THE 14TH SCIENTIFIC DAY
June 05th-06th, 2025
"LEVERAGING R&D FOR INNOVATION AND GROWTH"
Organized by

Recycling Construction and Demolition Wastes: opportunities for innovation

Luc Courard, Romain Libert, Yeakleang Muy, Imad Kanjo, Julien Hubert, Bao Minh Phuong Ta, Makara Long, Julien Troquay

Building Materials
Urban and Environmental Engineering
University of Liège, Belgium

Institute of Technology of Cambodia, Phnom Penh, Cambodia

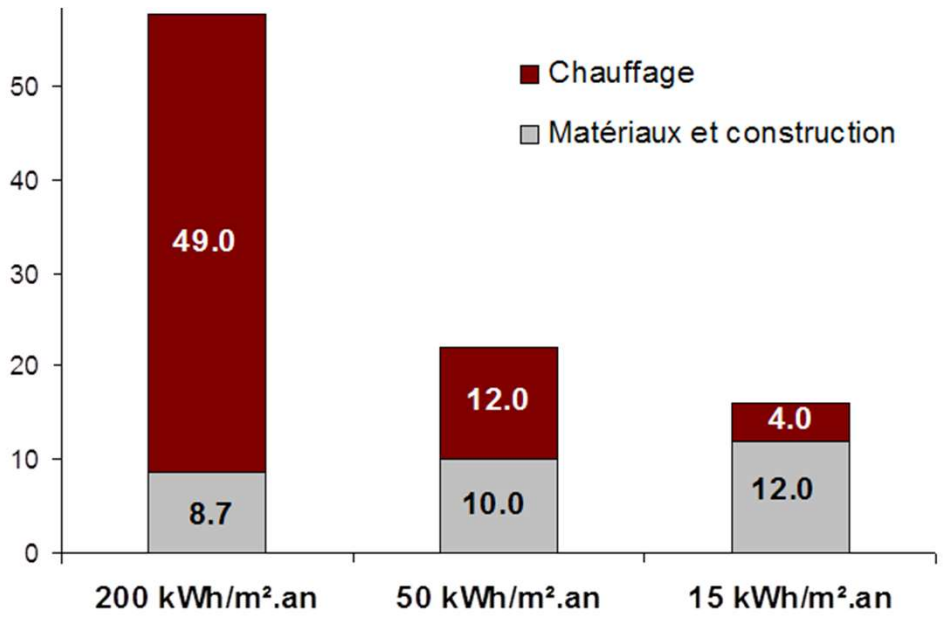
Global context

Development of materials and alternative techniques for buildings

Increasing thermal insulation performances of housing

Increase of relative weight of building materials *vs.* environmental impact

Needs for developing new materials



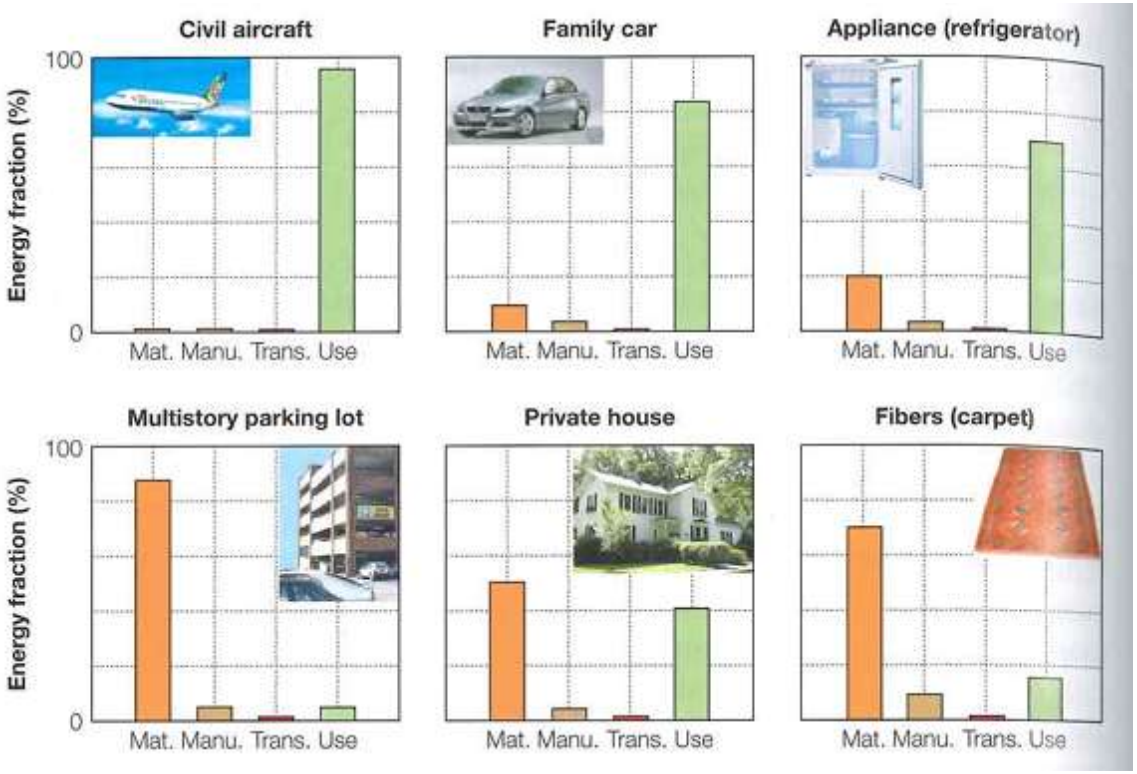
G. Escadeillas, Métamorphoses, Liège, 2011

Global context

Approximate value of energy consumed at each phase

➡ Importance of **material selection** for infrastructures and housing

3R theory: **R**educe, **R**euse and **R**ecycle

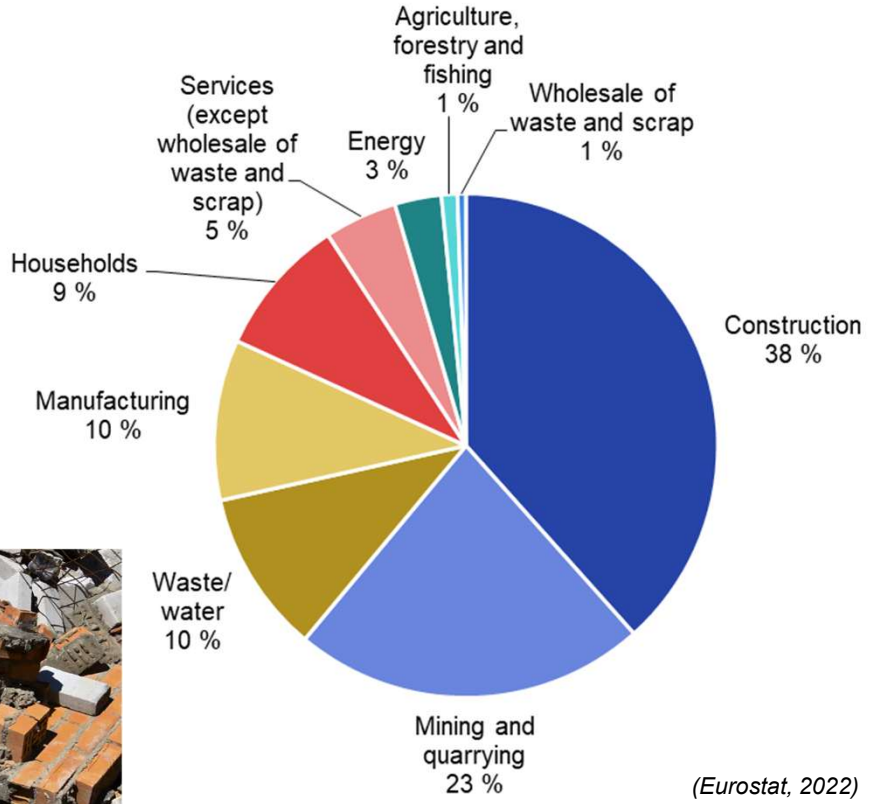


Ashby, 2022

Global context

Construction industry

- 850 millions tons of waste
- 1/3 world waste production
- >30% CO_2 total emissions
- 9 billion tons of concrete
  - 50% vol. aggregates
  - 25% vol. sand



