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Overcoming technical and regulatory barriers to a better circular economy in the construction industry

L. Courard, J. Hubert

Weimar, Progress of Recycling in the Built Environment
October 10-12, 2023

UEE
Urban & Environmental Engineering

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)

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Conditions for recycling: requirements, barriers, applications

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

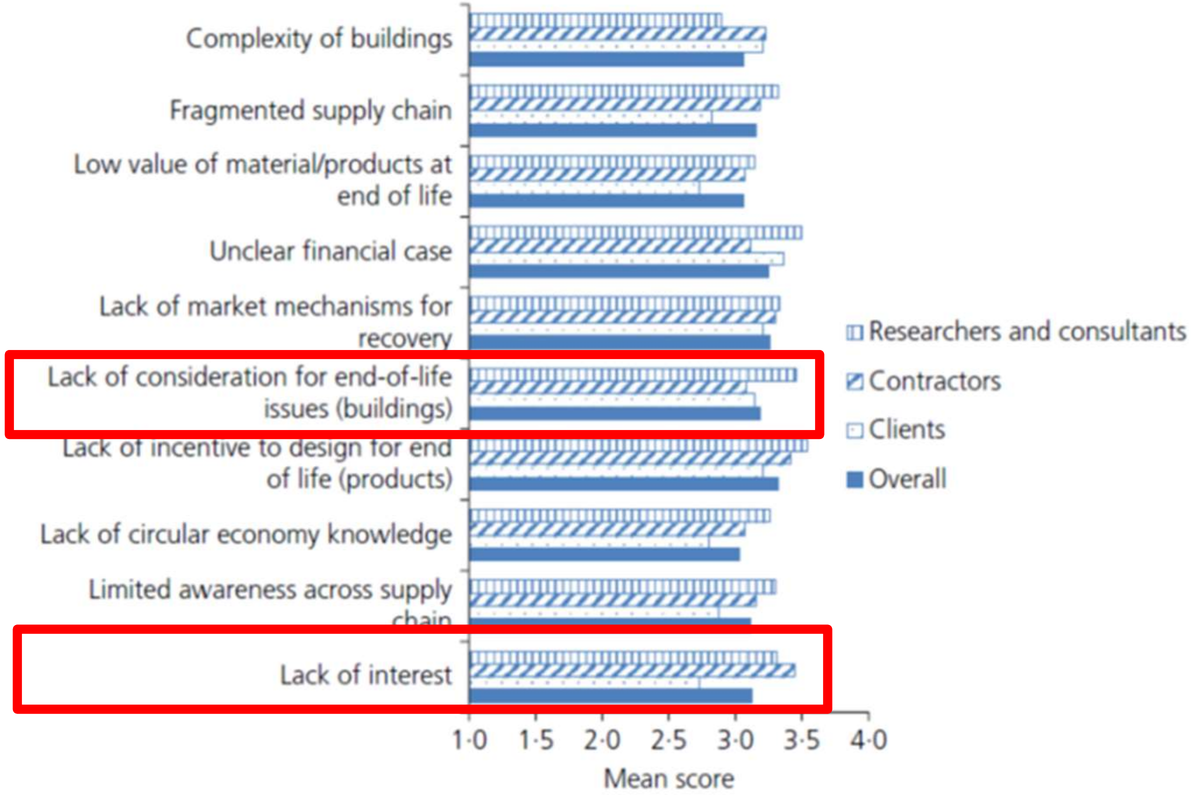
- Possible restrictions
  - Transport
    - Transport price = f(quantity, distance)
    - Independent of the quality
    - Interesting recycling if
      - Landfill far away (*if landfilling is accepted*)
      - High dumping charge
      - Expensive raw materials and difficult supply
  - Standards
    - *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

Barriers and challenges

- Most significant challenges for implementing circular economy in industrywide (survey-2017)



Tebbat Adams, K., Thorpe T., Osmani M., Thornback J., "Circular economy in construction: current awareness, challenges and enablers". Waste and resources management 170 (1) (2017) 15-24

Barriers and 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)

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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Recommendations: examples and applications

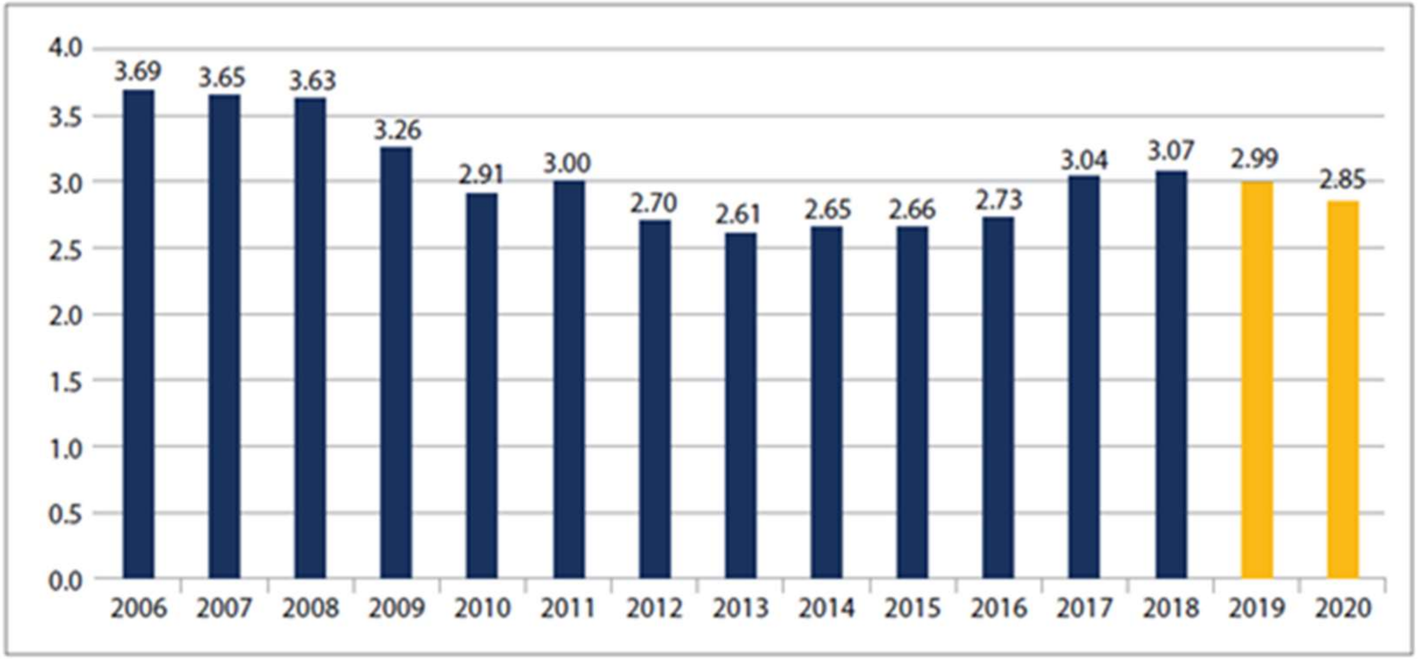
Reliable statistics

- 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
  - *Construction area is producing more or less than 40% of CO_2*
  - Annual production of **recycled aggregates** accounted for 278 million tons in 2019

