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

THEMATIC PRIORITY

RESOURCE AND MATERIALS EFFICIENCY

CIRMAP - 1st Public Meeting

Liège le 24/03/2022 à 14h00

Bat. B37 – Amphithéâtre 01

Welcome to ULiège

- Birthplace of Charlemagne
- Witness of a millenary principality
- Economic capital of Wallonia

LIÈGE université

Génie Minéral
Matériaux & Environnement

Welcome to ULiège

- Coal mining, steelmaking, weaponry
- Aerospace, logistics, mechanics,…
- Exceptional post-industrial and natural environments

LIÈGE université

Génie Minéral Matériaux & Environnement

Welcome to ULiège

- A widespread campus in the heart of nature
- 26.863 students among which 22% foreigners
- 11 faculties (Science, Applied Science, Medicine,…)

LIÈGE université

Génie Minéral Matériaux & Environnement

Welcome to ULiège

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

- 194 professors, researchers, technicians
- 11 laboratories
- 3 masters (civil, architectural and geological engineering)
- 316 students (Bachelor and Master degrees)
- 109 PhD students (2017)
- 63 on-going research projects

LIÈGE université

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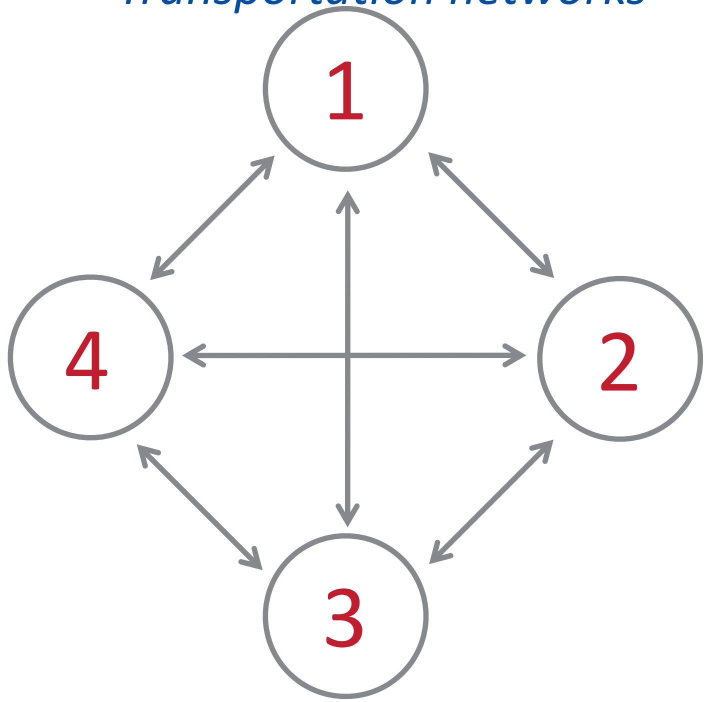
Welcome to ULiège

Buildings, Engineering structures and Transportation networks

Human activities and Living environment



Materials and Resource Efficiency

Risks and Environmental Engineering

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Welcome to ULiège

For helping you …

Luc COURARD - Professor

Julien HUBERT– Senior researcher

Frédéric MICHEL – Laboratory manager

Yeak Lang MUY – Post Doc Researcher

Céline VAN PUYVELDE – Technician

Marine MARECHAL – Administration officer

Laurence PONCELET – Financial officer

Génie Minéral
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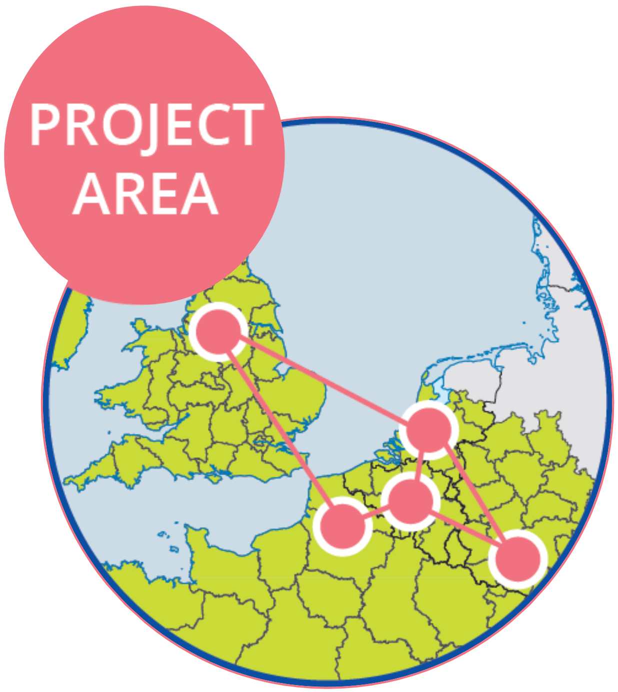
Project presentation

ARMINES

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

24/03/2022

Partner countries



- **FRANCE**
- **GERMANY**
- **NETHERLANDS**
- **BELGIUM**
- **UNITED KINGDOM**

Interreg North-West Europe CIRMAP
European Regional Development Fund

Total budget : € 6.98 Million

EU funding : **€ 4.19 Million**

Duration: 36 months (April 2020 – March 2023)

Partners and sub-partners

Project led by : ARMINES / IMT NORD EUROPE

ARMINES

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

17
partners and sub-partners

Manchester Metropolitan University

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

Technische Universität Kaiserslautern

neo-eco
Un monde sans déchets

LIÈGE université

Université d'Orléans

HEBERGER

VICAT

Gemeente Almere

Stadt Pirmasens

Université de Lille

CERIB
Expertise concrète

CTP
member of EMRA

AREBS

cnrs

PFA
Pompes Funèbres de l'Avesnois

Ecole Nationale Supérieure d'Architecture et de Paysage de Lille

Associate Partners

GreenFlex

CHRYSO
INNOVATION IS OUR CHEMISTRY

prefer

BESIX

DBV

AUTODESK

Hamilton
LABORATORY SOLUTIONS

GMCA
GREATER MANCHESTER COMBINED AUTHORITY

BRBS Recycling
Branchevereniging Breken en Sorteren

Betonhuis
Constructief Prefab

cstc.be
Recherche • Développe • Informe

General Objective

Recycled sand and recycled fine particles

Overall description

3D Printing (3DP) is developing rapidly in the field of construction.

+ **Fast realization** of customized or complex geometries and optimization of shapes are amongst the main advantages of the process that could allow significant breakthroughs.

- However, mortars used in 3DP contain very large amounts of cement and natural sand in comparison to ordinary concrete and the overall ecological and economic balance seems unfavourable to 3DP.

3DP of concrete pieces without formwork: great interest in precast industries when unique and costly pieces have to be built

Production of urban furniture: local public authorities want furniture to be a banner of their identity

2 levers of action :

- Binders
- Granular skeleton

Solutions

1 The use of construction and demolition waste could be used as a local granular material resource
→ in particular the coarse fraction Recycled Concrete Aggregates (RCA): greater than 4 mm

On the contrary, adherent cement paste concentrates in **fine** RCA during crushing which makes it much harder to valorise into concrete.

2 **Recycled sand and recycled fine particles** could be re-used as raw materials for the manufacture of 3D printing mortars for urban furniture
→ high mechanical behaviour is not required.

Project Objective

Developing new solutions

Ecological materials

Project Objective
Design and manufacture of customized 3D printed urban concrete furniture using recycled fine aggregate.

Organization of project

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IMT-Université de Lille

WP Management

General, administrative and financial management of the project

WP Communication

Coordinate communication actions around the project's achievements, as well as scientific productions and presentations made at conferences

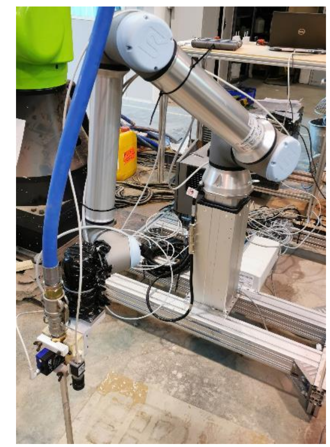
WP Long Term

Study of standards and regulations.
Creation of a training programme around 3D printing → Workshop in ULille

Organization of project

WP T1	WP T2	WP T3
University of Liège	University of Manchester	Polytech Lille

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WP 1 - Material flow, market and life cycle analyses

LIÈGE université

24/03/2022

Work Package 1

WP T1 : Material flow, market and life cycle analyses

Activity 1 : Material flow / Territorial analysis

Activity 2 : Life Cycle Analysis

Material flow/Territorial analysis

3 billion tonnes of aggregates produced in the EU27+UK+EFTA in 2019 (UEPG, 2021)