(Eurostat, 2022)

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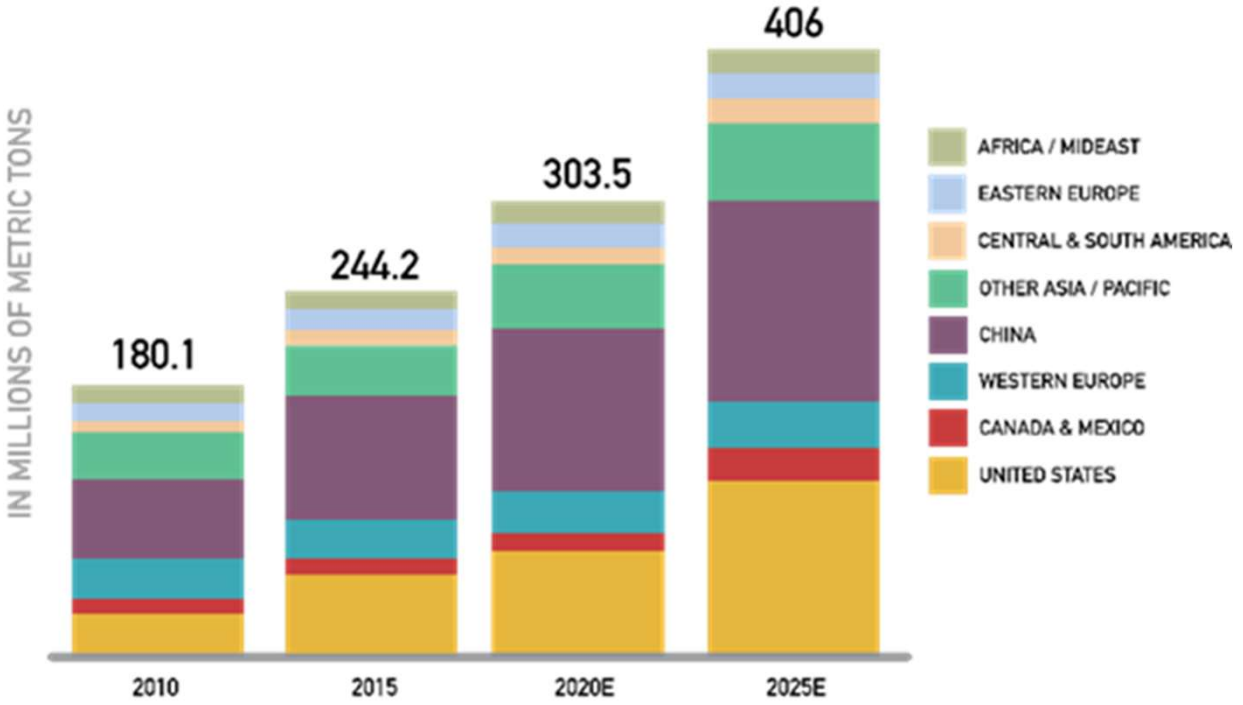
Global context

Sand production/consumption

In 2023, the leading exporters of sand were United States (563 M$), Australia (273 M$) and Netherlands (208 M$)



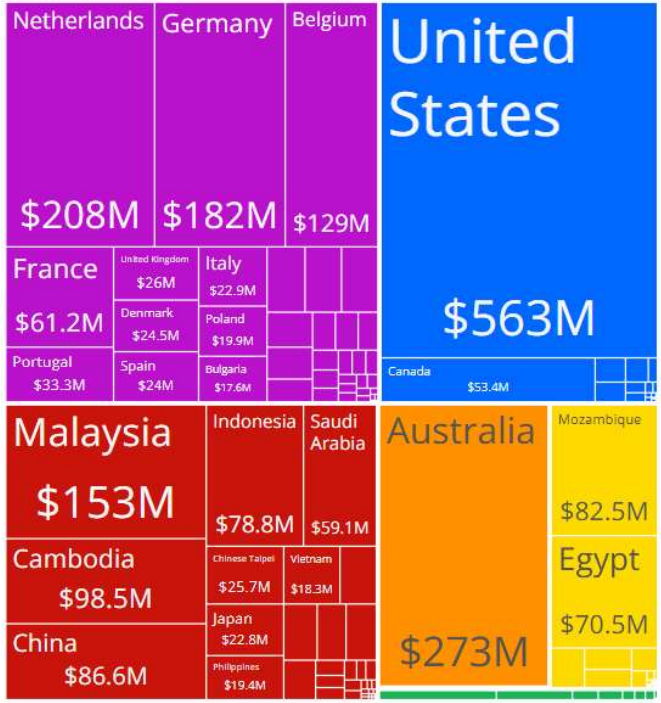
World sand demands in millions of metric tons (https://iveybusinessreview.ca/6580/lafargeholcim-the-plastic-solution-to-the-global-sand-wars/graphic-2-world-sand-demand/)

https://oec.world/en/profile/hs/sand

Global context

Sand production/consumption

In 2023, in South East Asia, Cambodia is an important producer/exporter: 98.5 M$



https://oec.world/en/profile/hs/sand

Global context

Sand production/consumption

Extraction of sand (BGS, 2023)

Erosion (rivers, coasts, ...)

(Nedeljkovic et al., 2021)

NATURAL SAND *VS.* RECYCLED SAND

Recycled aggregate production

Reception of C&DW

First crushing

Magnetic separator

Second crushing

Manual separation

Washing + air separation

Sieving

Recycled aggregates sorted by granulometry

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Recycled aggregate production

Construction and Demolition Waste

FRCA (d < 4 mm)

CRCA (d > 4 mm)

Sands
(0.125 mm < d < 4 mm)

Fines
(0 mm < d < 0.125 mm)

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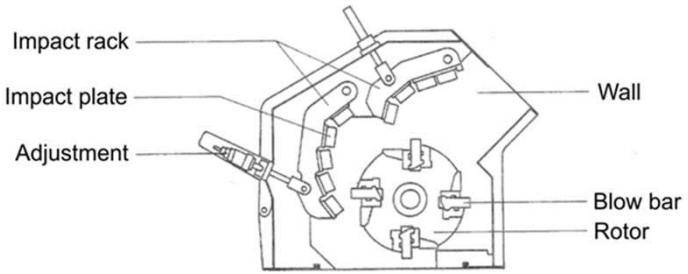
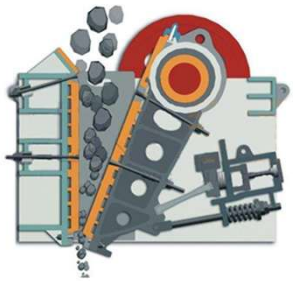
Recycled aggregate production