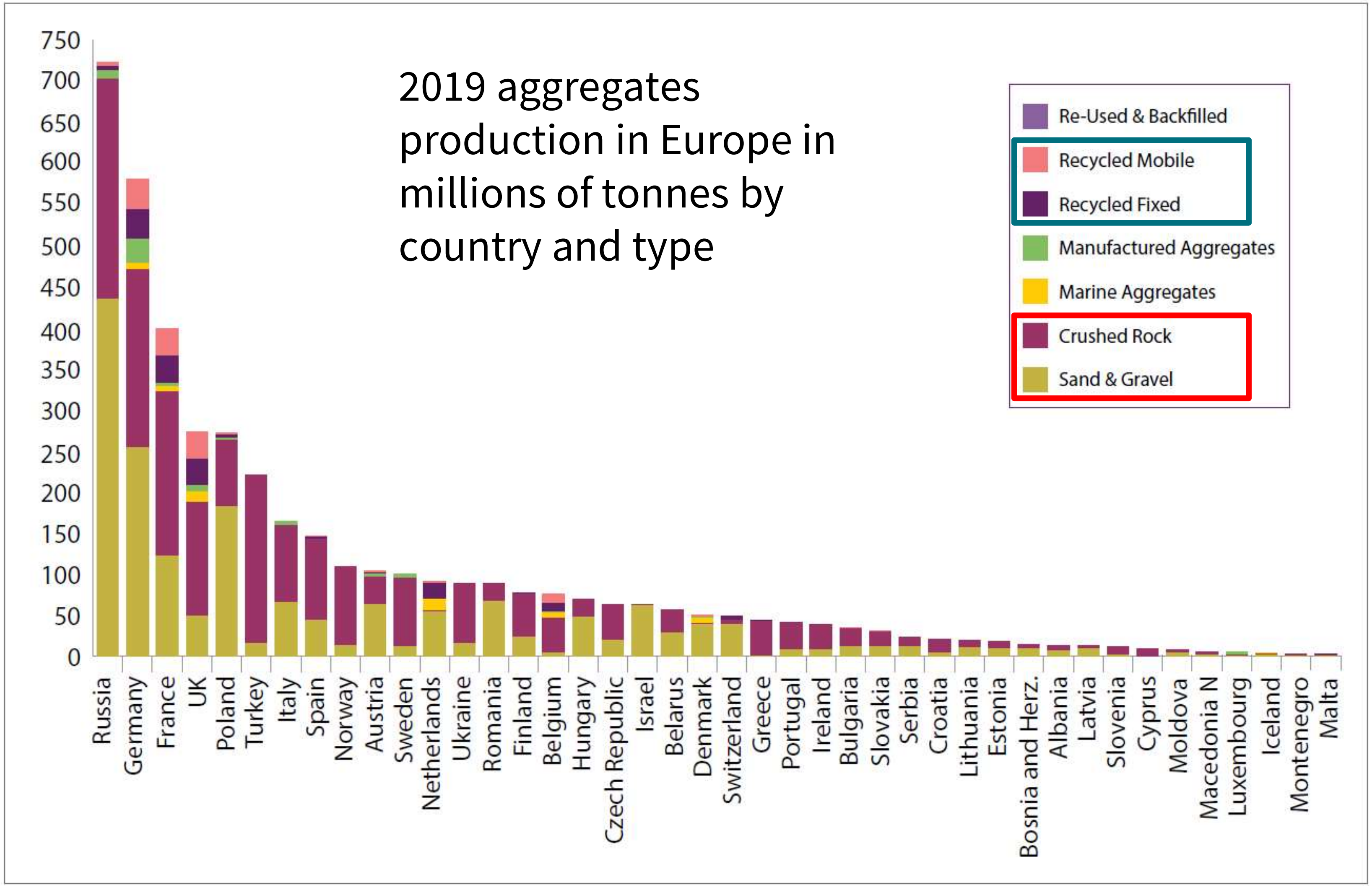
UEPG, 2021. European Aggregates Association – Annual Review 2020-2021, Brussels, 30 p.

Reliable statistics

- Market for aggregates/sand
  - Trend in total EU27 + UK + EFTA Tonnages (in billions of tonnes) for the production of aggregates (UEPG 2021) - 26,000 quarries and pits, operated by 15,000 companies



Reliable statistics



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

Reliable statistics

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

Virgin Aggregates		Recycled Aggregates	
46.9% crushed rock	**39.7%** sand & gravel	Construction & demolition wastes (CDW)	**9.3%** recycled (278 million tonnes)