Virgin Aggregates

46.9% crushed rock

39.7% sand & gravel

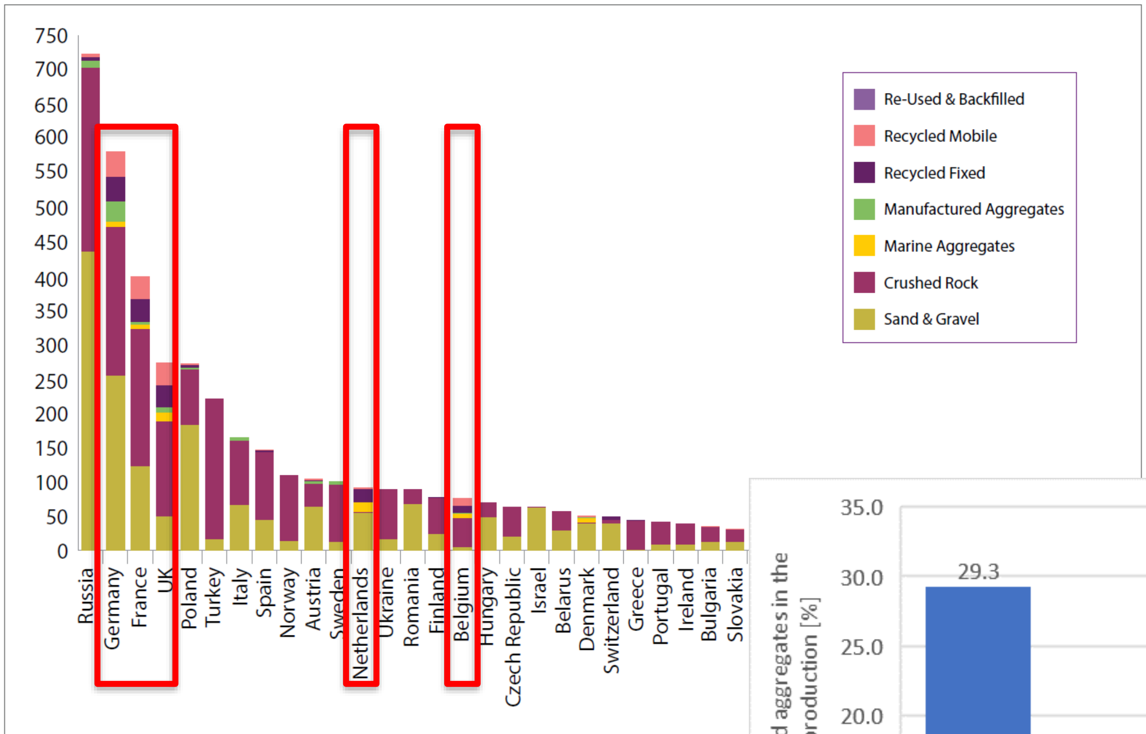
Recycled Aggregates

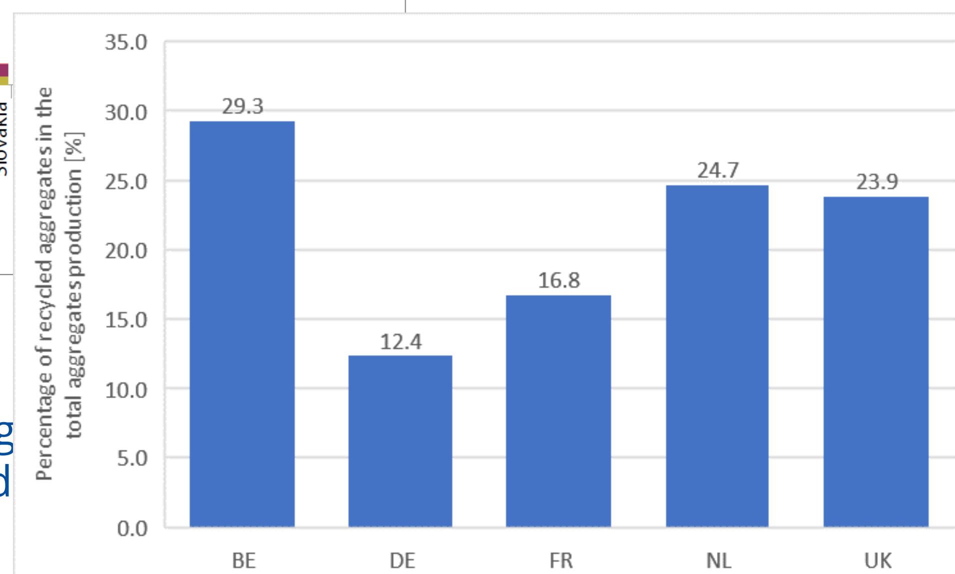
9.3% recycled (278 million tonnes)

Construction & demolition wastes (CDW)

Material flow/Territorial analysis

3 billion tonnes of aggregates produced in the EU27+UK+EFTA in 2019 (UEPG, 2021)

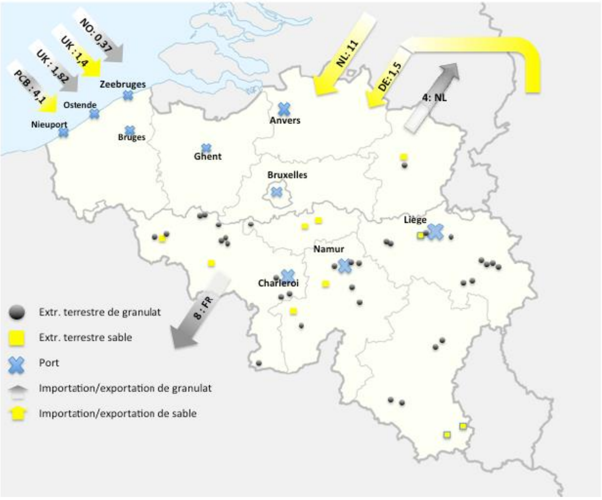


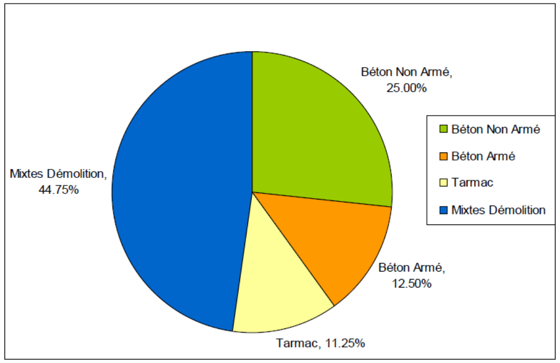


Partner countries are responsible for :

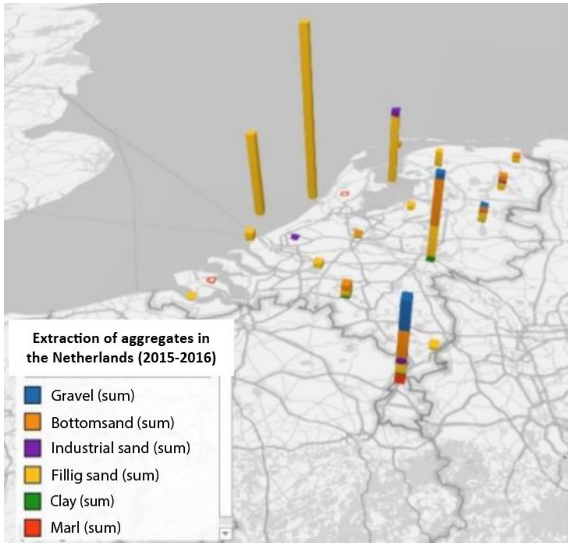
- **47%** of the virgin ag
- **89%** of the recycled

