RE4

REuse and **RE**cycling of CDW materials and structures in energy efficient p**RE**fabricated elements for building **RE**furbishment and construction

RE^4 Best Practises

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- Sustainability assessment
- Market potential

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The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583.

CDW IDENTIFICATION, SOURCE SEPARATION AND COLLECTION

Deconstruction strategies

Prerequisites for building dismantling and reuse

Reuse and recycling are not interchangeable strategies. The primary goal is to reuse the dismantled components, and the secondary goal is to recycle only the raw material.

The following types of buildings are likely to be good candidates for deconstruction:

A. Timber-framed buildings with heavy timbers and beams.

B. Buildings that are constructed using high value specialty items such as hardwood flooring, architectural moulding and unique doors or plumbing/ electrical fixtures.

C. Buildings constructed with high quality brick.

D. Buildings constructed with precast concrete.

E. Buildings that are generally constructed sound and water tight to minimise rotted and decay materials.

F. Building systems and materials that are similar throughout the building and laid out in regularity, repeating patterns and limited number of different material types and component sizes.

G. Modular construction buildings.

H. Buildings with assembly connections that allow each part to be replaced discretely, recognizing the very different time spans that different components have.

Identification of parameters for reusability

Concrete-based components

Crushed concrete is recyclable as an aggregate of new concrete, particularly the coarse portion; reinforcement is recyclable as are metals in general, but it must be separated from concrete during the crushing process. The material should not contain any amounts of harmful substances or other impurities (such as lead from paints, trash, wood, paper, etc.) that may reduce its environmental and technical suitability or totally prevent its use. The reuse of elements requires testing and standardization. Historical data might help to assess the material quality. The connections of the element affect substantially the deconstruction process regarding time, cost and success.

Timber-based components

In order to be suitable for reuse in the construction sector, wooden components must:

A. be free of pollutants, such as wood preservatives, or other pollutants resulting from previous use, that have penetrated wood components
B. be free of wood-destroying fungi and insects
C. demonstrate few, very strong, removable connections with high rigidity
D. demonstrate sufficiently large cross-sections and lengths

For areal wooden elements:

A. functional layers should also be easy to separate.

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CDW IDENTIFICATION, SOURCE SEPARATION AND COLLECTION

Non-destructive deconstruction strategy focused on highly reusable components

Level	Step	Task
Preparation	**1**	**Examination** / Preparation of a detailed building inventory to identify construction methods and fasteners, confirmation of presence/absence of pre-stressing/reinforcement as well as hazardous materials.
Preparation	**2**	**Assessment** / Pre-demolition audit to list and quantify materials and/or components that can be reused or recycled on site. Building reuse and deconstruction strategy audit ("End of life plan") including the identification of hazardous materials.
Preparation	**3**	**Deconstruction Plan** / Identification of the deconstruction method.
Preparation	**4**	**Decontamination. Removal of hazardous waste** / Hazardous material needs to be removed correctly and systematically prior to deconstruction.
Deconstruction	**5**	**Removal of building services, non-structural components and load bearingcomponents** The concrete building should be dismantled element by element and floor by floor following the reverse sequence to its construction and using the deconstruction method selected previously.
Process attendant		**Quality assurance** / Determination/specification of material properties in accordance to the applicable requirements and classification of the components. Matching against laws and regulations (e.g. CE-marking, performance criteria, CPR)

Timber construction

Disassembly of historic peat barn in Kolbermoor, Germany (©ZRS Architekten)

Concrete construction

Dismantling concrete beam

Source: Demolition of concrete structures, by Hal T. Hudgins

Concrete elements cut from cast in place concrete walls delivered to new building site (Linköping)

Source: The conditions and constraints for using reused materials in building projects

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CDW IDENTIFICATION, SOURCE SEPARATION AND COLLECTION

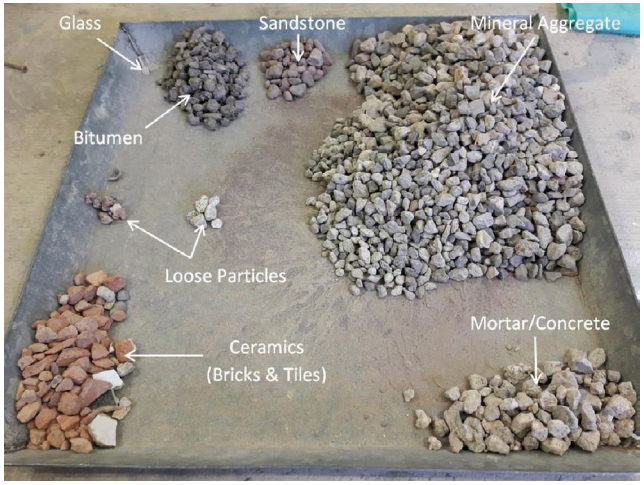
CDW scheme and rates

Unsorted N-EU CDW composition: 3% silt/clay, 7% fine sand, 8% medium/coarse sand, 4% concrete/mineral aggregate (4-8 mm); 6% concrete/mineral aggregate (8-16 mm), 1% concrete/mineral aggregate (16-20 mm), 35% concrete/mineral aggregate (> 20 mm), 6% mortar/plaster, 27% ceramics (bricks and tiles), 3% bitumen.

Unsorted S-EU CDW composition: 9% silt/clay, 6% fine sand, 10% medium/coarse sand, 5% concrete/mineral aggregate (4-8 mm); 6% concrete/mineral aggregate (8-16 mm), 2% concrete/mineral aggregate (16-20 mm), 38% concrete/mineral aggregate (> 20 mm), 11% mortar/plaster, 14% ceramics (bricks and tiles), 1% lightweight (plastics/ wood).