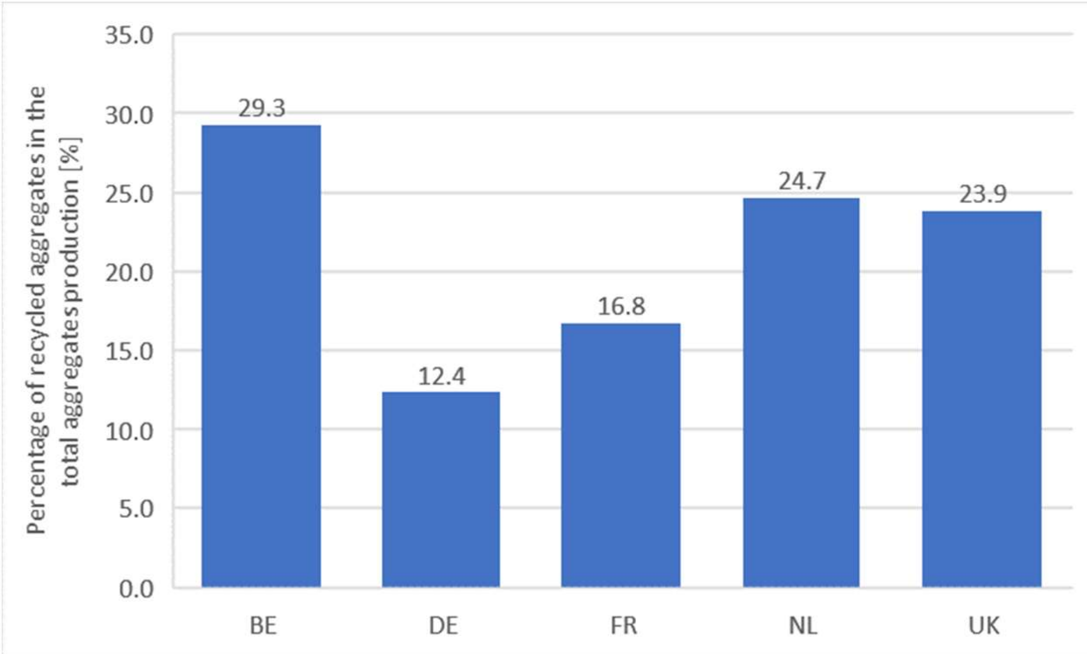
Concrete

Mixed

Reliable statistics

- 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

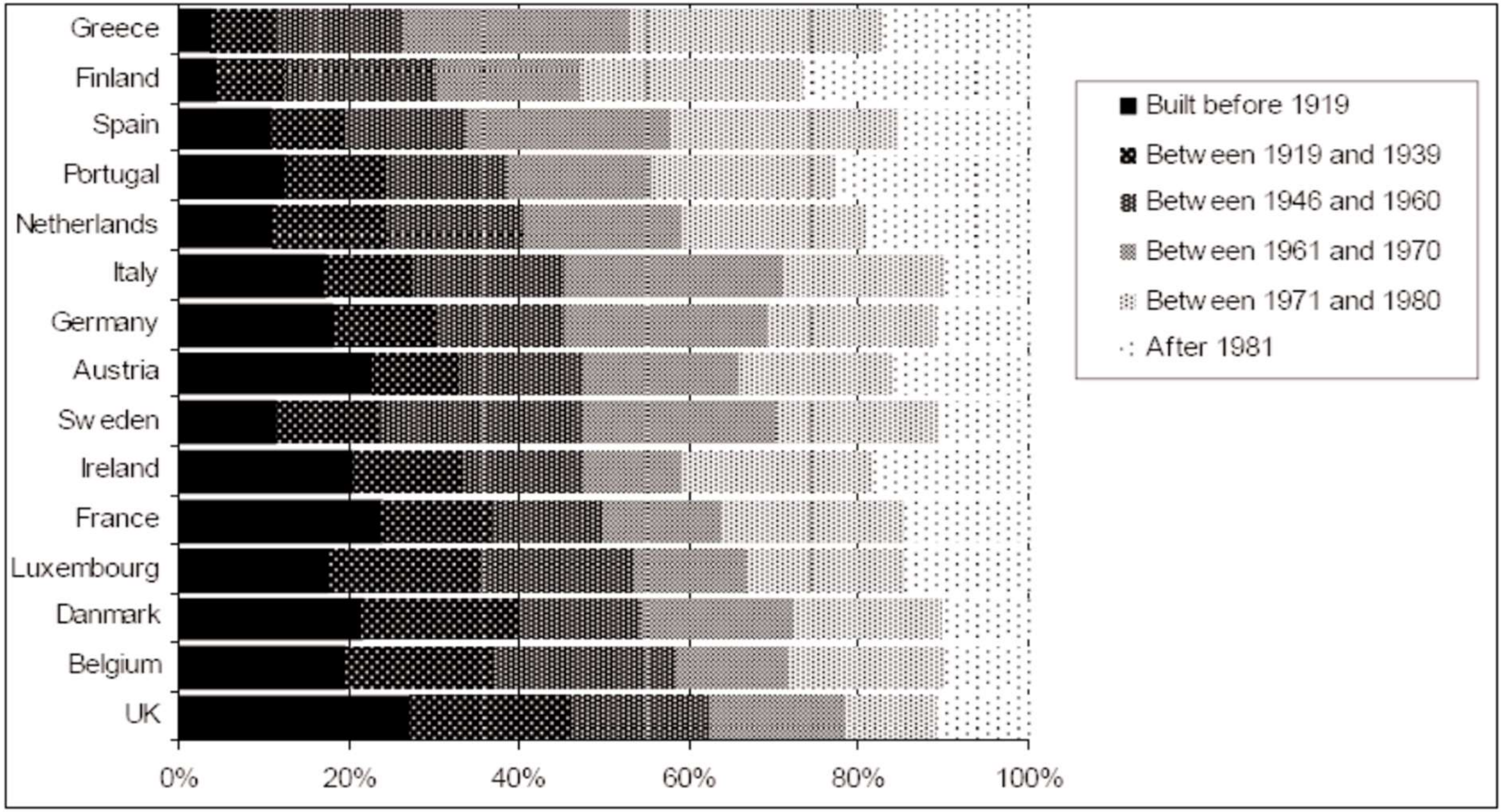


Reliable statistics

- **Non metallic material** extraction has increased nearly **5 times** over the **50 last years**
- It represents now almost **half of the total material extraction** (42.8 BT)
- Build stocks have grown 23-fold in the 21th century
- **In 2018**, 43.6 BT materials were added while 12BT was depleted form stock
- Net addition: **32.8 BT** (two-third of net stock addition in Growing Countries)

Reliable statistics

- Distribution of building age in different European countries (BE: 70% older than 1970)



Scientific Support Plan for a Sustainable Development Policy (SPSD II), (2006), Socio-technical factors influencing residential energy consumption (SEREC), Belgian Science Policy, Brussels

Knowledge transfer

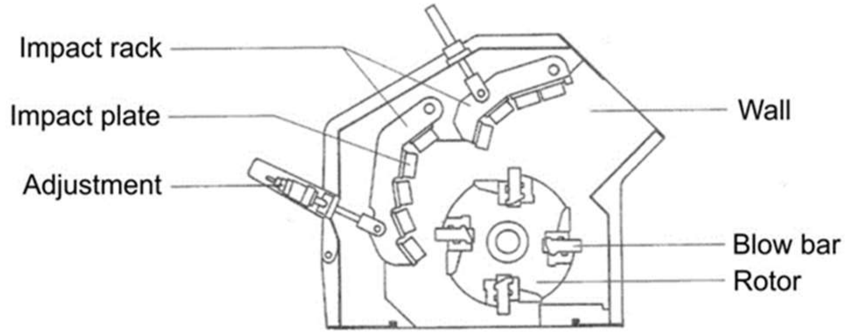
- Accelerate innovation through knowledge transfer and synergies

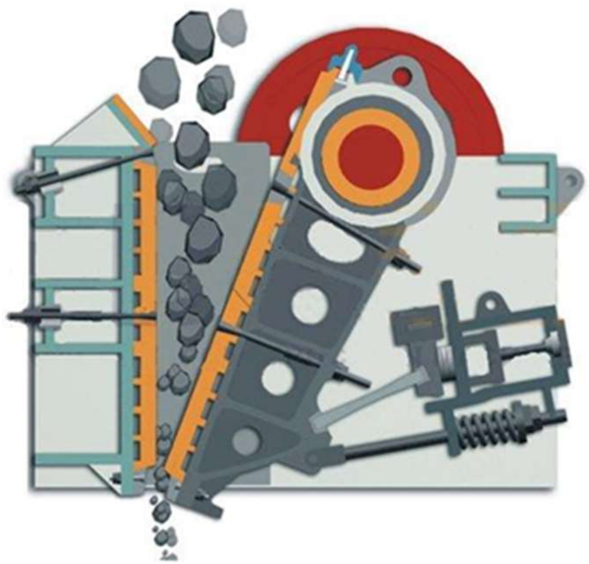
Research and innovation

- 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
  - CO_2 capture for increasing RCA properties

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)

