This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

RE[4] Project

REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

D8.6

Market Assessment

Author(s)[1]:	FENIX
Date:	29/05/2017
Work package:	WP8 - Training, dissemination and exploitation
Distribution[2]	PU
Status[3]:	Final
Abstract:	To properly evaluate the value of the RE[4] project products, a market assessment is necessary. This deliverable aims to identify and study relevant sectors and markets, examine competition and regulatory framework, as well as analyse the preferences of the target audience to evaluate the prospect position of RE[4] project products once they are introduced into the market.
File Name	Deliverable D8.6_Market Assessment_Final_V2.0

Version	Date	Description	Written By	Approved by
0.0	25.05.2017	Complete draft	FENIX	
1.0	25.05.2017	Draft revised by CETMA	FENIX	
2.0	29.05.2017	Final version	FENIX	CETMA

[1] *Just mention the partner(s) responsible for the Deliverable*
[2] *PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.*
[3] *Draft, Revised, Final*

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ACRONYMS & ABBREVIATIONS

BIM	Building Information Modelling
CDW	Construction and demolition waste
EU	European Union
ICT	Information and Communication Technology
ISS	Induction Sorting System

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1. EXECUTIVE SUMMARY

The present document constitutes a market assessment within the framework of the RE^4-project titled "Reuse and Recycling of CDW materials and structures in energy efficient prefabricated elements for building Refurbishment and construction" (Grant Agreement No.: 723583).

To properly evaluate the RE^4 outcome products and their prospect position on the market, a market assessment is necessary. The aim of this deliverable (D8.6) is to identify and examine relevant markets and sectors, which RE^4 technology addresses and based on this examination, evaluate the success potential.

The deliverable is divided into several sections. First, the aim of the "theoretical understanding" chapter is to make sure that a reader and author share the same understanding of the concepts dealt with in this document, as well as, to provide explanation of the purpose of this deliverable. Second, the description of RE^4 project and its outcome products is provided and the value proposition of the project is presented. To fully understand the current situation on existing RE^4-relevant markets, the analysis of RE^4 competitors is conducted in the Chapter 4. The following chapter examines the CDW situation in the EU and chapter 6 identifies and assesses markets relevant for the RE^4 project. Those are: construction market, retrofit market, and prefabricated construction market. Chapter 7 aims to identify the preferences of target audience, meaning what are the factors compelling consumers to purchase specific products. The Chapter 8 summarizes the findings from the previous chapters and Chapter 9 evaluates the prospect position of the RE^4 products on a market through the SWOT analysis. The final chapter offers recommendations for the RE^4 developers and concludes with the preliminary evaluation of the project results.

It is important to note that present document is created in the early stages of the project and thus the comparisons might not be precise as some of the data are yet to be identified. This market assessment is planned to be updated alongside the project development and the updated versions will serve as basis for the business models, plans and strategies creation.

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2. THEORETICAL UNDERSTANDING

As this market assessment will serve as basis for other Deliverables such as Exploitation Plan or Business models and plans, a common understanding of what is market assessment and why it is necessary is essential. The following sub-sections will describe what is mean by terms "market analysis", "competitive advantage/value proposition", "market drivers", and "SWOT analysis" from the theoretical point of view.

2.1 Market analysis

Market analysis is the study or process of examining in detail the performance, dynamism and attractiveness of the market with a view to suggesting future trends. Market analysis presents information regarding the market in which a company or a product is operating in and thus serves as a core instrument for creating a business plan for a company or a product. The market analysis includes an overview of the industry, a look at the target market, customer segments and buying patterns, the competition, projections for the business and the economic environment in terms of barriers to entry and regulation needed to comply with. Finally, with the help of a SWOT (strengths, weaknesses, opportunities and threats) analysis, adequate business strategy is defined. As the upcoming deliverables will be dealing with business plan and strategy, a market assessment must be done prior as a crucial factor.

2.2 Competitive advantage/Value proposition

Competitive advantages are conditions that makes the entity better than the competition in its customers' minds. The term was first applied to businesses, but it works for anyone, from employees to countries. Competitive advantages are attributed to a variety of factors, including cost structure, brand, quality of product offerings, distribution network, intellectual property and customer support. Whether it is a good or service, it must be clear what benefit the product or service provides. It must be something that the customers truly need and that offers real value. It is essential to know not only the product's features, but also how its advantages benefit the customers. That means being constantly aware of new trends that affect the product, especially new technologies. It is crucial to identify exactly who is the end-user, and how the product or service will benefit his or her life. In order to be successful, it is critical to be able to articulate the benefit provided to the target market and in addition, the benefits must be better than the ones of the competition. Such benefits are then called "competitive advantage". That message needs to be reinforced in every communication to the customers, including advertising, public relations and sales aids.

2.3 Market Drivers

Market drivers are the underlying forces that compel consumers to purchase products and pay for services. These are trends that make markets develop and grow. The most common market drivers are consumer demand, government policy and demand. Typically, only part of the technical and realizable potential of a new technology can be achieved and be turned into an economic or market potential. The market potential is referred to as a variant of the economic potential, but the latter

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potential takes into account factors such as market barriers, logistics, public acceptance, political and regulatory constraints or policy support.

2.4 SWOT analysis

SWOT analysis is a useful technique for understanding the strengths and weaknesses of the organization, project or business venture, and for identifying both the opportunities and the threats to face. A SWOT analysis can be carried out for a company, product, place, industry, or person. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favourable and unfavourable to achieve that objective. What makes SWOT particularly powerful is the fact that, with a little thought, it can help uncover opportunities that are well-placed to exploit. Moreover, by understanding the weaknesses of the business, the threats can be managed and eliminated in advance. In addition, by looking at the competitors using the SWOT framework, one can draft a strategy that helps to distinguish a company/product from the competitors, so that they can compete successfully in the market.

SWOT analysis aims to identify the key internal (the strengths and weaknesses internal to the organization) and external factors (the opportunities and threats presented by the environment external to the organization) seen as important to achieving an objective. Analysis may view the internal factors as strengths or as weaknesses depending upon their effect on the organization's objectives. What may represent strengths with respect to one objective may be weaknesses (distractions, competition) for another objective. The factors may include all of the 4Ps (Product, Price, Publicity, and Place) as well as personnel, finance, manufacturing capabilities, and so on. The external factors may include macroeconomic matters, technological changes, legislation, and socio-cultural changes, as well as changes in the marketplace or in competitive position. The results are often presented in the form of a matrix. SWOT analysis may be used in any decision-making situation when a desired end-state (objective) is defined. SWOT analysis may also be used in pre-crisis planning and preventive crisis management.

	Opportunities (external, positive)	**Threats** (external, negative)
Strengths (internal, positive)	**Strength-Opportunity strategies** Which of the company's strengths can be used to maximize the opportunities you identified?	**Strength-Threats strategies** How can you use the company's strengths to minimize the threats you identified?
Weaknesses (internal, negative)	**Weakness-Opportunity strategies** What action(s) can you take to minimize the company's weaknesses using the opportunities you identified?	**Weakness-Threats strategies** How can you minimize the company's weaknesses to avoid the threats you identified?

Figure 1: SCHEME OF SWOT ANALYSIS[4]

[4] Bplans.com, *What is SWOT analysis*, 2017.

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3. RE^4 PROJECT TECHNOLOGY AND PRODUCTS

The overall goal of the RE^4 Project is to develop a fully prefabricated energy-efficient building made of components containing up to 65% by weight of CDW-derived materials (ranging from 50% for the medium replacement of the mineral fraction up to 65% for insulating panels and concrete products with medium mineral replacement coupled with the geopolymer binder) and structures (the reusable structures will range from 15-20% for existing buildings to 80-90% for the fully prefabricated energy-efficient building developed in the RE^4 Project). This will involve the development of several intermediate but self-standing industrial results, like an innovative CDW sorting system based on automated robotics equipped with advanced sensors, a number of prefabricated building components (including connections) based on CDW-derived materials and structures, the related production processes and equipment. The building component will be suitable for both new construction and building refurbishment, while the materials flows will be managed by a new BIM-compatible ICT tool. Project results will be produced in an industrial environment, considering their perspective issues for the market uptake.

The overall Project goal will be achieved through the accomplishment of a set of verifiable specific Scientific and Technical Objectives:

1. Maximization of recycled CDW amount and value by advanced sorting technologies

RE^4 aims at the introduction of innovative effective solutions in terms of sorting technology in the CDW recycling value chain. A higher homogeneity (in composition, physical properties and morphology) of CDW-derived materials increases their technical and economic value, ensuring higher properties repeatability and the possibility to better exploit the specific features of each material. In the RE^4 Project, the maximization of recycled valuable materials from CDW for high-value applications will be pursued by the development of advanced sorting technologies based on innovative wet processing and classification systems and automated robotics equipped with advanced sensors and artificial intelligence software. The solutions will be demonstrated in two different geographic regions in Europe, adapted to the different characteristics of each location (materials and/or construction methodology, climate), aiming to reach 80% of the CDW available in high quality fraction for structural and non-structural concrete, plus a 10-15% for lightweight concrete, insulating panels, reconstituted tiles, plaster and adhesives to be used in prefab elements. The state-of-the-art recycling rate will be increased from 80% to 90-95%. The exploitable industrial results arising from this objective will be an innovative sorting system for high quality CDW-derived material for the partner CDE.

2. Assessment of CDW-derived materials properties for the production of building elements

In order to fully exploit the CDW recycling potential, the quality of the output of sorting has to be established in a quantitative way, assessing the compliance of each sorted fraction against relevant National and European specifications. The chemical and physical properties of the obtained materials (sorted/unsorted mineral aggregates, lightweight, timber) will be assessed. The effect of quality variability on the technical properties of developed products will also be investigated. Quality classes will be defined identifying the optimal recycling strategy for each fraction of CDW.

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3. Development of prefab elements integrating high level of CDW-derived materials for refurbishment and new constructions

RE^4 aims to radically modify the construction process and off-site production by the development of innovative prefab elements integrating high level of CDW-derived materials and structures, based on the set-up of innovative processes for mixing, casting, extruding or moulding prefab element, generating new markets for CDW-derived materials. Structural and non-structural prefab elements with CDW-derived materials will be designed for their assembling into the RE^4-prefab energy-efficient building concept. The replacement of traditional raw materials will minimize the environmental impact in terms of CO_2 thus contributing to energy savings. In detail, the substitution of ordinary Portland cement with geopolymeric binder from waste will allow a reduction of about 60% of the CO_2 emissions while the use of CDW as replacement of traditional aggregates for concrete can allow an avoided impact of 14 kg/t of CO_2 emission and saving of 250 MJ/t of non-renewable energy. The exploitable industrial results arising from this objective will be the fully prefabricated energy-efficient building and the building components with CDW (façade panels, load bearing and non-load bearing prefab element) made thereof for Creagh and Acciona and an innovative equipment for prefabricated extruded product from CDW for Vortex.

4. Development of innovative design concepts for smart installation and disassembly of the pre-fabricated elements into a prefabricated energy-efficient building unit

An innovative design concept will be developed for modular/smart installation and disassembly/re-use of the RE^4-prefab building, made of the RE^4-prefab elements (Objective 3) integrating advanced features (i.e. anti – seismic, durability), aiming at a sustainable, efficient, cost-effective and durable construction solution. Special emphasis will be put on reversible connections for all elements to enable future dismantling and reuse. Material homogeneity will be favoured to maximize future recycling. The concepts will be designed in such way that multiple applications for different building typologies (e.g. residential, commercial) will be easy to implement.

5. RE^4 demonstration in industrial environment, testing and evaluation, replication

Demonstration of the proposed RE^4 solutions for new constructions will take place in two specifically constructed mock-ups (residential or non-residential) representatives of building archetypes across Europe (i.e. type of building, climate, energy mix, design, etc.), consisting of a two-storey building (demonstrating foundations, support structure, façade panels, floor and roof construction, internal partition walls). Demonstration of the RE^4 solutions for refurbishment will be realized in a suitable existing building and/or in the demo site available at STRESS. Finally, demonstration of the strategy for disassembly and reuse materials and structures from dismantled buildings will be will either be realized in a suitable existing building and/or in the Acciona demo park. The replication of the RE^4 results in the EU and worldwide will be demonstrated by designing (starting from the general concepts defined above) building elements tailored to different climatic (i.e. appropriate glazing ratio, thermal mass of insulation) as well as structural (i.e. anti-seismic) requirements of different geographic zones across Europe (UK and Spain) and outside EU (Taiwan).

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6. Enhancement of the sustainability and future applications of RE^4 prefabricated products

From a quantitative point of view, the following objectives are targeted in relation to sustainability of RE^4 solutions. CO_2 savings (over 30 %), energy savings (20%), higher resource efficiency (minimum share of recycled materials in final product up to 65 %), less waste generation (thanks to the easier disassembly at the end-of-life), less CDW disposal in landfill (thanks to the enhanced recycle/reuse rate). Moreover, though RE^4 products will not get certification during the project, support to their future industrial applications will be provided by the analysis and definition of the most convenient certification strategy and by the development of technical documentation (i.e. technical data sheets, declaration of properties, EPD declaration).

7. Development of a BIM-compatible DSS and platform for CDW estimation and management

A BIM-compatible tool will be developed with the aim of supporting owners and construction/demolition companies by providing an estimation of the types and quantities of CDW that will be generated during construction/demolition, with possible utilization options and related logistic references. By means of the set-up of a centralized service, the system will also provide information to prefabricators about the CDW types and quantities that will be made available in the geographic zone of their interest ("close" to the factory). In this way, the planning of the off-site production of the innovative components made with CDW is made possible.

8. Development of business models for industrial exploitation

The expansion of size and attractiveness of CDW recycling and reuse for energy efficient buildings construction and refurbishment will promote an efficient value chain, creating attractive business opportunities for the involved stakeholders. New business models will be developed at a wide implementation of the proposed approach and the related project results, enhancing their replication potential. An economic assessment will be performed to evaluate the profitability of the revenue model, to understand future cash flows and to highlight the need for additional funding or external investment to reach the first sales.

The RE^4 Project will develop new technologies and strategies for the design and development of structural and non-structural pre-fabricated elements with high degree of recycled materials and reused structures from partial or total demolition of buildings. The RE^4 overall concept is illustrated in the figure below.

