Life cycle assessment of 3D printed furniture using fine recycled aggregates – CIRMAP project

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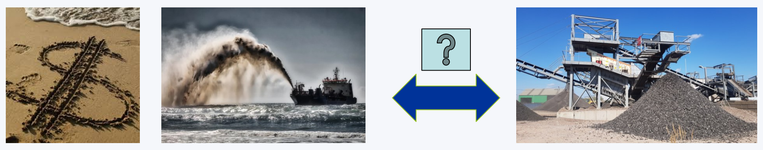
Context

In North West Europe – per year:

- **Use** of **54 Mt of marine sands** extracted in zone where natural aggregates are missing
- **Generation** of **65 Mt of recycled fine aggregates (RFA)** generated yearly from crushing of Construction and Demolition Waste (CDW) and disposed in landfill or bank
- **No market for RFA** cf. large **variability** → not suitable for mass production of concrete needing regular material for compliance with construction standards



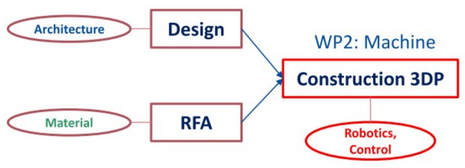
- **BUT use at small scale** for products without high (mechanical) performance
- ⇒ Manufacturing of **Urban, Memorial and Garden Furniture** (UMG)

3D Printing of concrete (3DP)

- ✓ 3D printing (3DP): rapid development in the field of construction
- ✓ **Advantages** of 3DP of urban furniture
  - No moulds / unique pieces → low cost compared to precast (moulds = 50% to 80% of cost!)
  - Fast realisation / on-site printing
  - Complex geometry, strong identity
  - Weight and shape optimisation: hollow forms ≠ solid forms
  - Online control to compensate material variability
- ✓ **Drawbacks** of 3DP
  - Large amount of cement and sand needed for "ink"
  - Overall ecological & economical balance unfavourable

➡ CIRMAP - CIrcular economy via customisable furniture with Recycled MAterials for public Places

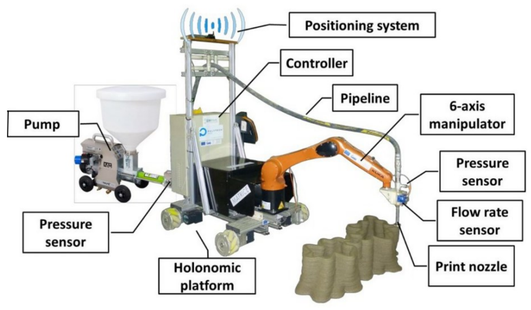
- ✓ Design and manufacture of customized 3D printed urban concrete furniture using Recycled Fine Aggregate (RFA) in different regions
- ✓ RFA (< 4 mm): fraction usually unused in concrete with recycled aggregates
- ✓ Cause: large amount of cement paste on RFA
- ✓ Local production (close to urban centres)
- ✓ 5 Mt of RFA potentially recycled into concrete



Project objectives

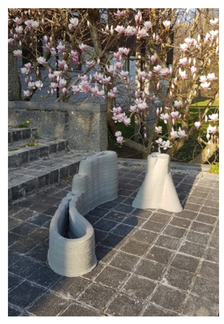
- ✓ **New Mixture Proportioning Method (MPM)** for the design of 3DP mortars with RFA and a new Design Methodology for Customized Shapes (DMCS)
- ✓ **New Master Control Command (MCC)** for concrete 3DP will be implemented for the equipment of 3DP machines, and an integrated mobile 3D printing unit will be developed for onsite 3D printing of UMG furniture

MATRICE
FABRICATION ADDITIVE POUR LE BATIMENT



First 3DP

- ✓ Starting point: solution developed in the MATRICE project (3DP but no RFA)
- ✓ ⇨ Formulation of new "ink" with RFA
- ✓ Challenges: blending, extrudability and buildability (cracks, collapsing), general aspect of the surface (smooth/rough), time of printability, ...
- ✓ CIRMAP ink formulation:
  - 100% Belgian RFA (no natural sand)
  - Vicat Cement (CEM I 52.5)
  - Additives (superplasticiser, viscosity modifying admixture)



PRELIMINARY LCA
RFA production ↔ Natural aggregates (NA)

- ✓ CIRMAP formulation similar for cement and additives (to be refined)
- ✓ ⇨ focus on the difference between NA and RFA

GOAL

Comparison of the environmental impacts of the production of natural aggregates and recycled sand - RFA (<4 mm)

SCOPE

- ✓ **Functional unit** (FU): **1 kg** of material
- ✓ Cradle to gate ; no quality factor (1 kg NA = 1 kg RFA)