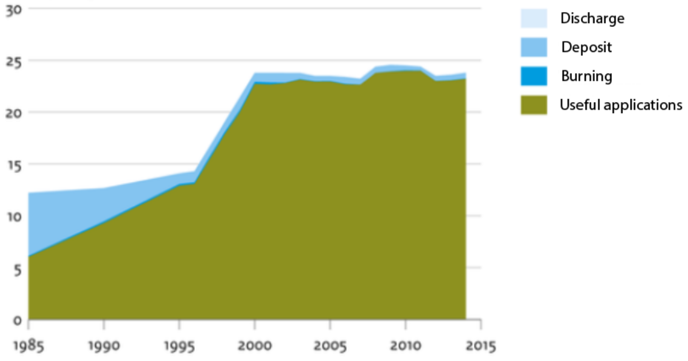
Material flow/Territorial analysis





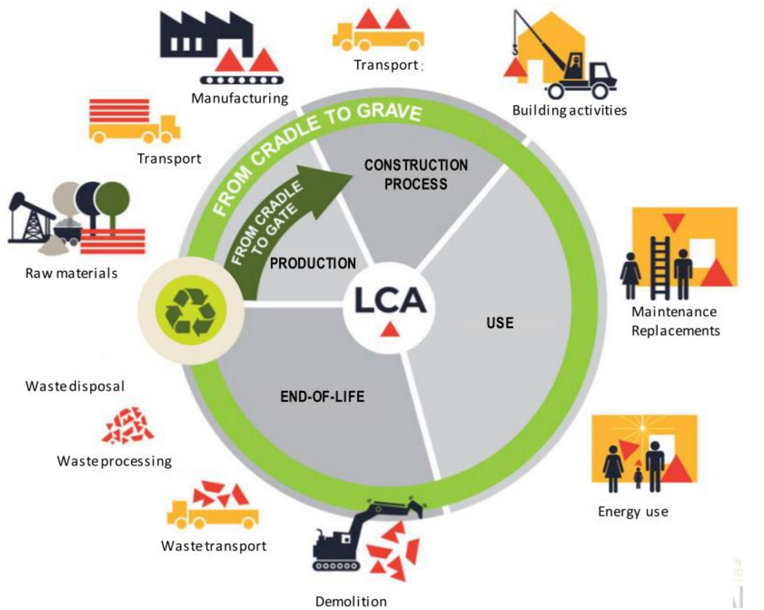
Primary to secondary ressources

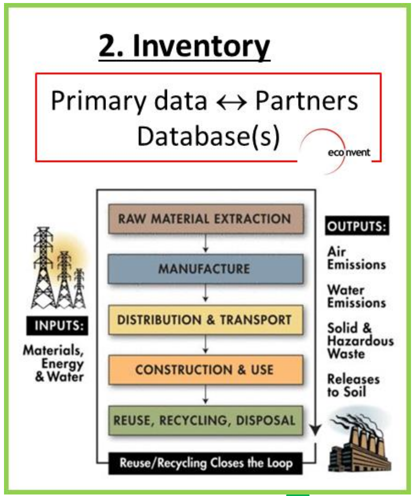


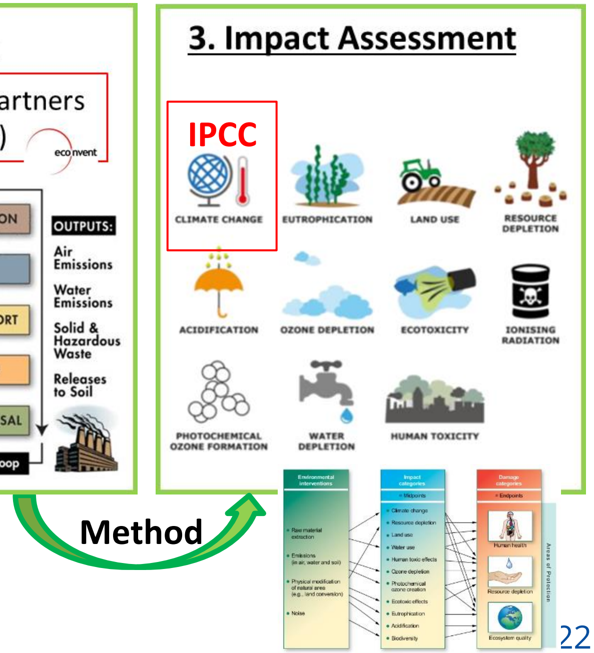


Life cycle assessment – ISO 14040/44:2006

- addresses environmental aspects & potential environmental impacts (use of resources and environmental consequences of releases)
- throughout a product life cycle







https://www.totem-building.be
https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/
https://www.researchgate.net/figure/Stages-of-products-life-cycle-4_fig1_312073799

WPT1 A2 – Life Cycle Assessment (LCA) – ULiège-PEPs

Bibliographic research → Scientific literature

- Advantages of recycling aggregates (especially upcycling vs downcycling)
- Importance of transport distance
- CO_2 capture by crushed aggregates
- Avoided landfill not taken into account (standard EN 15804+A2:2019)
- Importance of economic incitants to help recycling (taxes on natural resources such as river sand, or on landfill)
- Data on crushing, grinding, and aggregate processing in general
- Realization of concrete furniture, and additive printing of concrete

Life cycle assessment: preliminary LCA

- **LCA of recycled fine aggregates (RFA)**
  (based on PhD thesis - Mohamed Elkarim Bouarroudj – *Use of RFA as mineral addition in mortars*)
- Comparison with limestone fillers (NA)

Interreg France-Wallonie-Vlaanderen UNION EUROPÉENNE EUROPESE UNIE

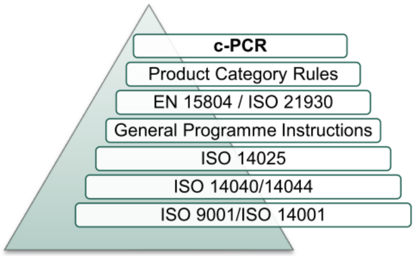
VALDEM

- **Goal** : <u>comparison</u> of the environmental impacts of the production of additives for the mortar, either natural limestone filler, or recycled sand (<4 mm) (or fines, <125 µm)
- **Scope:**
  - **Functional unit (FU)**: the output of **1 kg** of material
  - **System boundaries:** include only the production of the material, at the gates of the quarry (natural materials) or the sorting center (recycled materials)
  - The substitution is considered equivalent (1 kg limestone filler = 1 kg of recycled sand)

Life cycle assessment: preliminary LCA

- **Inventory:** Evaluation of **grinding energy**
- Previous study: mobile crusher (PREFER) → 12.1 MJ/ton (diesel)
- B-EPD: default values for sorting center with shredder:
  1.5 kWh/ton (BE mix) + 11.8 MJ/ton (diesel)
- Ecoinvent : limestone crushed for mill:
  0.51 kWh/ton (BE mix) + 18 MJ/ton(diesel)

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




Belgian Standard
EN 15804:2012+A2:2019
NBN EN 15804:2012+A2:2019
NBN
Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

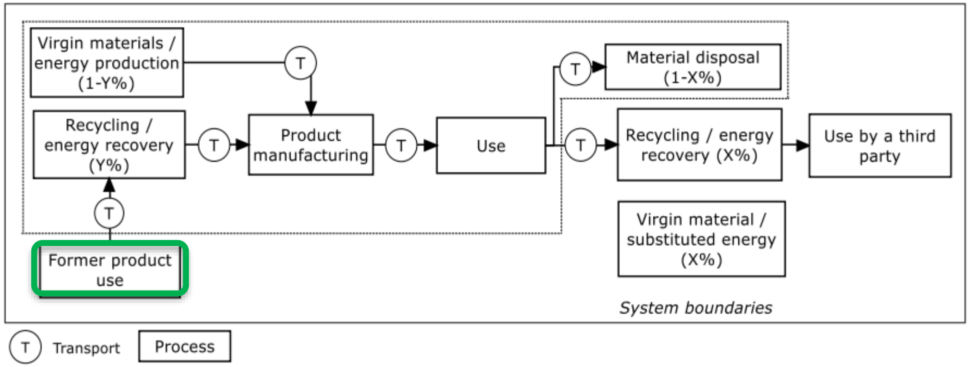
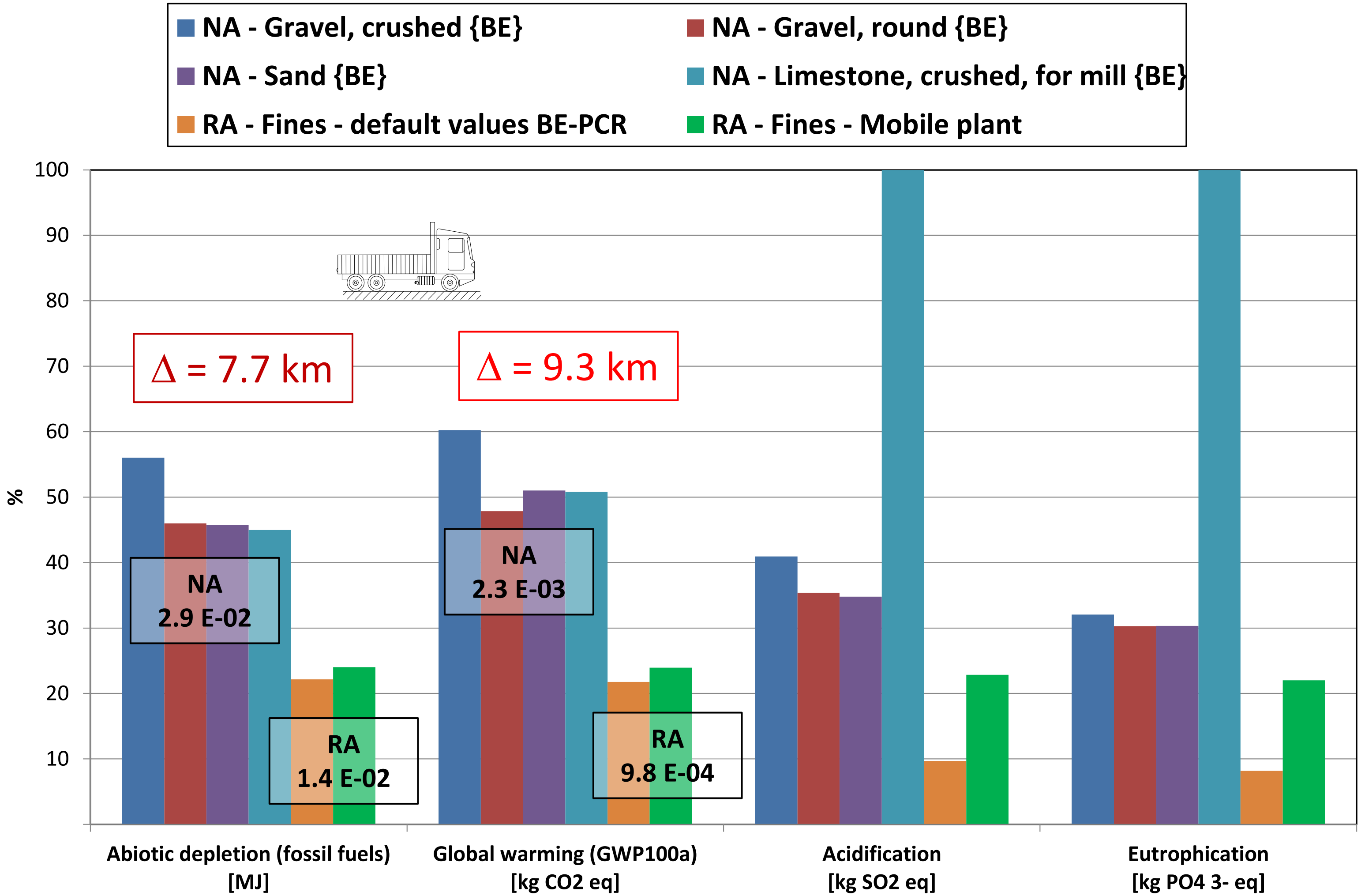