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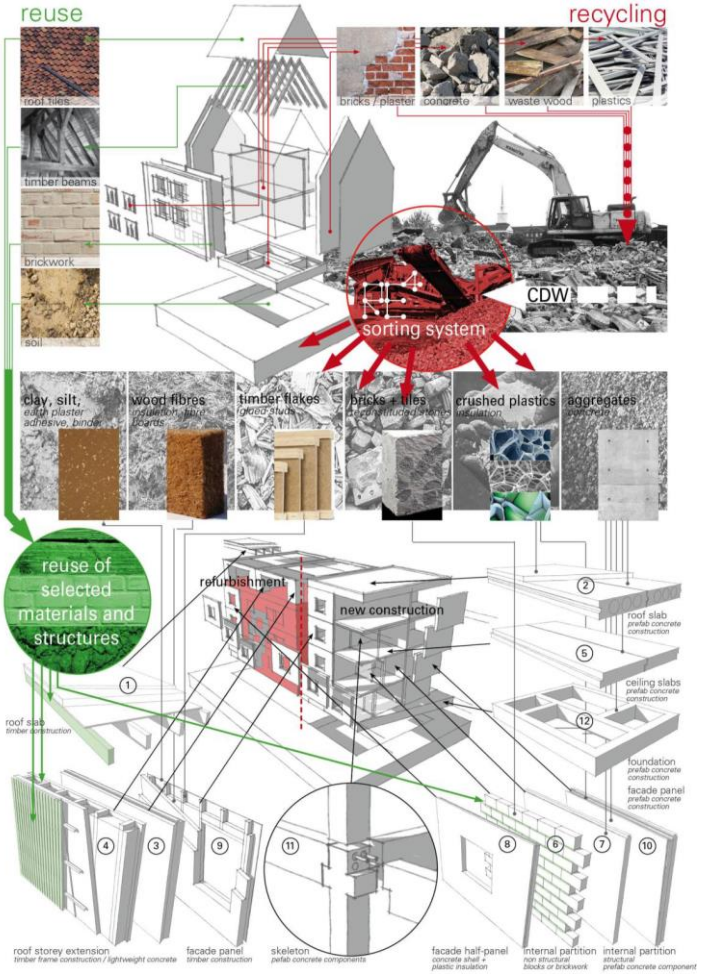

Figure 2: RE[4] conceptual architecture (© RE[4] Project - GA No 723583 - Roswag Architects)

The technical activities of the RE[4] project are focused on stone, ceramics, wood and timber, concrete, plastics and clay. The following figure summarizes prefabricated elements RE[4] wishes to develop.

field of application	refurbishment *(4 elements)*	RE[4]	new construction *(8 elements)*
roof	roof - lightweight timber construction (includes insulation, beams and boards)	1.	
		2.	roof - concrete slab (includes insulation)
densification	roof storey extension prefab LW-concrete construction	3.	
	roof storey extension - timber construction	4.	
ceilings	*preserved existing ceiling element*	5.	prefab ceiling slab
internal partition	*preserved existing partition walls*	6.	internal partition - non structural
		7.	internal partition - structural
facade	halfpanel - concrete	8.	
		9.	facade - non- loadbearing - timber construction
		10.	facade - non- loadbearing - prefab concrete construction
supporting structures	*preserved existing supporting structure*	11.	skeleton - prefab concrete construction (beams + columns)
foundation	*preserved existing foundation*	12.	foundation - prefab concrete construction (piles + beams or/and slab)

Figure 3: List of RE[4] prefabricated elements with CDW-derived materials and structures

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3.1 Value proposition of the RE^4 project technology

The following sub-chapter identifies the value of RE^4 project products, which make them superior to their competition. For an end-user, it is important to know products features as well as what benefits they bring.

- Sorting system developed in this project is expected to maximize the percentage of recycled CDW from 80% up to 90-95%
- Production of high-application products
- Although many prefabricated construction components are being produced in Europe, there are none that are made of CDW. The RE^4 project aims to produce such prefabricated products. The average percentage of recycled materials from CDW integrated into the RE^4 prefabricated elements will be up to 65% in weight while the percentage of reusable structures will range from 15-20% for existing buildings to 80-90% for the RE^4 prefabricated building concept
- Easy installation, disassembly and reuse
- Focus on anti-seismic performances and needs of different European regions
- RE^4 aims to develop a BIM-compatible tool supporting building owners and construction and demolition companies by providing them with types and quantities of CDW that can be generated from a building
- RE^4 will offer a centralized platform service connecting the users providing the updated information about the CDW availability in their region
- Recyclability of materials from demolitions of buildings is very high
- Excellent ROI
- Energy efficiency
- Cooperation and sharing of best practices with other same-focus projects (HISER and IRCOW).

Assessment of CDW-derived materials properties

Due to the down cycling of some of the materials from CDW (unsorted mineral fraction) or even the dumping of certain materials (lightweight fraction, fine fraction) the materials lack a detailed characterisation for the definition of the optimal recycling strategy, maximising the technical and economic value of sorted materials.

RE^4 will carry out a detailed assessment on physical, geometrical and chemical properties of each CDW-derived material in a quantitative way, assessing the compliance against relevant National and European specifications. Moreover, the project will also characterize materials that are currently dumped, such as lightweight fraction and fines (clay and silt) from water thickening.

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4. COMPETITORS ANALYSIS

To understand the situation on the market, a business owners must be aware of their competition. The following chapter aims to identify RE^4 technology competitors and describe their products. First, sorting technologies including both existing companies and projects with similar focus are described. Second, the analysis of prefabricated elements integrating CDW-derived materials are investigated. This chapter also studies geopolymeric binders, re-use of timber and fine fraction from the mineral CDW. Last but not least, innovative design concepts for modular installation and BIM compatible DSS and Platform are examined.

4.1 Advanced sorting technologies

Commonly, sorting is carried out by separation of metals, lightweight and mineral fraction. Subsequently, the mineral fraction is washed and sieved for the production of different size classes. RE^4 will build on the CANDY project results (http://www.cdecandyproject.com/) due to the participation of CDE in the RE^4 Consortium. A robotized system for the sorting of different mineral aggregates based on 3D cameras and NIR sensors will be developed. An innovative system for the removal of silt from 0-2 fraction will be investigated. This will produce a high value building and concrete sand and a valuable clay fraction.

STEINERT

STEINERT provides innovative solutions for the separation of valuable materials, increasing customer profitability through higher recovery and reducing operational costs. In the areas of treatment of secondary and primary raw materials, STEINERT operates in both the resource recovery and mining sectors. STEINERT is a global leader in consulting, manufacturing, installation and services in innovative sensor sorting and traditional magnetic separation technology. Based in Cologne, Germany for 126 years, and with around 300 employees worldwide, STEINERT provides a global network to support its customers with local contacts and local expertise. STEINERT provides few solutions for the Demolition Waste as described below.

List of products/services

STEINERT Suspension Magnets - thousands of STEINERT suspension magnets are used throughout the mining and resources industries, offering sustainable solutions which guarantee permanent advantages in the long run, options are permanent magnets, electromagnets (oil-cooled or air-cooled), self-cleaning, stationary or manual cleaning). Suspension magnets are usually mounted at a fixed working distance above a conventional conveyor belt. Ferrous metal in the material conveyed is attracted by the magnet and magnetically removed from the material flow. STEINERT suspension magnets may work up to 3000mm belt width and up to 900mm suspension height. The wide range of products offers the chance to find the right solution for your needs. The well proven and dense coil design with aluminium strip allows a constant, efficient cooling and thereby reduces the risk of coil burn-outs. The design enables maximum coil turns and a compact unit even when offered as a self-cleaning magnet. No external expansion tank is needed.

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Overview

Function:	Separation of iron
Grain size:	10 - 300 mm
Cut height:	up to 1 m
Working width:	500 - 3000 mm

Figure 4: STEINERT suspension magnets

STEINERT NES - non-ferrous metal separator, the mechanical recovery of non-ferrous metals is the economic basis of all recycling – and the STEINERT NES Eddy Current Separator with Eccentric Pole System fulfils the associated requirements perfectly, high yield and long life are the qualities that make for assured, long-term operating result). The non-ferrous metal separator can be used wherever non-ferrous metals have to be recovered or separated, e.g. where shredder material, municipal waste, WTE bottom ash, electronic scrap, wood chips, glass, batteries or foundry sand are processed.

A non-ferrous metal separator system of permanent magnets – the pole system – which generates high-frequency changing magnetic fields, is incorporated in the head drum. These fields create strong eddy currents in the non-ferrous metal parts, in which their own magnetic fields, opposing the external fields, now build up. The NF-metal parts jump out of the remaining material flow. STEINERT's patented eccentric pole system guarantees the maximum efficiency in this process, delivering top-quality separation and long-term operation.

OVERVIEW

Function:	Ejection of non-ferrous metals
Grain size:	1 - 200 mm
Throughput:	40 m3/h*m (* depending on the respective conditions)
Overall size:	Diameter of pole drum = 500, 610 mm, Working width = 500 - 2500 mm

Figure 5: STEINERT non-ferrous metal separator

STEINERT EddyC FINES - combines the tried and tested STEINERT features, such as the eccentric magnetic pole drum and high-frequency pole changes (1.3 kHz and a pole drum rotational speed of up to 4,000 rpm), with especially developed features for the fine-grain segment. Self-supporting frame structure for fast belt change, new splitter for precise and reliable settings for extremely fine materials, steeples adjustable eccentric pole system, new viewing panel that ensures the splitter can be securely adjusted during operation. The new splitter can be set with millimetre precision - horizontally and vertically at the same time. This makes separation more precise, which is essential for fine-grain separation. A gearbox enables users to precisely set the splitter plate along different axes and adjust it even more accurately to the parabolic trajectories of a wide variety of materials. Thanks to a clever design, it is possible to change the belt in 10 minutes without requiring additional lifting equipment.

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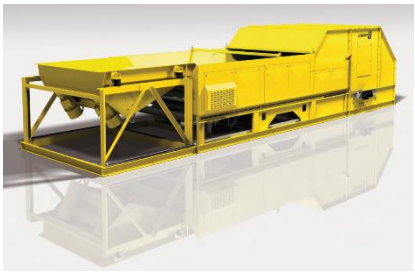
Technical Parameters:

Belt speed:	1 - 2.5 m/s
Working width:	1 m, 1.5 m, 2 m
Particle size range:	0.5 - 10 mm

Figure 6: STEINERT EddyC FINE

STEINERT ISS – The Induction Sorting System (ISS) offers a solution to recover the non-ferrous metals not recovered by ECS processing or magnetic separation. The ISS provides efficient and effective automated recovery of metals, stainless steel and any other metals, eliminating the need for hand picking. The primary applications for the ISS are shredder residue, electronic scrap, wood chips, glass, domestic waste, and mould sand. The recovery of stainless steel from ECS waste streams and the processing of electronic scrap are ideal uses for the ISS. The ISS is the solution for removing tramp metal from bulk material to ensure the quality of the processed product. Previous experience has shown that the rate of both purity and recovery is considerably greater than 90%, depending on the conditions in the plant. Therefore, automatic separation using STEINERT ISS sensor technology can more than double the recovery of valuable materials as compared to the manual sorting methods often used today, which at best have a 40% yield. The STEINERT ISS increases throughput three- or fourfold – all factors that have a substantial impact on your company's bottom line. Precise screening and further crushing improve the results even more.

The previously separated bulk material is transported by a fast conveyor belt to a sorting zone. Below the conveyor belt, immediately in front of the main coil of the STEINERT ISS, there is an arrangement of sensors. These sensors analyse the material over the whole width of the conveyor belt by means of magnetic induction. As soon as metallic particles are detected, electronic signals are sent to the central computerized control unit. The compressed air jets, individually controlled by the programming, push the detected metals over the diverter gate.



Overview

Function:	Separation of all electrically conductive components
Grain size:	1 - 200 mm
Throughput:	up to 1003 /h*m (* depending on the respective conditions)
Working width:	600 - 3000 mm

Figure 7: STEINERT ISS

STEINERT XSS - x-ray transmission "sees" through the materials, recognising different material densities, components containing halogens, and organic components. Composite materials and internal adhesions are also detected. This allows light metals to be sorted from heavy metals, or PVC from plastics, scrap wood from stone, aluminium castings from wrought alloys. In mining, x-ray transmission is probably one of the most versatile types of sensors; it can be widely used in narrow

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vein mining applications where there is a difference in density between the vein and the host rock. It measures amount of X-ray radiation absorbed within individual particles and negates the effect of particle size by measuring the radiation at two different energy levels. X-Ray Fluorescence – XSS F – can be used to differentiate alloys, metals and ores based on their surfaces.[5]

Figure 8: STEINERT XSS

CP MANUFACTURING (a division of the CP group)
CP Group is a team of manufacturers and leaders of innovation in the waste and recycling industry. CP Group comprised of CP Manufacturing, Krause Manufacturing, MSS, Inc., and Advanced MRF - provides a variety of sort solutions worldwide, including MRF manufacturing, retrofits, audits, consulting, and engineering services. Custom turn-key systems are designed, installed, and serviced by CP Group for residential recycling, commercial and industrial, municipal solid waste, engineered fuel, construction and demolition, and electronic waste processing. Made in USA all of their high-efficiency solutions for plastics, paper, beverage cartons, glass, metals, and e-scrap recycling facilities are designed and built in the USA. The CP Group keeps the focus on customer needs and the evolution of resource recovery.

KRAUSE MANUFACTURING, a division of the CP Group, engineers, manufactures and installs the industry's most durable construction and demolition (C&D) recovery systems. Processing C&D requires extremely resilient equipment. Combining heavy-duty conveyors with state-of-the-art automated screening technology, they can custom design the most rugged and effective C&D recycling system for your operation to recover concrete, wood, metals, glass, plastics and other salvaged building components.

List of products/services
<u>Krause Trommel Screens</u>
The Krause Trommel Screen is positioned at the beginning of the equipment line, replacing the need for multiple pieces of equipment. All their trommel screens are engineered with simple, energy efficient design that utilizes gravity and centrifugal force to reduce maintenance and separate different material sizes from the waste stream.

<u>Krause Disc Screens</u>

[5] http://www.steinertglobal.com/de/en/products/sensor-sorting/

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With the latest application of state-of-the-art disc screen technology, they have developed the C&D recycling efficiency. The heavy-duty disc screens are field-proven to provide the highest throughput, reduced labour costs, super-low maintenance, increased diversion rates—and deliver the highest quality end products.

The Krause Super Portable

The Krause Super Portable Conveyor & Systems provides labour-saving efficiency, high productivity, and the highest landfill diversion rate—up to 75%. With the various options available, the Super Portable becomes a versatile modular sorting system that can be customized to meet specific needs. The basic unit consists of a two-belt, variable-speed, in-feed system which helps meter the material onto the variable-speed sort line with has an 11' clearance underneath. They offer the industry's largest and most durable portable C&D sorting conveyor. The Super Portable Conveyor sets up easily on almost any surface, requires no pre-installation investment, & can handle 30-40 tons per hour of the most rigid C&D material.

The Krause Rocket™

The Rocket™ Wet Separator automatically separates the large quantities of rock and wood typically found in C&D debris. Materials are fed into a horizontal drum, which is partially filled with water. The rotating cylinder sends the high-density materials such as rocks and gravel onto a paddle system, which moves it above the waterline and expels it out of the drum. High velocity jets positioned within the drum, and facing the infeed end, shoot water creating a river that washes the wood and other floating debris back out the in-feed end of the drum. A water reclamation system collects and stores the water for reuse, limiting the need for disposal and decreasing costs.[6]

Figure 9: Krause Manufacturing products

MSS INTELIGENT SORTING TECHNOLOGY

MSS is a division of CP Group, the world's leading provider of waste diversion solutions and manufacturer of material recovery facilities. Processing CDW requires extremely resilient equipment. MSS combines heavy-duty mechanical processing and separation equipment with state-of-the-art automated optical sorting technology for various applications around a C&D facility.

Ultra-Efficient Separation, Powerful Optical Sorters

There are several areas in a C&D processing facility where optical sorters are in a position to provide added value for their customers. The automated removal of wood, fibre, plastics and metals by the optical sorter provides excellent sorting performance and high efficiency.