Materials processing: washing

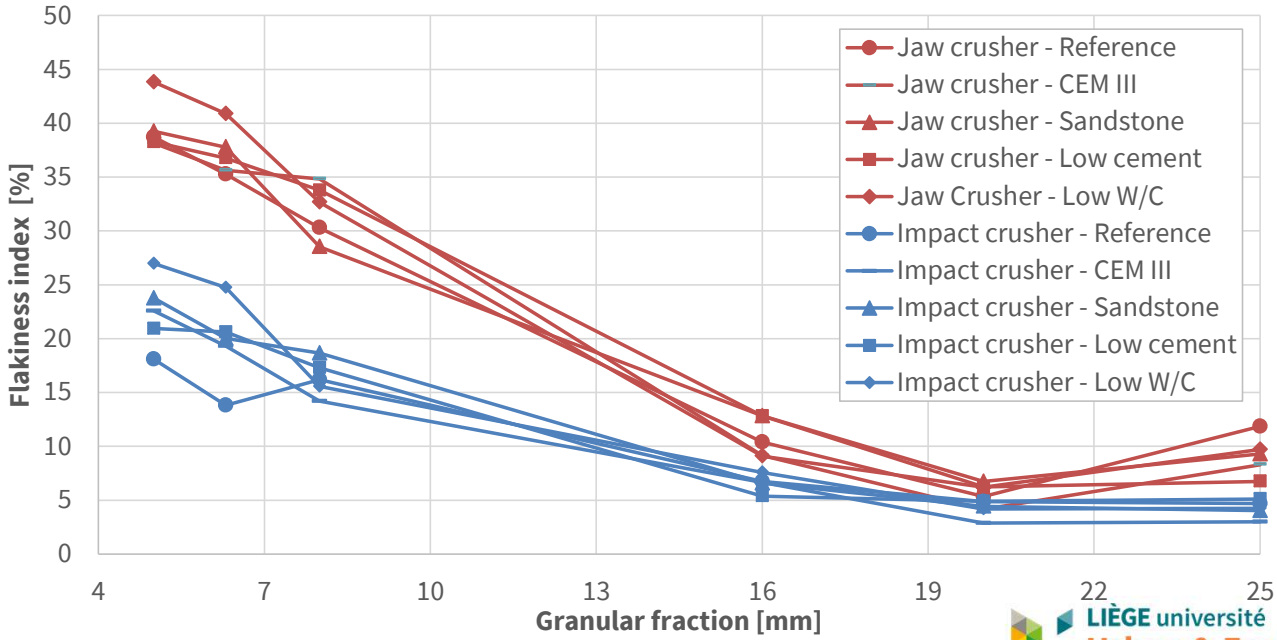
- The flakiness index decreases with increasing granular fraction
- The jaw crusher produces **flakier aggregates ➡ sand!**
- No influence of the concrete composition



Impact crusher



Jaw crusher



Effects of crushing method on the properties of produced recycled concrete aggregates. J. Hubert, Z. Zhao, F. Michel, L. Courard. Buildings 2023, 13(9), 2217 (https://doi.org//10.3390/buildings13092217)

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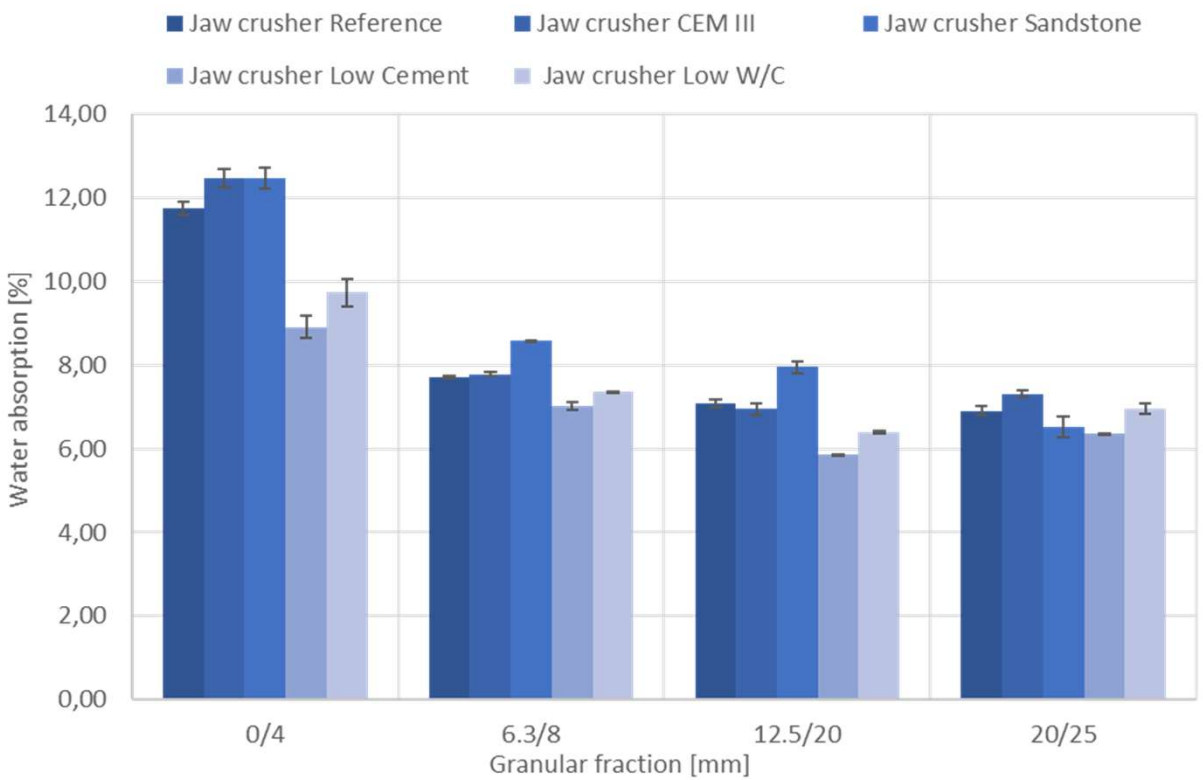
Recycled aggregate production

Materials processing: crushing

- **Porosity** is due to the presence of hardened cement paste and mortar
- **Water absorption** coefficient of aggregates increases as coarse particle size decreases



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Recycled aggregate production

Materials processing: crushing

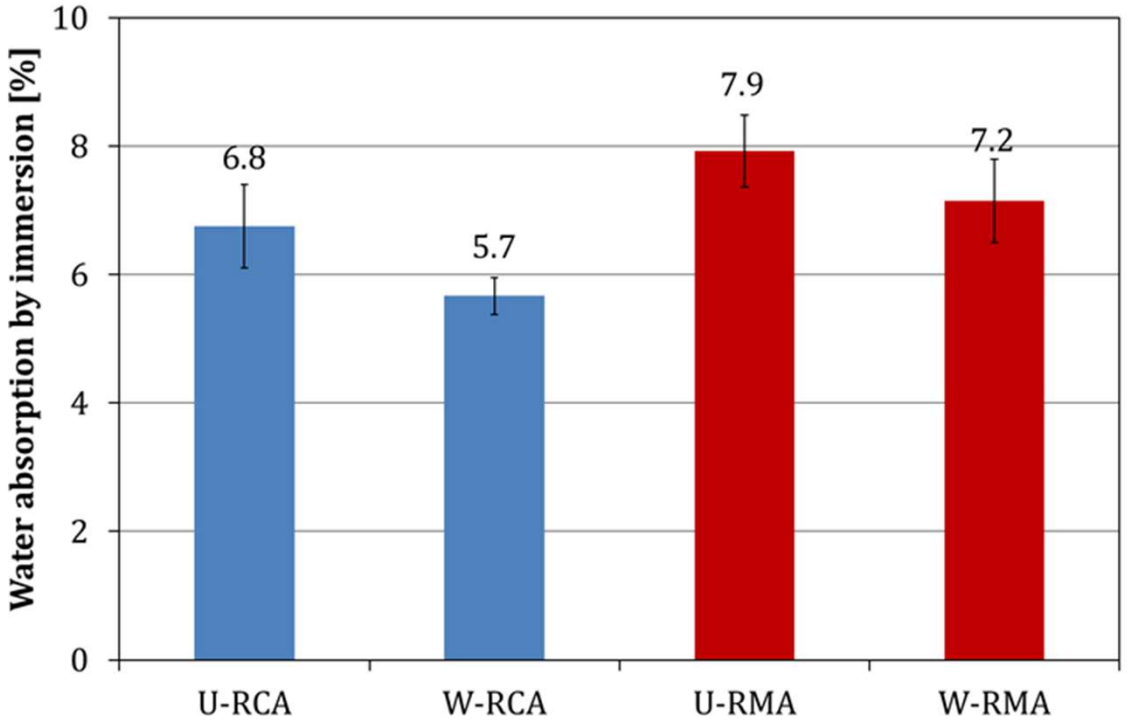
- Fine content (< 63µm) higher in mixed aggregates and **significantly reduced by washing**
- Fine fraction **higher in mixed aggregates**
- **Washed aggregates** respect **regulations**

Effects of crushing method on the properties of produced recycled concrete aggregates. J. Hubert, Z. Zhao, F. Michel, L. Courard. Buildings 2023, 13(9), 2217 (https://doi.org//10.3390/buildings13092217)

Recycled aggregate production

Materials processing: crushing

- Water absorption of the washed RCA significantly **decreases following washing**: from 6.5 to 5% between U-RCA and W-RCA, and from 7.9 to 7.2% between U-RMA and W-RMA.