The analysed mineral fractions (0-2, 2-8 and 8-16 mm) were deemed suitable for use in different types of structural concrete. For some type of structural concretes the percentage of replacement can be 100% for all the fractions. The fine material was characterised as silt with high plasticity. Lightweight fraction has the potential to be used as received as lightweight aggregate for concrete. Timber elements from dismantled buildings can be reused as structural components. Ceramics (bricks and tiles) fraction can be used as alkali activated binder. It is possible to choose replacement rates depending on the final application. We have developed a way to manage CDW depending on their quality, that may vary from time to time.

We have proposed new quality classes and we have proposed them to standardisation committees (European Committee for Standardization CEN/TC104 responsible for EN 206 Concrete: Specification, performance, production and conformity; RILEM Technical Committee TC 273-RAC; Swedish Institute for Standards SIS/TK190).



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RE⁴ Best Practises

CDW LOGISTICS

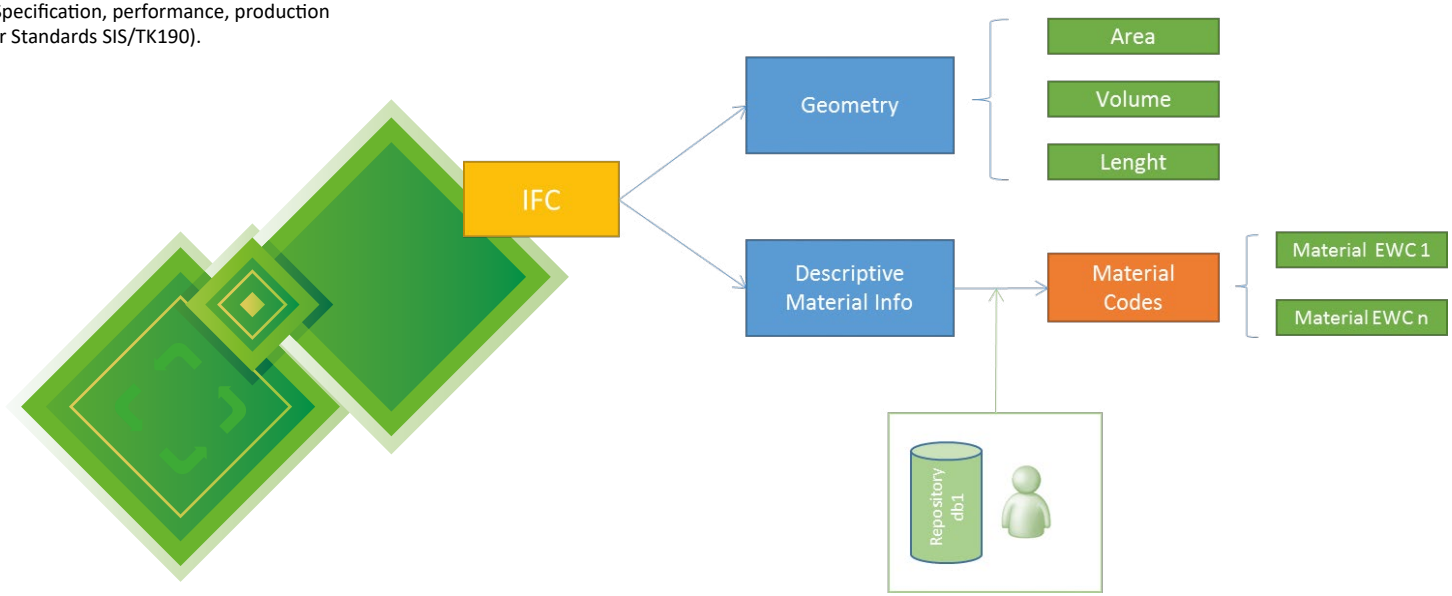
BIM-compatible DSS platform

The DSS is a web application, developed using modern technologies, that provides different functionalities to different types of users (Demolisher/Builder, Utilizer, Collection plant Manager, Landfill/incineration plant manager).

The tool supports construction/demolition companies by estimating types and quantities of CDW that will be generated during a project and by providing possible utilization options and related logistic references to final CDW users (including prefabricators). The system also supports the general CDW market/management by assisting Collection Plant Managers and Landfill/Incineration Plant Managers in the timely awareness of CDW types and quantities which final destination is relevant to them.

The RE⁴ tool also aids to:

- estimation of demolition and construction waste;
- providing information about possible end uses of the CDW



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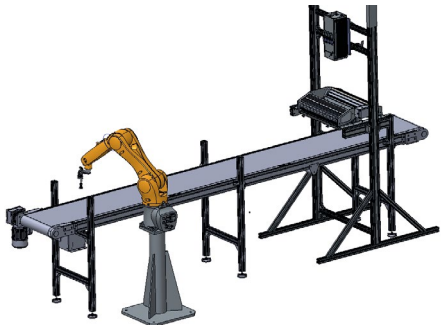
CDW PROCESSING AND TREATMENT

Sorting

The RE⁴ sorting system was developed to exploit both mechanical and digital/robotic methods to improve the quality of recycled materials from CDW.

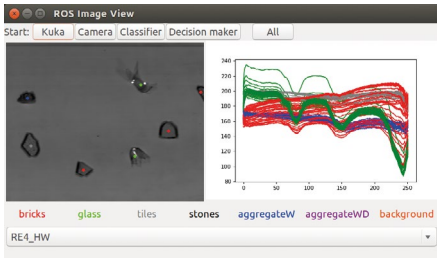
Mechanical methods were exploited to remove organics and improve the overall sand quality by attrition and density separation.