[6] http://www.cpmfg.com/material-recovery-facility/construction-demolition-recycling/cd-recycling-equipment/

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MACHINEX

Machinex is an industry leader in engineering, manufacturing, and installing Material Recovery Facilities all around the world. As an expert in sorting technologies, Machinex provides turnkey systems, along with custom-built and flexible solutions, to help ensure our customers remain ahead of the competition. They also offer a full range of high quality recycling equipment manufactured in-house, giving customers complete system integration.

Machinex Construction & Demolition Recycling Systems maximize recovery rates and material quality, as well as minimize the volume of residual waste to be landfilled. Their solutions are made to maximize the separation of commingled debris such as: wood, metal, cardboard, plastics, polystyrene, gypsum, asphalt shingles, and mixed rocks. They consider the changing needs of the market, the increase of landfill costs, as well as environmental law demands.
Machinex offers two types of systems in C&D recycling waste; either a dry or wet system. The wet sorting system includes sink float tanks for high wood recovery rates. They can provide a wide range of dry C&D sorting systems, from simple handpicking lines to full-blown wood grading optics. Weather a pre-shredding or grapple loading is preferred, Machinex offers systems to achieve maximum recovery.

Highlights & Benefits: optical sorting for wood grades, ferrous and non-ferrous metal magnetic separation (up to 99% chipped wood purity), heavy-light separation, sink float system to separate wood for higher recovery (wet system), dust collector to keep the environment clean. The full line of MACH Series screening separators is suitable for all material recovery needs. They offer an excellent separation rate that slashes labour costs. Designed with flexibility in mind, they can be adjusted according to the material being processed. Whether working with other solutions or used as a standalone product, our fully automated MACH Separator Solutions offer remarkable performance and efficiency.[7]

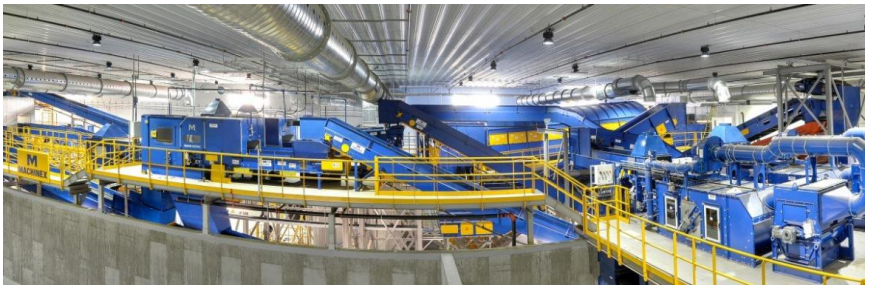

Figure 10: MACH construction and demolition recycling

BAETSEN

Baetsen Recycling has two of Europe's most modern waste sorting systems at its disposal, in order to process construction and demolition waste into dozens of recyclable waste subtypes. The waste wood reprocessing line ensures that waste wood is processed into a high-grade raw material that

[7] http://www.machinexrecycling.com/

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can be used in the chipboard industry and to generate power. Baetsen uses sorting systems for construction and demolition waste to process 200,000 tonnes of waste a year. This sorting process yields 21 waste subtypes such as PVC, foil, carpets, rubble and waste wood that, in turn, are suitable for recycling by various clients.

List of products/services
Rubble recycling - Baetsen Recycling has rubble processing systems at its disposal that enable us to process all kinds of rubble and asphalt into granules of various dimensions and certified qualities. Baetsen has mobile rubble crushers and sieving systems so that all of the granule particles can be delivered. The locations have a wide variety of options and permits for various activities. They can offer the following services: crushing stone materials, sorting various waste types, storage and transhipment of primary and secondary building materials, sieving stone materials, mixing and separating various particles.

They process 125,000 tonnes of waste wood a year on our wood sorting line, waste wood into raw materials for the chipboard industry, power stations and for the sludge thickening process for the incineration industry. These raw materials comprise wood chips and wood dust. In addition, the sorting process also yields various other individual waste types, including iron, construction waste and demolition waste. Very high-grade raw materials are obtained in this way.

Wood recycling - Baetsen processes 125,000 tonnes of waste wood a year on our wood sorting line, waste wood into raw materials for the chipboard industry, power stations and for the sludge thickening process for the incineration industry. These raw materials comprise wood chips and wood dust. In addition, the sorting process also yields various other individual waste types, including iron, construction waste and demolition waste. Very high-grade raw materials are obtained in this way.

Soil board - Baetsen activities contribute to the recycling of secondary building materials and, therefore, to a healthy environment. As a certified BRL 9335 soil board, they also perform environmental batch testing in the context of the Dutch Soil Quality Decree. Due to the extensive experience in the fields of environmental engineering, civil engineering and logistics, they can provide a complete package of building materials.

The following competitors' analysis revolver around the examination of projects with similar focus.

CANDY Project: development of washing plant for the recycling of Construction, Demolition & Excavation (CD&E) waste.
Over the last decade the construction, demolition and excavation waste recycling systems have been employed throughout the UK and have successfully raised the profile of recycled sand and aggregates and their many applications. The CANDY project will allow to bring these market leading recycling systems to Germany and is supported by the Eco-Innovation Fund from the European Union.

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As part of the initial work programme CANDY project is required to conduct considerable research into the German market for recycled sand and aggregates as well as a detailed analysis of the type of equipment currently widely used to process this material. Discussions are also well advanced with a number of companies involved in the recycling of construction, demolition and excavation waste and over the next few months a decision will be made on where the recycling plant will be located. The CDW recycling system will include: Feed arrangement, aggregate screening, attrition by RotoMax log washer, sand washing, aggregate sizing, water treatment & recycling.[8]

TURBOWASH Project: Construction and Demolition Waste Washing System with Increased Mobility through Rapid Coagulation of Turbid Water (FP6-SME, Project ID: 16757).
A consortium of European small- and medium-sized enterprises (SMEs) with a rare combination of skills have participated in a project to develop a compact water turbidity removal system with faster water usage through the use of innovative electrocoagulation techniques coupled with novel coalescer and separation technology. The project has investigated problems associated with the use of chemical coagulants in the CDW water recycling industry by employing combined electrochemical and separation technologies. The novel solution can increase the rate of cleaning and water treatment, removing the requirement for coagulation chemicals and for large volumes of water, significantly enhancing contaminant removal from the construction waste and thus promoting the reduction of harmful chemicals. This offers significant improvements in the performance of construction and demolition waste techniques and will overcome the barriers for their application.
In TURBOWASH, the SMEs and researchers have proposed a combined electrocoagulation and separation system with continuous in situ monitoring and feedback to increase efficiency and quality of water recycling in the EU industry. The overall objective of the TURBOWASH project was to develop and validate an innovative compact water turbidity removal system for effluent from CDW and primary aggregate processing. The system will provide faster water usage (a 10-15 minute turbidity removal cycle) permitting more efficient and reliable water treatment. The prescribed technology involves the use of electrocoagulation techniques coupled with novel coalescer technology. This will negate the requirement of chemical additions, thereby achieving a purer clay phase suitable for reuse, and lower contamination in the aqueous phase through the inherent chemical oxidation effect of the electrocoagulation process. Furthermore, developing a modular transportable water treatment system, of no more than 15 000 litres, will enable the addition of further treatment applications and wider use by SME's at construction sites, significantly reducing vehicle movements. Scientific and technical objectives include an increased knowledge of the characteristics and performance of construction waste processing technology. The focus is on mixed waste streams contaminated with various materials, where reduced water usage and a fast and efficient water treatment system are of paramount importance.
The project aimed to develop an innovative mobile washing system of 15 000 litre capacity to reduce the waste and safety hazards associated with chemical treatment of water in the European construction and demolition waste (CDW) industry. The TURBOWASH product is intended to replace

[8] http://www.cdecandyproject.com/

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conventional wash water treatment processes which involve the use of chemical coagulants and large settlement tanks or ponds. The TURBOWASH system will provide an environmentally-friendly and cost-effective method of treating waste wash water negating the need for chemical additions. The system will be modular in nature, compatible with existing washing technology and easily assembled with the added flexibility of being suitable for variety of waste streams.
The CDW wash water and electrocoagulation technology has been validated on a pilot basis using two case studies with conditions representing the processing of building rubble, soil extraction deposits and roadway demolition residues. The proposed research and development is therefore pre-competitive. Further development will be necessary to produce an integrated product to gain market acceptance. It is planned that the commercial product will be developed for production within an 18-month period following the project end.

During this time, the group will further undertake targeted marketing surveys and capability analysis to ensure that the manufactured products meet customer needs across the various EU countries. Designs will be standardised as far as possible and made compatible with the manufacturing capabilities of the producing partners in the supply chain. Funding will be obtained as necessary through venture or other sources, having prepared our Investment Readiness case as early as possible using the dissemination and market awareness information gathered during the later months of the project itself.[9]

4.2 Prefabricated elements integrating high level of CDW-derived materials

4.2.1 Concrete construction materials

Currently the percentage of CDW included in building elements, particularly in concrete, is low, due to the low quality of aggregate when a sub-optimal sorting process is adopted. Research suggests that up to 30% coarse or 20% fine recycled concrete-derived aggregate had no effect on the strength of concrete. The application and utilization of recycled CDW aggregate in the manufacture of construction materials can minimize the environmental impact significantly and greatly reduce the consumption of enormous natural resources.
RE^4 will develop not only prefabricated elements from CDW, but also design approaches that will integrate such elements with other green materials, maximising the future reuse and recycle and minimising the embodied energy and carbon footprint of the developed solutions. Furthermore, also lightweight fractions and fine mineral fraction that are not currently recycled will be considered for high technical and economic value. This sub-chapter focuses on the projects dealing with the development of concrete products made of waste.

C2CA Project: "Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste" (2011-2014).

[9] http://cordis.europa.eu/result/rcn/46933_en.html

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The C2CA project builds on strong European academic-industrial partnerships in the fields of waste processing and recycling, including those involved in areas such as cement chemistry and sensor technologies for quality control. This ensures the project covers the different regions and markets. The project goes beyond state-of-the-art advances, in particular in materials separation technology (Advanced Dry Recovery - ADR), sensor quality control, process modelling, life-cycle analysis, life-costs analysis and policy development.
C2CA developed a 100% end-of-life (EoL) concrete separation process that produces both aggregates of quality equivalent to natural (virgin) aggregates suitable for use in new concrete production and a Calcium rich (C-S-H) rich feedstock for low-carbon cement production and other special products eliminating problematic residues. The economics of the process is attractive for the following reasons:

- The low energy demand of the unit operations involved
- The possibility of in-situ processing (no transportation cost)
- The possibility to use largely the same facilities as for the production of primary concrete
- Very small number of residues to be disposed of

Hence C2CA may contribute to creating a sound material-cycle in which there is a simultaneous pursuit of environmental preservation and economic development in the form of new business opportunities and improved competitiveness of European SMEs and industries.
The demonstration of the economic and ecological viability of this technology have been tested on a case study in which the recycling of old buildings and the building of new one was integrated into a single project. It was demonstrated that an appropriately designed, equipped and performed selective demolition in the Netherlands costs only 15% more than the traditional demolition practice, the cost being nearly compensated by the value of the quality materials recovered from the post-demolition waste via the C2CA smart processing of the recycled concrete. Because of the positive results obtained, two start-up companies (named „**Grondstoffen Recycling Hoorn**" - RAW Materials Recycling Hoorn and **ADR Technologies**) have been set up to exploit the project results on the market. Besides the innovative C2CA recycling technologies for the recovery of the EoL concrete fraction, different business models to implement them have been devised. These models should minimize the trade costs along the value chain thanks to no transfer of ownership of waste along the process (thus no fees) and to the long-term trust-based cooperation links.
Possible governmental policies that facilitate an efficient transition towards a combination of optimal value recovery from CDW and sustainable building should promote green public procurement, by means of minimum recycled material use targets that can be requested in public tenders.

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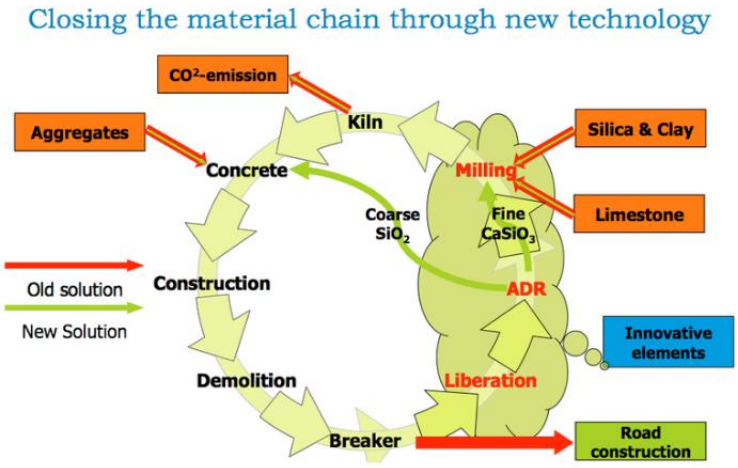

Figure 11: C2CA concept

Within the frame of this C2CA project, an innovative sensor system based on Laser-Induced Breakdown Spectroscopy (LIBS) has been developed for both documentation of properties of high throughput secondary materials (e.g. classification of waste components, determination of material composition) and online quality control (e.g. tuning of processing parameters based on sensor data) in the complete recycling chain from demolition to mortar production. Combining online LIBS sensor system with innovative processing technologies such as Advanced Dry Recovery (ADR) and autogenous milling, the C2CA recycling proves to be a dynamic upcycling approach adaptive to varying input materials that can still produce homogenous outputs with constant quality.[10]

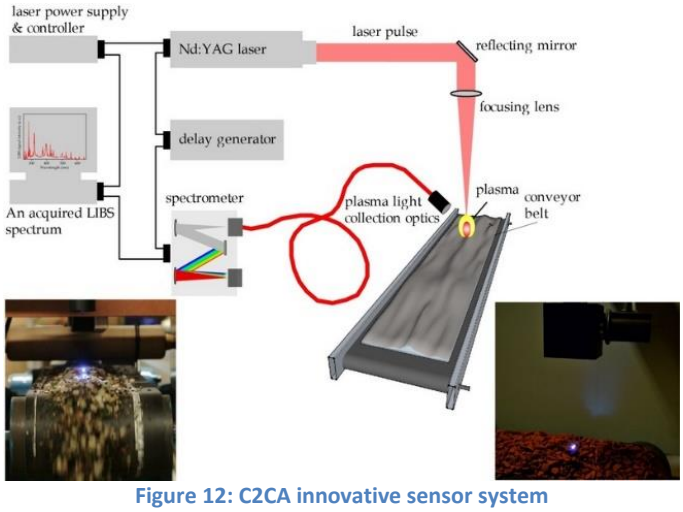

Figure 12: C2CA innovative sensor system

Sus-Con Project: SUStainable, innovative and energy-efficient CONcrete, based on the integration of all-waste materials (2012-2015).