Effects of crushing method on the properties of produced recycled concrete aggregates. J. Hubert, Z. Zhao, F. Michel, L. Courard. Buildings 2023, 13(9), 2217 (https://doi.org//10.3390/buildings13092217)

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CIBER

CIrcularité des BEtons pRéfabriqués

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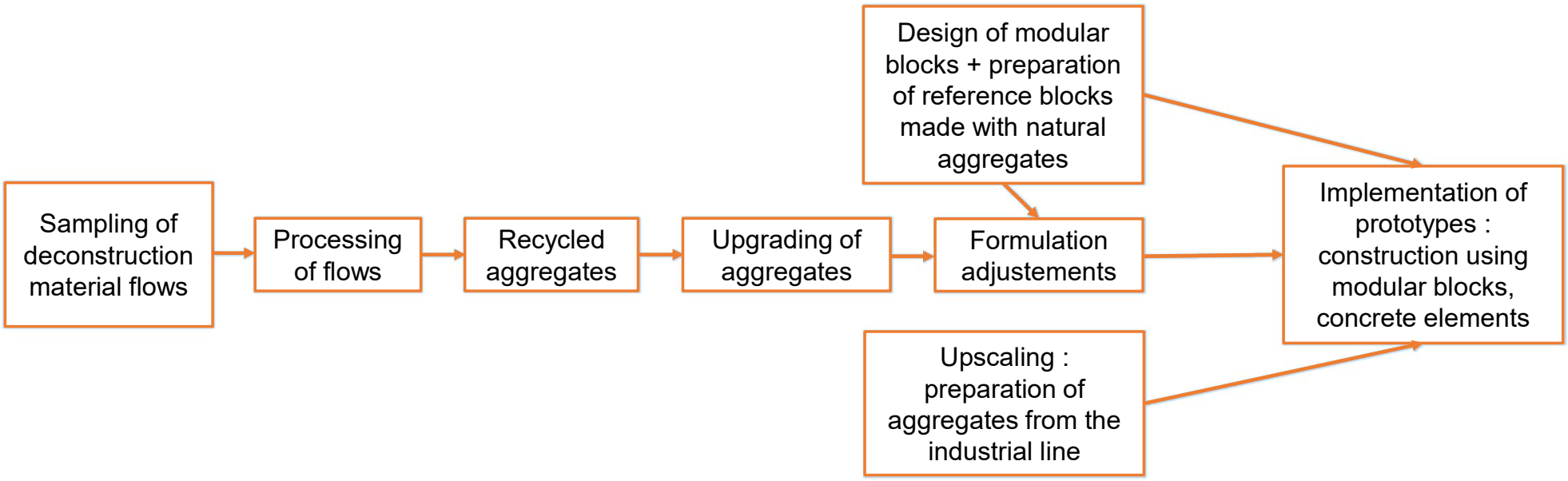
CIBER project: PREFAB concrete



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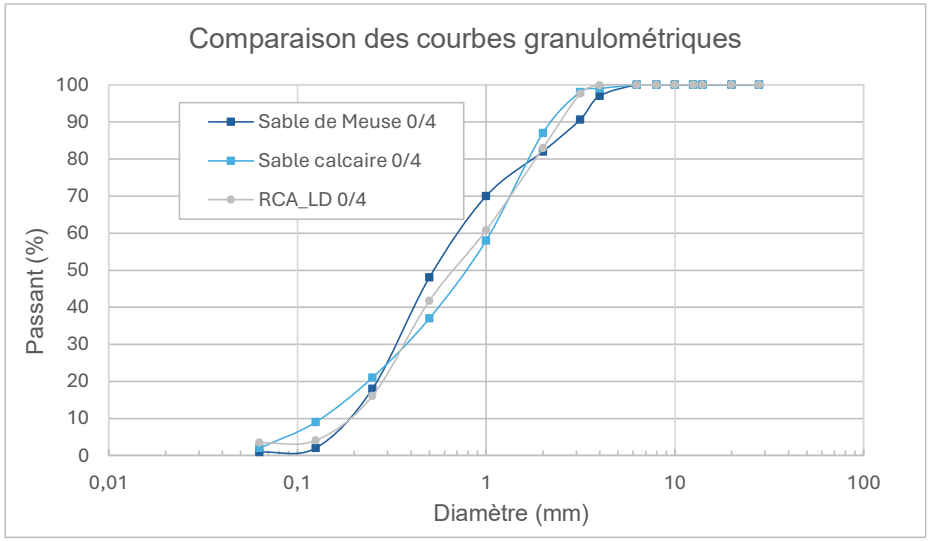
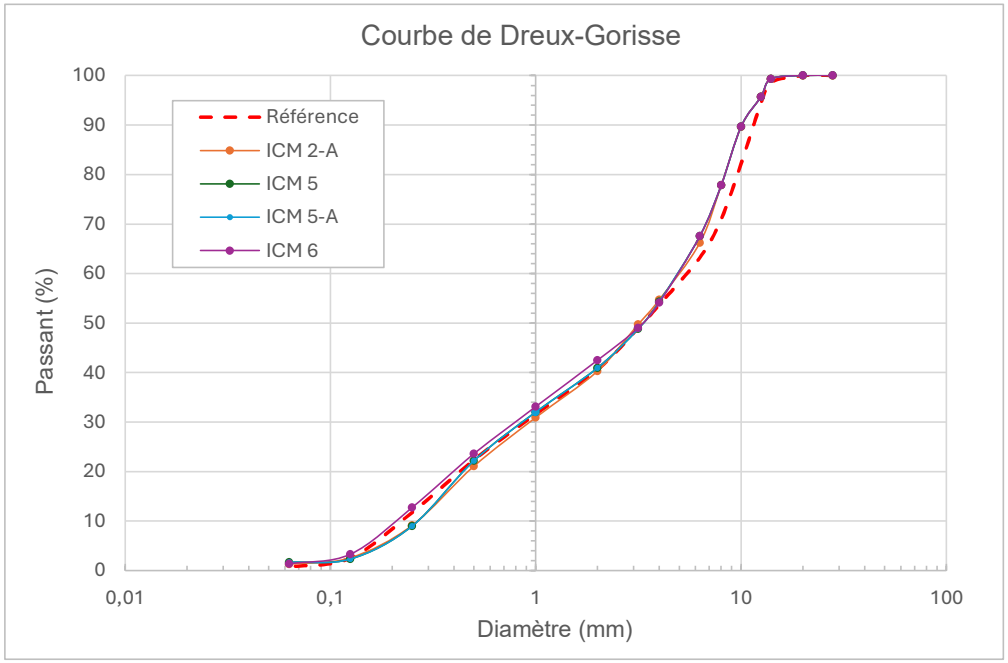
CIBER project: PREFAB concrete

Comparison between natural and recycled sands





Aggregates	Fine content (%)	Water absorption (%)	Density (kg/m³)
Meuse sand 0/4	0.9	0.5	2750
Limestone sand 0/4	2	0.75	2700
RCA_LD 0/4	**3.44**	**5.88**	**2296**