- Attrition cells scrub the sand to liberate the clay from the sand particles, with an optimal treatment time of 9 minutes;
- Spirals separate sand into light particles, middlings and heavy particles, with aggressive cutpoint obtaining high quality for heavy materials;
- Counter Flow Classification Unit (CFCU) uses a cutpoint around 125-250 µm to separate good quality, coarse sand.

Robotic and machine learning technologies were adopted to develop an automatic sorting system for different CDW material classes. The system exploits the flexibility of a 6 DoF (Depth of Field) antropomorphic robot and the different wavelength signatures of materials in the NIR spectral range, together with the linear discrimination potential of Support Vector Machine algorithm. The system was demonstrated to be able to:

- Discriminate between bricks, stone/aggregates, ceramics and glass in the Heavyweight clasifier mode;
- Discriminate between plastic and wood in the Lightweight clasifier mode;
- Process around 780 CDW fragments per hour;
- Reach high purity sorted classes (classification and pick-and-place errors arouond 1%).



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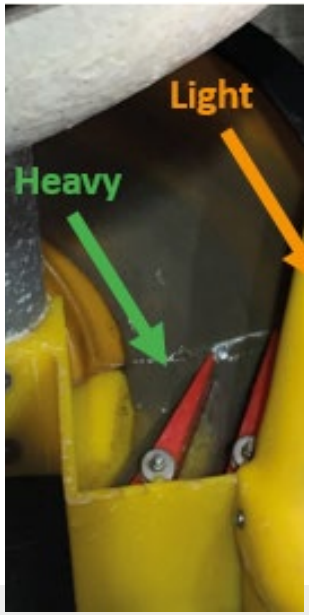
CDW PROCESSING AND TREATMENT



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CDW-BASED ELEMENTS AND COMPONENTS

Structural concrete precast elements

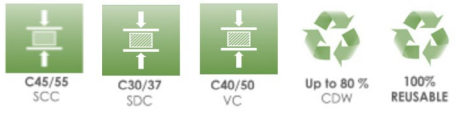
The RE⁴ loadbearing concrete precast elements are made from steel reinforced CDW concrete and contain up to 80% CDW per total mass. They use structural bolted connections meaning they are fully reusable. The RE⁴ concretes for the structural elements contain 50-100 % of CDW-derived aggregates. The range of concretes for these elements are: Self-compacting concrete (SCC); Semi-dry concrete (SDC); and vibrated concrete (VC).

Structural elements: Beams; Columns; Slabs; Walls.

Technical data

- **Fully reusable**
- Compressive strength classes: C30/37 to C45/55
- 50-100 % of the aggregates used are CDW-derived
- 30-80% of CDW per total mass
- Manufactured off-site and suitable for fastrack modern methods of construction

Suitable for new buildingas as for refurbishments, single storey or multi-storey buildings.



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CDW-BASED ELEMENTS AND COMPONENTS

Non-structural sandwich panel

The RE⁴ non-loadbearing concrete sandwhich panel consists of inner and outer CDW-based concrete layers, sandwiching a PIR insulation sheet. The inner layer is made from steelreinforced self-compacting concrete (SCC) where 50-80 % of the aggregate is CDW, whereas the architectural (outer) layer is made from carbon textile reinforced high-performance concrete (HPC), where 50-90 % of the aggregate is CDW.

Main properties: compressive strenght classes are C60/70 for the HPC and C40/50 for the SCC, the reduction of architectural layer thickness is from 80 mm in the conventional panel to 40 mm in the RE⁴ panel, and the weight reduction is 20 % compared to conventional sandwich panel.

The RE⁴ non-loadbearing sandwhich panels have been casted in real factory production, proving concept is working also on industrial scale.

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CDW-BASED ELEMENTS AND COMPONENTS

Extruded tiles

CDW extruded tile is the base element of a cladding system intended for the erection of façades for multipurpose buildings and manufactured within the RE⁴ project using CDW derived aggregates in lieu of virgin aggregates.

Replacement percentage of virgin aggregate is up to **85%**. CDW extruded tiles are **100% recyclable.**

Standard equipment is suitable for the manufacturing process: **no upgrade required.**

Technical data

Dimensions of each piece:600 x 107 x 10 mm

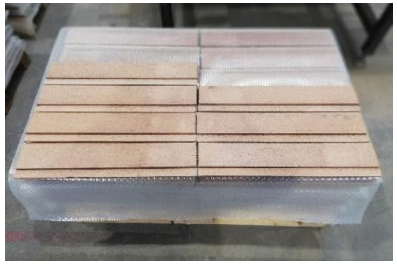
Weight of single tile: 2 kg

Pieces/m²: 16,67

Weight/m²: 33 kg/m² (without mounting rails)

480 N

100 %



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RE4 Best Practises

CDW-BASED ELEMENTS AND COMPONENTS

Timber elements - panel

The prefabricated façade element from CDW timber is conceptualised as non-load bearing, rear ventilated system, which can be fixed as hanging façade to the loadbearing structure of the building. The anchor points are to be defined on a project by project basis and can vary from beam, to ceiling and column. The size of the elements is generally determined by the following factors:

- architectural aspiration and respective design proposal
- technical possibilities of prefabrication
- limitations of transport and assembly
- static requirements
- hygrothermal requirements
- requirements determined by building services

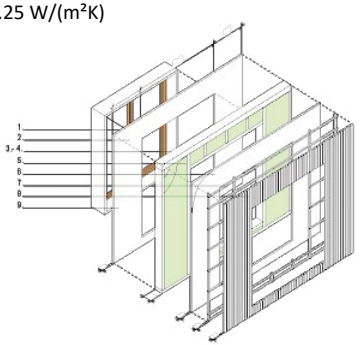
The width of the element follows the standard grid established in timber construction, which is defined by the dimensions of the stiffening boards. Deviations, due to site constraints or design aspirations can easily be accommodated by modification of the edge section through either addition of another stud or reduction of the axial dimension. The structural system of the element is designed as a stiffened frame and composed of a threshold (bottom), studs and a plate (top). All bearing components consist of either structural solid wood (KVH) or glued laminated timber (BS timber).