Figure 6-2: Cut-off approach

Life cycle assessment: preliminary LCA – Characterization for 1 kg of NA/RA



WPT1 A2 – Life Cycle Assessment (LCA) – ULiège-PEPs

Life cycle assessment: preliminary LCA

- CIRMAP primary data: 3D printing
  → concrete formulation
- Primary data collection from producers (Vicat, Chryso, Carrières du Boulonnais)
- RFA: Helfaut
- Model for LCA of concrete with NA – RFA
- Missing data: 3DP

Raw materials used for the study

2 hydraulic binders:
Used separately
- Eqiom cement: CEM I 52.5 N
- Vicat cement: Performat®, CEM I 52.5 N

1 Natural sand:
Screened at 2 mm beforehand (only grains < 2 mm are used for the 3DP tests)
- Boulonnais quarry natural sand (France)

3 Recycled Fine Aggregates (RFA):
Screened at 2 mm beforehand (only grains < 2 mm are used for the 3DP tests)
- Recynov RFA (France, northern area)
- Revaga RFA (France, eastern area)
- Tradecowall RFA (Belgium, western area)

2 admixtures:
- Liquid superplasticizer (SP): Chryso®Fluid Optima 100
- Solid viscosity modifying admixture (VMA): Chryso Belitex® Addichap

Excel file for data collection from partners

- Formulation, origin of raw materials, processing of raw materials (N or R)
- Energy for 3D printing, water, losses, waste, …: MATRICE data, primary data
- ⇒ data WPT1 - A2 - 1.1 - Formulation of 3D printable RFA-based mortars - 2021.08.30.xlsx / 2022.02.01 / …

- **Modelling** of missing records in database(s): river sand, additives
- **Bibliographic** research on traditional precast concrete process & 3DP
- **Adaptation** of OPC record of Ecoinvent (→ Vicat / SeRaMCo)

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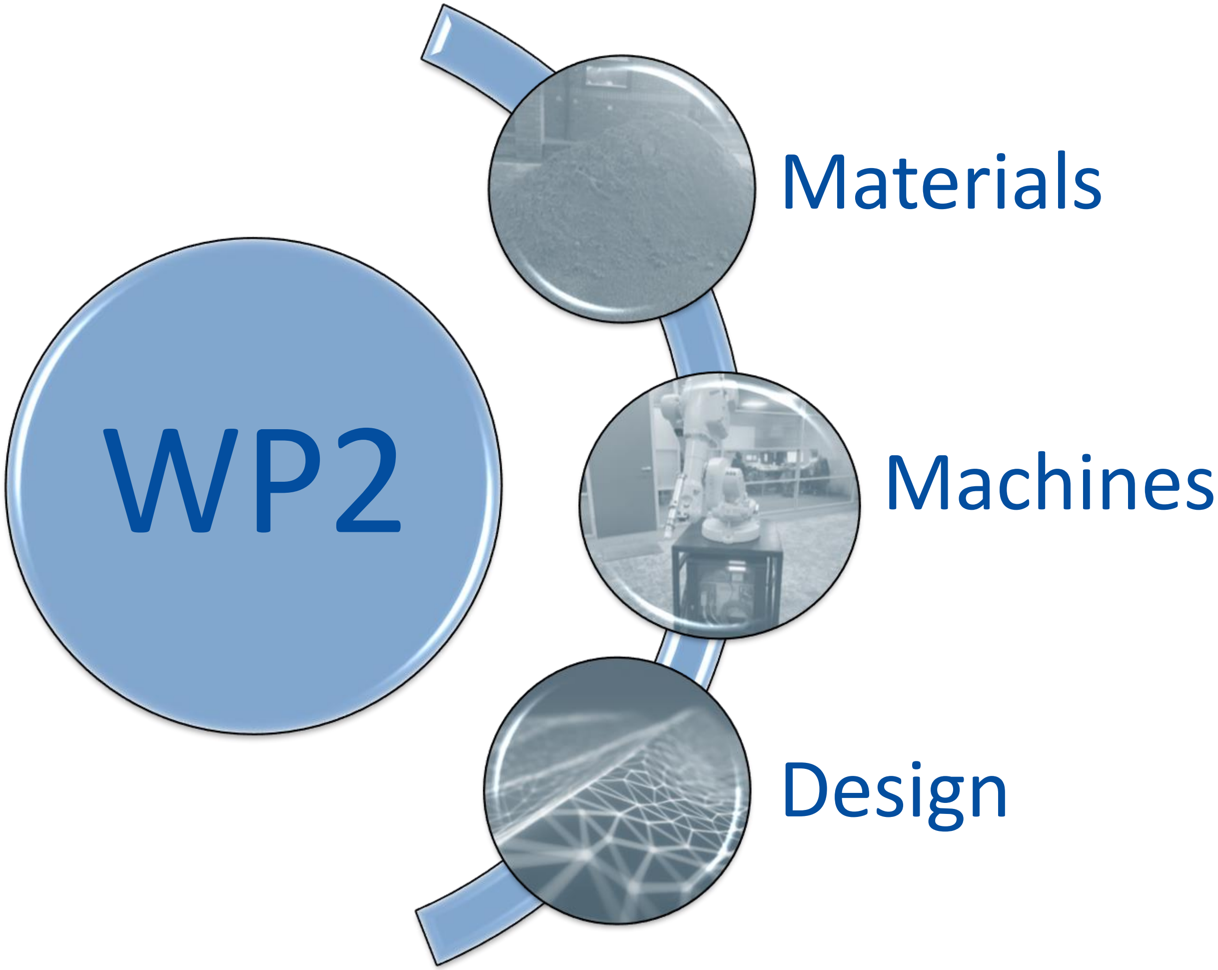
WP 2 – Development of methodologies and process for the 3DP of mortars containing RFA