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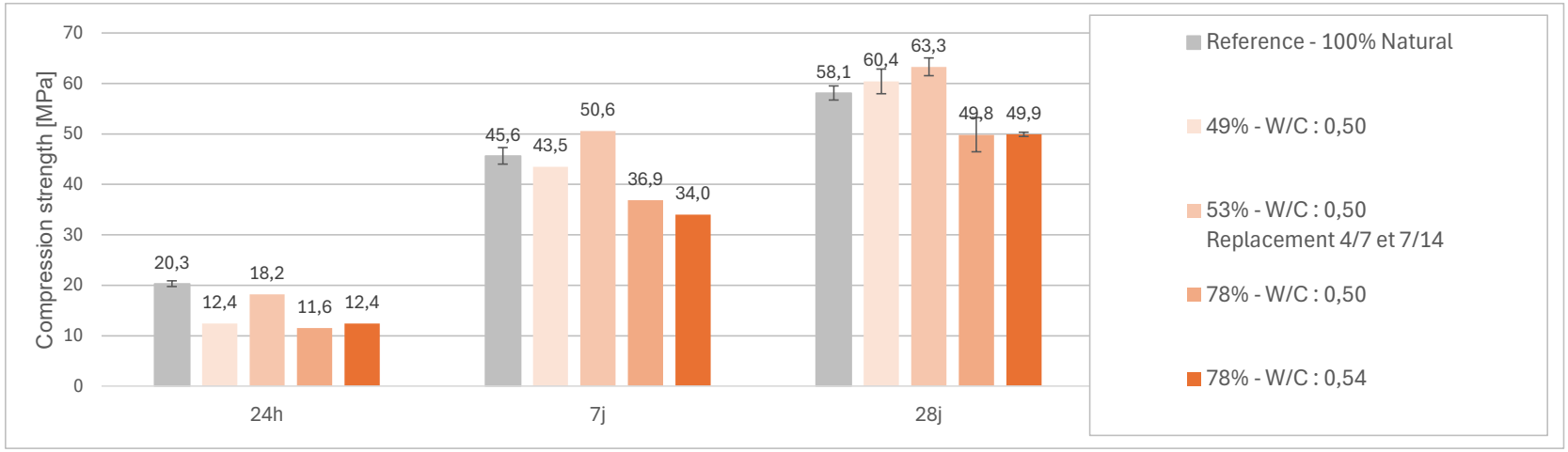
CIBER project: PREFAB concrete

Results for fresh and hardened concrete

Resistance : C30/37
Environment : EE3

Results			
Composition	**Density (kg/m³)**	**Slump (mm)**	**Air content (%)**
Reference	**2361**	**230**	**2,2**
ICM 2-A	2266	245	2,8
ICM 5	2190	220	3,6
ICM 5-A	2204	210	3,1
ICM 6	2313	230	1,6



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3D PRINTING WITH RECYCLED SAND

3D printing with FRCA

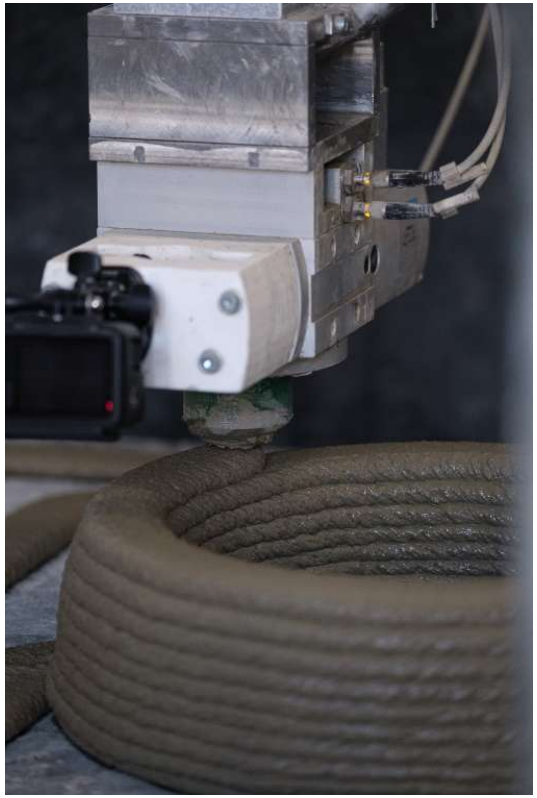
3D printing

(+) design opportunities

(−) environmental impact

→ alternative binder

100% recycled sand



Interreg North-West Europe CIRMAP

European Regional Development Fund

EUROPEAN UNION

THEMATIC PRIORITY:

RESOURCE AND MATERIALS EFFICIENCY

PROJECT AREA

Project objectives:
CIRMAP aims at finding new opportunities for the valorisation of Recycled Concrete Fine Aggregate through 3D printing of customized shapes.

Total budget : **€ 6.98 Million**
EU funding : **€ 4.19 Million**
Duration: 36 months (April 2020 – March 2023)

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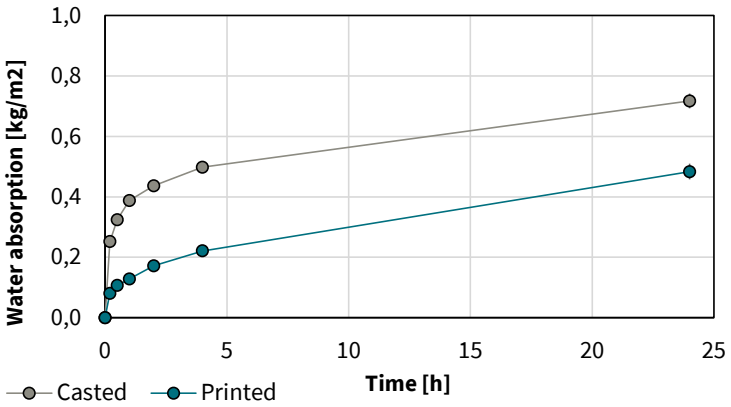
3D printing with FRCA

Interreg North-West Europe CIRMAP

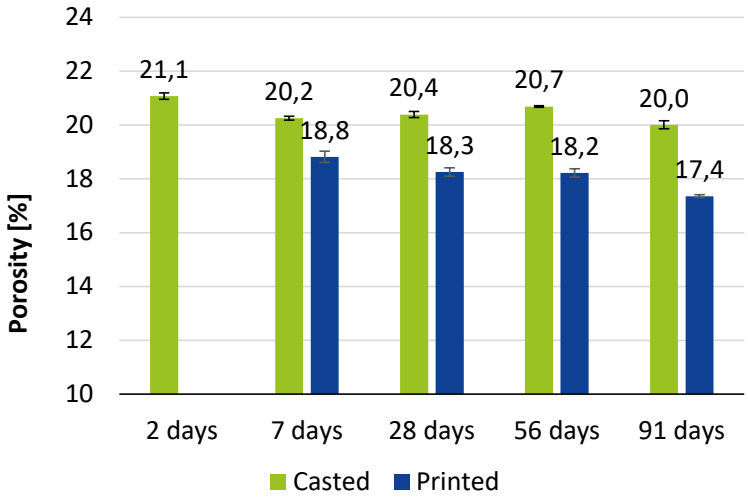
Capillary absorption tests NBN EN13057

- 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)



Use of recycled fine aggregates in high added value applications. J. Hubert, Y. Muy, L. Courard. International Conference on Advances in Engineering and Technology for Sustainable Development. Hanoi University of Civil Engineering, Hanoi, Vietnam, Nov 2-3, 2023 (https://hdl.handle.net/2268/308792)

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3D printing with FRCA

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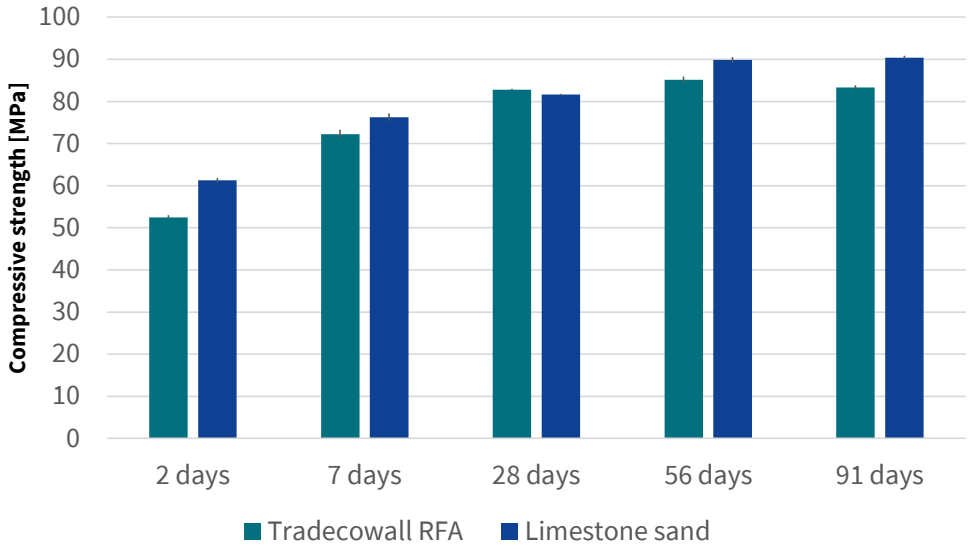
Three points bending and compressive strength :