[10] http://www.c2ca.eu/

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The SUS-CON project aimed at developing new technology routes to integrate secondary materials in the production cycle of concrete, for both ready-mixed and pre-cast applications, resulting in an innovative light-weight, eco-compatible and cost-effective construction material, made by secondary raw materials and characterized by low embodied energy and CO_2 and by improved ductility and thermal insulation performances.
The project developed completely new concepts and technology routes to integrate secondary materials in the production of concrete, for both ready-mixed and pre-cast applications, resulting in an innovative, eco-compatible and cost-effective construction materials, characterized by: lightweight, low embodied energy, low CO_2 footprint, improved thermal and acoustic insulation performances (multi-functionality).
The project results will be used to set a new best practice for concrete manufacturing in order to help both the setting of new standards and the establishing of a public policy for higher energy efficiency and reduced environmental impact.
The proposed technological developments will be the demonstration/showcasing of SUS-CON concrete prototype systems:

- use of recycled aggregate component in a conventional cement binder system
- use of recycled binder system for a conventional aggregate particle skeleton
- use of recycled binder and aggregates in the development of a total eco-sustainable solution.

Recycled aggregates
Novel lightweight aggregates from plastics will be tailored made and thus will allow making the target material lightweight and heat-insulating. In fact, it is expected that, using light plastic aggregates, a lower thermal conductivity can be obtained with respect to commercial comparable solutions (like expanded clay), as the thermal conductivity of the raw material is lower. Moreover, new expanding agents will be studied in order to further reduce the density of the expanded plastic aggregate and then to further decrease the thermal conductivity. A proper mix-design will help in compensating the strength decrease that is associated to a lower aggregate density, and/or to optimize the thermal properties of the resulting concrete mix.

Recycled binders
The complete replacement of cement by secondary materials of high (aluminium-) silica content is aimed. These materials will be used in combination with secondary alkali materials/powders in order to activate these aluminium silicates to a binder which does not dissolve in water anymore. The project will investigate the use of secondary alkali solutions and will concentrate on secondary ash sources (i.e. ashes from power stations that is placed in lagoons, municipal ash incinerator, etc), and by-products such as ferronickel slag and natural or man-made pozzolans, like µ-silica and metakaolin. The replacement of cement in concrete products will reduce the CO_2 released into the atmosphere by approximately the same amount of ash that can be utilised for this purpose (production of one ton of cement produces approximately one ton of CO_2). The work will be supported by the development of specific models able to consider the effect of different alternative binder formulations and secondary materials on the final performances of concrete.

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Total eco-sustainable concrete

Combining the recycled aggregates with the recycled binders, ensuring a good compatibility between the constituents, is the next step towards a new eco-friendly concrete. The innovative solutions set-up at material level will then be employed to develop innovative concepts of modular building components. This will not rely upon the mere integration of the developed materials, as the target performances will be pursued also through the set-up of innovative engineering solutions at component design level, able to allow the effective exploitation, once installed on the building, of the improved performances of the new constituent materials.[11]

Figure 13: SUSCON construction material made by secondary raw materials

4.2.2 Extruded products for easy assembly/disassembly and reuse with inclusion of CDW

The extrusion process is a well-established manufacturing operation that improves the efficiency and allows a continuous production. Typically, the system works with virgin materials that fulfil the requirements in terms of fresh paste rheology.

In RE^4 the extruded products will be manufactured including the highest fraction of mineral CDW. The production of extruded elements is beneficial in two ways: (1) improving the recycling ratio (2) providing building elements that can be assembled and then disassembled for reuse. Reconstituted stones, roof tiles and concept for block production will be developed. The list of competitors includes companies such as FLYNN, POLYCON, and project FIBCEM.

FIBCEM Project: Nanotechnology Enhanced Extruded Fibre Reinforced Foam Cement Based Environmentally Friendly Sandwich Material for Building Applications (2011-2014, GA 262954).
Fibre Reinforced Cement (FRC) is a durable, fire and corrosion resistant material widely used in the construction industry. Coupled with the low cost of Portland cement, these properties make it ideally suited for applications such as roofing tiles and sidings. However, the production of cement is associated with a large CO_2 'footprint', for each tonne of cement produced nearly one tonne of CO_2 is emitted. This has resulted in FRC becoming stigmatised as a 'dirty' material. In addition, the

[11] http://www.sus-con.eu/

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high density of cement and hence FRC products results in high transport costs for the producers and high end user installation costs.
In order to improve the poor environmental impact of FRC and improve its specific properties, FIBCEM will develop a cement based, nanotechnology enhanced material produced by a low energy consuming process. The material will consist of a cement based sandwich consisting of a foam cement core and fibre reinforced cement 'skins'. The foam core will be produced using a nanoscale foaming agent to ensure the formation of an optimum closed cell foam structure with a micro-scale cell size with a narrow cell size distribution. Both the foam and the 'skins' will be reinforced with nanoclays to improve both the mechanical and transport properties of the material. The foam cement core will result in a lower density compared to existing FRC, whilst the reinforced skins will ensure the mechanical properties are improved. Added functionality in the form of decreased thermal conductivity and increased sound insulation properties will result from the foam core.
The material will be produced by a low energy multilayer extrusion process in which both the foam cement core and fibre reinforced skins are simultaneously formed such that no discontinuity is formed between them. By using a foam core and replacing part of the cement with materials such as fly ash and silica fume, the CO_2 footprint of the material will be significantly reduced compared to existing FRC.[12]

FLYNN
Flynn has grown to become North America's only trade contractor of complete building envelope solutions. With 28 offices, Flynn is committed to delivering quality and value with health and safety as a top priority. The Service teams provide roofing service and maintenance with the capabilities of managing programs for a single facility as well as for those organizations with National real estate portfolios. The company was founded in 1978. During the 1980's, they established our reputation across the country as a top-notch commercial roofing contractor. Over the years, Flynn recognized that architectural projects were becoming increasingly complex, and they branched out to provide the clients with durable products for the entire building envelope. Flynn supplies commercial, industrial and institutional builders with a range of architectural products and roofing services, including metal panelling, contract glazing and curtain wall.
Today, Flynn employers in excess of 5000 people and serve a diverse portfolio of clients across North America. The commitment to service and innovation has made them a leader in building envelope products and services. Flynn has watched the needs and goals of the clients change, and has evolved to meet them, adding, for example, green roofs to the list of products and helping to found the "Green Roofs for Healthy Cities" initiative.
Fibre-reinforced cement panels free architects and designers from the constraints of concrete, acting like a skin made of concrete and opening entirely new possibilities for modern ventilated wall design. Concrete skin cladding is compact and flexible, adjusting to any shape an architect choose to design – curves, straight lines, slanted or straight walls or roofs. Interior and exterior surfaces fuse into one spatial unit, giving the impression of a building that has been cast in one piece.

[12] http://www.fibcem.com/

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The flexible, compact skin can be finished with sandblasted or brushed surfaces in a variety or iron oxide colours. A special process also allows us to incorporate company logos or patterns into the surface. Each manufactured part is unique in size, colour, and surface finish, creating a truly individual look.
Portfolio: roofing, curtain wall and glazing, architectural metals, environmental systems.[13]

POLYCON
Polycon is the leading European manufacturer of glass fibre reinforced concrete products. The company was founded in 2000 based on many years of previous experience in the area of research and development of modern building materials. Since the very beginning, the company has been focusing and specializing in the manufacture and development of fibre reinforced concrete composite which finds application especially in the area of modern architecture, particularly in the design and implementation of sheathing of buildings. The modern production equipment including fully automated operations and CNC machining centres allows the company to keep accepting new challenges and constantly move the implementation possibilities forward. In the production and development of fibre reinforced concrete composite, Polycon products have been technological leaders for a long time. The company regularly introduces products, technologies and services with innovative features that significantly shift the implementation possibilities of every project. They have been intensively working on the development of these technologies with technicians, engineers and leading professionals from various disciplines allowing the company to keep up with new trends in the field of construction, architecture and design. Thanks to the intensive development of technology, focus on high-quality but non-standard execution of building elements both in terms of form as well as execution and finally thanks to the focus on maximum service and customer satisfaction, the Company manages to implement more and more new projects and strengthen its position in the international market.

Polycon glass fiber reinforced concrete is non-combustible (A1) concrete composite with properties that enhances the architectural requirements of structures in solution. It improves fundamentally aesthetic requirements for implementation and finally makes a significant contribution for economic savings in building industry. Prescriptions of Polycon composite materials are based on the mixtures of cement, fine aggregate, water, dispersed alkali resistant glass fibre and other material additives. In this form Polycon material retains its unique properties that guarantee the highest quality of building components with regard to their long-term aesthetic and functional requirements.

The possibility of using - Polycon glass fibre reinforced concrete can be effectively used in the design and implementation of structural elements not only outdoor but also in interior design. Due a wide spectrum of imprinting structural matrices application, as well as an additional surface treatment, this can be easily accomplished by a huge variety of different visible surfaces, not only for the

[13] http://www.flynnco.com/

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cladding board materials and panels, but also for complicated shape architectural elements, shapes and spatial elements and design solitaires. None of the products from material Polycon is limited by "dimensional constraints", which completely eliminates the issue of waste and residual materials which disproportionately burden the economy of works beyond the normal calculated costs. Their contribution is significant in the context of environmental requirements.

Appearance - Completely natural character is the principal advantage of GFRC material Polycon, which fulfils the sense of the basic characteristics of "Living Facade". Each realization gets by that an absolutely unique character that is defined against a completely uniform, artificial and standard material. Significantly greater freedom for their own ideas is also available for the implementation of designs and ideas; this makes it possible to reproduce the most architectural styles and elements without taking into account the standardized formats, colours or surfaces. The Polycon material can materialize your dreams into reality.

Surfaces - The material Polycon can materialize your dreams into reality. Visible structure surfaces from Polycon glass-fibre reinforced concrete products can be realized from hundreds of patterns and surface structures (plaster, wood, masonry, stone and rocks, geometric patterns, oriental structures, disruptive patterns, ribbed and corrugated profiles, slip-resistant structures, texts, numbers, logos, pictograms, autotypic matrix, engraved structures). It is also possible to define a completely unique request to perform a visible surface according to your preferences and fantasies.

Coloring - Components of Polycon material can be delivered with completely the natural design, i.e. without any coloured pigments but also the material can be pigmented during the production using a suitable colour pigments according to the desired shade of pigmented glass-fibre-concrete mass. Characteristic appearance of natural materials is still maintained by material colouring. If interested, you can also adjust the surfaces using paint suitable for alkaline substrates. Surface finishing with special resins is also possible. Using of coating compositions suppress the creation of the characteristic appearance that is formed by unified paints.

Natural character - Polycon glass-fibre-concrete composite is a material, whose basic characteristic is the natural appearance. Irregularities in the context of colour tonality, not entirely consistent and unified surface, small surface tension trajectories caverns, including the inclusion of material inequalities represent the typical material properties that distinguish it from unified artificial surfaces. Just this material irregularities form the basic difference between invention and uniformity. Projects implemented by the Polycon material acquire their own character due its unique properties, because the material continuously responds to external stimuli related to external influences and creates not yet realized objects. Therefore, the individual projects become completely unique and unrepeatable.
Polycon Material is hard, tough, and long-lasting. Due to the possibility of production of thin-walled elements is also cost-effective. Polycon material is categorized as non-combustible class A1 in accordance with EN 13501. 1 (Fire classification of construction products and buildings).

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Quality - An important aspect for material selection and its actual implementation is general agreement in the essential requirements within the expected realization design. It is Important to learn the final customer or user from the beginning thoroughly with all facts which relate to the present work and inform them with all details of material specifications. It is appropriate that all active participants in the implementation process are informed about these facts prior the final products implementation of individual projects. When all the facts and circumstances relating to the project are defined in advance clearly and distinctly, then the overall impression of the overall implementation will have maximum efficiency and lead to customer satisfaction. The total clarification of technical details (including the approval of the submitted samples, the scope of which correspond proportionately making the final solution) allows to solve in advance all aspects relating to the required specifications and final design.

Hydrophobization - Resistance of the surface structures of glass-fiber reinforced concrete Polycon products can be increased using the hydrophobization to external influences such as water, dirt, grease, frost, chemical and deicing compositions. Correct use of the appropriate type hydrophobization can easily achieve better functional and useful properties of glass-fibre reinforced concrete cladding, especially with regard to its long-term use under technical aesthetic requirements. Hydrophobized products have substantially reduced water absorption of the surface layers and the associated effects.

Antigrafiti - While in the case of spray, a substantial part colouring ingredient in solid particulate form (with the exception of the present organic dyes) can penetrate into the porous structure is limited. In the case of markers colouring component dissolved in the liquid easily penetrates into the space between the crystalline limestone and marble materials with high porosity (sandstone, limestone, plaster, etc.). Inorganic pigments (as part of sprays) are very stable to light and it is usually not possible to change their chemical structure, without challenging the substrate. In contrast, organic dyes (contained in the pens) can be under certain circumstances chemically decompose and thereby change their colour or bleach completely. The different behaviour of markers and spray make effect when cleaning. Solubility of organic dyes markers in appropriate solvents on the one hand gives the possibility to facilitate their removal, but also causes a danger that, when such a cleaning portion penetrates deeper colour components into the structure of the purified material and remains unremoved. This is also true for the soluble component of sprays. When cleaning sprays they try to dissolve or soften the paint binder and then insoluble coloured pigment particles is mechanically removed (e.g. high pressure water).

Polycon Aura

Glass fibre reinforced concrete facings Polycon AURA bring freedom, creativity and natural harmony into architecture. Thanks to the great variability of possible solutions, it is possible to design individual implementations as unique projects without any restrictions. The high potential of the material in the designing and implementation of various projects can be widely applied within the requirements of both classic and modern design. It is possible to effectively utilize the large amount of surface structures and also design an entirely unique surface in your project that will be

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completely original and incomparable with any other project. In designing, it is also possible to use the standard colours as well as the possibility of high production flexibility and prepare an entirely unique colour tone of the material according to the client´s wishes and requirements. The possibility of flexible pigmentation is not restricted to any minimum quantity and may be used for any project or implementation.

Polycon Aura real 3D

The POLYCON AURA real3D material allows for creative solutions for every idea. The shape diversity and production flexibility offers an elegant solution to structurally complex details. With the production technology of pressure shotcrete, it is possible to produce individual parts and elements precisely according to the required shape of individual projects. An appropriately shaped mould allows the production of thin concrete panels and facing executed as required according to the entirely individual requirements of each implementation. The shape variety of manufactured elements allows addressing the requirements not only in 2D (or bent plates) but especially in real 3D design. Corner elements and shaped solutions to corner façade elements, including attic elements, can be now executed within a single product, without the need for a structural solution to emerging gaps and the resulting consequences. It is now possible to address structurally complex details simply by using a shape element POLYCON AURA Real3D.

Polycon Acoustic

Due to its excellent properties and aesthetic possibilities, the glass fibre reinforced concrete is also used for designing and producing technically complex systems in the field of acoustics and noise control. The design and manufacture of these systems is an entirely individual matter when there is an idea and requirement of the customer on one side and the cooperation with experts in the design and measurement of specific solutions for acoustic systems and elements on the other side.
Spatial and structural acoustics: conference rooms and convention centres, theatres and cultural centres, concert and lecture halls, schools and educational institutions, noise barriers. The aim of the POLYCON acoustic facings - panels is to achieve the best sound scattering to the fullest extent of frequencies with the lowest sound absorption possible.