Manchester Metropolitan University

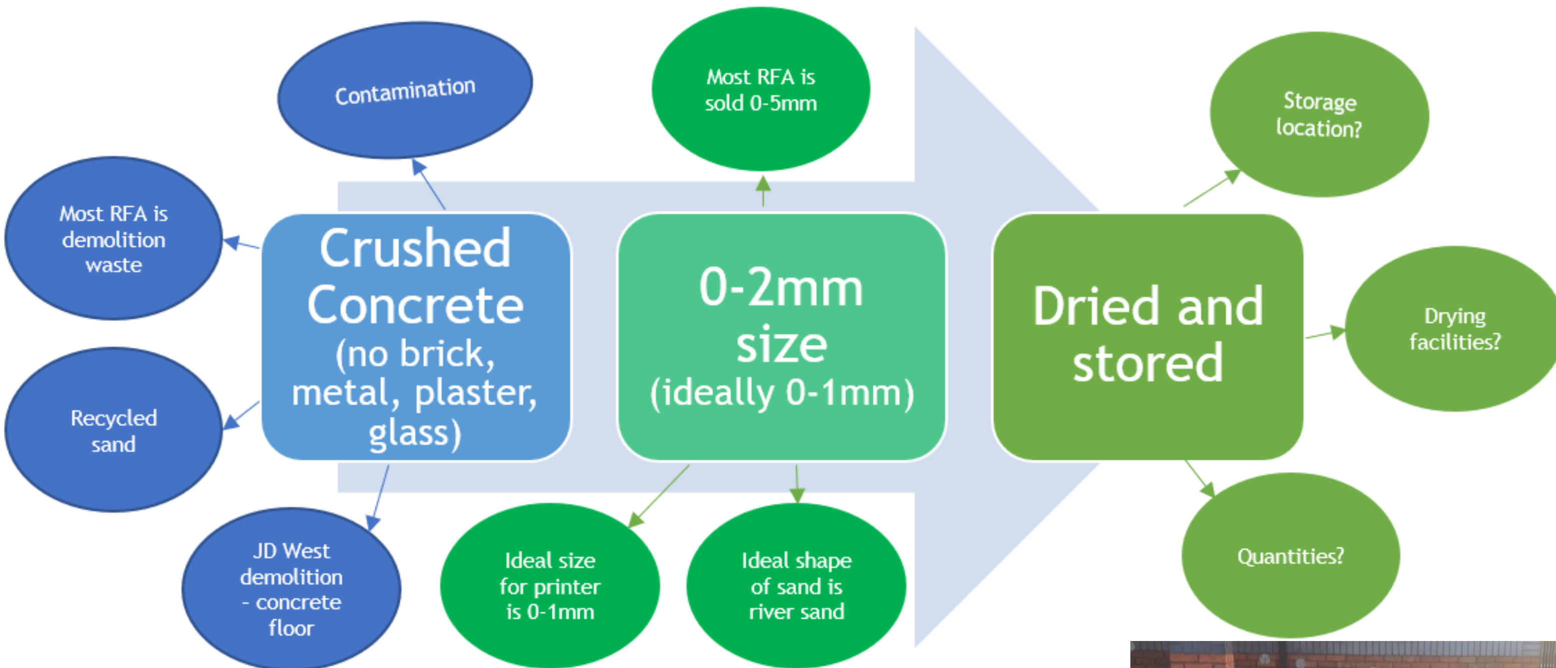
24/03/2022

Work Package 2



Materials

Source the Recycled Fine Aggregate (RFA)



Characterising the RFA in 3 MPM Labs

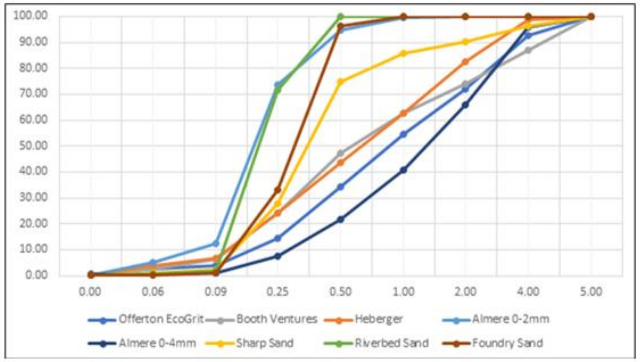
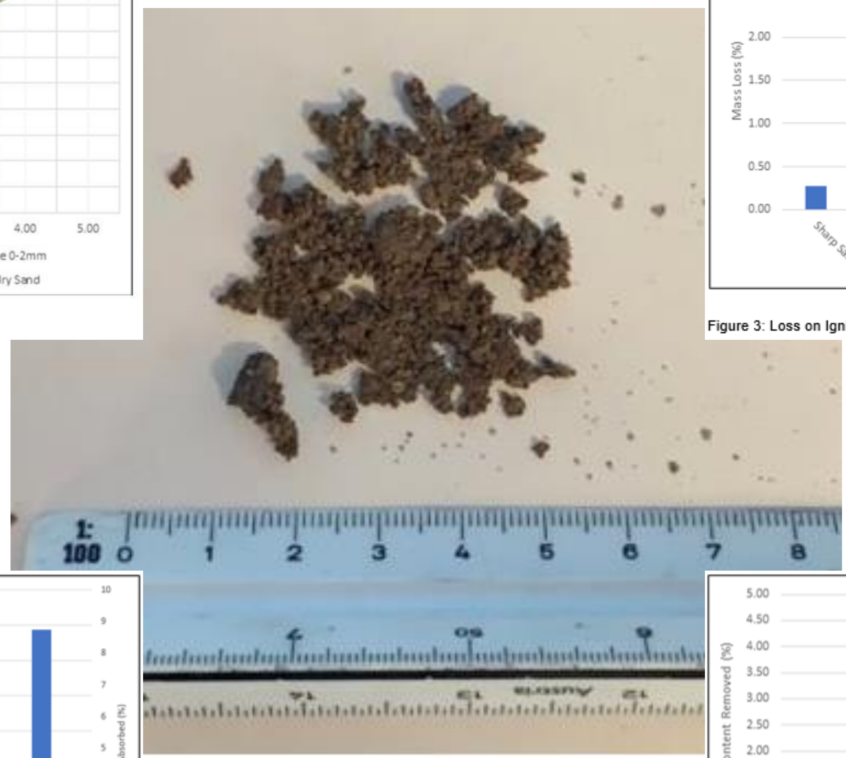


Figure 1: Particle Size Distribution



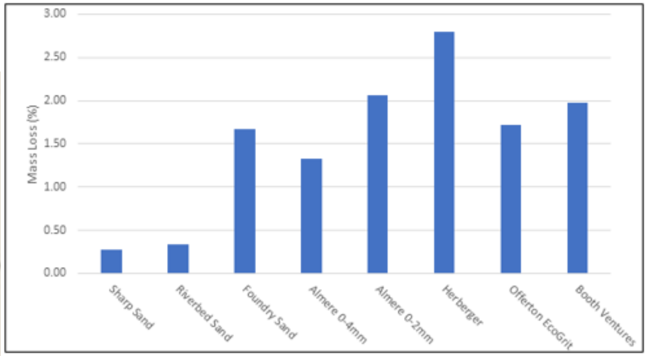


Figure 3: Loss on Ignition

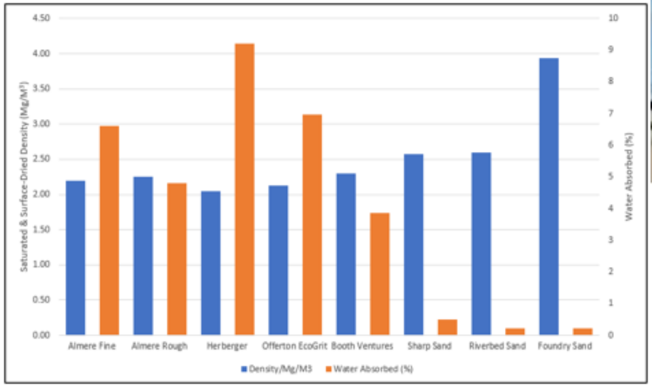


Figure 2: Particle density and water absorption

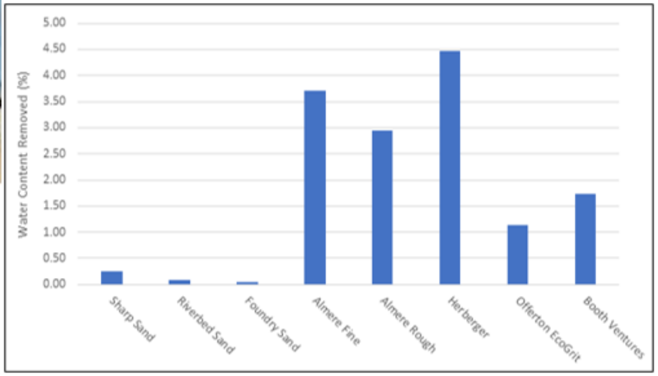
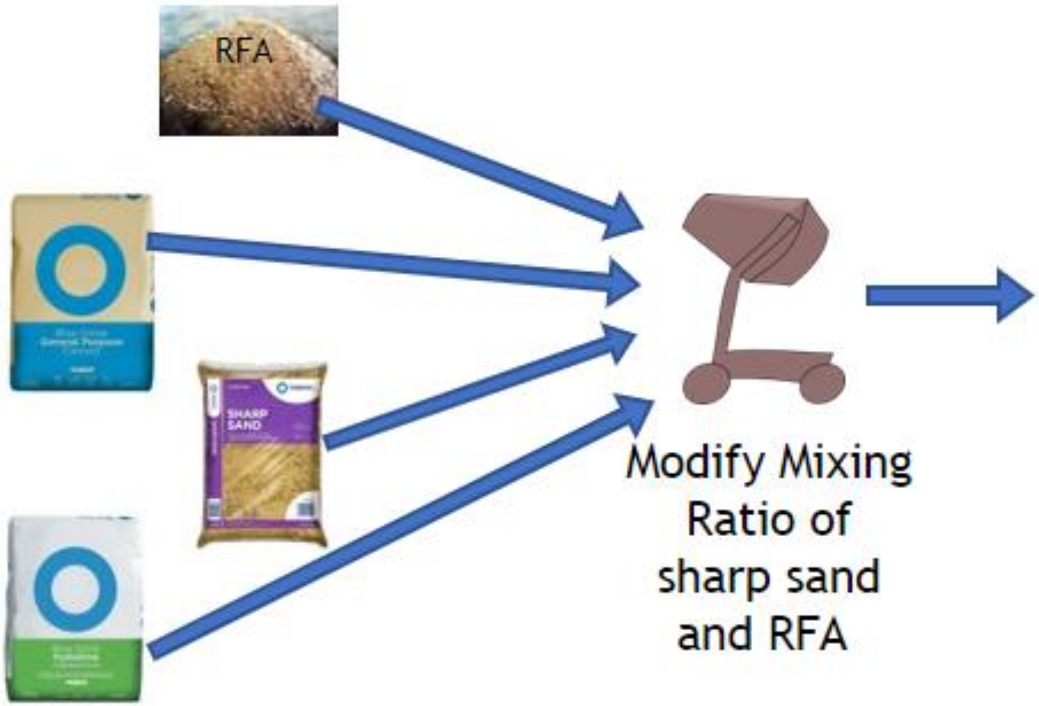