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

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



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3D printing with FRCA

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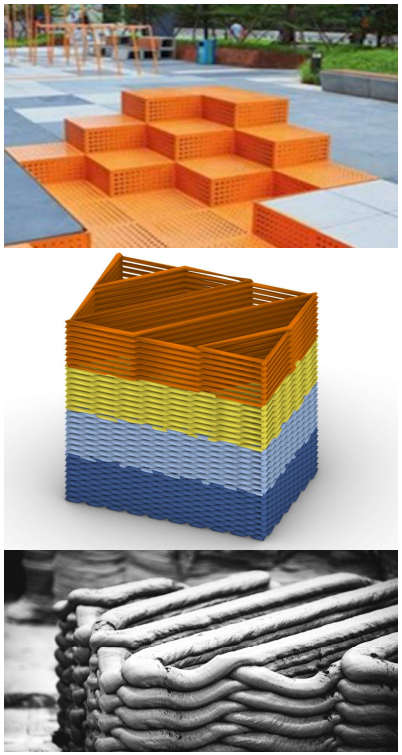
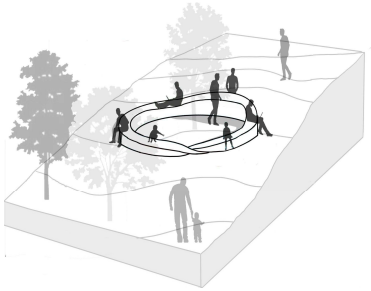
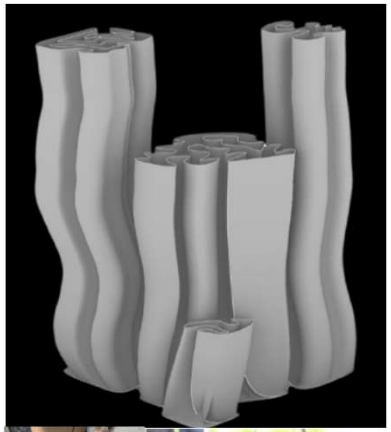
3D printing: student contest







3D printing with FRCA

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RAMMED CONCRETE WITH FINE RECYCLED MATERIALS

Rammed Concrete

Rammed earth (« pisé ») with Fine Recycled Aggregates

Peter Zumthor's Secular Retreat (Walsh, 2018)

Rammed concrete for one-storey private house (Astbury, 2019)

The chapel, by Thomas von Arx

Rammed Concrete

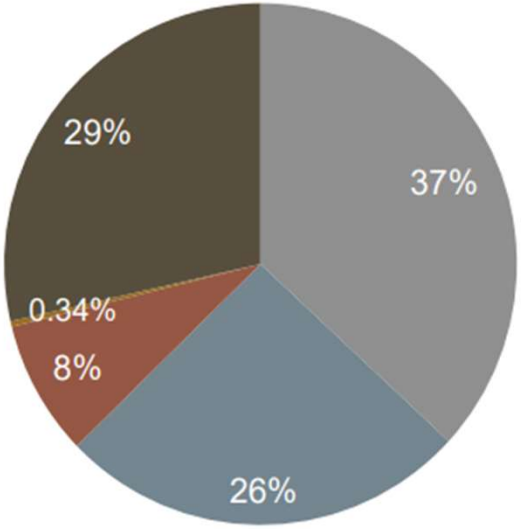
Rammed earth (« pisé ») with Fine Recycled Aggregates

- low maintenance, low-tech construction process and economical to build

Rammed Concrete

Fine Recycled 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 with Recycled Concrete Aggregates : opportunities and performances. M. Long, S. Grigoletto, R. Libert, J. Troquay, L.Courard. Building Materials (under reviewing)

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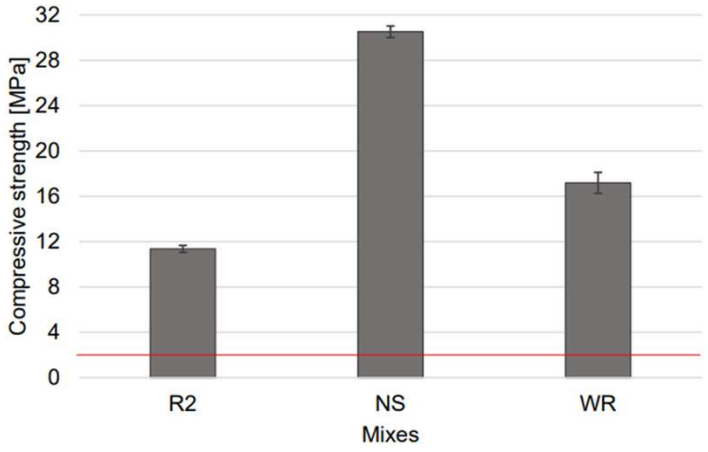
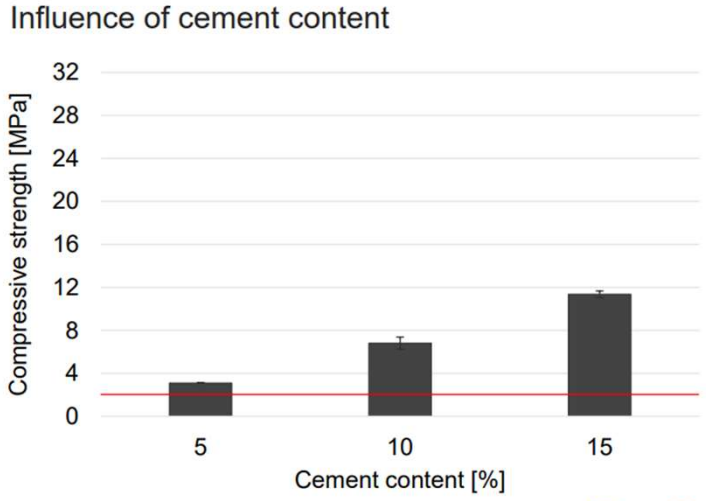
Rammed Concrete

Fine Recycled Aggregates

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





Rammed Concrete with Recycled Concrete Aggregates : opportunities and performances. M. Long, S. Grigoletto, R. Libert, J. Troquay, L.Courard. Building Materials (under reviewing)

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Rammed Concrete

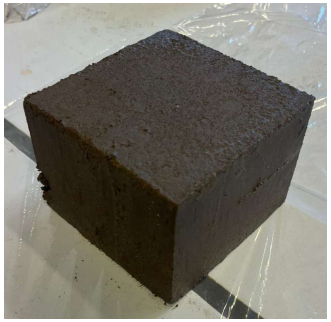
DUN³ES FTJ project: composition & design