Polycon Fireproof Thermal Insulation Wall Panels (PTD)

In the construction of residential homes, office and industrial buildings, the contractor is often faced with the need to address the thermal insulation fire protection elements. With regard to the normative requirements of the implementation and the resulting technical requirements, in recent years there has been a significant expansion not only in new constructions but also in their regeneration for the purposes of meeting the thermal technical, static, acoustic, hygienic and, last but not least, user requirements. Polycon fireproof thermal insulation wall panels (PTD) are lightweight non-bearing structures that serve as fireproof fillings in structural openings in perimeter and internal walls with high thermal insulation capability.[14]

[14] http://www.polycon.info/en/info/product

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Figure 14: Polycon portfolio (left Chur - Switzerland, right Antwerp - Belgium)

4.2.3 Insulation panels from CDW materials

Insulation panels are a key product both in new buildings and in renovation projects, as main solution for retrofitting and/or high insulation. Insulation panels are often produced with raw materials that have a high embodied energy, thus making the global sustainability of energy saving intervention less environmental friendly and costly.
In RE^4 a design will be developed for a non-structural or structural - insulated panel (SIPs) attached to structural support system (either timber or concrete construction). The proposal will mainly consist of a layer of insulation made from recycled wood fibres that is covered different types of waste wood cladding. The competitors in this field are: ECO-SANDWICH, Ecose®, and KNAUF INSULATION.

ECO-SANDWICH: "Energy Efficient Recycled Concrete Sandwich Façade Panel – ECO-SANDWICH" has been recognized, and is being financed within the framework of CIP-EIP-Eco- Innovation 2011 programme.
ECO-SANDWICH is a ventilated prefabricated wall panel utilising recycled construction and demolition waste and mineral wool produced using innovative and sustainable Ecose® technology for reduction of primary energy consumption in building stock.
Innovative concreting solution of outer layer distinguishes prefabricated ECO-SANDWICH wall panels, from similar products and makes it unique on the market. ECO-SANDWICH represents improvement of existing prefabricated wall panel products, aligning itself the mandatory targets of EPBD and EPBD II thus tackling 20-20-20 targets, thus representing a possible technological solution for fast construction of very low energy buildings on a large scale.

The ECO-SANDWICH tackles three major environmental problems:

- Reducing greenhouse gas emission (by enhancing energy efficiency of buildings, and reducing embodied energy)

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- Increased resource efficiency (through the use of construction and demolition waste (50% of total aggregates is obtained from recycled aggregate) in panel manufacturing, and recycled glass in manufacturing ECOSE® mineral wool)
- Minimising the use of regulated chemicals (like phenol and formaldehyde from the insulation material production process)

In order to reflect of the concurrent trends in lifecycle way of thinking, during the production of ECO-SANDWICH wall panels 50% of the total aggregate quantity needed for production of concrete layers has been replaced with recycled aggregate obtained from CDW.

Ecose® technology

A newly developed mineral wool manufactured using Ecose® technology, which uses bio based minerals as binder, is used as a thermal insulation material. The ECOSE based mineral wool provides significant environmental advantages. It is manufactured from abundant recycled (glass bottles, plate glass, internal waste; up to 85% of total of total content of resources) and naturally (silica) occurring materials. According to the BRE green Guide rating, BREEAM system respectively, Ecose® technology mineral wool uses bio-based materials free from formaldehyde, phenol, and petrochemicals and its embodied energy is 70% lower than for conventional mineral wool.

Glass mineral wool with Ecose® technology contributes to improved indoor air quality compared to conventional mineral wool. Ecose® technology products meet the industry´s most stringent standards and guidelines related to indoor air quality (M1/RTS Finland, GREENGUARD for Children and School/ USA, AFSSET/France).

Ecose® based mineral wool is certified as exceptional material, conforming to the Volatile Organic Compounds (VOC) emissions regulations and thresholds, together with regulations regarding the indoor air quality. Eurofins laboratories, Galten Denmark, awarded the Ecose® technology mineral wool with Indoor Air Comfort Gold Certificate. Sampling, testing and evaluation were performed according to ISO 16000-3; ISO 16000-6; ISO 16000-9; ISO 16000-11; ISO 16017-1; EN 13419.

- No cancerogenic substances were detectable above their limit values, including 4 carcinogenic, mutagenic and toxic for reproduction (CMR) substances regulated in France
- Formaldehyde was below the limit value of 10µg/m^3
- Sum of volatile organic compounds – VOC (Total volatile organic compounds – TVOC) was below the limit values of 1000 µg/m^3 after 3 days and 100µg/m^3 after 28 days.
- Sum of semi-volatile organic compounds (SVOC) after 28 days was below the limit value of 20 µg/m^3
- Evaluation of individual VOC: R values were below the limit values of 1 for both German NIK (niedrigste interessierende Konzentrationen) and French LCI (Lowest Concentration of Interest) lists after 28 days. Sums of VOC without NIK and of VOC without LCI both were below 50µg/m^3
- Quality management system and factory production control program at production site complied with requirements

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Knauf Insulation mineral wool with ECOSE Technology also complies with the voluntary EUCEB (European Certification Board for Mineral Wool Products) certification and Nota Q of Directive 67/548/EEC as amended 97/69/EC and is therefore free from suspicion of carcinogen effects and any associated hazard classification. Glass and stone wool fibres are pre-registered under the REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances) regulations (EC 1907:2006).

By implementing ECO-SANDWICH wall panel system, new business possibilities are emerging, together with promoting innovative and green economy, for building new or refurbishing existing: apartment buildings, family houses, storage facilities, production facilities, office buildings, schools, farms, etc.

ECO-SANDWICH wall panels were developed during the three years of research and development, during which extensive testing were performed using internal and external laboratory facilities, all in order to determine properties of individual components as well as the whole ECO-SANDWICH wall panel.[15]

Material	Properties	Value
Concrete made with recycled brick aggregates (50% of total aggregate content is replaced)	Average thermal conductivity at +10°C, in dry conditions	0,746 W/Mk
	Relative resistance to the water vapour diffusion	1,40 m
	Water vapour diffusion coefficient	29
	Density in dry state	1971 kg/m³
	Concrete strength class	C 30/37
	Three point bending strength (28 days)	6 MPa
	Modulus of elasticity (28 days)	18,2 GPa
	Gas permeability coefficient	0,76*10^-16m²
	Air void spacing factor in hardened concrete	0,114 mm
	Hardened concrete air content	10.55%
	Air void specific surface area in hardened concrete	26,13 mm^-1
	Capillary absorption	0,9 kg/(m²√h)
	Freezing and thawing with de-icing salts	56 cycles
	Water permeability	24 mm
ECOSE mineral wall	Identification code HRIN EN 13162 **MW-EN 13162-T4-WS-WL(P)-AF10**	
	Declared thermal conductivity,	0,034 W/mK
	Water vapour diffusion coefficient	1
	Reaction to fire - non-combustible	Classified as Euroclass A1
	Thickness tolerance	T4
	Tensile strength	> double weight
	Airflow resistivity, Afr	≥ 10,0 kPA´s/m²
ECO-SANDWICH wall panel	Thermal transmittance (U-value)	<0,20 W/m²K
	Airborne sound reduction index Rw	53 dB
	Thermal mass	458 kg/m²

Table 1: properties of the ECO-SANDWICH products

[15] https://issuu.com/bojanm/docs/eco-sandwich_bros__ura_en_web

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Figure 15: ECO-SANDWICH prototype and first house in Koprivnica

Prefabricated building elements are widely used in construction of non-residential buildings. Energy efficiency, low noise pollution and fire safety are key requirements, which determine the design of such buildings. Rock mineral wool sandwich panels are the most convenient solution for meeting all of those requirements.

KNAUF INSULATION

Knauf Insulation is recognized as one of the insulation leaders in the OEM industry owing to the fact that they offer unique insulation solutions, which can be entirely tailor-made according to the needs of our customers and in line with their production processes. They provide the customers with supreme and tailor-made rock or glass mineral wool insulation solutions. As required properties vary by application, they offer a wide range of insulation products for a variety of applications in: automotive, chimney systems, domestic appliances, doors, machine production, prefabricated building elements, road sound barriers, and thermal solar collectors.

Knauf Insulation rock mineral wool is widely used as the core of sandwich panels owing to its excellent fire resistance, non-combustibility, thermal and sound insulation properties. Due to advanced mechanical properties, the products are cost effective solutions for even the most demanding constructions. Knauf provides customised insulation solutions for façade elements, roof elements, partition walls, refractory construction elements.

Application: Unique rock mineral wool insulation core for higher load resistance and longer single-span sandwich panels.

Benefits:

- Supreme mechanical properties of the insulation core
- Excellent acoustic properties
- Good thermal insulation properties
- Thermal conductivity: 0.039 W/mK (PBE LX)
- Fire-resistant (Euroclass A1) – melting point above 1,000 °C
- Dimensional stability.

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Standard dimensions.
Thickness: 80 – 200 mm +/-1 mm, upon specific request (PBE Board X-Tend, PBE Board Thermal, PBE Board), customised according to customer requirements (PBE Lamella, PBE Board Special), 50 - 150 mm +/- 1 mm (PBE LX)
Length & Width: according to customer requirements, 2.000mmx300-1.200mm (PBE LX)[16].

Figure 16: Knauf insulation prefabricated elements (Rockwool)

4.2.4 Geopolymeric binders from the ceramic fraction of CDW

The ceramic fraction (tiles, bricks) is not currently sorted from the CDW bulk, resulting in recycled aggregates of a lower grade due to the lower mechanical performance of ceramic rubbles. In RE[4] the development of geopolymeric binder from CDW will be integrated in a wider strategy for increasing the technical and economic value of mineral CDW. The development of binder from ceramic waste will improve the economic viability of the proposed sorting system.

DURECOBEL Project (Recycling of quarry dust and construction and demolition wastes for the production of novel ecological building elements) investigated the development of binder from mining wastes and CDW.
The project aims to develop innovative but still simple and non-energy-intensive processes for the production of novel ecological building elements consisted mainly of quarry dust and construction and demolition waste (CDW). The ultimate objectives of DURECOBEL are preservation of raw materials, reduction of the carbon footprint associated mainly with their extraction and treatment and elimination of environmental impacts due to disposal of large volumes of these wastes. The project is performed under the framework of the operational program "Cooperation 2011-Competitiveness and Entrepreneurship", it is co-funded by the European Regional Development Fund (ERDF) and managed by the Greek General Secretariat for Research and Technology.

New innovative technologies, which will be investigated in DURECOBEL project for the development of building elements, are the following:

- *Compaction moulding*. According to this technology, suitably prepared mixtures of quarry dust, recycled aggregates (from construction and demolition wastes) and cementitious binders, are homogenized, mixed and sprayed with water. The resulting semi-dry mixture is

[16] http://www.oem.knaufinsulation.com/en/content/prefabricated-building-elements-insulation

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compressed to form specimens. These specimens are cured in a climatic chamber for 28 days to reach their final mechanical strength.

- *Free flow casting*. Appropriate blends of quarry dust, recycled aggregates, cementitious binders and admixtures are homogenized and mixed in a laboratory mortar mixer. By adding chemical additives and appropriate quantities of water the resulting mixture gain fluidity so it can casted easily into moulds to form building elements of simple geometry such as a decorative building brick or an artificial stone.
- *Extrusion*. Fine aggregates (e.g. quarry dust), cementitious binders, cellulose and other chemical additives are mixed with proper amounts of water until reaching the required plasticity for extrusion. The resulting mixtures are extruded to form self-supported specimens with simple or complex cross-section (e.g. hollow bricks).
- *Geopolymerization*. Mixtures of fine aggregates from construction and demolition wastes are mixed with standard alkaline solutions, casted in special moulds and then heated to low temperatures (60-90o C) for a short time. The so formed specimens are left to mature in ambient conditions until reaching their final mechanical properties.

Under the project, there have been developed building elements prototypes in semi-industrial scale in the type of:

- Floor screed slabs and stone paving blocks by substituting natural aggregates with excavation, construction and demolition waste aggregates (CDW).
- Artificial load bearing or decorative building elements produced mainly by raw materials such as quarry dust filler and CDW. CDW come from recycled roof tiles, recycled concrete, stone paving blocks, paving slabs, curbs, ceramic wall tiles, bricks and coatings.
- Thermal insulating slabs using quarry dust filler, cement and CDW derived from recycled roof tiles/ bricks and recycled wall tiles.
- Lightweight building elements using quarry dust filler, cement, lime and expanding agents.
- Floor screed mortar produced mainly by quarry dust filler, cement and CDW.[17]


Floor screed slab with tile paper surface finish.


Prototype development of stone paving blocks.

[17] http://www.durecobel.gr/index.php/en/the-project

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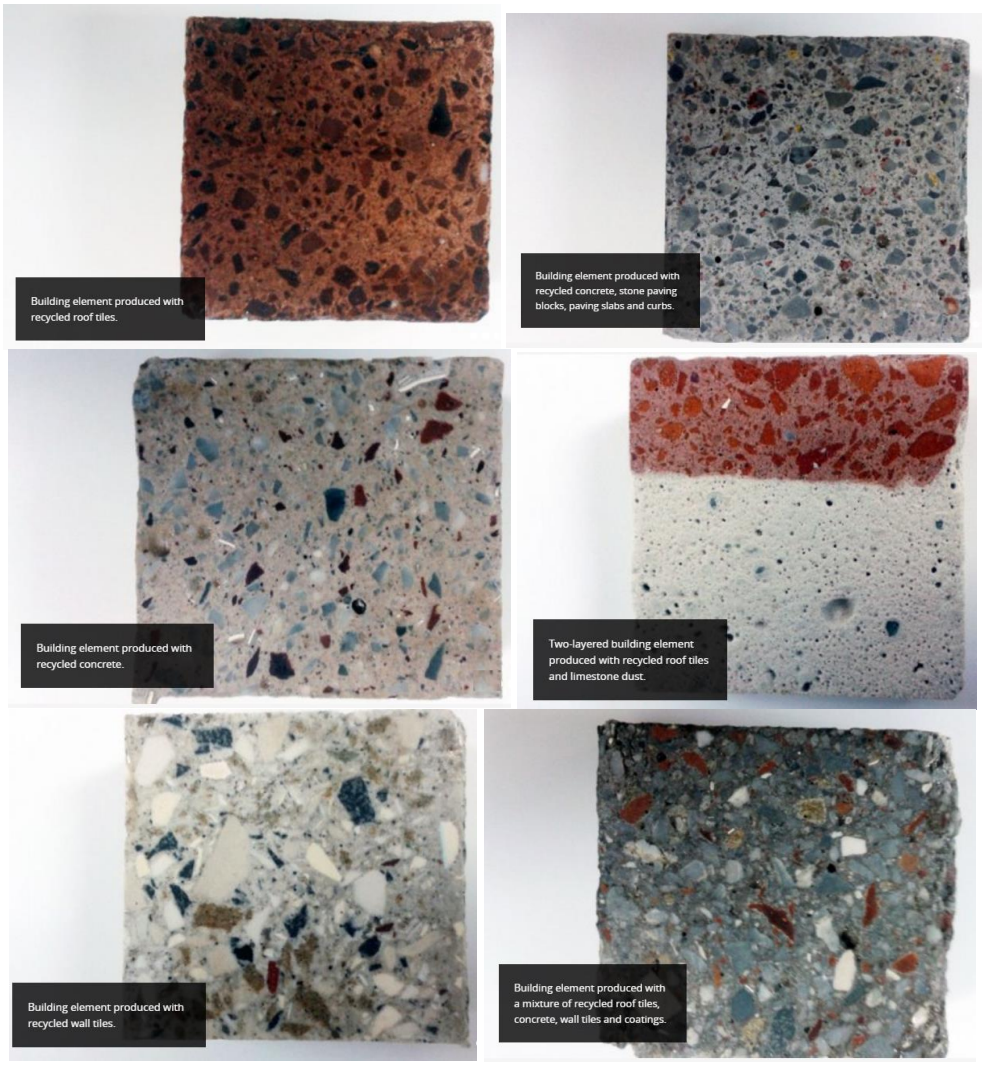

Figure 17: DURECOBEL project results

4.2.5 Reuse of timber for structural and non-structural purposes

The fraction of waste timber being used as fuel is increasing in comparison to the reuse or recycling. Important resources are not optimally used and stored carbon is released to the environment. Utilisation of waste wood mainly for fuelling, chipboard or furniture production (down cycling) due to economic reasons or technical reasons (manufacturer fear damages of machinery due to connection means in waste wood). In RE^4 innovative elements will be developed, such as: timber façade panel based on reused structures and elements and recycled timber; timber roof construction based on reused structures and elements and recycled timber. New concept for connecting wooden beams or posts in combination with new machinery could enable the reuse or up cycling of waste wood. National R&D Project to promote recycle and reuse of timber constructions in Japan (Building Research Institute, Tsukuba, Ibaraki) are identified.

