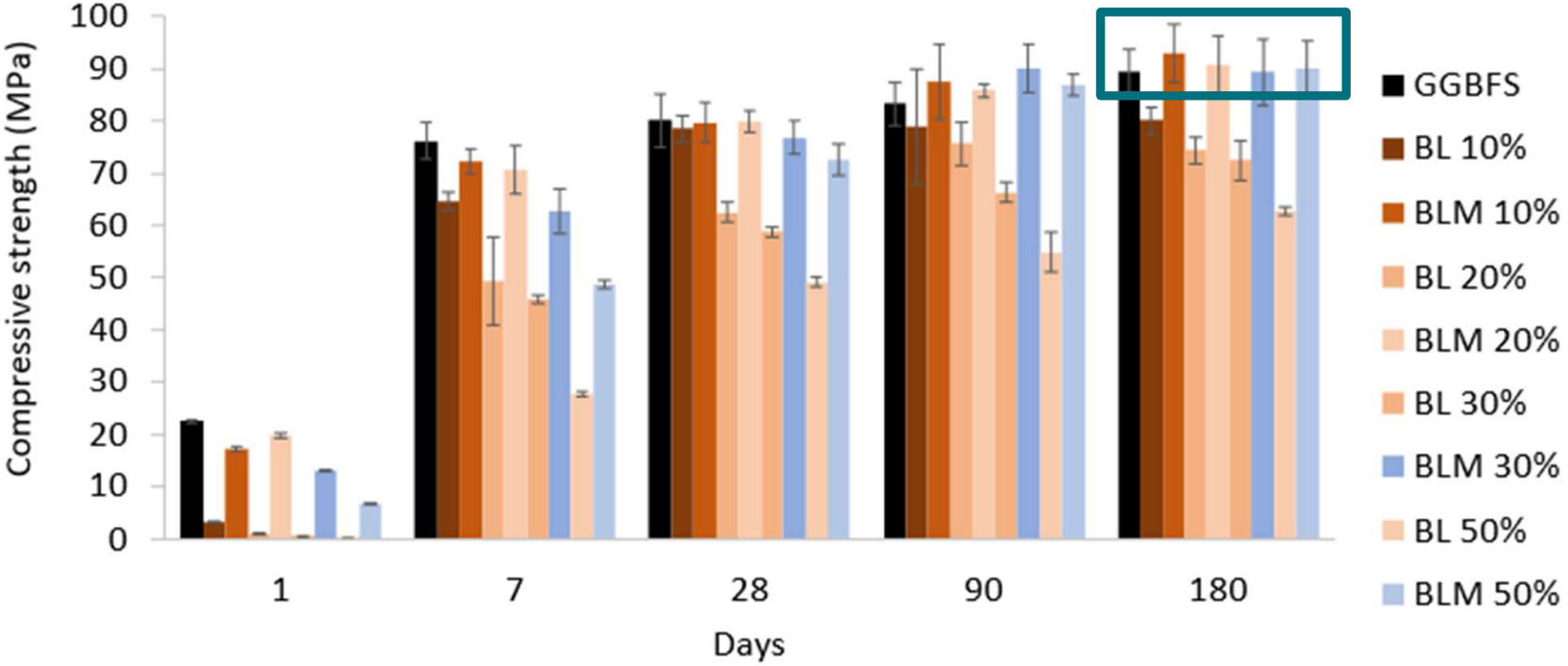
- Poral distribution



  - Finer porosity with time for all the mixes
  - Finer porosity with BLM 50% than BL 50%

Fine bricks

- Mechanical strength



  - BL: slower kinetics – Rc ↓ when [brick fines] ↑
  - BLM: quicklier kinetics - Rc ≥ GGBFS from 90 days
  - Brick fines can act as a *precursor*

Recycled sand for 3D printing

3D printing:

(+) Design opportunities

(−) Environmental impact

→ Binder

Granular skeleton (100% recycled sand)

Siam Research and Innovation Company - Triple S (2017)