The overall thickness of the panel is mainly determined by the hygrothermal requirements set out in the national regulations of the respective country of construction. The RE⁴ project addresses both, the design of façade elements suitable for the Northern European climate as well as for the Southern European climate. The CDW timber façade element has been designed as a vapour permeable wall build-up, that consists of multiple layers. The order of the single layers follows a compulsory vapour pressure gradient to enable vapour diffusion through the panel. In such way moisture is not trapped at any point within the element. The indicative U-values have been defined fairly strict, so that they undercut current regulations in order to improve the energy efficiency performance of the developed RE⁴ in comparison to current market solutions.

- U_{NE} (Northern Europe) = 0.15 W/(m²K)
- U_{SE} (Southern Europe) = 0.25 W/(m²K)

CDW timber façade element

1 RE⁴ earth plaster
2 Wood fibre board
3 Wood fibre hardboard
4 RE⁴ timber studs & RE⁴ timber threshold (bottom) and plate (top)
5 RE⁴ Wood fibre insulation
6 RE⁴ DWD – Wood fibre board
7 RE⁴ Batten and counter batten
8 RE⁴ Weather boards
9 Windows and openings



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CDW-BASED ELEMENTS AND COMPONENTS

Reversible corner connections of the façade element

Several reversible corner connections have been taken into account for the non-loadbearing façade element, which can basically be divided into two different categories: carpenter (timber in timber) and metal connections. Steel connections consisted of l-shaped or flat steel plates.

Other reversible connections of the façade element

Other reversible connections consisted mainly of screws. Attention was paid to the use of same sizes screw heads to improve assembly and disassembly times on site.

Connections between façade element and support structure

To enable an easy, speedy and non-disruptive dismantling of the prefabricated façade panel, a fully reversible connection between the element and the structural support system of the building is required. Plates should be mounted on a 1 m grid.

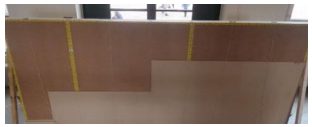
The bottom the panel is standing on a L shaped steel plate, functioning as a support for vertical loading. The proposed dimensions of the plate are as following:

- length 120 mm
- height 120 mm
- width 100 mm
- thickness 10 mm

The steel plate on the top of the panel secures the façade element against tilting and should not be taken into account for vertical loading. The proposed dimensions of the plate are as following:

- length 320 mm
- width 100 mm
- height 8 mm



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CDW-BASED ELEMENTS AND COMPONENTS

Timber partition

During the RE⁴ project, an innovative internal partition wall system which fosters the idea of prefabrication to enable easy installation and dismantling was developed. Prefabrication for internal wall systems is not common, as such walls often require adaptation to on-site situations. Furthermore, such systems are normally not designed for disassembly. In consequence a significant amount of waste is generated, when elements are dismantled, as single components are often demolished.

The innovative RE⁴ solution aims to address such challenges and developed a system based on the standard grid for timber construction (62.5 cm) that can easily be installed on site and joined together. Single elements are mounted against timber rails, which again are fixed to floor and ceiling. The size of the element creates a high level of flexibility, however, corner or end sections might require customised sizes in order to match dimensions on site. The weight of single elements enables easy transport to and on-site as necessary. The main components are as following:

- RE⁴ earth plaster
- Wood fibre board
- RE⁴ timber studs
- RE⁴ threshold and plate
- RE⁴ wood fibre insulation

The overall dimensions of one element are presented in the table below.

Description of element	Weight	Outer dimensions		Thickness	
		Height (mm)	Width (mm)	Total Thickness (mm)	Thickness of CDW studs and insulation layer (mm)
Non-load-bearing partition wall	114 kg (incl. cladding and render)	210 0	100 0	120	55

Reversible connections

Several possibilities have been taken into account, which can be divided into two different categories: carpenter (timber in timber) and metal connections. Metal connections considered for this element are basically off the shelf screwed connections joining the single components, whereas different carpenter connections have been developed to fix the elements against floor and ceiling but also to join different elements vertically.

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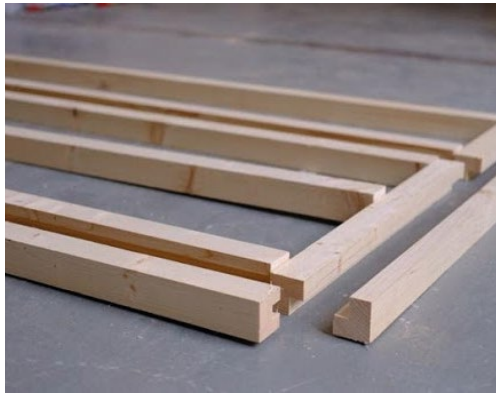
CDW-BASED ELEMENTS AND COMPONENTS



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RE⁴ Best Practises

CDW-BASED ELEMENTS AND COMPONENTS

Insulating wood panel

CDWood Panel is a thermally insulating soft panel, with reduced weight and tailorable dimensions, binder free and made of wood waste from CDW recycling plants.

Main properties: density of 175 kg/m³, compressive stress at 10% of strain of 30 kPa and thermal conductivity coefficient of 0.06 W/mK.

CDWood panel is suitable for application in new construction and refurbishment works where eco-sustainability is a must.

CDWood panel is 100% recyclable.