Fines

Sand

Cement

Water



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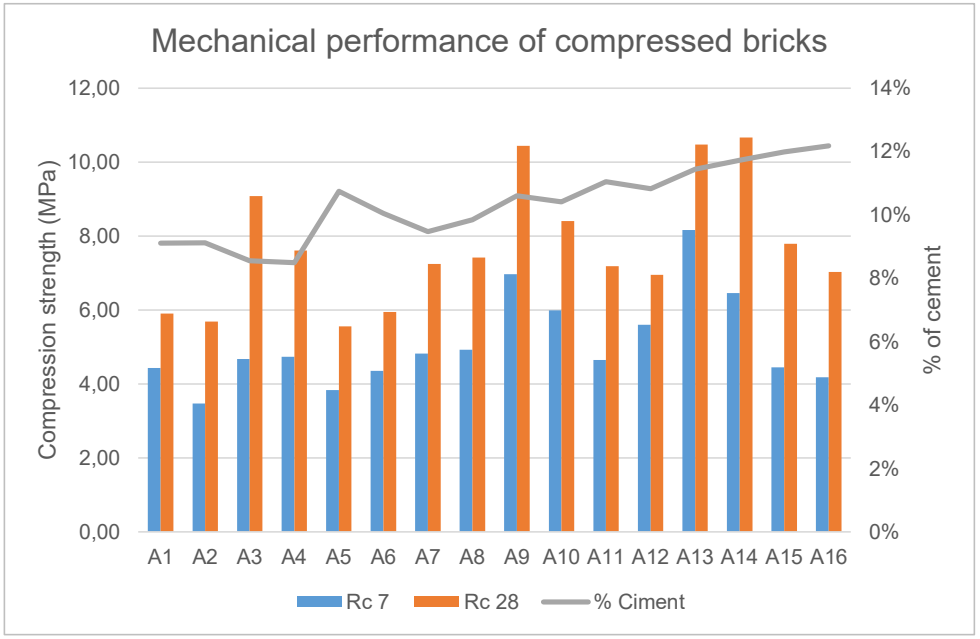
Rammed Concrete

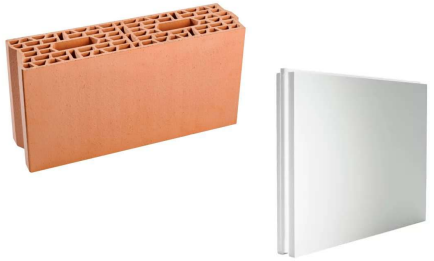
DUN³ES FTJ project: mechanical performances



Cement : CEM III/B 32.5 N

Concrete block : 15 MPa

Fire bricks : 10 MPa



Gypsum : 5-6 MPa

Compressed earth brick : 4 MPa

Stabilised Compressed Earth Brick : 6 MPa

Reuse of fines particles from concrete recycling (< 63 µm) for the manufacture of compressed bricks. R. Libert, J. Troquay, F. Michel, L. Courard. 2nd International Conference on Net-Zero Built Environment: Innovations in Materials, Structures, and Management, November 05 - 07, 2025 | Cape Town, South Africa.

CARBONATED SAND FROM INCINERATED MUNICIPAL SOLID WASTE

Carbonated IMSW

Grey colour material (200 kg/ton)

Variable granulometry

CaO content

Humidity content
- up to 20% by weight after extinction
- 10% by weight after draining

Density
- 1000 kg/m^3 when extracted
- 1100 to 1200 kg/m^3 after treatment

ReMEX GmBh

REMIND Wallonia

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CARBOC

Carbonated IMSW

Parameters:

- Particle sizes: 0/2 & 0/20 mm
- Exposure period: 1, 2, 4, 8, 24, 48 & 168 h
- Moisture content (WC): 2, 20 & 45%

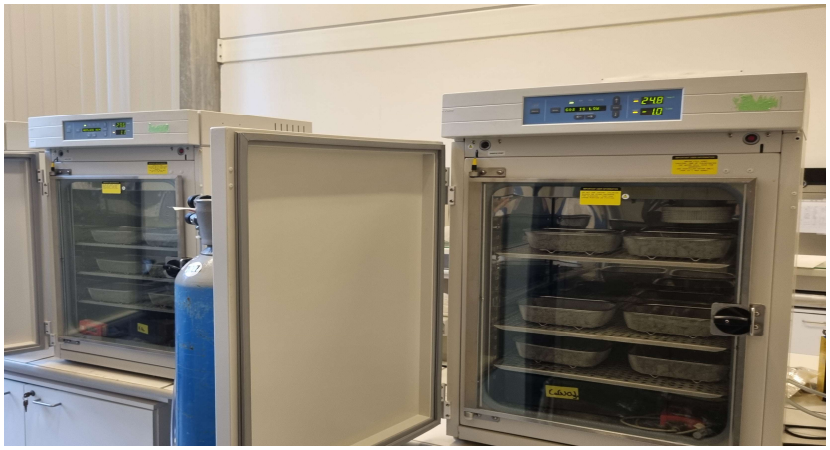
Carbonation

$CaO + H_2O \rightarrow Ca(OH)_2$

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Carbonation conditions:

- Temperature: 30 ±1 °C
- RH: 60 ±3%
- CO_2 concentration: 12 % (vol.)



Accelerated carbonation of municipal solid waste incineration bottom ash for alternative aggregate production. I.E. Kanjo, J. Hubert, J.T. Tchuindjang, S. Marquis, Ph. Descamps, L. Dupont, L. Courard. 10th International Conference on CONcrete under SEvere Conditions – Environment and Loading 2024, Chennai, India

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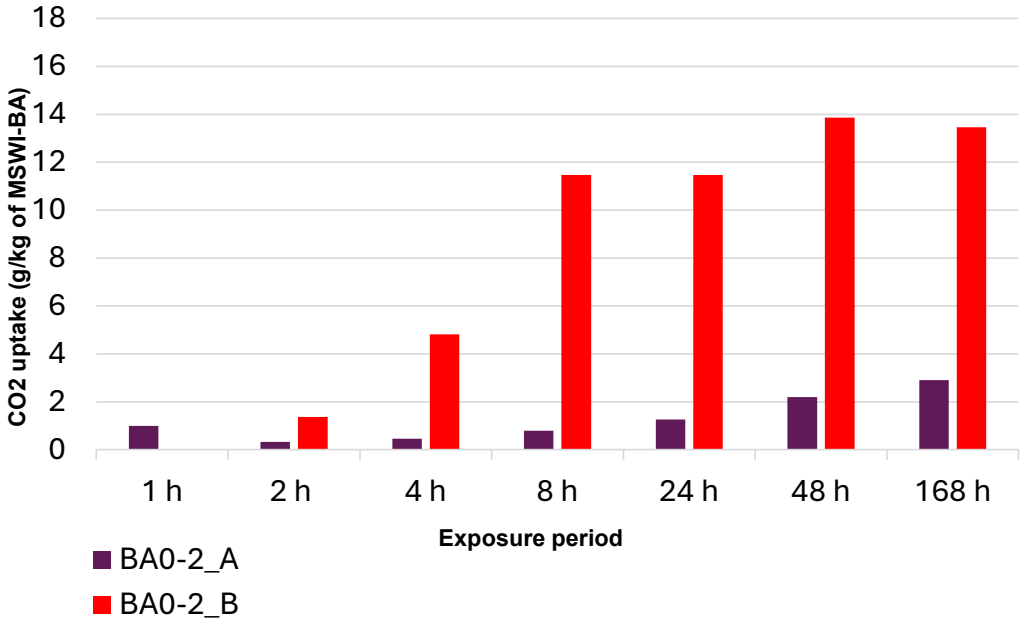
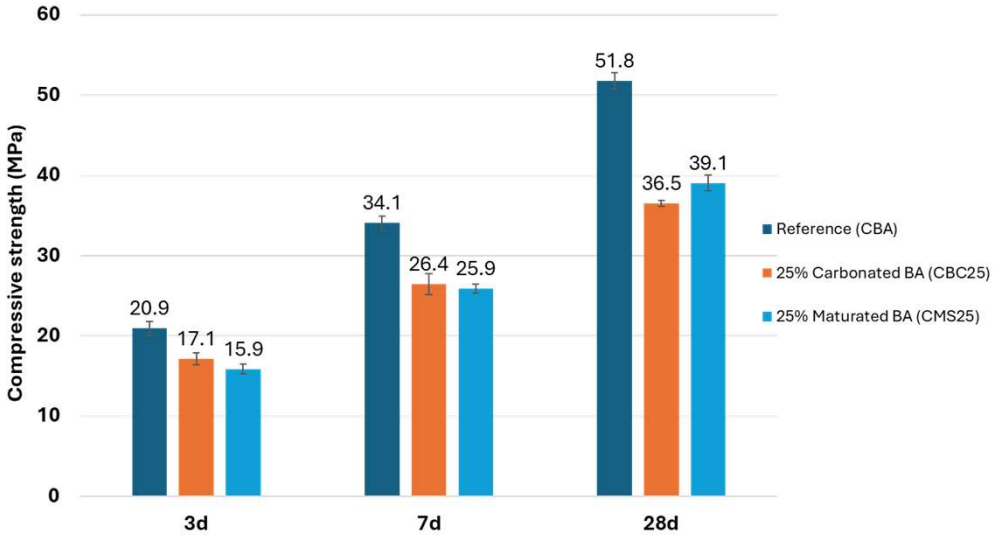
CARBOC