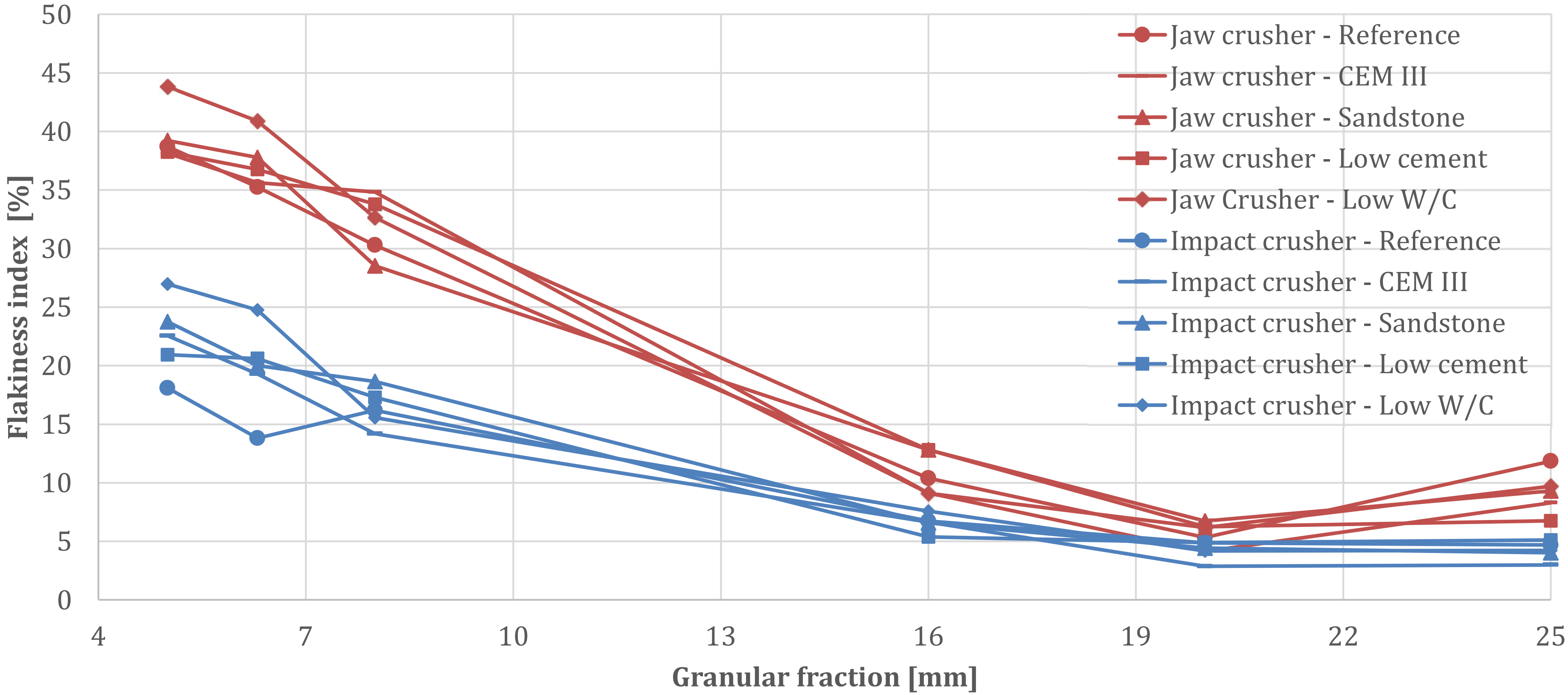
Material processing

- 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

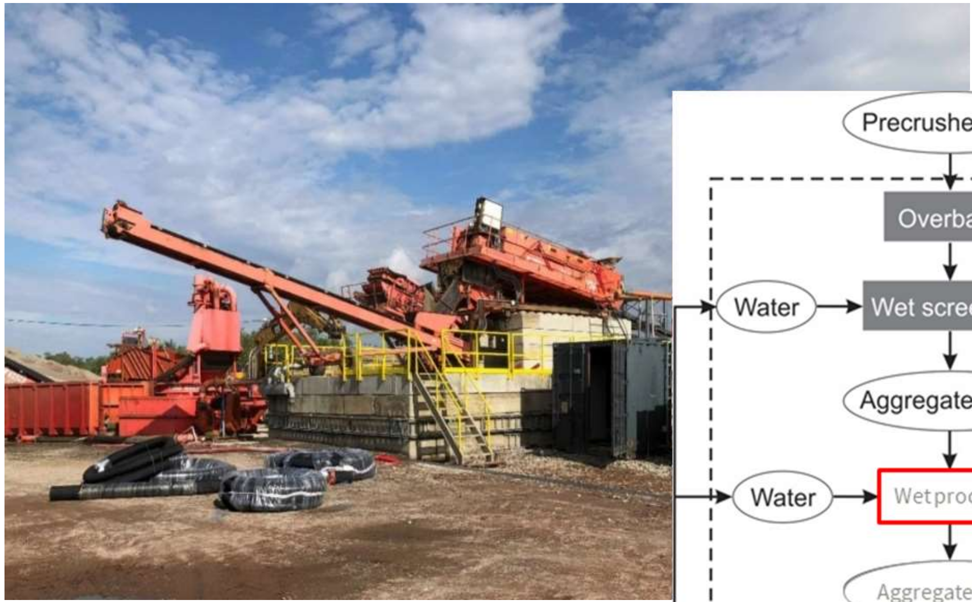
Material processing

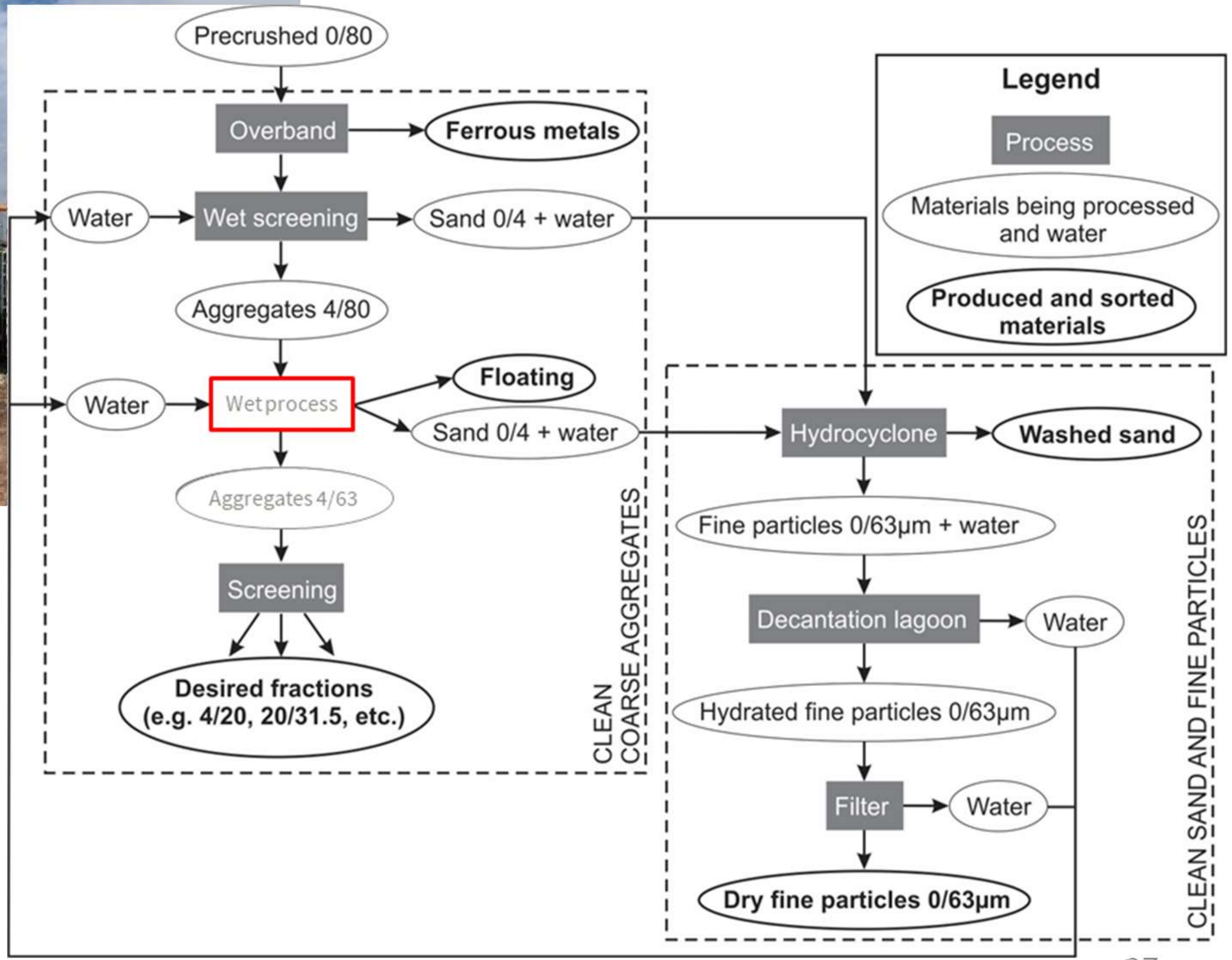
- The flakiness index decreases with increasing granular fraction
- The jaw crusher produces flakier aggregates
- No influence of the concrete composition



Materials processing: washing

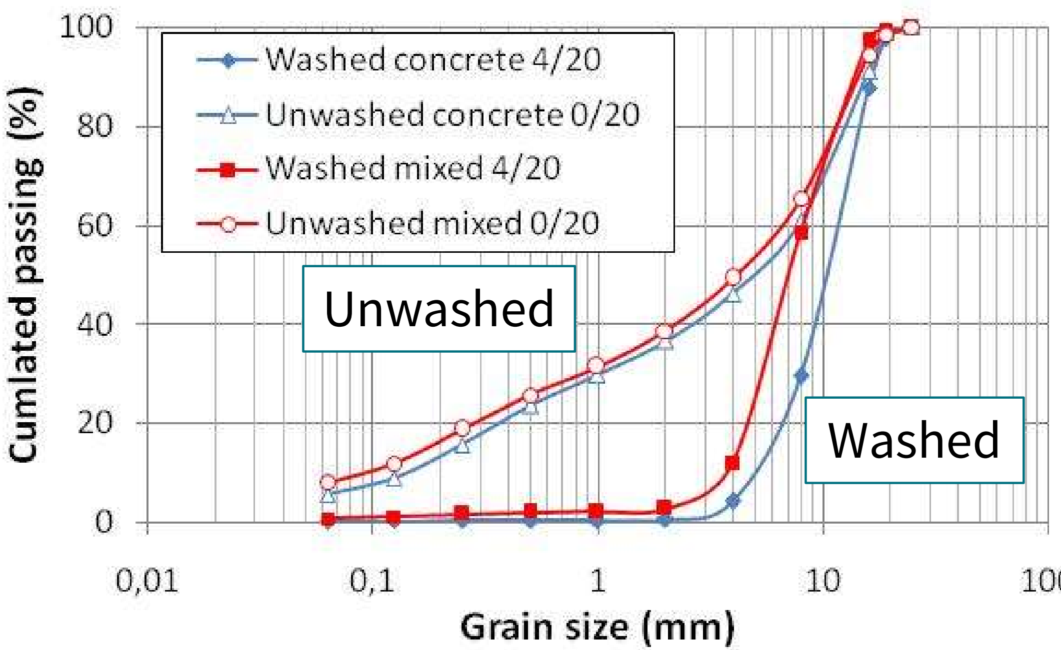
SeRaMCo recycling plant (Tradecowall)