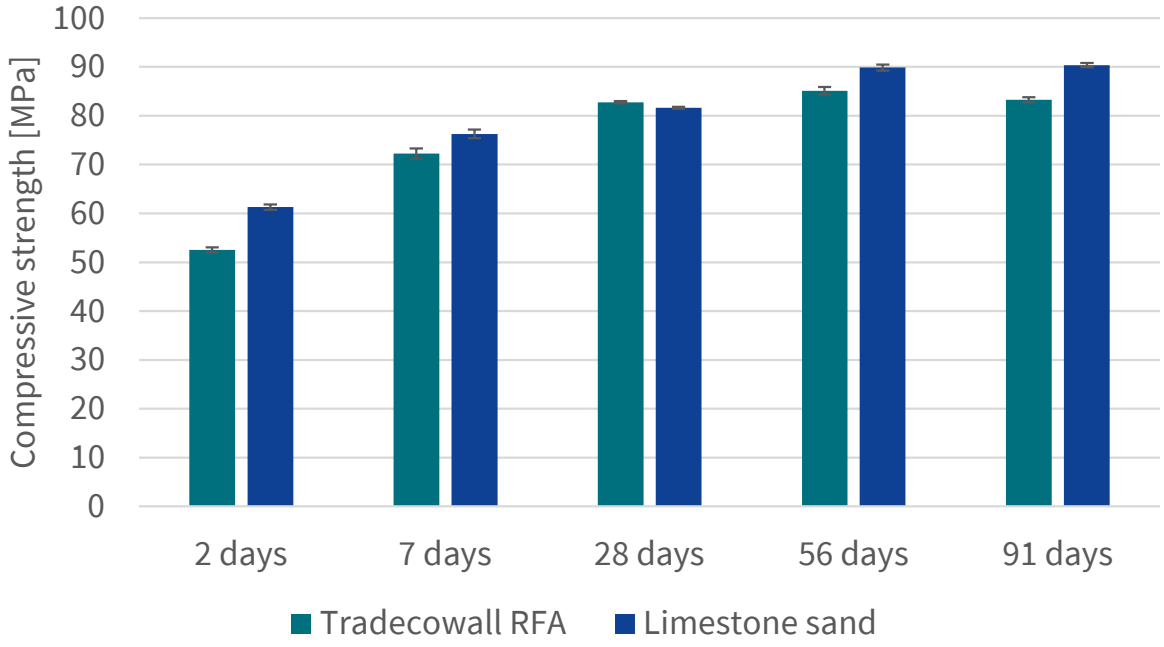
Recycled sand for 3D printing

Casted samples (4x4x16 cm prismatic samples are casted)

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

Three points bending and compressive strength :

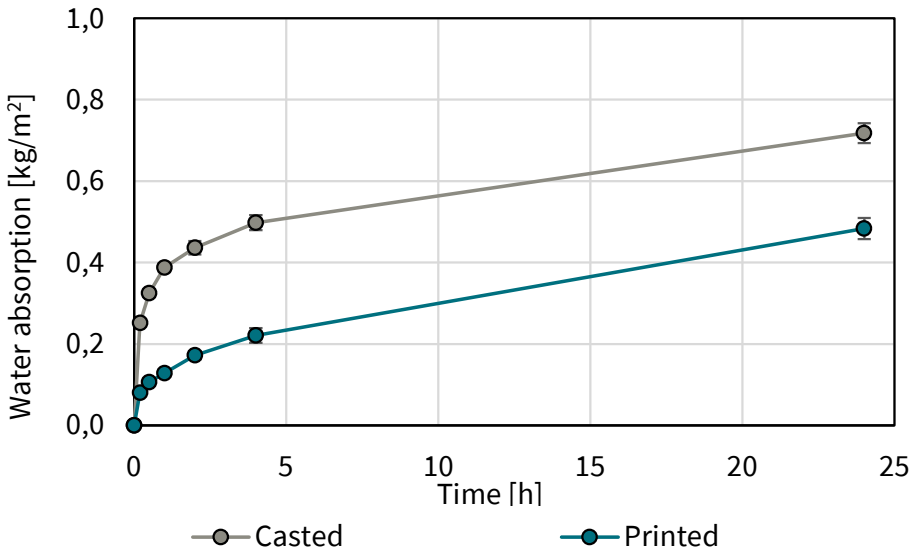
- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Compressive strength
- Water curing (20°C and 95±5% relative humidity)