INVENTORY

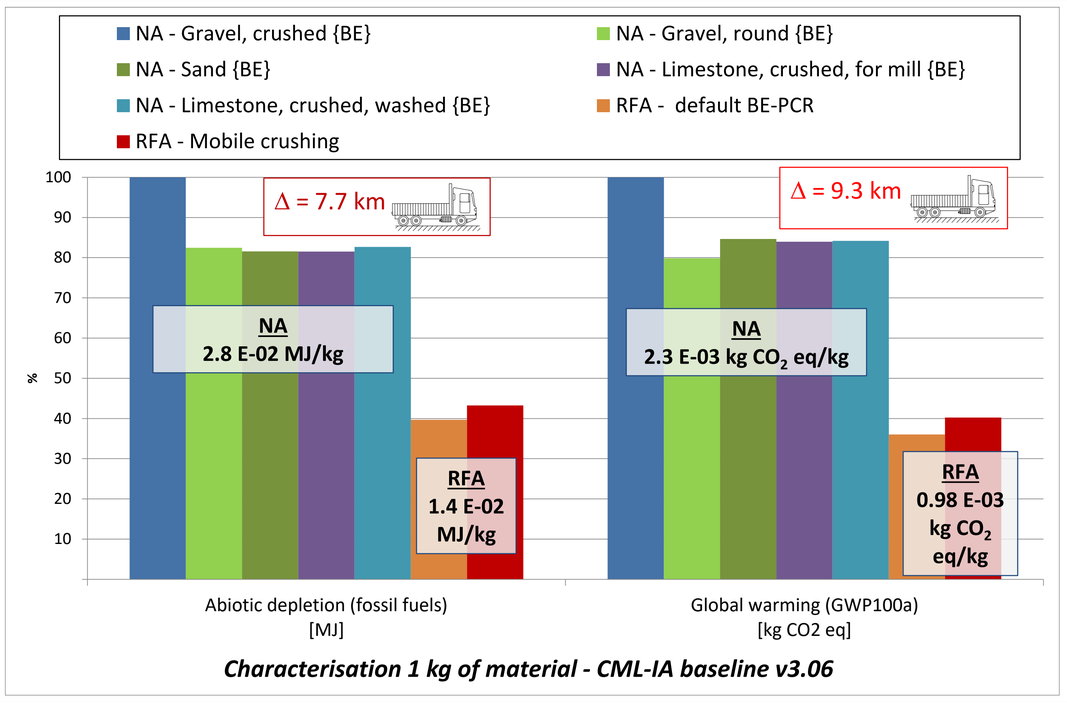
RFA: Evaluation of grinding energy

- Primary data : mobile crusher 12.1 MJ/ton (diesel) (Metso 250m³/h)
- B-EPD: default values for sorting center with shredder:
  1.5 kWh/ton (BE mix) + 11.8 MJ/ton (diesel)

NA: Ecoinvent 3.7.1 for NA records – adapted for Belgium (BE grid mix)
Gravel, crushed – Gravel, round – Sand – Limestone, crushed (washed and for mill)

ASSESSMENT

- **CML IA baseline** v3.06/EU25+3, 2000
- Consistent with EN15804+A2:2019
- **Cut-off** approach: waste is "free"



Characterisation 1 kg of material - CML-IA baseline v3.06

INTERPRETATION

RFA better than NA in all impacts categories (other results not shown)
⇨ validation interest of replacing sand by RFA and valorisation in 3DP furniture

Difference between NA and RFA : corresponding transport distance for 1 kg produced (lorry EURO5):
7.7 km (per kg) for AD-FF or 9.3 km (per kg) for GWP100a

Next steps:

- LCA of marine sand for further comparison (missing in Ecoinvent except BR special case)
- Comparison of 3D printed furniture with "plain solid" moulded concrete bench

Project and Partnership

- ✓ **Duration:** 36 months project (April 2020 – March 2023)
- ✓ Total Budget: 6.98 M€ - EU funding: 4.19
- ✓ **Workplan**
  WP LT –Long term effects
  WP M - Management
  WP T1 – Material flow, market and life cycle analysis
  WP T2 - Development of methodologies and process for the 3DP of mortars containing RFA
  WP T3 – Industrial feasibility
  WP C – Communication

✓ **Funded by Interreg and supported by The Walloon Region**

Consortium
The project is led by ARMINES and gathers 17 partners and sub-partners. Several associate partners also support the project.

Partners & Sub-partners

Associate Partners

NoMaD 2022
Nouveaux Matériaux et Durabilité 2022
16-17 nov. 2022 à l'Ecole Nationale Supérieure d'Architecture de Montpellier (France)