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4.2.6 Fine fraction (silt, clay) from the mineral CDW washing and water thickening operations

Usually this fraction is dumped, or used for pond lining. Currently there is no clear reuse/recycle strategy for this material. RE^4 Project will investigate several further recycling options for this fraction: as a precursor material for geopolymer reaction, as a Supplementary Cementitious Material, as a filler, as an earth plaster (for surface finishing) and adhesive (for blocks).

4.3 Innovative design concept for modular/easy installation and disassembly/re-use of energy-efficient prefabricated elements

The BRE Deconstruction Cluster Group in the Deconstruction Market Share report concluded that further investigation is required to develop performance-based specifications, in-situ 'fit for purpose' tests, technological solutions to deconstruct current structures, and design of de-constructible joints/fasteners for future structures. Prefab houses are not very popular, despite a range of benefits that this technology can bring. Prefab houses in the market are not currently designed for further disassembly.
RE^4 will develop reversible connections for all prefab elements and materials and foster material purity in favour of composite materials to enable future non-destructive dismantling and reuse or recycling. The development of a reversible prefab building concept will allow the re-use of CDW-prefab components in the next decades. RE^4 will target standardization processes for the component design, with the aim of reusing entire building elements.

4.4 High replication potential

There is a barrier in the replication of prefab solutions as local conditions (climate, seismic requirements, aesthetic, building typology, public acceptance, etc.) require different designs. One-size-fits-all approaches cannot fulfil needs from the involved stakeholders.
In RE^4 the design of the structure will be flexible for taking into consideration different requirements from different local realities. Different climatic zones will be targeted by demonstration activities, as well as different seismic requirements for ensuring the resilience of the design. The participation of National Taiwan University of Science and Technology in the Consortium will open the potential for replication outside EU.

ADAPTIWALL Project: Multi-functional lightweight WALL panel based on ADAPTive Insulation and nanomaterials for energy efficient buildings (FP7, 2013 – 2017, GA 608808).
ADAPTIWALL solves the problem by using nanotechnology to develop a multifunctional and climate adaptive panel for energy-efficient buildings. This novel panel consists of three elements:

- Lightweight concrete with Nano additives for efficient thermal storage and load bearing capacity.
- Adaptable polymer materials for switchable thermal resistance.
- Total heat exchanger with nanostructured membrane for temperature, moisture and anti-bacterial control.

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ADAPTIWALL panel is innovative due to: its lightweight design and quick low-cost installation; switchable thermal resistance for heat exchange and storage; highly improved energy efficiency; and suitability to be used for façade or roof in cost-efficient retrofitting and new buildings in different European climate regions. When used for façades, ADAPTIWALL panels reduce the building's energy consumption by more than 50% in comparison with conventional retrofitting. Their ventilation and heat exchange properties significantly contribute to create a healthy and comfortable indoor climate, while eliminating the need for auxiliary installations.
The ADAPTIWALL research project focuses on developing adaptive (nano) materials; applying the materials in a lightweight panel; enhancing the panel's structural, fire safety and sound insulation properties; and demonstrating the novel prefabricating systems to European construction industry.

ADAPTIWALL delivers a proof-of-concept of an integrated envelope product, with the following components and system:

- An adaptive prefab panel with more energy savings at reduced cost with respect to current (retrofitting) solutions and suitable for retrofitting in different climate regions, building regulations and building practice throughout Europe. This adaptive prefab panel consists of integrated innovative adaptive material components including nano-additives such that the panel is thin, easy and quick to install, lightweight and multi-functional, with potential energy savings of more than a factor 5 and largely reducing (>75%) the need for auxiliary ventilation and heat recovery systems.
- An adaptive insulation panel component consisting of non-traditional polymer materials, such as 3D non-wovens and flexible foams, that are particularly suitable for adaptive insulation and have the potential to have high thermal resistance values in relation to thickness. Additionally, an innovative microcontroller device connected to a sensoring and monitoring system for ensuring an adaptive insulation regulation that fits indoor comfort needs.
- An innovative lightweight concrete panel component based on lightweight aggregate impregnated with phase change materials (PCMs) and new binder types including nano-additives in order to combine lightweight with high thermal buffering potential (comparable or better than normal concrete) as well as to ensure fire protection and sound insulation and to improve mechanical properties in relation to thickness (reduction of dead load by 40%).
- A ventilation system including a total heat exchanger component to integrate in the prefab panel, allowing heat recovery (>75%) and humidity control during ventilation. An optimized membrane for the heat exchanger consisting of nano-structured substrates for more efficient heat exchange and nano particles for avoiding microbial growth. Additional integrated moisture sensoring and control if needed to avoid condensation.[18]

[18] http://www.adaptiwall.eu/mainmenu/home/#.WSQsBWjfqUk

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Figure 18: ADAPTIWALL system

4.5 BIM compatible DSS and Platform for CDW estimation and management

Typically, BIM tools do not deal with demolition/deconstruction stage of the building life-cycle. Moreover, few reliable CDW estimation methods are available; one of the most advanced is a BIM-based solution, realized in Revit API, which can extract material and volume information from the BIM model and integrate the information for detailed demolition waste estimation and planning. It can also account for the recycling and reuse quota of such waste, as well as provide the pick-up truck requirements and waste disposal charging fees. Nevertheless, it lacks:

- Applicability to estimation of construction waste
- Providing information about possible end uses of the CDW
- Extensive database of waste volume adjustment factors (needed to estimate the waste volume from the volume of the component to be demolished)
- Openness to future database enrichment by the users.

The RE^4 tool will present equivalent functionalities to those proposed in reference work, but with the addition of: applicability also to construction waste, information regarding possible end uses of the CDW, enrichment of the database of volume adjustment factors for including the CDW focused in RE^4, openness to future database enrichment by the users, centralised service, gathering information from all the DSS users and providing to the prefabricators updated information about the CDW types and quantities available in the geographic zone of their interest.
Unlike the tool developed in the HISER Project, the RE^4 tool will allow applicability also to construction waste. Further innovation element will be the centralized service. The RE^4 tool will make wide use of the data contained in the IRCOW platform in order to feed its knowledge base in terms of CDW end-uses and related processing plants.

HISER Project: Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste (H2020, GA 642085).

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The main objective in HISER is to develop and demonstrate novel cost-effective holistic solutions (technological and non-technological) for a higher recovery of raw materials from ever more complex construction and demolition waste (CDW) by considering circular economy approaches throughout the building value chain (from End-of-Life Buildings to new Buildings).
HISER project goal is to formulate, develop and test novel harmonized cost-effective methodological solutions and tools facilitating the data gathering and data processing on types, qualities and quantities of building waste materials for a highly efficient selective sorting at source during the execution of demolition and refurbishment works. Through the use of a new Smart BIM-SD tool and an innovative supply chain tracking system, more accurate information on building waste materials from existing buildings will be available. Those solutions will contribute to the improvement in decision making about the execution process, onsite sorting and management of subsequent waste materials arising during the demolition/refurbishment of residential and non-residential stocks. Consequently, higher amounts of onsite sorted waste materials will arise from the early beginning of the End-of-Life building.
One of the HISER project goal is to design, develop and optimize advanced cost-effective technologies for the production of highly-purity raw materials (purity levels ranging from 80 to 100%) from complex CDW.
Through the adaptation, integration and enhancement of automated identification, sorting, selective electro-fragmentation and advanced comminution technologies, an upgraded recovery of pure materials contained in complex CDW will be achieved. In addition, the development of novel inline automated quality assessment systems will provide potential users with higher levels of certainty about the quality of secondary raw materials recovered from CDW. The global cost effectiveness of new solutions will be up to 20% higher in comparison with current recycling technological schemes. The smart combination of new HISER technological solutions will facilitate the market uptake of larger amounts of recycled raw materials for use in new building products.
HISER partners are going to develop and optimize new cost-effective building products through the partial replacement of virgin raw materials by higher amounts of secondary high-purity raw materials recovered from complex CDW.
The most common building products will be considered for the achievement of this global objective:

- lower (up to 10% in comparison with the current patented solutions) CO_2 footprint and cost-effective cements;
- new cost effective green concrete containing more than 1300 kg of recycled aggregates per cubic meter of new concrete;
- new cost effective bricks manufactured with a partial replacement (up to 10% (by weight) of inert sand fraction by C&D recovered ceramic material ('brick-to-brick');
- new cost effective VOC-absorbing plasterboards, fire resistant gypsum plasters and plasterboard composite panels manufactured with partial replacements (up to 50%) of natural gypsum and fibres by C&D recovered gypsum, wood fibres and filler from mineral wool;
- new low cost extruded composite structural products by incorporating up to 60% of C&D recovered wood fibres, mineral wool and other recycled materials.

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HISER will propose holistic solutions (technological and non-technological) aiming to achieve a superior recovery of valuable raw materials from ever more complex CDW by covering the whole circular supply chain: from early beginning of End-of-Life buildings to the incorporation of recovered CDW material into new building material cycles.

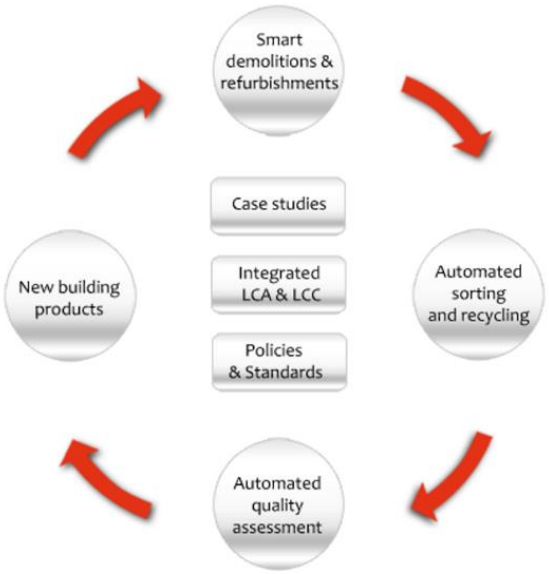

Figure 19: HISER holistic solution

HISER partners will design, develop, test and validate novel harmonized procedures and smart tools contributing to a cost effective highly efficient selective sorting at source during the execution of demolition and refurbishment works. A new Building Information Modelling based tool (so called as Smart BIM-SD tool) will be designed and developed. That specific BIM for selective demolitions/renovations of existing buildings will help European demolition companies to quickly identify and quantify potential new raw materials through the smart processing of data.
The BIM based tool will provide users with harmonized inventories and supply chain tracking information with the purpose of identifying the most feasible and secure recovery options for the subsequent CDW materials. Another innovation deals with the creation of the BIM data required for the aforementioned smart analysis. New building designs might include specific modules for the End-of-Life but existing buildings are not under BIM domain. The methodology and guidelines in HISER will enable demolition companies to elaborate more accurate inventories from existing buildings. Integration of existing techniques for the fast data capture and processing will be considered. Finally, the tool will be conceived in a web-based, open and flexible architecture, integrated with existing Facility Management tools, thereby facilitating the updating. The Smart BIM-SD will be easily adaptable to those existing BIMs incorporated at the building design phase.

Five main innovative automated sorting and recycling technologies will be introduced to the market. All of them are aiming to achieve a better cost-effective recovery of the pure materials contained in the CDW stony fraction.

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1. New generation of sensor based automated sorting technology

The innovative system will be the fusion of two very different optical sensor systems into 1 single system aiming to save around 35% costs and energy when comparing to inline separate sensor based sorting solutions. A popular approach is to split the light information via a beam splitter into two sensor systems (VIS and NIR-sensors). The resultant weakening of light makes this method not very powerful. Here, new ways must be found to develop a very compact optical sensor system. In addition to the detection, separation represents another challenge, especially for CDW. The aim should be to produce two good fractions from a waste stream in one step plus a third fraction with unwanted material. Such three-way sorting machines will make high demands on the design and the quality of the input current. It will also be adapted for selectively sorting of contaminated particles arising from industrial assets (non-residential buildings). The engineering innovation in the HISER project according to an automatic sensor-based sorting machine is to find a harmonious interplay of all construction components, taking into account economical and energy efficiency boundary conditions.

2. Modernized electro-fragmentation technology

The adaptation of existing technology to the selective release of materials included in the red (adhered gypsum or insulating materials) and grey fractions (adhered particles or fibers reinforcing the concrete) of CDW will be the innovative challenge in HISER project. This step is essential for the production of a monophasic fraction and has to be based on intergranular breakage (i.e. fragmentation along grain boundaries) in order to avoid damaging the materials allowing then its high-value recycling. The evolved mobile electro-fragmentation will also aim to minimize the fine-size production and to develop a low energy intensive process of fragmentation to limit economic and environmental impacts of the recycling treatment plant.

3. New low-cost classification technology (ADR system)

One of the main environmental challenges in the construction industry, is existing a strong social force in order to decrease the bulk transport of the building materials in urban environments. Considering this fact, applying more in situ recycling technologies for Construction and Demolition Waste (CDW) could be the key. To achieve this goal, a new low-cost classification technology, called Advanced Dry Recovery (ADR) is being developed. ADR performs purely mechanically and in the moist state, i.e. without prior drying or wet screening. This choice reduces process complexity and avoids problems with dust or sludge. ADR is applied to remove the fines and light contaminants with an adjustable cut-point of between 1 and 4 mm for mineral particles. It uses kinetic energy to break the bonds that are formed by moisture and fine particles and can classify materials almost independent of their moisture content. After breaking up the material into a jet, the fine particles are separated from the coarse particles. ADR separation has the effect that the aggregate is concentrated into a coarse aggregate product and a fine fraction which includes the cement paste and contaminants such as wood, plastics and foams. Within HISER, field experiments will be performed by means of a novel mobile pilot plant containing different unit operations such as: attrition milling, screening (>16mm), and mobile ADR insulation beside integration of the sensors and quality control elements. Both the up-scaling of the ADR technology and the process design for

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the integration of all unit operations in the plant (requiring basic design, detailed engineering and built engineering) will be carried out as to finally build the mobile pilot plant.