Figure 4: Water content

RFA feasibility testing



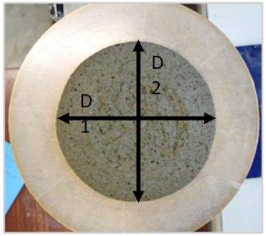
Materials

Fresh state testing

- Flowability
- Pumpability
- Buildability

Flow table test

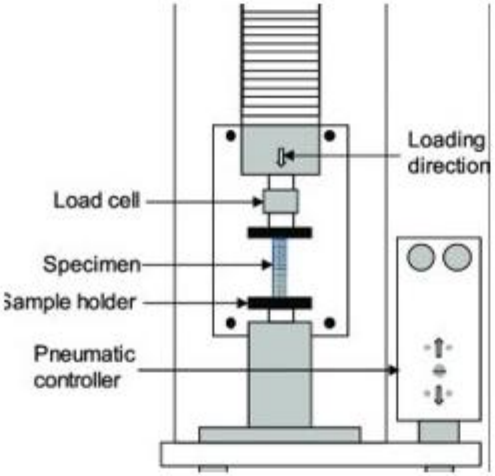
Table used to apply the jolts, with the packing cylinder and the conical mold



Mortar after applying 15 jolts (the black arrows represent the two perpendicular length measured)

This test gives information about the mortar's ability to slump and to spread.

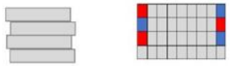
Strength testing

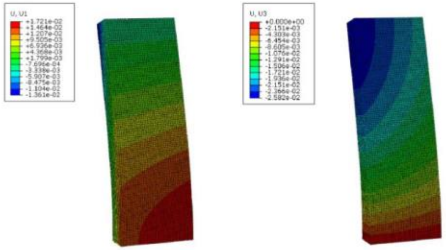


Validation of models

➢ Elastic buckling:

- Geometrical imperfections during printing



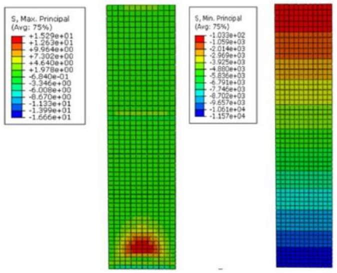


➢ Plastic failure

- Elasto-plastic (Mohr-Coulomb) model

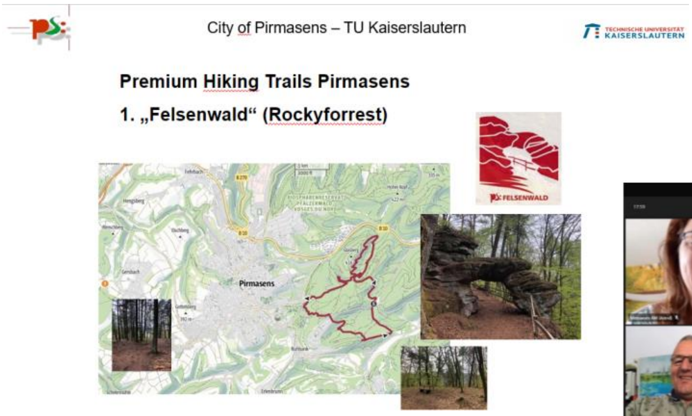
$$FoS = \frac{2 * \sqrt{(C_t + S_1 \tan(\varphi_t)) * (C_t + S_3 \tan(\varphi_t))}}{\sqrt{(S_1 - S_3)^2}}$$

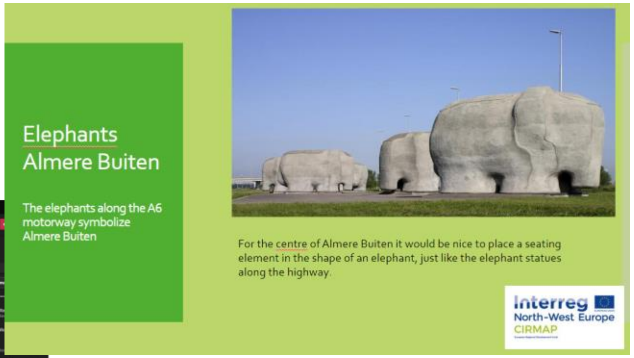
$FoS < 1$ ➡ Plastic Failure

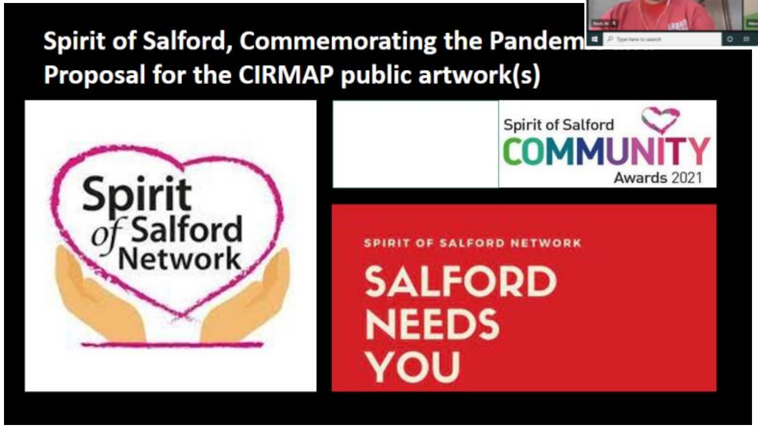


Design

Transnational online conference with municipalities



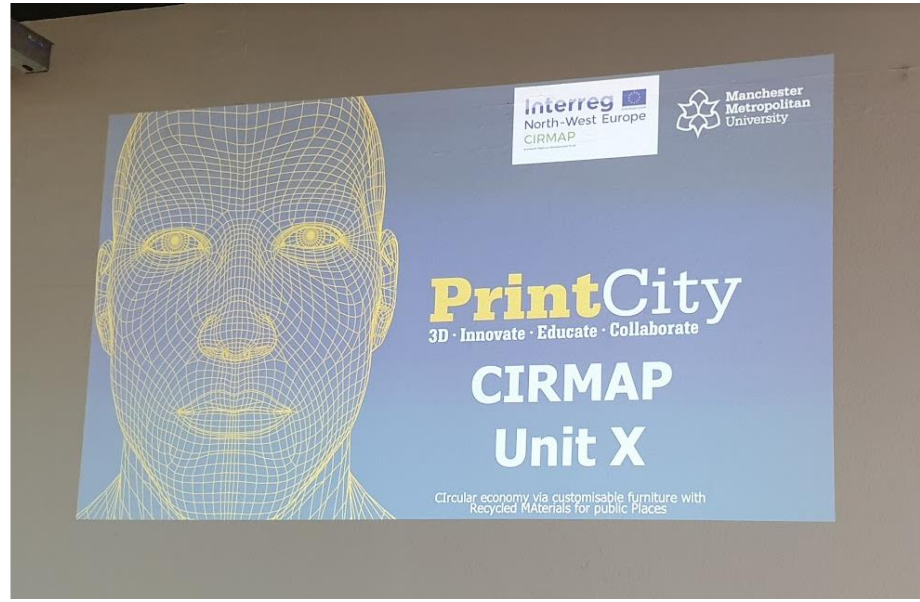


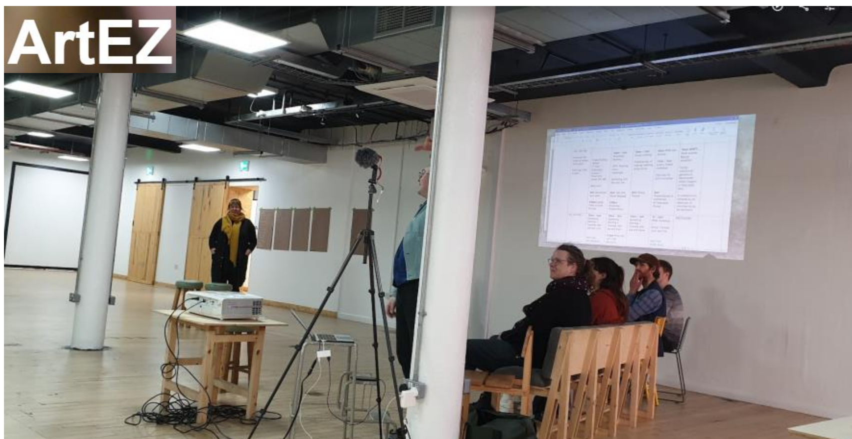


Design

Student design

- Unit X student design (NL and UK)
- Lille student workshop (FR, BE and DE)
- MSc Industrial Digitisation (MMU) - 2 workshops





TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Machines (MMU)

EVA 1600

iMakr

CIRMAP

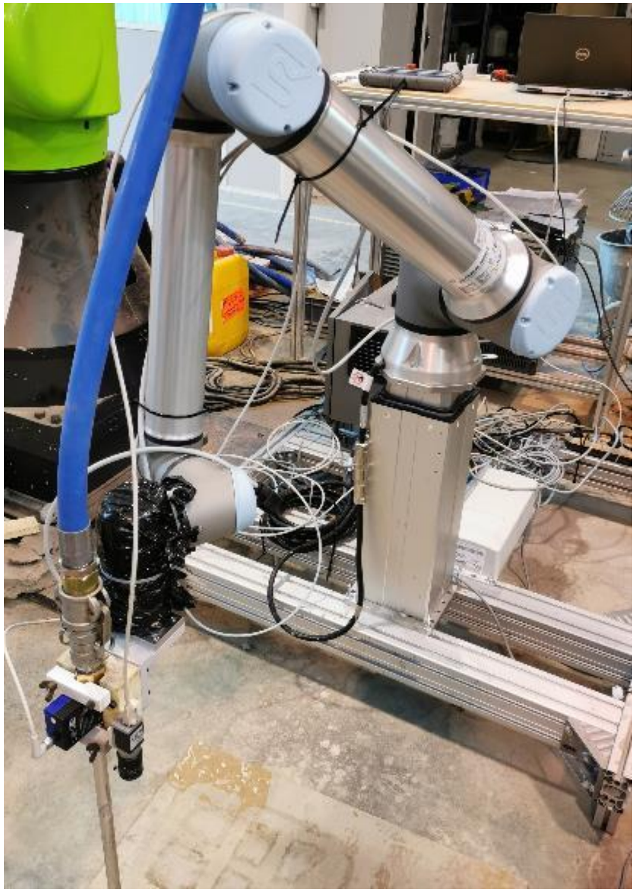
WPT3: Industrial feasibility

University of Lille

24/03/2022

WPT3 Objectives

- Validation of laboratory procedures in terms of:
  - models and design methodologies developed in **WPT2** at a larger scale and in real printing conditions.



- Demonstration that the concrete 3DP process allows for the manufacture of customized shapes with RFA mortars by printing and installing pilots in several places in Europe

WPT3 Activities

- Activity 1 aims to select and collect of large-scale samples of RFA close to the 5 locations of testing;
- Activity 2 concerns trial 3DP campaign for large scale experimental validation;
- Activity 3 concerns the identification of the construction sites for 3DP campaign;
- Activity 4 aims implementing the 3D printing pilot in the 5 sites for construction of 5 type of furniture;
- Activity 5 demonstrates the technological transfer of 3DP concept to industrial scale.

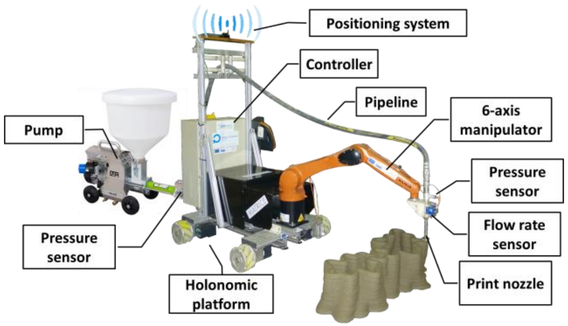
• Activity 2 : Pilots preparation

Pre-printing (emulated environment)

- Simulated environment
- Rapid calibration of machines according to environmental variations

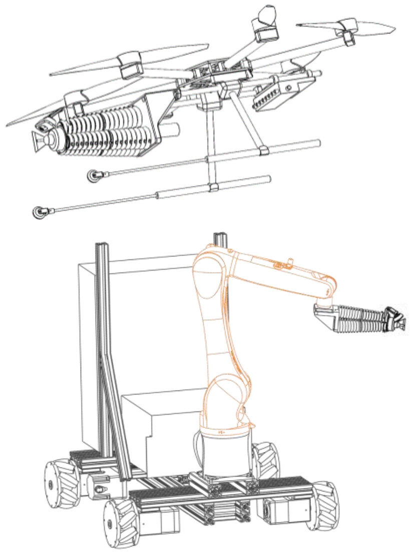
Printing (on-site)

- Uncontrolled environment
- Online adaptive printing



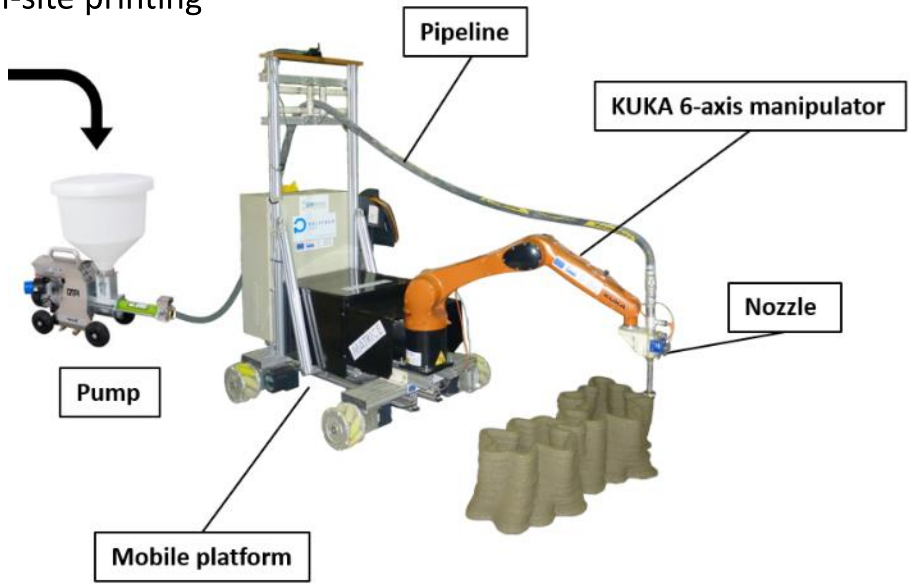
Post-printing (maintaining the quality)

- Quality control
- Predictive maintenance of structure

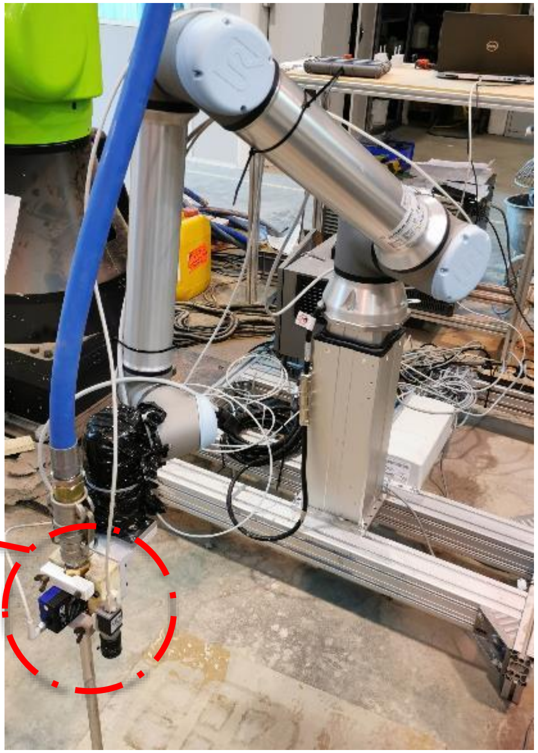


• Activity 2 : Pilots preparation

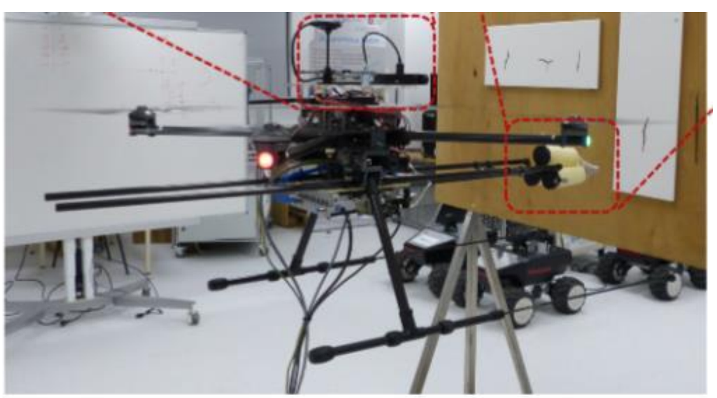
Pilot 1
Mobile Manipulator for on-site printing