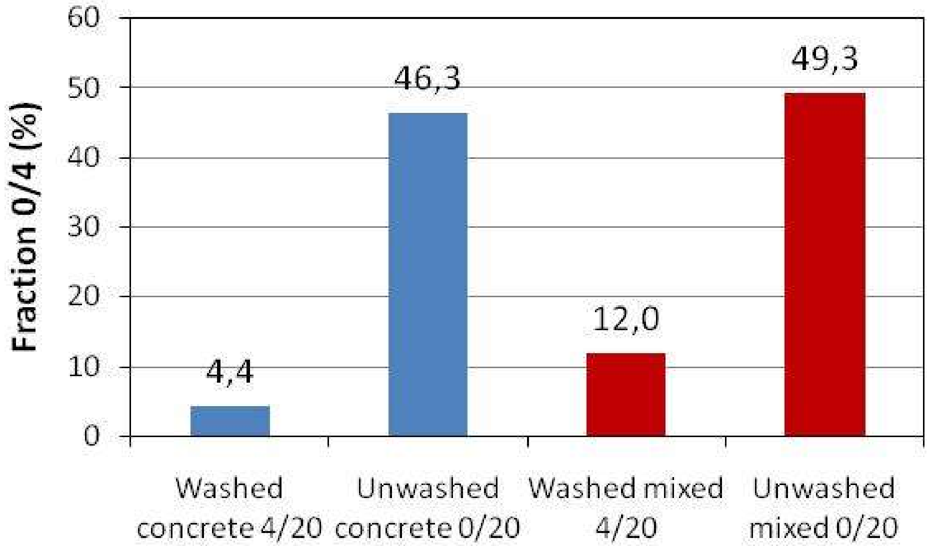




Materials processing: washing

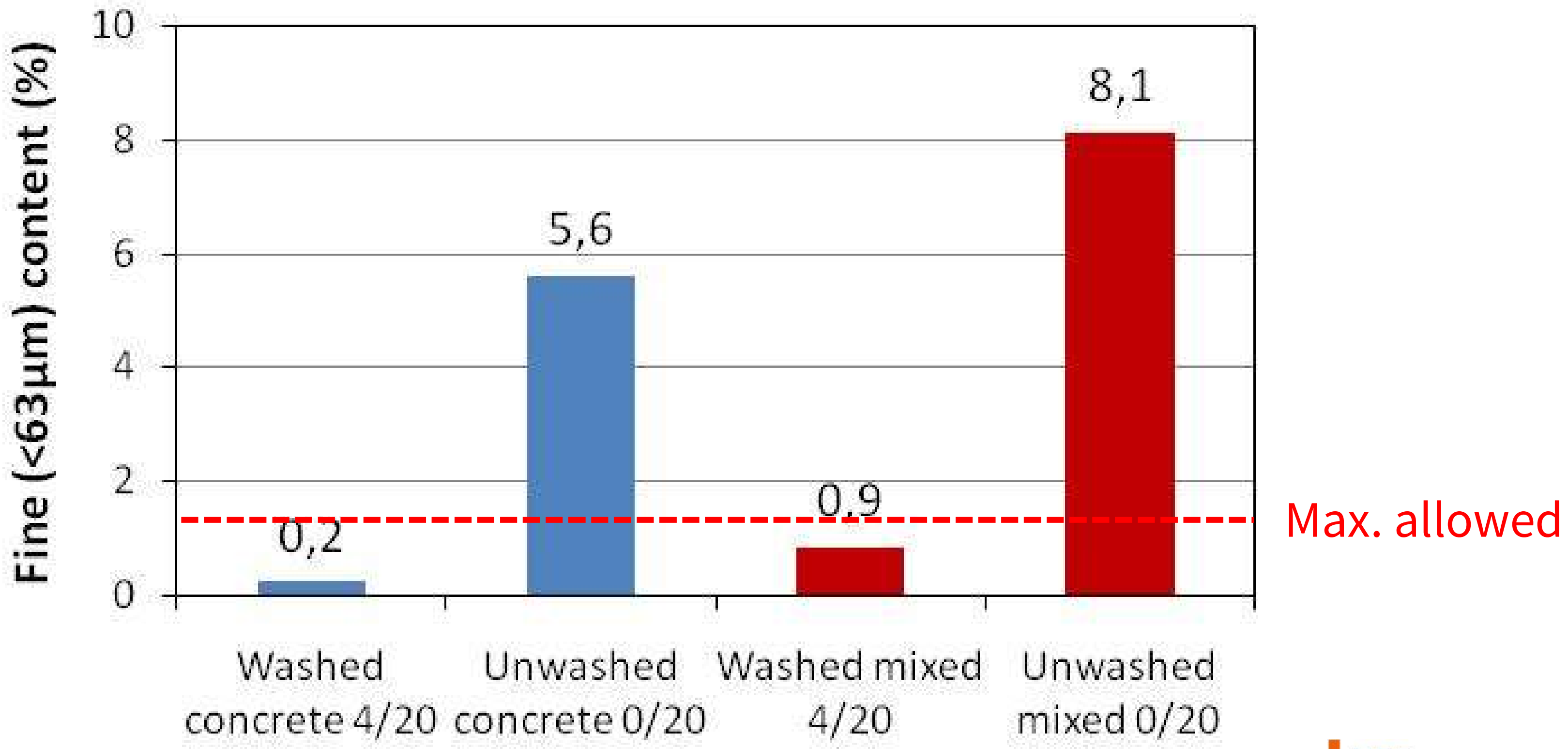
- 0/4 fraction comprises nearly 50% of the unwashed aggregates composition
- 0/4 fraction a bit higher in mixed aggregates
- Washing significantly reduces the sand fraction of the aggregates