4. Innovative recycling technologies for gypsum plasterboards

HISER partners will innovate in the following gypsum recycling technology: Development of low cost mobile compact equipment – instead of multistage recycling processes, this compact portable apparatus will guarantee the selective onsite recovery of preconsumer gypsum and cardboard with purity levels 85% for both fractions.

Development of advanced gypsum sorting and recycling schemes - providing high purity recycled gypsum, enabling manufacturers of gypsum building products to easily accept higher amounts of recovered gypsum from waste postconsumer products. NIR and X-ray fluorescence (XRF) sensors will be integrated in such novel schemes. This approach constitutes an innovative field of application for automated identification and sorting.

5. New recycling technologies for C&D waste wood and other minor emerging waste fractions

Develop and validate new cost efficient sorting and comminuting technological solutions for C&D wood, glass and mineral wool waste materials is one of the aim of HISER project. It will integrate material pre-crushing, fine crushing, sorting and cleaning into one system which effectively separates impurities and classifies the cleaned raw material into desired fractions. Refining and post refining processes will be optimized for the production of high quality wood fractions and fibers from both C&D wood waste and mineral wool waste to be used as reinforcement in composites and gypsum plasterboards. Additionally, specific refining and post refining processing techniques will be adjusted for producing high quality silica from C&D glass waste to be used as reactive filler in low-CO_2 footprint cement.

HISER project emphasises the following building products under pilot manufacturing processes and pilot execution conditions:

- **New green cements**: A new generation of lower CO_2 footprint and lower embodied energy cements (up to 10% when comparing to current patented products) by using alternative raw materials recovered from CDW (recycled gypsum, recycled glass and fine recycled concrete and ceramic aggregates).
- **Concrete**: 1. Practical model of the phenomena and mechanisms resulting in high-quality concrete with higher incorporation levels (higher than 30%) of recycled aggregates (coarse and fine fractions); 2. Wide validation of the model on different types and conditions of concrete waste and using different process parameters for the production of the recycled aggregates. This will allow the demonstration of the degree of robustness of the technology and product to the building sector; 3. New green concrete recipes with slightly lower cement amounts in favour of fine recycled aggregates inducing hydraulic and pozzolanic reactivity; 4. New reinforced concrete with CDW recovered fibres.
- **Bricks**: New bricks manufactured with recycled ceramic material
- **Gypsum**: New families of gypsum based products containing not also recovered gypsum but also wood fibres, mineral wool fibres and other inorganic materials from CDW (replacement

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levels of virgin raw materials by recycled ones ranging from 10% to 50%). Diverse optimized recipes and prototypes will be performed for the following type of products: VOC-absorbing plasterboards, fire resistant plasters and gypsum plasterboard composite panels. This approach will offer new possibilities to produce strong and lightweight structures based on the circular economy concept and also with excellent functionality and competitiveness.

- **Composites**: Main targets related to composites are: 1. The improvement of the performance of WPCs to a high level by minimizing the fibre degradation; 2. Diminishing of the costs of WPC-manufacturing by >50% to allow WPCs being sold at about the price level of wood products and to become a volume business with "green image" by year 2020 in Europe. A major qualitative progress in the development of next generation "high performance, low cost" WPCs can be obtained by new composite co-extrusion process techniques and multilayer product structures from CDW wood incorporating molecular orientation and cavitation. For both plasterboards and composites, the supply chain of CDW wood based material does not exist. So it must be first created and made reliable and consistent to guarantee sufficient amounts of sorted grades of suitable fractions of recovered wood to build long term new business. Therefore, the supply chain has to be feasible in industrial and commercial criteria. One target is to clarify the performance of different CDW wood fractions for the production of fibre based products. Based on these results and needed processing steps, classification system for C&DW wood fractions will be created. [19]

IRCOW Project: Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste (FP7, 2011 – 2014, GA 265212).
The main goal of the IRCOW Project is to develop and validate upgraded technological solutions to achieve an efficient material recovery from CDW by considering a life cycle perspective. The innovation beyond the state-of-the-art will focus on:

- Developing new approaches and models aimed at raising the rate of reuse components.
- Developing and adapting recycling technology with the overall purpose of improving the quality of C&D recycled materials: recycled aggregates, wood, plastics, granular gypsum from mixed streams and emerging waste materials.
- Developing high-grade construction products by using C&D recycled materials, not only those related to the stony fraction, but also the other fractions where there is currently a strong knowledge gap.
- Demonstrating results under real conditions with the aim of providing potential stakeholders with information on the global performance.
- Setting the basis for specific European policies on C&D waste aiming at fostering a high and efficient level of material recovery.

[19] http://hiserproject.eu/index.php/our-activities/smart-demolitions-and-refurbishments

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Three TECHNOLOGICAL INNOVATIVE SOLUTIONS have been obtained within IRCOW:

- The new software for NIR (Near Infrared) Sorting Equipment provides improved recycling processes for CDW recycling plants, with the main objective of high-grading recycled aggregates and their use.
- On-site microwave energy thermal treatment, which allows the disintegration of asbestos and other mineral fibres.
- Multilayer composite extrusion technology.

Two TOOLS have been developed within IRCOW.

- Stock-Exchange tool: a demo dedicated e-commerce portal for sale and purchase of CDW recovered materials and elements.
- The Human Health and Environmental Risk Indicator (HERI): a computer based tool which can be used by the building or recycling industry to indicate the potential risks due to the use of recycled CDW materials or based products.

Finally, two SERVICES have been developed within IRCOW:

- An integrated service aimed at the recycle of CW into high-grade applications (business model).
- Eco-design as an established approach to design new products applying secondary resources.[20]

[20] http://www.ircow.eu/Default.aspx?menuid=m-0

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4.6 Other research projects focused on CDW

GREEN INSTRUCT Project Prefabrication for refurbishment from a modular perspective by way of a universal building block with customization potential (H2020, 2016-2020, GA 723825)
The Green INSTRUCT project develops green integrated structural elements for retrofitting and new construction of buildings. The Green INSTRUCT project develops a prefabricated modular building wall panel, that is superior to conventional precast reinforced concrete panels by virtue of its reduced weight, improved acoustic and thermal performance and multiple functionalities: six integrated layers, structural performance, insulation, comfortable healthy indoor environment, aesthetics, CO_2 capture and grey & storm water management, easy installation, light weight, recyclable, reusable, over 70% CDW, energy and resource efficient, based on extrusion, cost effective, no specialized work force required.

Competitive advantages:

- Multi-layered integrated building block with more than 70% CDW of resource materials
- Prefabrication for new buildings and refurbishment in modular perspective
- Easy and fast installation, 30% lighter than conventional envelope walls of the same size
- Development of a universal building block with customisation potential
- Installations at least 15% faster – on a product stage 30%
- Eurocode standards – fire safety, thermal insulation with U value of 0,14 W/m^2.°C, acoustic insulation 55-60dB
- Green technologies
- On site grey and storm water management through integration of a vertical green wall.

The Green INSTRUCT project achieves sustainability and cost savings through CDW sourced materials and C2C strategies (Consumer-to-consumer strategies engage stakeholders that the critical to the plan or product development), develops efficient, robust, eco-friendly and replicable processes, enables novel cost efficient products and new supply chains, develops a building block that renders refurbished or new buildings safe and energy efficient and safeguards a comfortable, healthy and productive environment.[21]

[21] http://www.greeninstruct.eu/overview/

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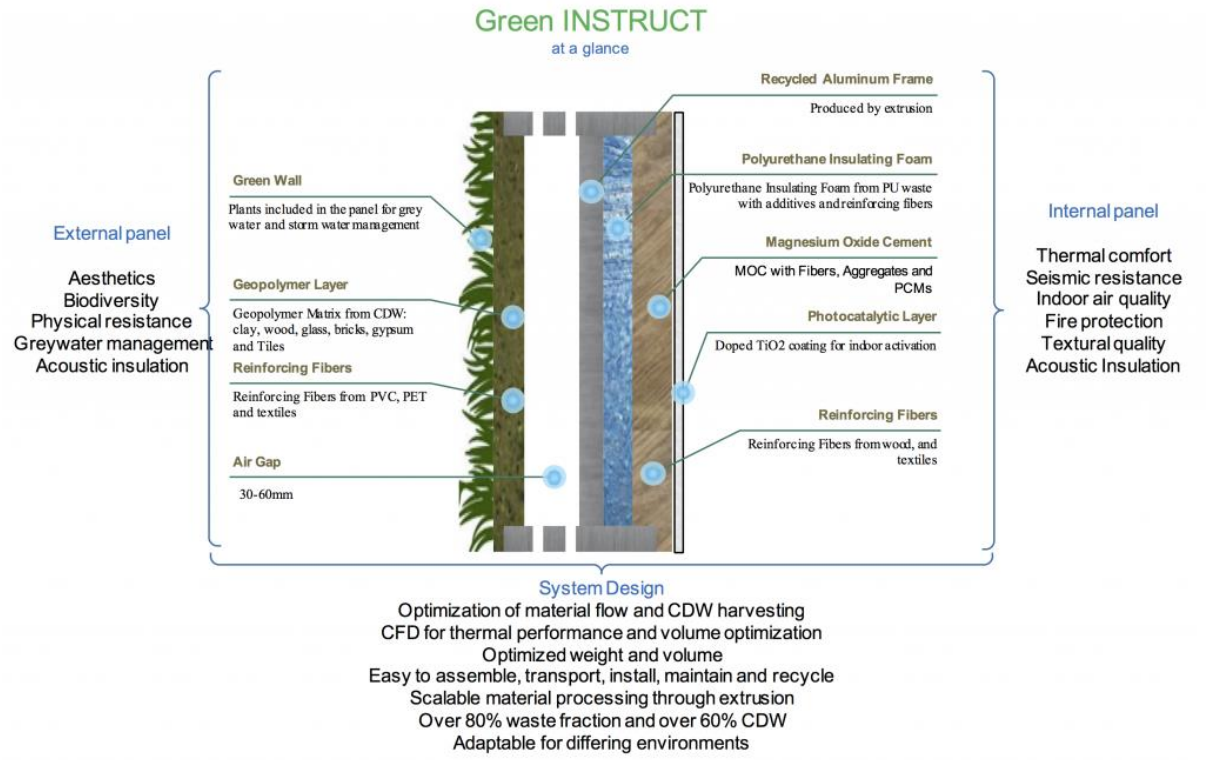

Figure 20: Green INSTRUCT system

LIFE ECO TILES Project: ECO innovative methodologies for the valorisation of construction and urban waste into high grade TILES (LIFE Programme of the European Union).
The Life ECO Tiles Project will demonstrate the possibility to produce fully recycled (up to nearly 70%) pre-casted cement-based products (Terrazzo tiles) using recycled glass from urban and industrial waste, ceramic and CDW. The production will have a substantial less (-20%) environmental impact than for traditional tiles and achieve the manufacture of high-grade pre-casted products.
ECO TILES products will contribute to the achievement of EU 2020 goals on Waste and Resource Efficiency, by reducing emissions, resource waste, impacts on human health and the environment.

Specific objectives are to:

- Demonstrate an innovative methodology that integrates promising research results to produce a new generation of tiles made almost entirely (up to 70%) with recycled materials and with substantially lower environmental impacts compared to current best-in-market products. Main innovations are related to: the creation of pozzolan cement made with CDW and/or construction waste precursors (15% weight of the tile); the substitution of aggregates with recycled glass (around. 50-60% of total weight); the production of high-grade precast products; and the adaptation of a patented low-energy production process (less than 20% compared to current state of the art);
- Demonstrate using a set of well-designed testing and validation activities on 300 m2 of demo products the improved environmental performance in the production process of precast

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products, through the re-use and recycling of several streams of urban waste as well as lower energy consumption;
- Build and maintain a collection and valorisation network in the Marche region (with a focus on CDW, production of building material and glass), including fostering of green public procurement;
- Increase awareness of the improved eco-innovative solutions among the general public, policy-makers and in the European industry, focusing on the environmental and economic advantages as well as on the technical feasibility of innovations such as LIFE ECO TILES.[22]

INNOWEE Project: Innovative pre-fabricated components including different Waste construction materials reducing building Energy and minimising Environmental impacts (H2020, 2016 – 2020, GA 723916).
The main aim of InnoWEE is the development of new economically viable, flexible and modular solutions able to process high amounts of CDW and reaching at the same time a high performance in terms of energy efficiency and environmental impact.
The main objectives are:
- To develop realistic performant and cost-efficient solutions with innovative products for new and existing buildings thereby creating new business and real estate development opportunities
- Recovery, disassembling and selection of CDW to yield suitable raw materials and development of new high performance prefabricated versatile geopolymeric panels
- To verify the performance of the panels installing them first in a pilot and then in three real demo sites. To model the real and "virtual" demo sites with different climate to obtain different scenarios
- Introduction and incisiveness of the new materials and solutions in the markets
- Evaluation of the reduction of energy and environmental sustainability
- Development of information guidelines for applications installation and training on the new solutions and dissemination of the results.

Implementation of geopolymer technology
Results with brick dust, crushed recycled concrete aggregates, mortar waste and glass waste show that inorganic CDW can effectively act as nearly inert fillers in geopolymers yielding similar properties as could be obtained with other mineral inert fillers commonly used with geopolymers allowing to recycle inorganic CDW of different types with contents at least 40-50% by weight.
Results also prove the ability to incorporate wood wool or wood chips/dust into geopolymers to yield geopolymer bonded wood panels similar to cement bonded wood panels. Based on these facts in the project different geopolymer panels will be developed: prefabricated ETICs panels and façade cladding tiles for building envelope insulation and radiating wall and ceiling panels for in-door

[22] http://www.ecotiles-lifeproject.eu/

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heating/cooling. After obtaining positive results at laboratory site and demonstration site, the production of ETICs, radiating walls and cladding panels can start. Introduction of innovative solutions into the market. These products will go beyond the state-of -the-art and are feasible to apply in building, obtaining energy efficient parameters.

ETICs

The most commonly used ETICs presently applied are prepared "on-site" and therefore are associated with high manual labour cost. Prefabricated ETICs are relatively new products and therefore are not yet widely applied.

It is proposed a new type of ETICs which consists of pre-fabricated insulating panels composed of an outer High Density Geopolymer layer (HDG) 8 mm thin and an inner EPS insulating layer 30-50mm thick fixed in a reversible manner (Velcro or other) to the HDG layer.

The panel weight will be ca 16 kg/m². A dedicated fastening system will be designed to provide seismic safety while still allowing the separation of EPS from the geopolymer HDG layer at the end-of life.

The HDG layer will be produced using a geopolymer binder mainly formulated with metakaolin, slags potassium/sodium silicate and/or other components, incorporating at least 40-50% selected inorganic CDW with a low thermal conductivity (e.g. masonry waste).