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CDW-BASED BUILDINGS

Demo Spain

- New construction building
- Prefabricated energy-efficiency building concept / Calculated U-value= 0.30 W/m²k
- Designed as a two-storey building with a concrete frame of a single column and four beams with a set of bearing and non-load bearing prefabricated wall (façade) elements.
- Designed for easy assembly and disassembly (reversible structural connections)
- Saving of circa 40% overall time in construction compared with a reference building built with common construction techniques used in Spain (cast in place concrete structure and brick walls).
- Prefab elements & components incorporating CDW (replacement rate 50-100% CDW)

RE⁴ ELEMENT	MATERIAL	TYPOLOGY	RECYCLED	REUSABILITY
Wall panel	Concrete inc. CDW*	Structural	50%	✓
Beam (L-section)	Concrete inc. CDW*	Structural	50%	✓
Beam (square section)	Concrete inc. CDW*	Structural	50%	✓
Column	Concrete inc. CDW*	Structural	50%	✓
Solid floor slab	Concrete inc. CDW*	Structural	50%	✓
Sandwich panel	Concrete inc. CDW*	Non-structural	50%	✓
Block wall	Concrete inc. CDW*	Non-structural	75%	X
Façade panel	CDW* timber	Non-structural	-	✓
Internal partition wall	CDW* timber	Non-structural	-	✓
Ventilated exterior wall cladding				
Insulation boards	Extruded wood scraps	Non-structural	100%	✓
Extruded Marmoroc® Baltic tiles	Concrete inc. CDW*	Non-structural	85%	✓

**CDW= construction and demolition waste*

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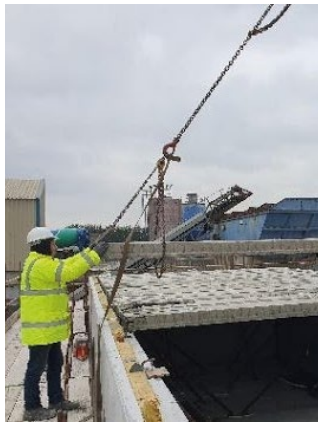
CDW-BASED BUILDINGS

Demo UK

- New construction building
- Prefabricated energy-efficiency building concept / Calculated U-value= 0.20 W/m²k
- Designed as a two-storey building using a panelised fastrack precast system with hollow-core RC slabs spanning the full width of the building and supported into loadbearing prefabricated sandwich panels on the perimeter (façade elements).
- Designed for easy and cheaper assembly.
- Saving of circa 40% overall time in construction compared with reference buildings built with common construction techniques used in the UK (cast in place concrete structure and brick walls).
- Prefab elements & components incorporating CDW (aggregates replacement rate 50-100% CDW)

RE⁴ ELEMENT	MATERIAL	TYPOLOGY	RECYCLED	REUSABILITY
Sandwich Panel	Concrete inc. CDW*	Structural	50%	X
Hollow-core slabs	Concrete inc. CDW*	Structural	50%	X
Stairs	Concrete inc. CDW*	Structural	50%	✓
Block walls	Concrete inc. CDW*	Structural	75%	X

**CDW= construction and demolition waste*



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CDW-BASED BUILDINGS

Demo Italy

- Ventilated façade for refurbishment.
- High energy-efficiency façade dry installed / In-field measured U-value= 0.24 W/(m²K).
- Designed as an open joint ventilated façade made by insulation wood boards and extruded tiles as cladding system, held togheter due to vertical and horizontal steel rails. The air cavity, 10 cm thick, has 5 horizontal holey rails.
- The existing wall to be refurbished, now back wall of the ventilated façade, is made of aerated cellular concrete blocks, cement plaster and an external finish layer based on lime and cement. The final in-field measured thermal transmittance was 1.10 W/(m²K).
- Designed for easy assembly and disassembly (reversible structural connections)
- Prefab elements & components incorporating CDW (replacement rate 50-100% CDW)

RE⁴ ELEMENT	MATERIAL	TYPOLOGY	RECYCLED	REUSABILITY
Ventilated exterior wall cladding				
Insulation boards	Extruded wood scraps	Non-structural	100%	✓
Extruded Marmoroc® Baltic tiles	Concrete inc. CDW*	Non-structural	85%	✓

**CDW= construction and demolition waste*

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RE⁴ Best Practises

CDW-BASED BUILDINGS

Demo Taiwan

- Refurbishment
- New Prefabricated CDW-HPC panels
- Designed for easy assembly (reversible structural connections)
- Designed to protect existing structures against earthquakes and Typhoons
- Prefabricated panel incoporating CDW (replacement rate at 40% by volume for both RCA and RFA)

RE⁴ ELEMENT	MATERIAL	TYPOLOGY	RECYCLED	REUSABILITY
Wall panel	CDW (RCA & RFA)	Non-Structural	40% RCA 40% RFA	✓
Steel frame	Steel	Structural	-	✓

**CDW= construction and demolition waste*
** RCA = Recycled coarse aggregate*
** RFA = Recycled fine aggregate*
** HPC = High performance concrete*

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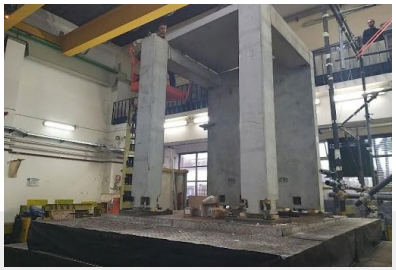
CDW-BASED BUILDINGS

Seismic mockup

- New construction building
- Prefab elements & components incorporating CDW (replacement rate 50-100% CDW)
- Full scale prototype unit which reflects the RE⁴ building concept, including two columns, one shear wall, two horizontal beams, a solid slab and mechanical commercial devices for mutual connections and fundation elements
- Seismic design for medium/high hazard, according to European standards, which results in specific construction details for structural elements, mutual connections and fundation elements
- Designed for easy assembly and disassembly (reversible structural connections)
- Experimental test for seismic qualification using shaking table facility
- Bidirectional dynamic input, in terms of base acceleration, up to 13m/s²
- The seismic test confirms very high performance for precast CDW concrete elements which did not exhibit damage during the test
- The seismic test pointed out the crucial rule of mutual connections for the seismic performance of precast CDW concrete buildings: the assembly strategies adopted for the seismic mockup ensured a right balance between structural perfomances and components reusability up to high seismic demand.