Pilot 3
Manipulator robot for physical lab printing

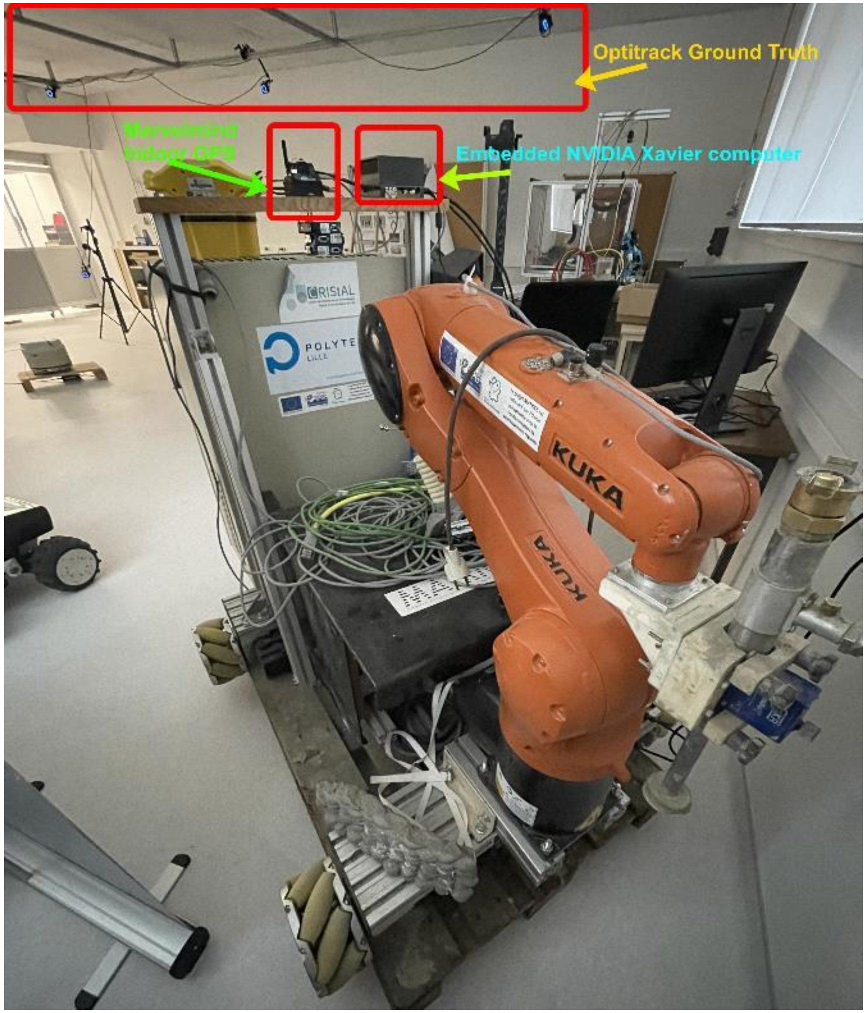


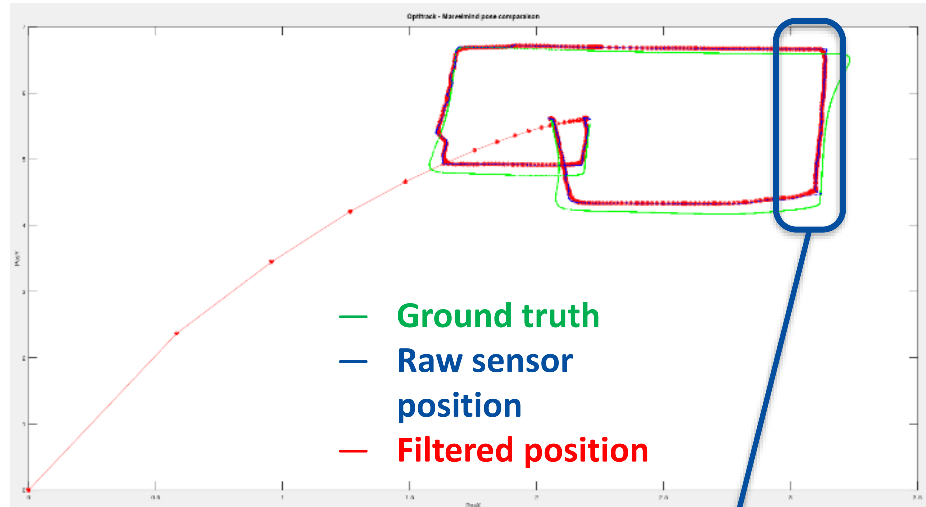
Pilot 2
Flying robot for on-site printing



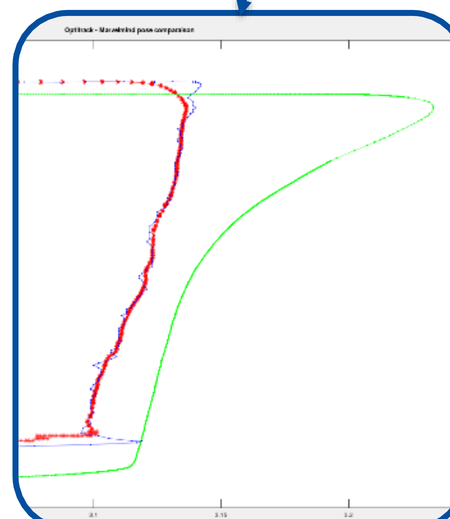
- **Activity 2 : Pilots**

Pilot 4 Navigation of mobile manipulator robot





Accuracy: 5 to 10cm



WPT3: Activity 5: Non controlled Environment

Mortar mixer

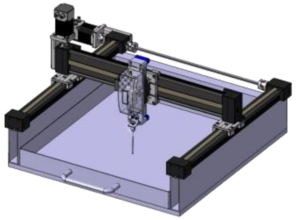
Material

- Designation
- Components
- Volumes
- Weight

Walk-in environmental test chamber

Centralised system

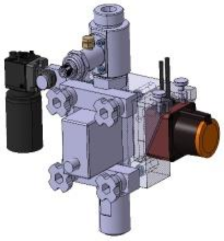
Online characterisation system



Pump

Robot printing

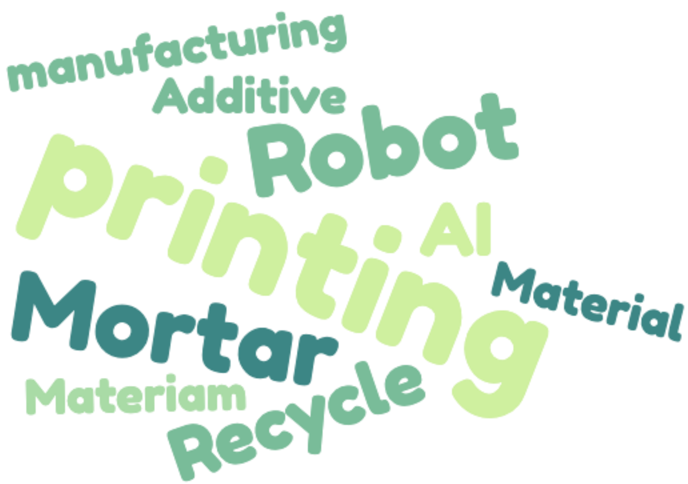
Instrumented nozzle



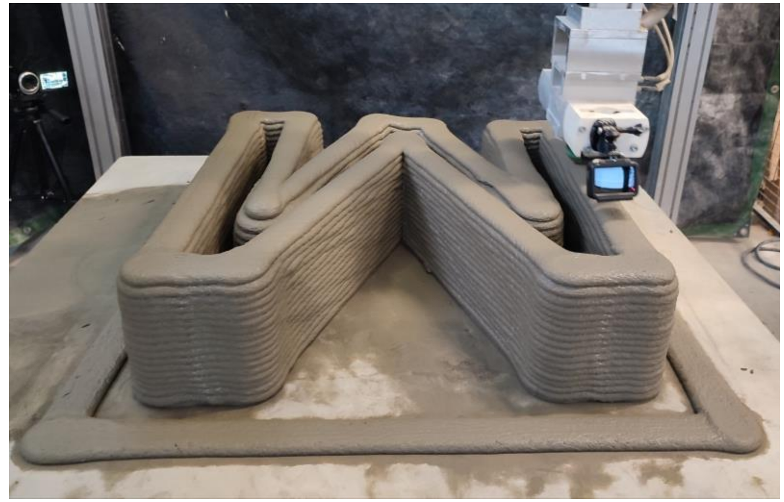
Printed structure

Online measurement and quality control

Keywords Cloud



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




Thanks for your attention

Public Meeting
24 March 2022






LIÈGE université

Diner

– Diner on Thursday, March 24th at 19:30

– Restaurant Terra terrae

- rue Hors Château 48, 4000 LIEGE
- https://terraterrae.be
- Phone number :+32495321643

– Recommended parking :

- Parking: Saint Georges (Liège) Quai de la Batte, 4000 Liège
- Parking Cité (Liège) Quai de la Goffe 15, 4000 Liège

Steering Committee

For meetings on Friday 25th

Building B52 – Room 0/429 – Arrival at 8:30