Carbonated IMSW

CO_2 uptake - 0/2 particle size





Efficiency of processes for the carbonation of municipal solid wastes bottom ash. I. J. Kando, L. Courard, J. Hubert. 1st International Conference on Research and Application of Carbonation Technology for Wastes and Concrete (ReACT2024), Hong-Kong, 11-13 Dec 2024

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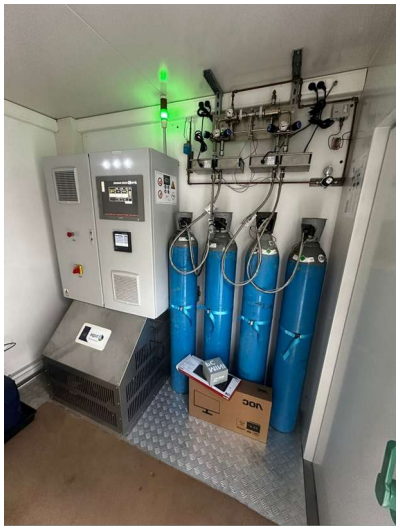
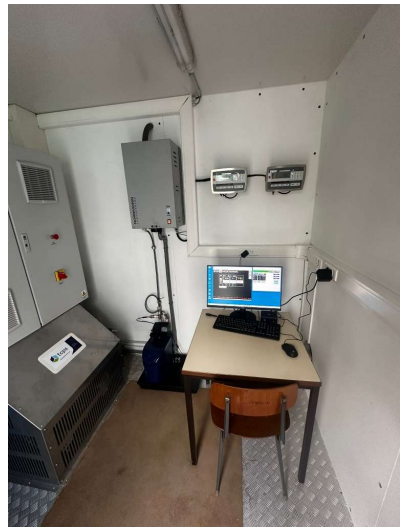
CARBOC

Carbonated IMSW

CarboNEX

- Experimental room for accelerated carbonation (temperature, humidity and CO_2 concentration regulation)



PNRR Wallonia

Wallonie

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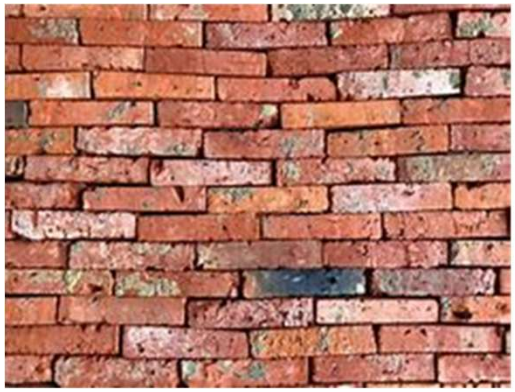
RECYCLED FINE AGGREGATES FROM BRICKS

Recycled brick fines

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.

Recycled brick fines

Physical charactristics

- 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

- 3 types of grading
  - B1 : d_{50} = 3.3 µm (with supplementary cyclogrinding)
  - B2 : d_{50} = 20 µm
  - B3 : d_{50} = 190 µm

Substitution of limestone filler by waste brick powder in self-compacting mortar: properties and durability. Z. Zhao, A. Grellier, M.E.K. Bouarroudj, F. Michel, D. Bulteel, L. Courard. Journal of Building Engineering 43, 102898 (2021) (https://doi.org/10.1016/j.jobe.2021.102898) (http://hdl.handle.net/2268/261528)

Recycled brick fines

Alkali-Activated Materials

Interreg France-Wallonie-Vlaanderen
UNION EUROPÉENNE EUROPESE UNIE
VALDEM

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

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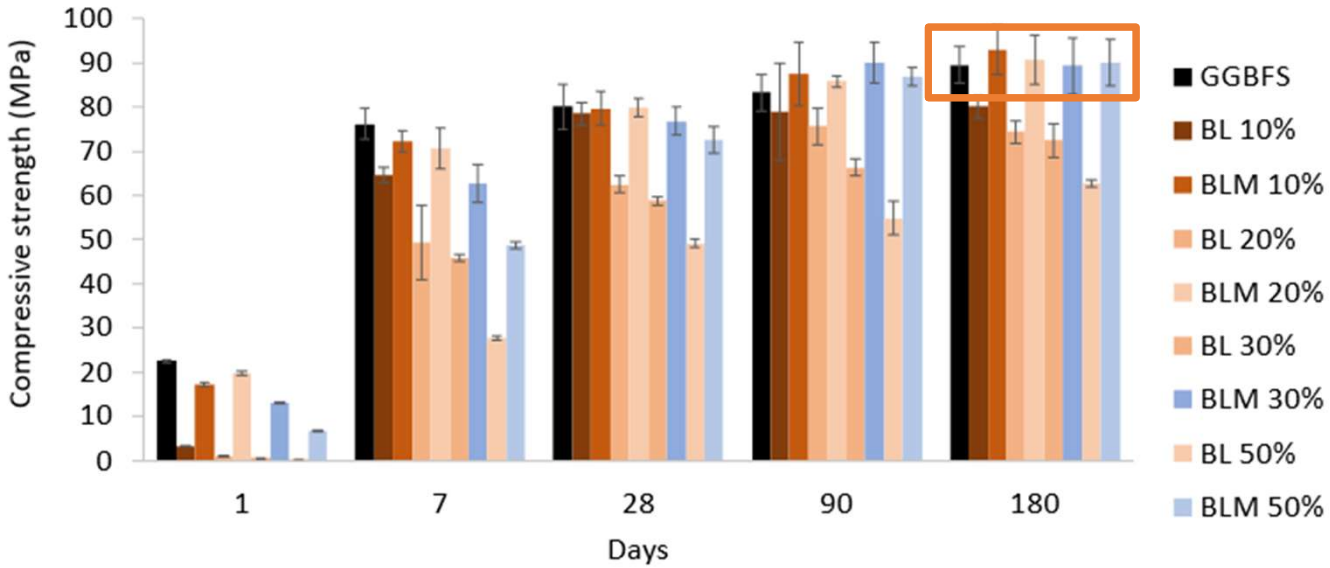
Recycled brick fines

SD 14TH

Mechanical strength



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

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CONCLUSIONS AND PERSPECTIVES

Conclusions

Natural resources *vs.* recycled resources for sand

Good opportunities (quantities)

Preparation is important

Grading and washing

Specific treatment (fineness, shape, grading)

SAND FROM RECYCLING

is suitable for several applications

Perspectives

ARES Amorce project 2025-2027

3CFoLEx (**C**ircularité des matériaux de **C**onstruction au **C**ambodge: mise en place d'une **Fo**rmation spécifique et d'un **L**aboratoire **Ex**périmental)

1. Report on the global situation of Construction and Demolition Waste in Cambodia (production, composition, management and recycling solutions, applications)
2. Develop a specific training project (bachelor and continuing education levels) on the ITC site in Kep
3. Equip a Living Lab, oriented towards the circularity of materials
4. Carry out two end-of-master's degree projects on the recovery of C&DW (master 1) and the recovery of rice husk ash and recycling fines (master 2)
5. Organize continuing education for industry, architects and administration