Seismic mockup: experimental setup for shacking table test

- The seismic test pointed out that components reusability is possible, after a selected seismic event, if specific construction details and tecniques are undertaken during assembly and disassembly phases.

RE⁴ ELEMENT	MATERIAL	TYPOLOGY	RECYCLED	REUSABILITY
Wall panel	Concrete inc. CDW*	Structural	50%	✓
Beam (L-section)	Concrete inc. CDW*	Structural	50%	✓
Beam (square section)	Concrete inc. CDW*	Structural	50%	✓
Column	Concrete inc. CDW*	Structural	50%	✓
Solid floor slab	Concrete inc. CDW*	Structural	50%	✓

**CDW= construction and demolition waste*

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REuse and **RE**cycling of CDW materials and structures in energy efficient p**RE**fabricated elements for building **RE**furbishment and construction.

RE⁴ Best Practises

POLICY AND FRAMEWORK CONDITION

CDW Management strategies

APPROACH

Definition of current CDW management strategies across EU28 (including Switzerland and Taiwan), Key Performance Indicators for the CDW-derived materials and structures and the new or adapted prefabricated components made thereof, technical regulations and legislations, policy measures among the EU countries, and identification of certification issues related to CDW-based products.

Diagnosis of CDW management in the EU

LESSONS LEARNED

- Presence of unfavourable market conditions for recycled CDW materials
- Low perceived quality of CDW derived materials
- Needs of improving the legislative framework for CDW recycling, revising the target for 70% recycling of CDW across Europe, and improving CDW data availability, quality and comparability at EU level;
- Need to turn waste management into resource management for a Cultural revolution in construction.

In addition, several **recommendations** were provided in order **to unlock secondary raw materials currently unexploited or underexploited** within the EU (e.g. a stronger legislative framework, a harmonized use of economic instruments at EU level, a common definition of CDW in Europe).

Current status of construction of prefabricated elements with reused/recycled material

LESSONS LEARNED

- The use of prefabricated elements from CDW in Europe is still a relatively undeveloped topic and CDW is still not used for prefab structural elements.
- European technical standards are in favour of using prefabricated elements with recycled materials from CDW, (e.g. standard EN 13369:2013 which provides rules about the use of recycled aggregates in prefabricated concrete elements)

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POLICY AND FRAMEWORK CONDITION

• Among EU28 countries the main external factors, such as economic incentives, regulatory framework, presence of infrastructure and labour skills, positively or negatively determines market performance. Harmonization is needed from the point of view of incentives and the quality of secondary materials and prefabricated elements.

The main 3 **recommendations to promote the use of prefabricated elements with CDW materials** in construction at European level, are: a) establishing and effectively enforcing standards related to waste reuse targets, and codes to increase the efficient use of prefabricated elements and provide standard definitions about these in construction sector; b) transparently disclosing information and data to support informed decision making, to help build market demand for prefabricated elements in construction sector; and, c) supporting construction sector about materials recycling and promoting innovation that increases the reuse of them, significantly reduces costs, and increases utilization of prefabricated elements in the construction sector.

Current status on policy measures and regulatory frameworks

LESSONS LEARNED

• according to the Construction Products Regulation (CPR) 305/2011/EC, construction manufacturers have to release the Declaration of Performance (DoP) for each product intended for market;

• the European standards are moved towards the awareness that they have not covered the performance of a product per se, but taking into account if the materials used are primary or secondary ones;

• the products to be developed in the project are covered by harmonized European standards, a part from the oriented strand board (with the aim to develop a DoP of the final products, it has to refer to the harmonised standard for wood based panels); indeed the innovation in RE⁴ products is in the constituent materials based mainly on recycled materials from CDW;

• according to EN:13367:2018, “common rules for precast concrete products” define the use of recycled aggregates for the production of prefabricated elements, for RE⁴ precast concrete products it will be possible to draw up a DoP document according to the legal criteria; particular attention should be paid to the verification of limit values of the performance requirements;

• since there are no standards covering the use of recycled materials from CDW (except for recycled aggregates) in prefabricated elements, their use is not widespread among manufacturers of prefabricated elements. However, RE⁴ experience about prefabricated elements with recycled CDW materials should foster the standardisation process for the use of CDW materials in prefabrication.

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RE4 Best Practises

POLICY AND FRAMEWORK CONDITION

Design Concept for New Construction

The concept design is developed on the basis of a list of indicators that ensure the achievement of the goal of obtaining a reversible, dismountable and fully reusable building system made of CDW-based elements and materials. For instance, the reversibility of connections, modularity of elements, as much as transportability and durability are considered.

The structural system consists of a reinforced concrete frame with shear walls and stiff concrete ceiling slabs providing adequate horizontal stiffening. Timber is considered as alternative to concrete for non-bearing elements, namely the façade panels.

Preliminary calculations are carried out under the assumption that the newly developed system shall achieve the same level of performance and capacity of conventional systems. A European design scenario is taken into consideration, meaning that a set of unfavourable loading conditions is chosen by collating the prescriptions of the national annexes to Eurocode 1, so that the concept is applicable to a number of cases across Europe. This includes moderate seismic loading.

The developed concept relies on commercially available products or simple slotted-bolted elements for the structural connections; this ensures availability as well as ease of use and dimensioning for the end user.