Recycled sand for 3D printing

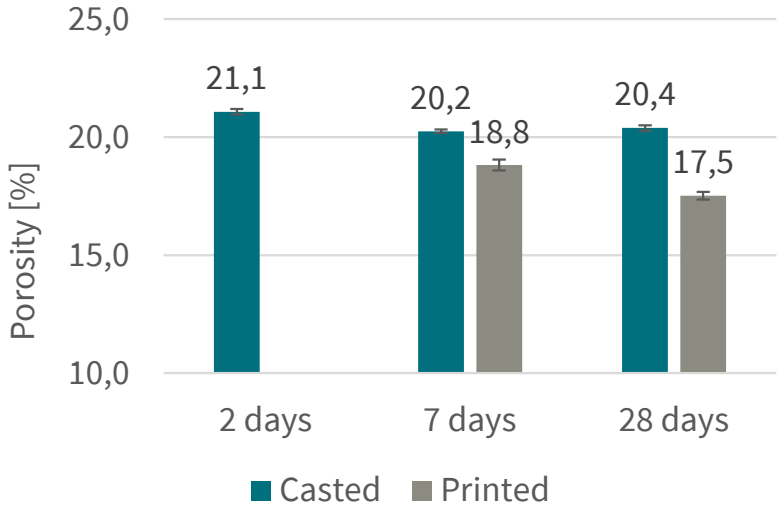
Capillary absorption tests NBN EN13057

- Influence of the ***printing process*** (casted samples vs printed samples)
- Water absorption [kg/m^2] and absorption coefficient [mm/h^{0,5}]