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 considered countries



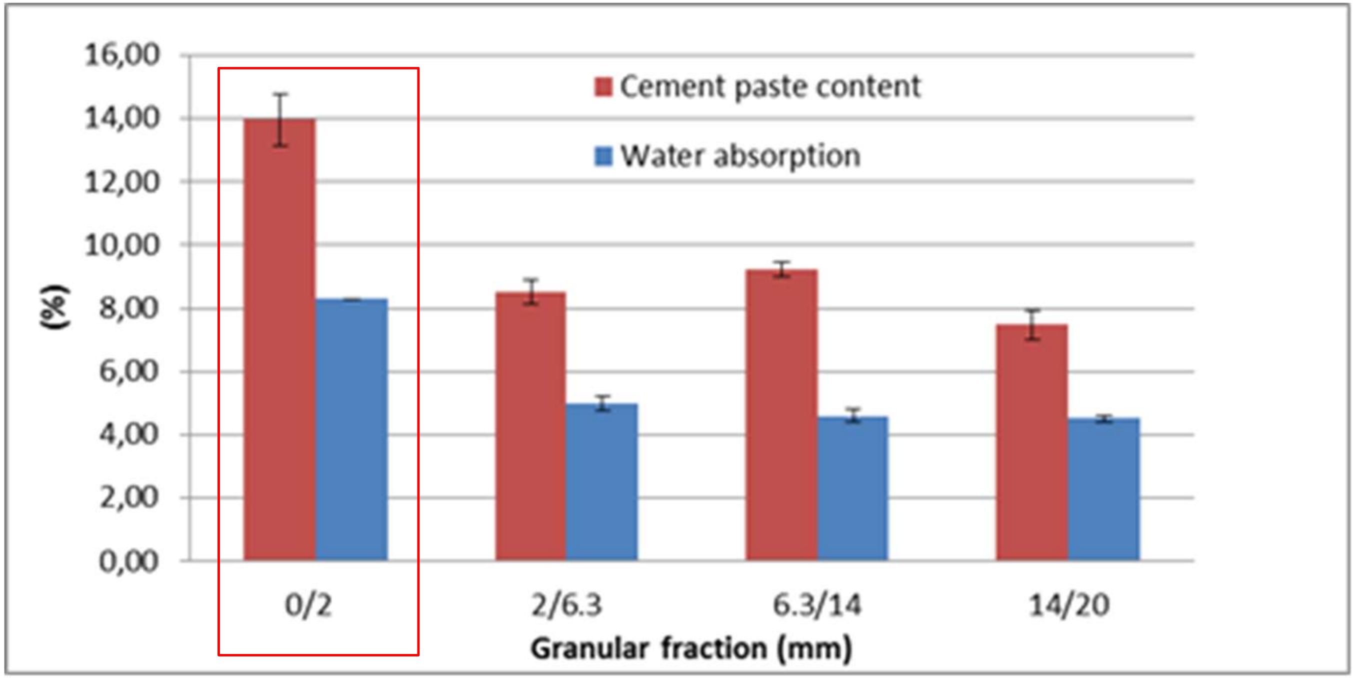
Production wastes

- 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

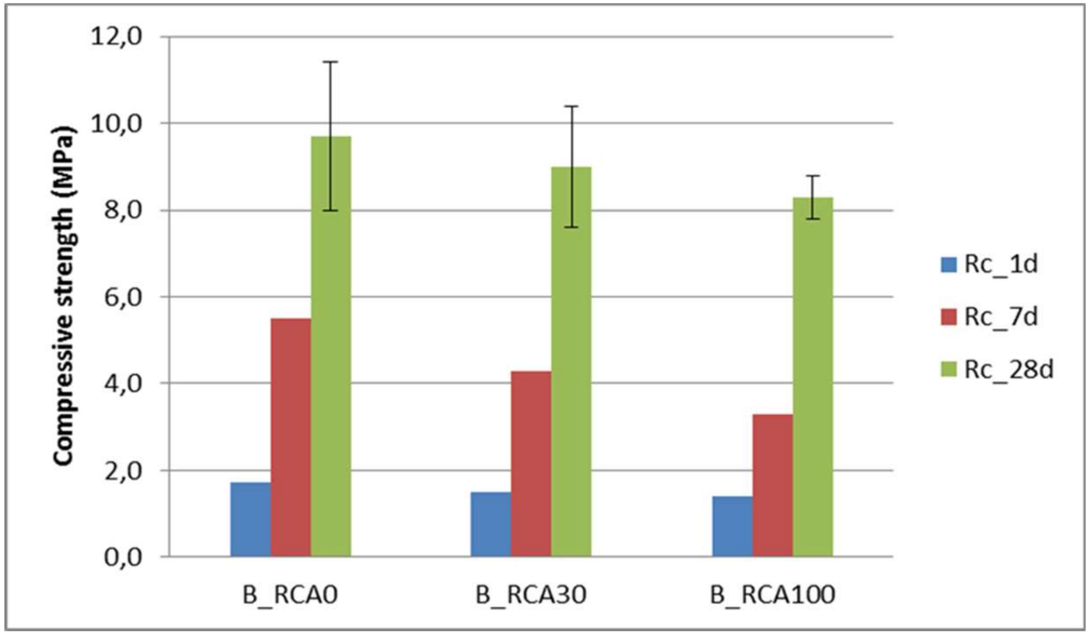
► Water absorption W_A (EN 1097-6)



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

Production wastes

- Compressive strength

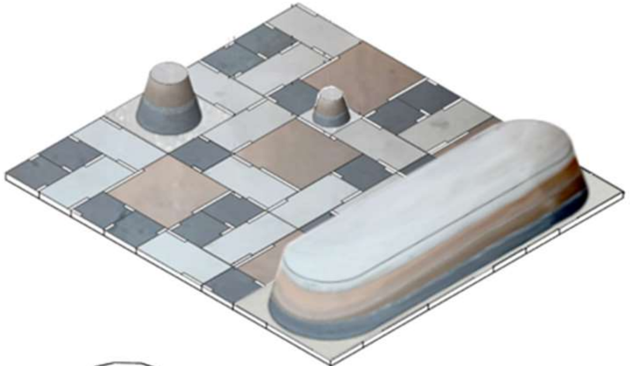


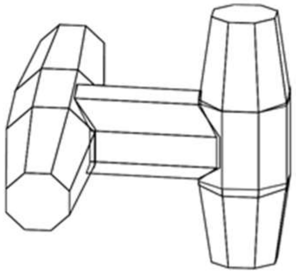
  - Compressive strengths of concretes with RCA are slightly lower than those of concrete with natural aggregate
  - Compressive strength of concrete made with 100% RCA at 28 days is 8 MPa (14.4% decrease)

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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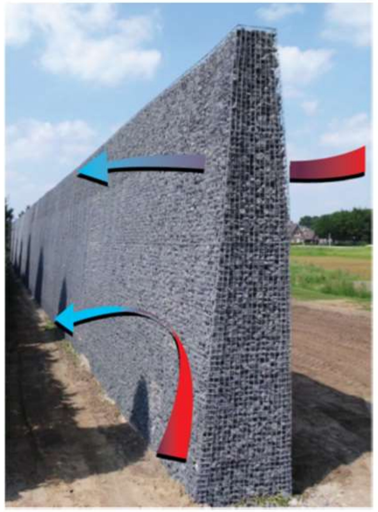
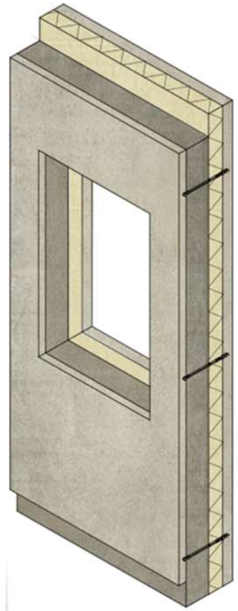
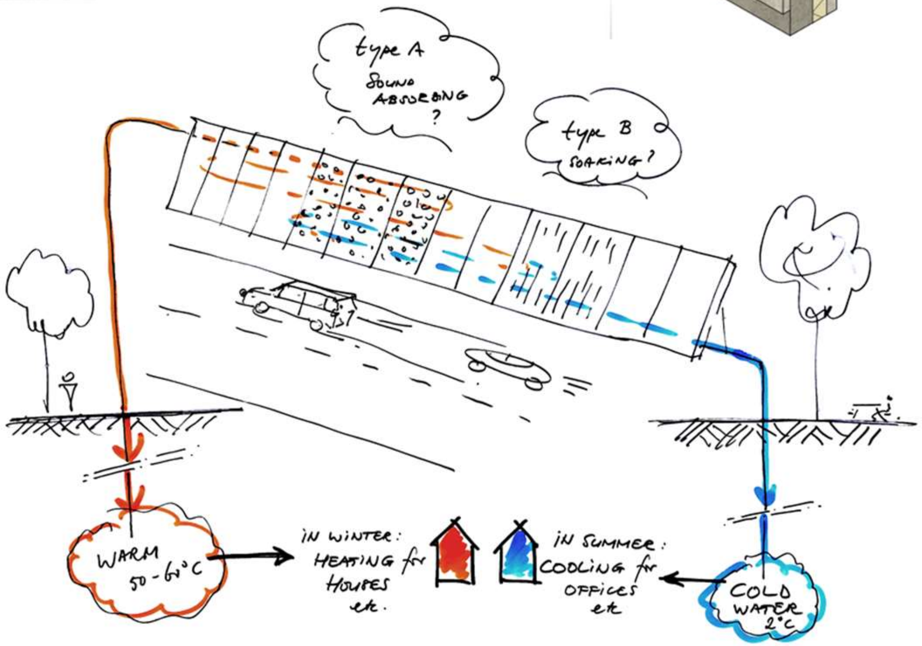