The design developed in the projects, although simplified, provides a proof of concept, thus showing that, in principle, the creation of a fully dismountable and re-usable building is possible. Elements are developed so as to have standard, repeatable cross sections that meet the load demand set forth by current codes.

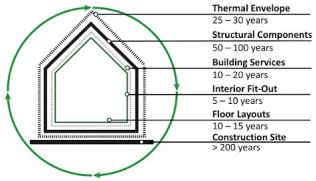
Nevertheless, several architectural layouts are possible. Indeed, the use of a frame system enables great adaptability, not only for stand-alone buildings, but also in case of adjoining buildings or large complexes. Flexibility and applicability are hence ensured.

The concept design strives to fulfil the best energy efficiency standards shall according to the relevant national requirements. It is recommended to focus on an improved A/V ratio (<0.4) through an efficient building shape.

The use of a fully reversible green roof is also recommended, especially in warm climates. Technical solutions, such as a waterproofing layer connected through a Velcro system, are commercially available and easy to install. All elements are designed to provide adequate durability according to their function within the building system, as shown in the pictures.

Concept

Building elements with a different life span shall be separated



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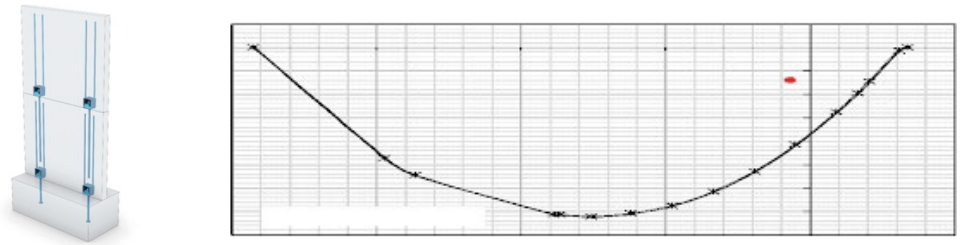
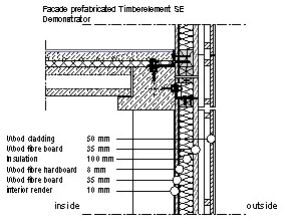
POLICY AND FRAMEWORK CONDITION

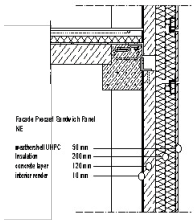
Possible scenarios and extension of axes of the building for terraced houses and solitaire structures



Schematic view of vertical connections of shear walls (left, from PEIKKO). M-N domain at the joint vs. design demand (red dot, in the graph on the right)



CDW Timber Facade Panel NE



CDW Concrete Facade Panel NE

Building design for a reversible RE⁴ building made out of recycled timber

Building design for a reversible RE⁴ building made out of recycled concrete

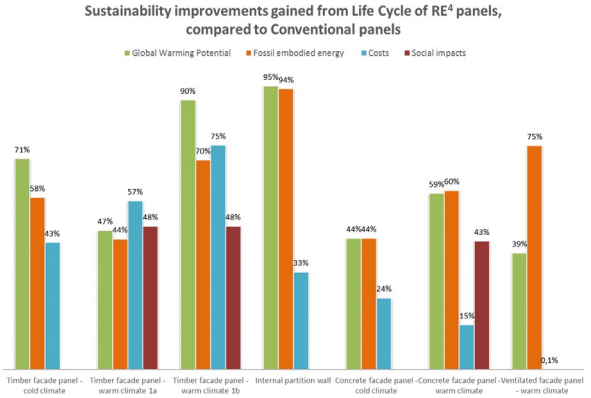
SUSTAINABILITY AND MARKET POTENTIAL

Sustainability Assessment

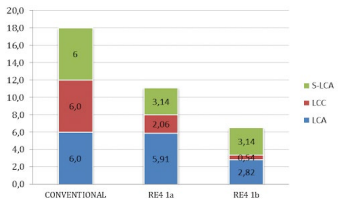
Within Work Package 7, sustainability assessment has been performed for the products realized during the RE⁴ project, by means of strong existing methodologies, based on a Life Cycle perspective. Indeed, the products have been analysed taking into account the three aspects of the sustainability, i.e. environment, economy and society, through Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) methodologies, according to the ISO 14040 and method-specific standards.

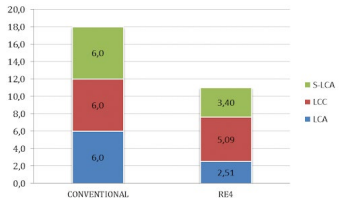
Six panels have been analyzed: 3 timber-based panels (timber façade panel, designed for cold and for warm climates; internal partition wall) and 3 concrete-based panels (concrete façade panel, designed for cold and for warm climates; ventilated façade for refurbishment, designed for warm climates). RE⁴ panels include components realized starting from Construction and Demolition Waste (CDW), such as, e.g., insulation layers made of CDW wooden fibers, CDW earthen plaster, concrete elements including CDW aggregates. Panels have been compared with conventional ones, having same dimensions and same thermal performances, but including components made of virgin materials. Comparisons have been performed considering the life cycle stages (production, construction, use, end of life) that differ from the single conventional and RE⁴ panel solutions.

Results are summarized in the following figure. It can be noticed that, when comparing RE⁴ solutions with conventional ones, reductions of more than 40% of Global Warming Potential, fossil embodied energy and social impacts are observed; moreover reduction of more than 15% of costs are observed.



Finally, results from LCA, LCC and S-LCA have been combined to provide an overall sustainability score. Results have shown that for each panel, conventional solution provides the worse sustainability score. Precisely, RE⁴ solutions leads from 38% to 64% sustainability improvement when compared to conventional solutions.