Porosity

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

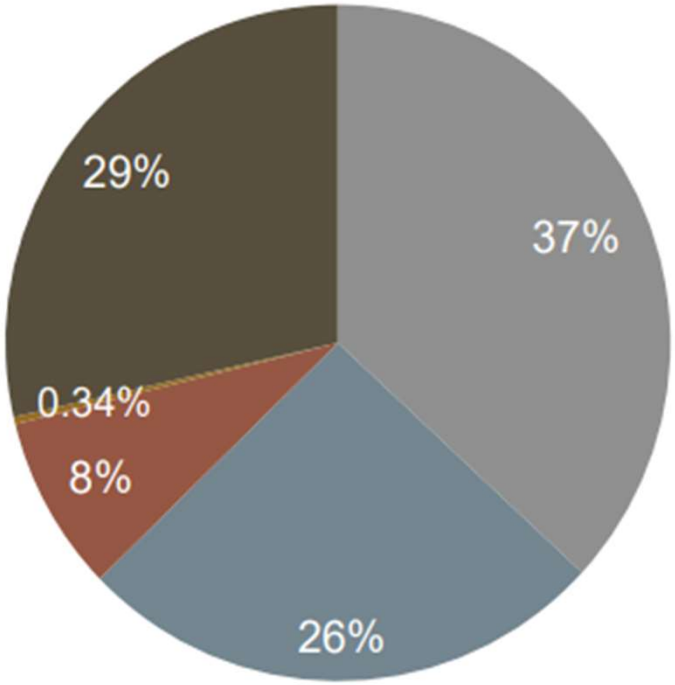


Recycled sand for 3D printing

Urban furniture
Bernard Serin park in Seraing

Rammed concrete

- Recycled Fine Aggregates
  - Composition
  - Granulometry 0/4



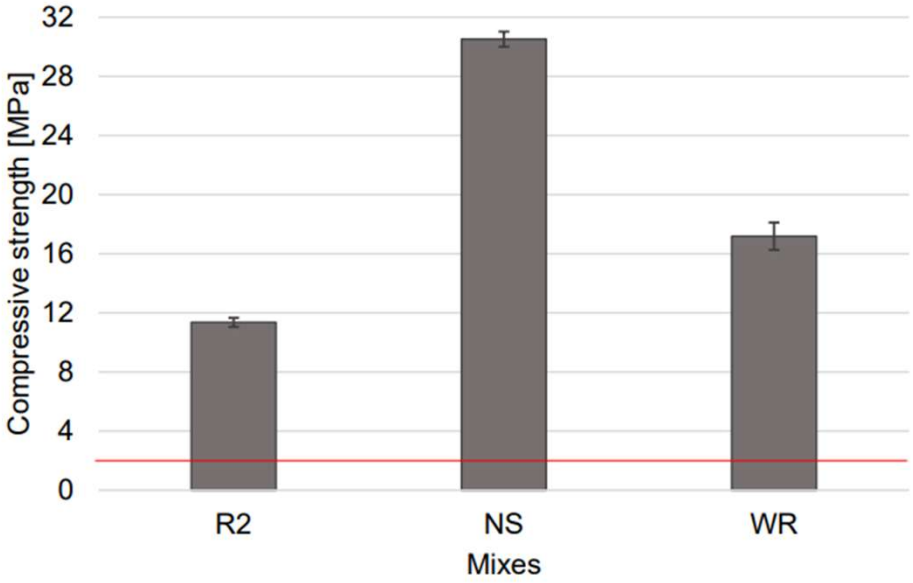
Percentage by component mass

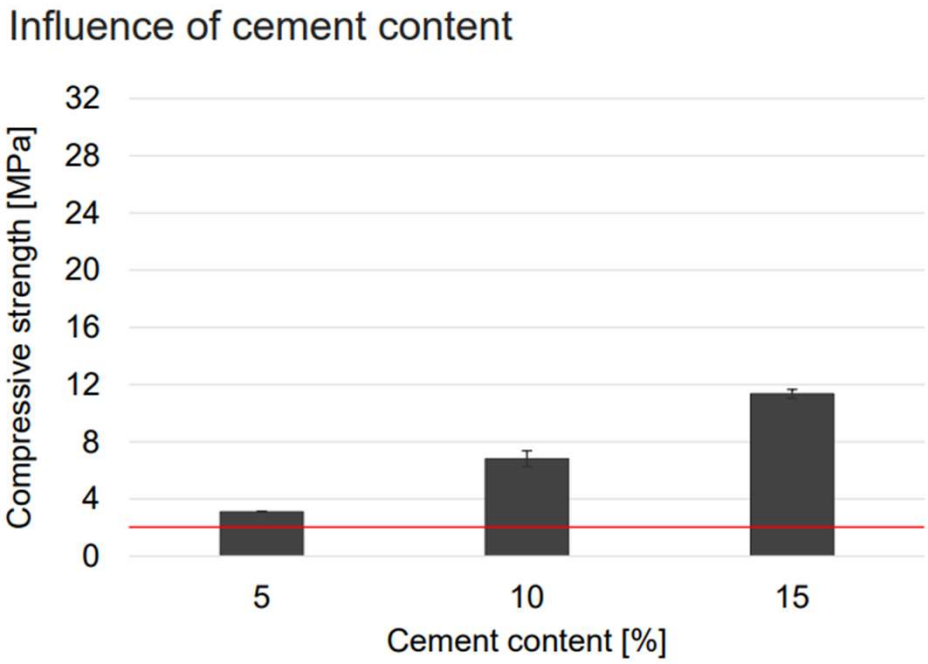
- Rc: concrete, mortar (37%)
- Ru: natural stone (26%)
- Rb: brick (8%)
- Rg: glass (0.34%)
- X: other; wood, rubber, plastic, … (29%)

Rcu: 63%
XRg: 29.34%

Rammed concrete

- Recycled Fine Aggregates
  - Compressive strength vs mixes (15% cement + 10% water + 75% RFA 0/4)) used different aggregates (NS = natural sand – R2 = Original RFAs – WR = Washed RFAs





Rammed concrete

- Recycled Fine Aggregates
  - low maintenance, low-tech construction process and are economical to build

…and finally

- 11 recommendations (JRC report)
  - Scientific developments
    - Recycled sand, sorting and crushing methods, mineralization, …
  - *Efficient supply chain*
    - *Value chain, circular vs fragmentation, geographical coverage, organic vs inorganic)*
  - *Legislation*
    - *Standards, requirements, prohibiting landfilling, certification CE2+*
  - *Reduce (sobriety)*
  - *Acceptability*

Use of recycled aggregates in concrete – opportunities for upscaling in Europe. J. N. Pacheco, J. de Brito, M. L. Tornaghi, 2023 (JRC Science for policy report (ISSN 1831-9424))

Acknowledgment

- VALDEM INTERREG FWVL
  - Integrated solutions for valorizing waste flows from building demolition: a circular economy over borders
- 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 France-Wallonie-Vlaanderen UNION EUROPÉENNE EUROPESE UNIE VALDEM

Interreg North-West Europe CIRMAP European Regional Development Fund

Interreg North-West Europe SeRaMCo European Regional Development Fund

Wallonie - Bruxelles International.be

UEE Urban & Environmental Engineering

Recommendations (JRC-2023)

1. **Public authorities** need to understand the full picture (*i.e. prohibiting landfilling, do not mix organic and inorganic*)
2. Reliable **statistics** for monitoring of C&DW recovery performances (*national and regional levels*)
3. Ensure broad **geographical coverage** of C&DW recycling facilities – capacitate concrete producers for RA use (*i.e. transportation costs*)
4. Create a **demand**, ensure a **market** (*i.e. mandatory percentages*)
5. **Legislation** to enforce policy, inspection to enforce legislation (*i.e. certification CE2+, end-of-waste product*)

Use of recycled aggregates in concrete – opportunities for upscaling in Europe. J. N. Pacheco, J. de Brito, M. L. Tornaghi, 2023 (JRC Science for policy report (ISSN 1831-9424))

Recommendations (JRC-2023)

6. Provide **guidelines and standards** and train the supply chain (*i.e. EN 206 + national standards*)
7. Accelerate innovation through **knowledge transfer** and synergies
8. Research and innovation in **improved methods for reuse and recycling**
9. Large scale, nation-wide **holistic industry-oriented** program
10. Increase public outreach and **clear communication** – circular models require public trust and transport
11. Do not underestimate the importance of **local authorities**

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