Prefab products: Parkour Park

Cement produced with recycled fines

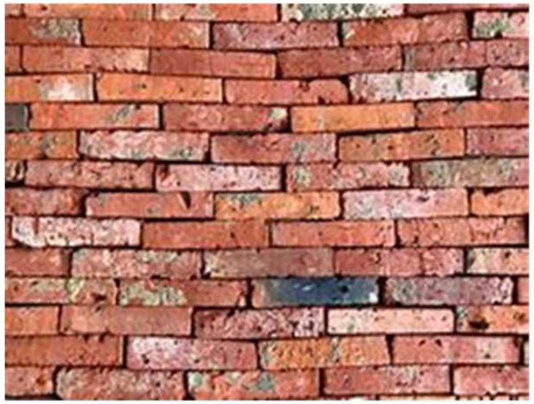
Recycled concrete aggregates

Natural sand

Rc : 50-55 MPa
W/C <= 0.45
Ciment >= 340 kg/m^3
Absorption d'eau <= 6.5%

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

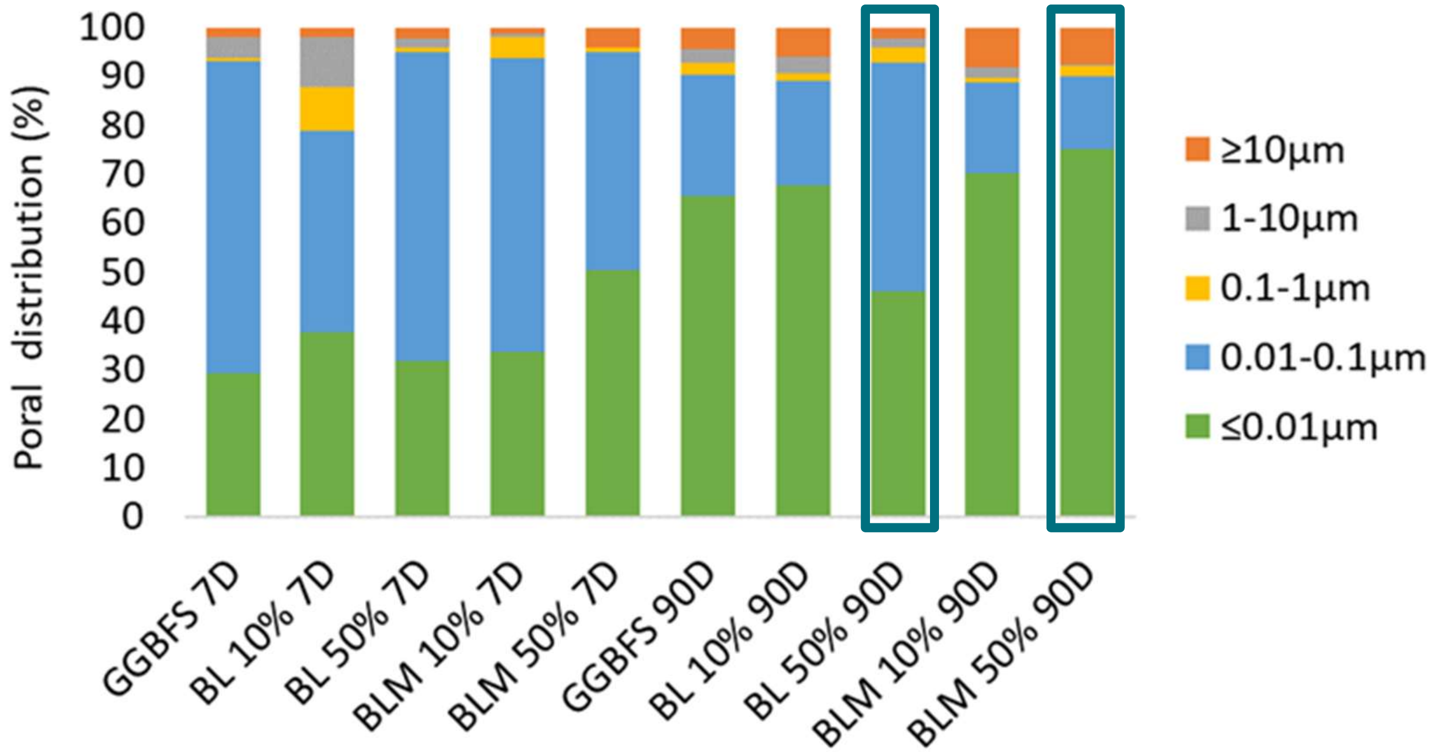
Soda (NaOH)
Sodium Silicates (Na_2SiO_3)
(SiO_2/Na_2O: 1.45)

Substitution
10, 20, 30 and 50 %

Characterization at
7 and 90 days

Fine bricks

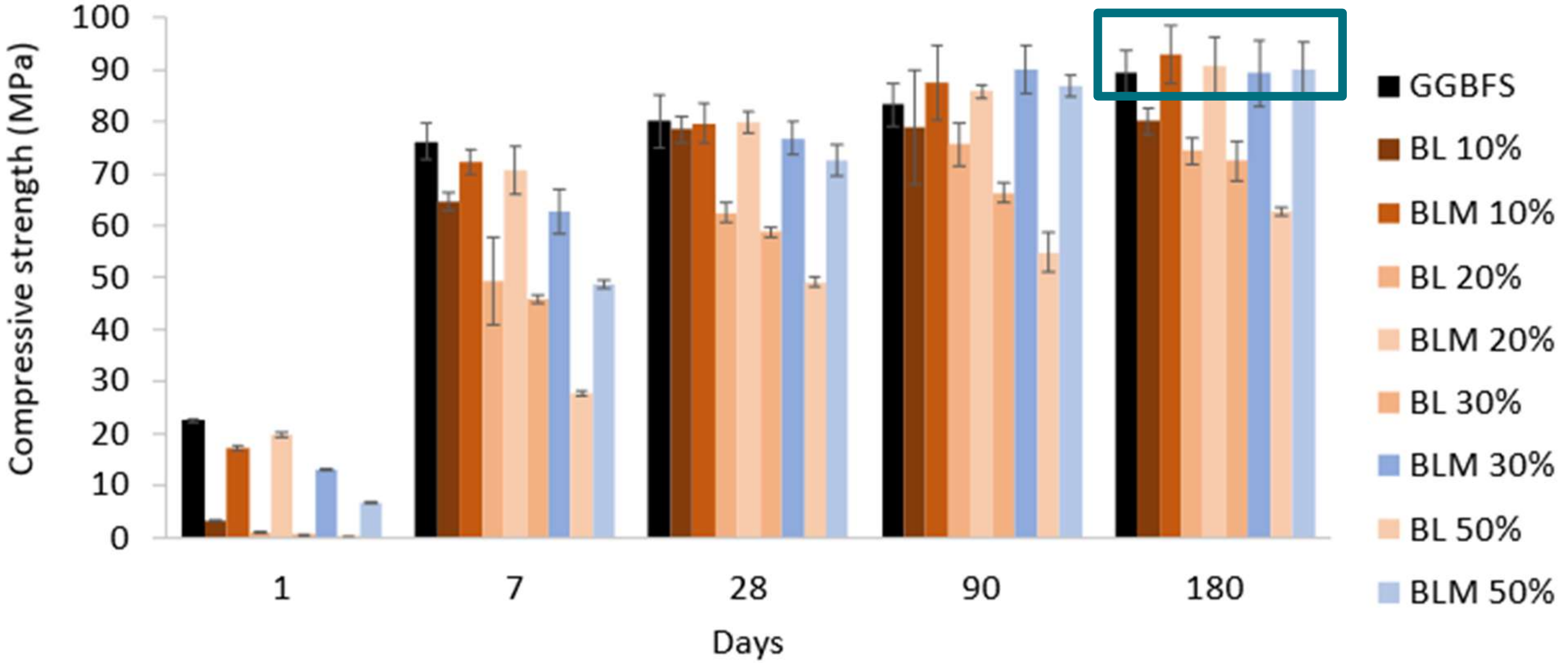
- Poral distribution



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

Fine bricks

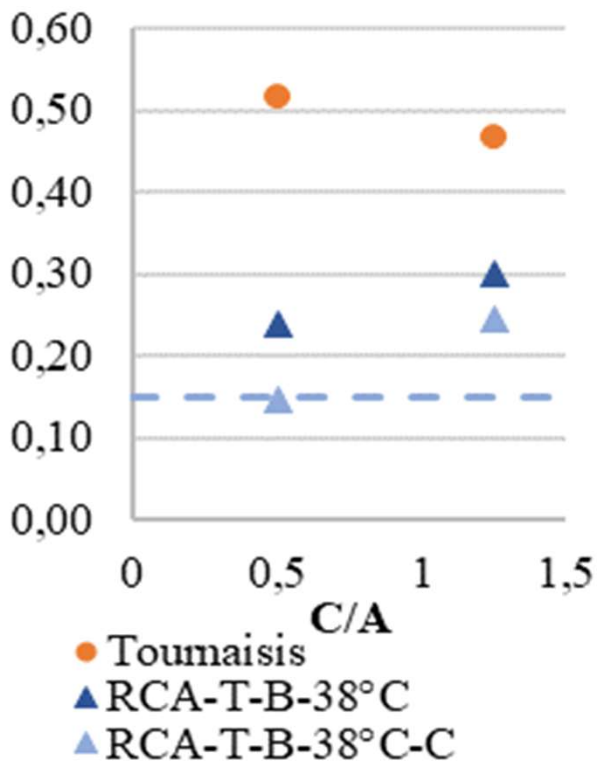
- Mechanical strength



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

Carbonation of RCA affected by AAR

- Expansion (%)
  - Laboratory manufactured RCA from boosted concrete stored at 38°C (+ carbonation 20%)