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SUSTAINABILITY AND MARKET POTENTIAL

Market potential

RE⁴ relevant markets – European construction, retrofit, and prefabrication markets

Construction Market growth

North-western + Southern Europe - forecasted at 2.5% a year on average in 2018–2022

Central Europe – forecasted at 4.4% on average in 2018–2022

Construction companies are becoming increasingly aware of the opportunities arising from the economic growth of local construction markets, which is reflected in the increase of their activities, and their interest in new technologies and research.

Potential for RE⁴ project

MARKETS: Europe offers **the biggest market for retrofitting** and it is one of the most **cost-effective** ways to reduce operational costs. The prefabrication construction market is growing and provides an opportunity for **RE⁴ products and technologies** to be placed on an **expanding market**. Existing European building stock is dominated by **energy-ineffective buildings**, which contributes to **energy and heat losses**. From the environmental point of view, the reconstruction of this building stock is inevitable.

LEGISLATION: EU legislation regulates the construction of new buildings from the environmental point of view and is in favour of **energy efficient renovation solutions** –> higher **end-user's acceptance**. European legislation and strategies are favourable for the RE⁴ technology. The excessive amounts of CDW are overburdening Europe and RE⁴ **project offers a solution**.

Over 868 million tonnes of CDW are generated annually in Europe

COMPETITION: Although many prefabricated construction components are being produced in Europe, there are none **that are made of CDW**.

RE⁴ project technologies potential

- RE⁴ sorting system - maximizes the percentage of recycled CDW from 80% up to 90-95%
- RE⁴ prefabricated elements - CDW integration in the RE⁴ prefabricated elements are 65% in weight and 80-90% for the RE⁴ prefabricated building concept
- RE⁴ BIM-compatible tool and platform- supporting building owners and C&D companies by providing them with types and quantities of CDW that can be generated from a building, RE⁴ offers a centralized platform service connecting users and providing updated information about the CDW availability in their region

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REuse and **RE**cycling of CDW materials and structures in energy efficient p**RE**fabricated elements for building **RE**furbishment and construction.

RE⁴ Best Practises

SUSTAINABILITY AND MARKET POTENTIAL

Strengths

- Easy installation, maintenancem reuse
- RE⁴ sorting system can recycle up to 95% of CDW
- Green technology which is in line witch EU strategies
- High recyclability potential
- High replication potential
- Excellent ROI
- The use of the RE⁴ technology contributes to energy saving
- Positive LCA
- Long-term cost saving

Weakness

- Cost of deep renovation is often as high as cost of demolition and new build
- Cultural barriers - how to convince end-users that CDW can be used in the construction as raw material
- The initial investment might be costly
- Testing, examing and verifying is still needed

Opportunities

- Minimal competition on the European market
- A favourable regulatory environment
- Redeuced consumption of raw materials
- Entire components can be reused
- Energy efficiency
- RE⁴ technology contributes to solving the issue with excessive CDW
- Market potential is large with existing and growing need for energy-effciency

Threats

- Public acceptance

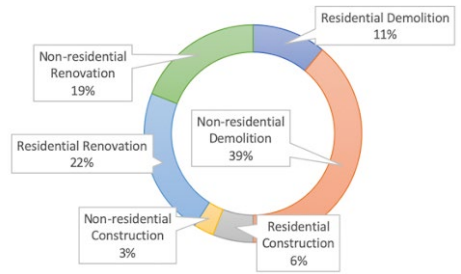
Certification and standardization

- Ongoing similarly oriented projects
- New low-energy buildings might reduce demand for RE⁴ technology

Replication potential of prefabricated solutions

The RE⁴ design is flexible and takes into consideration different requirements of different locations. This was proven by demonstrations in the UK, Italy, Spain and Taiwan.

Activities generating CDW



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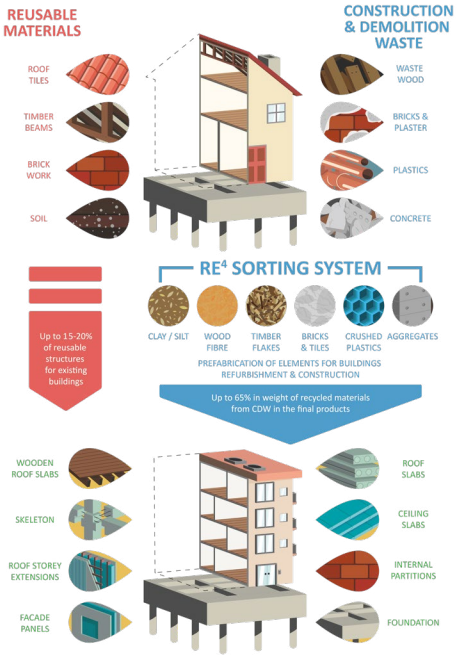
Project description

The RE[4] project aims to radically modify the construction process and off-site production by promoting the development of a fully prefabricated energy-efficient building made of components containing up to 65% by weight of CDW-derived materials and structures. The RE[4] building can be easily assembled and disassembled for future reuse.

This goal is achieved building upon a set of self-standing industrial results, like:

- an innovative CDW sorting system based on automated robotics to increase the quality of CDW-derived aggregates
- a number of prefabricated building elements (including connections) based on CDW-derived materials and structures, suitable for both new construction and building refurbishment, and
- the related production processes and equipment.

The materials flows will be managed by a new BIM-compatible ICT tool.



Up to 80-90% of reusable structures for RE[4] -prefabricated building concept

Partners and contact

Project Coordinator
Alessandro Largo (CETMA)
alessandro.largo@cetma.it
+39 0831449406

Please visit our website www.re4.eu

IG: **@RE4_project**
E-MAIL: **info@re4.eu**

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