Effect of carbonation on recycled concrete aggregates affected by alkali-silica reaction. S. Grigoletto, J. Hubert, J. Duchesne, B. Bissonnette, F. Michel, L. Courard. 17th International Conference on Alkali Aggregate Reaction in Concrete ICCAR 2024, 18-24 mai 2024, Ottawa (Canada)

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)

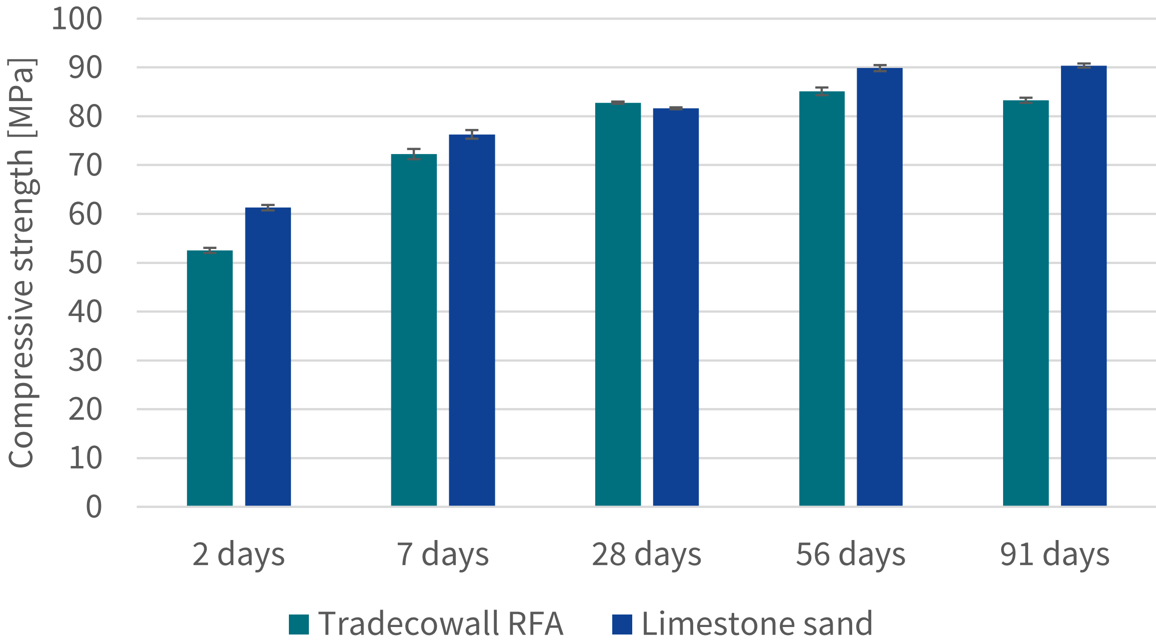
Recycled sand for 3D printing

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 :

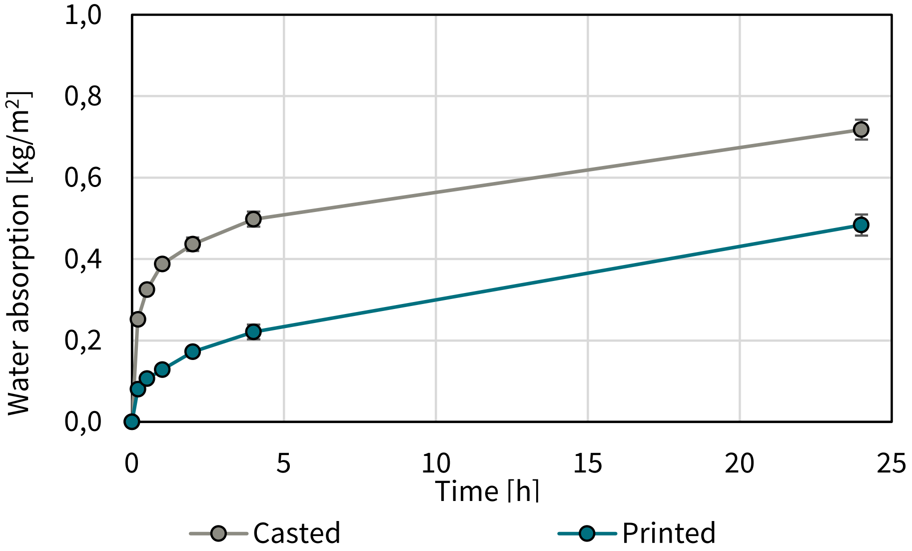
- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Compressive strength
- Water curing (20°C and 95±5% relative humidity)



Recycled sand for 3D printing

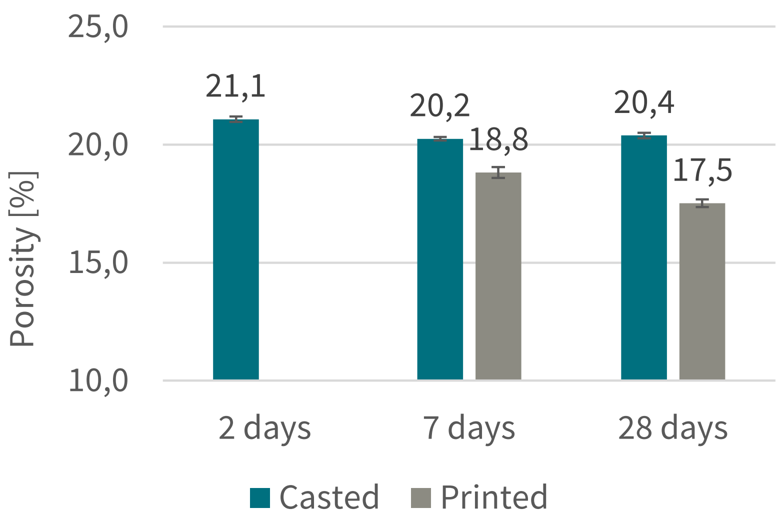
Capillary absorption tests NBN EN13057

- 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

…and finally

- 11 recommendations
  - Scientific developments
    - Recycled sand, sorting and crushing methods, mineralization, …
  - *Efficient supply chain*
    - *Value chain, ciruclar vs fragmentation*
  - *Legislation*
    - *Standards, requirements, taxes*
  - *Reduce (sobriety)*
  - *Acceptability*

…and finally

- 11 recommendations
  - Scientific developments
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  - *Efficient supply chain*
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  - *Legislation*
    - *Standards, requirements, taxes*
  - *Reduce (sobriety)*
  - *Acceptability*

- *Be optimistic: technology is (a part of) the solution ….*

Acknowledgment

Interreg France-Wallonie-Vlaanderen UNION EUROPÉENNE EUROPESE UNIE

VALDEM

- VALDEM INTERREG FWVL
  - Integrated solutions for valorizing waste flows from building demolition: : a cricular 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 North-West Europe CIRMAP EUROPEAN UNION European Regional Development Fund

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

Wallonie - Bruxelles International.be

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