The addition of brick or masonry waste will also decrease the water absorption of the geopolymer. The HDG layer can be produced with a variety of surface textures/reliefs by using suitable casting supports. The colour will be changed by using different types of inorganic CDW (concrete, bricks, glass waste) and where necessary other minerals (carbonates, etc.) or suitable additives according to the advice of the Architect. The benefits revolve around:

- Low on-site manual labour requirements and low material cost because of use of CDW and other industrial waste.
- Cost reduction of 10 €/m² compared to conventional ETICs (product and installation) whilst another 10 €/m² can be saved on scaffolding due to the prefabricated nature of the product.
- Better mechanical properties and better durability of the surface finishing compared to conventional rendering mortars in ETICs.
- Wider variety of surface textures and finishes that can be applied compared to on site prepared ETICs, further reducing the total installed cost.
- Environmentally friendly because of the use of geopolymers and high amounts of CDW and other industrial wastes, substantially reduced CO_2 emissions and energy consumption during manufacturing.
- Designed for easy dismantling/separation for better recycling of the panel at the end-of life.[23]

[23] http://innowee.eu/project/

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5. CDW IN EUROPE

Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for more than 30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled. In Europe, around 868 million tonnes in 2014 of CDW is generated annually[24] and although CDW recovery offers high technical and economic value, the average recovery rate is below 50%[25]. That is because the existing building stock was not designed to be dissembled and reused. The CDW which is recovered is then destined for a low-grade application – most commonly as unbound road base, fill and hardcore.

5.1 Current status

Construction and demolition activities can generate a wide range of different waste materials. These include excavated material such as rock and soil, waste asphalt, bricks, concrete, plasterboard, timber, asbestos and contaminated soil. The generation data on each type of CDW in particular EU Member States can be found in the deliverable D1.1. The construction and demolition activities in Europe generate approximately 860 million tonnes every year. The following figure illustrates the proportion of CDW these activities generate.

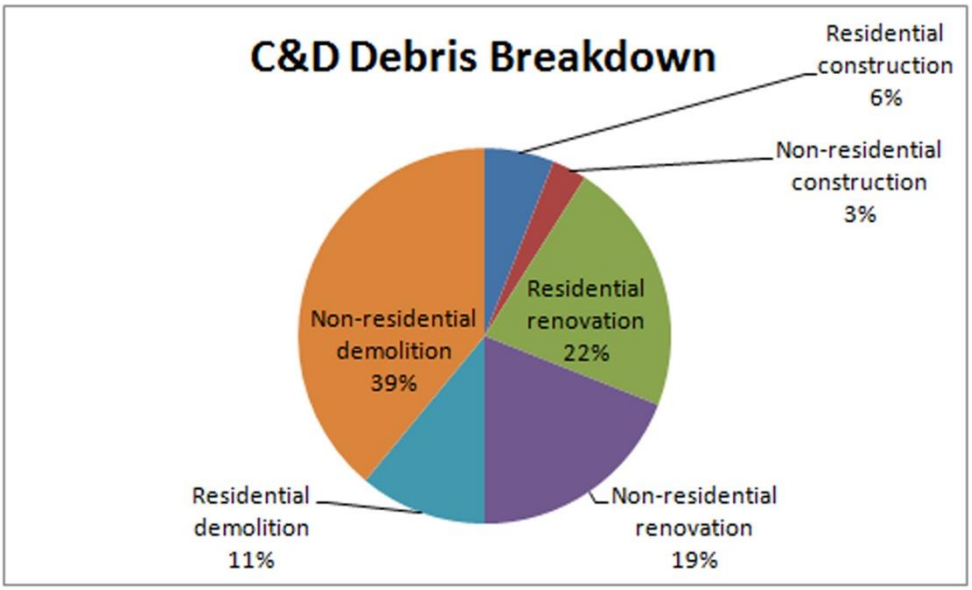

Figure 21: CDW breakdown[26]

[24] EUROSTAT DATA (Reference year 2014)
[25] Implementing EU waste legislation for green growth, DG ENV (2011)
[26] https://www.intechopen.com/books/integrated-waste-management-volume-i/waste-management-at-the-construction-site

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There are great variations across Europe regarding the CDW generation per capita – the lowest 0.04 tons per capita in Latvia while in Luxembourg the generation of CDW is 5.9 tonnes per capita. Denmark, Finland, France, Germany, Ireland and Luxembourg report high quantities of CDW generation while Bulgaria, Greece, Hungary, Latvia, Lithuania, Poland and Slovakia show very low levels of CDW generation per capita. These differences can be explained by various economic reasons, architectural habits, cultural issues and other factors. Nevertheless, they might also be caused by unequal levels of control and reporting of CDW in states[27].

5.2 EU legislation

As the regulatory framework often generates market drivers of a product, this sub-chapter will examine EU legislation regarding the CDW management. The detailed analysis of this EU legislation is provided in the D1.1.

The Waste Framework Directive 2008/98/EC

The Directive sets concepts and definitions dealing with waste management. It states when waste ceases to be waste and becomes a secondary raw material. The most important part of the Directive for the RE[4] project is a fact that it requires Member States to take any necessary measures to achieve a minimum target of 70% (by weight) of CDW by 2020 for preparation for re-use, recycling and other material recovery, including backfilling operations using non-hazardous CDW to substitute other materials.

EU Construction and Demolition Waste Protocol

The Protocol is the non-binding guidelines as a proposal to the industry. Its ultimate goal is to increase confidence in the CDW management process and the trust in the quality of CDW recovered materials. It should be achieved by:

- Improved waste identification, source separation and collection
- Improved waste logistics
- Improved waste processing
- Quality management
- Appropriate policy and framework conditions.

Moreover, during the **COP21 Paris meeting**[28], the international community set forth the following objectives:

- Increase the percentage of recycled materials and reused structures from CDW
- Increase the technical and economic value of CDW-derived materials and structures
- Minimize future CDW coming from the next generation of buildings

[27] http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf

[28] Global Alliance for Buildings and Construction - Raising the Sector's Huge Climate Action Potential to assist in limiting global warming to below 2 °C path (http://web.unep.org/climatechange/buildingsday)

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- Increase the building energy efficiency.

6. IDENTIFICATION OF RELEVANT MARKETS

In the early stages of the project, it is crucial to determine whether a product will be competitive once it is introduced to a market. To do so, the examination of relevant markets is necessary. Through the thorough analysis of said markets, one aims to identify market drivers, meaning the underlying forces that compel customers to purchase product or pay for a service. RE^4 project results will address several European markets; among those are construction market, retrofit market, and prefabricated construction market. The following sections will analyse the aforementioned markets.

6.1 European construction market

6.1.1 Current Status

The construction sector, meaning construction, building and civil engineering, plays a crucial role in EU Member States economies. The construction sector of states' GDP varies across Europe – from 4.9% of GDP in Ireland and Hungary to 13.2% of GDP in Sweden. On average, the GDP share of the construction sector is approximately 8.8% for the EU-28[29]. Simultaneously, the construction sector provides 18 million direct jobs. The construction value chain includes a range of activities such as extraction of raw materials, the manufacturing and distribution of construction products, construction works and their maintenance, renovation, demolition, and recycling of construction and demolition waste.

Until the end of 2006, the growth in construction sector was steadily increasing; however, with the financial crisis in 2008, construction sector experienced a dramatic decline until 2013. The following year, the sector recovered and remained stable. Research analysts predict an increase in construction activity with growth of up to 3% per annum[30]. Compared to February 2015, February 2016 noted an increase of 2.3% in production in construction. According to Eurostat, construction output in 2016 was more positive than predicted. The EU construction industry returned to growth and by comparing the data between 2014 and 2017, the output remained relatively stable[31].

[29] European Construction Sector Observatory, Stimulating favourable investment conditions, analytical report, 2016.
[30] https://buildingradar.com/construction-blog/european-construction-market-forecast/
[31] Eurostat, *Industry and construction statistics – short-term indicators*, May 2017

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Figure 22: Index of production, construction, EU-28, 2007–2017[32]

The construction of buildings – both residential and non-residential accounts for approximately 78% of the total construction in the EU in comparison to civil engineering works (22%)[33]. An annual growth of the residential sector is approximately 1%, due to the financial crisis in Europe; however, it is expected to increase in near future. The increasing number of new dwellings is projected until 2030 – the total increase of the floor space is predicted to be 29% during 2004 – 2030. The following table displays expected construction outputs in EU Member States for the period from 2014-2020.

	2014 CONSTRUCTION OUTPUT	% CHANGE IN REAL TERM						
	Billion euro	2014	2015	2016	2017	2018	2019	2020
Germany	285	2,4	1,8	0,2	-0,4	0,3	0,39	0,48
France	200	-2,8	-0,4	1,8	1,6	1,66	2,13	2,47

[32] Construction production (volume) index overview, http://ec.europa.eu/eurostat/statistics-explained/index.php/Construction_production_(volume)_index_overview

[33] Ibid

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United	177	5,2	5,1	3,5	2,4	3,12	4,21	5,1
Italy	163	-2,2	1,1	2,5	2,8	3,72	5,18	7,2
Spain	63	-2,4	1,8	3,6	5	6,5	7,93	9,04
Netherland	60	0,3	3,4	3,5	4,7	5,78	7,98	9,73
Switzerland	53	0,8	-0,7	1,4	1,5	1,97	2,71	3,01
Norway	46	2,1	3,9	2,5	2,9	3,8	3,87	5,04
Poland	44	4,9	7,1	6,2	6,7	7,5	8,78	10,45
Belgium	39	0,7	0	1,5	2,4	2,93	3,4	3,94
Sweden	34	5,3	1,3	1,1	1,6	2,13	2,6	3,25
Austria	32	1,7	1	1,3	1,5	1,91	2,63	3,52
Finland	29	-0,2	1,5	1,7	3,2	4,1	5,2	5,41
Denmark	27	2,5	2,9	3,5	3,7	4,26	5,49	6,48
Czech	16	1	2,5	3,3	4	4,96	5,56	7,67
Portugal	15	-1	2,5	3,6	5	6,55	8,25	10,4
Ireland	9	10,1	9	10,6	9,2	9,29	9,94	9,94
Hungary	9	14,3	5,1	3,8	2,9	3,45	4,35	5,52
Slovak	4	-0,4	1,8	2,7	3	3,51	4	4,16

Table 2: Output development by Member States - % change in real term34

6.1.2 Residential Buildings

The RE[4] project outcome, i.e. fully prefabricated energy efficient building, addresses mostly residential buildings market. The residential stock is the biggest segment with a floor space of 75% of the building stock. An analysis of the building sector suggests that 64% of the residential building floor area is associated with single-family houses and 36% with apartments[35]. The division between single-family houses and apartments varies among EU Member States – the following figure illustrates that the proportion of floor areas for single-family houses is highest in Greece, Ireland, Norway and the UK while the proportion of floor areas for apartments is highest in Estonia, Latvia and Spain.

[34] https://buildingradar.com/construction-blog/european-construction-market-forecast/

[35] BPIE, Europe's buildings under the microscope

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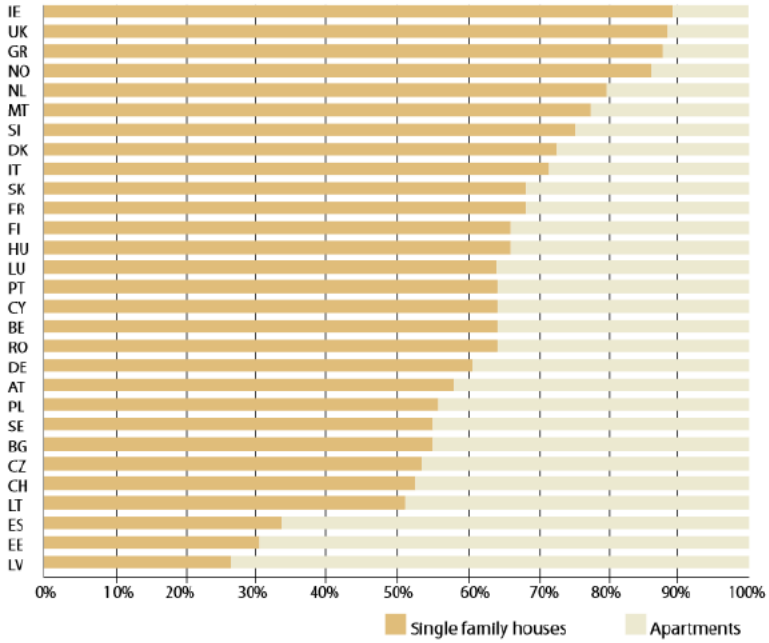

Figure 23: Floor area share of residential buildings

The number of m^2 of useful floor area in EU residential buildings, which obtained permits in 2016, was 15% higher than a year before. The highest increase since 2015 was recorded in Hungary (+139%, compared with 2015), Spain (+107%), Croatia (+33%) and Portugal (+31%). At the same time, the number of m^2 of useful floor area in EU residential buildings which obtained permits decreased only in the Netherlands (-1%, compared with 2015)[36]. Table 3 shows the expected growth rate in the construction of new residential buildings.

	2013	2014	2015	2016	2017	2018	2019	2020
New Residential	-4	0.1	2.6	4.7	3.7	5.0	6.2	7.6

Table 3: Output development by market segments – % growth rate in real terms

6.1.3 European legislation and the construction sector

In 2013, the European Commission put in place a **'Construction 2020' Action Plan**, which outlines a strategy for sustainable competitiveness of the construction sector and its enterprises. It focuses on five objectives: (1) stimulating favourable investment conditions; (2) improving the human-capital basis; (3) improving resources efficiency, environmental performance and business opportunities; (4) strengthening the EU internal market and (5) fostering the global competitiveness of enterprises.

[36] Build-up, *The EU construction industry in 2015 and 2016: promising growth prospect*, 2017.

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Furthermore, the EU has introduced an extensive legislative and regulatory framework – among those are European standards, financial tools, information platforms, labelling schemes and other instruments.

The Energy Performance of Buildings Directive

The EPBD boosts the improvement of the energy performance of buildings. It takes into consideration both outdoors and indoors climate conditions and requirements as well as cost-effectiveness. The Directive lays down minimum requirements for energy performance and enhances the role of energy performance certificates and inspections. The Directive brings several requirements for MS:

- All new buildings must be nearly zero energy by December 2020; public authority buildings must be nearly zero energy by December 2018
- Developing a comparative methodology to calculate cost-optimality of minimum energy performance requirements for buildings
- Member states must provide financial incentives to enable the transition towards nearly zero energy building
- All new buildings must have energy certification
- Member states should enhance heating and cooling system inspection and develop a system of penalties for non-compliance.

6.1.4 Opportunities for the RE^4 project outcomes

The European construction sector is projected to remain stable with increasing number of new dwellings. The construction of new residential buildings was particularly visible in Hungary, Spain, Croatia and Portugal and thus those states would be highly suitable for the RE^4 project results. Other EU Member States can be targeted as well – the Table 2 shows that all Member States are expected to recover from the financial crisis and are expected to expand their building stock. Simultaneously, the EU legislation regulates the construction of new buildings from the environmental point of view. As the RE^4 project outcomes are expected to excel in the "green" aspects, the prospect market position is expected to be large.

6.2 European retrofit market

6.2.1 Current Status

According to the FIEC[37], in 2012 the renovation and maintenance represented 26% of the activity in the European construction industry. RE^4 products are designed to be suitable for both new construction and retrofitting purposes. Consequently, European renovation market has been chosen as another relevant market.

The building stock in the EU consists of about 160 million buildings and 25 billion m^2 of useful floor space. The vast majority of these buildings (approximately 80%) was built in time when the green

[37] European Construction Industry Federation (2016), The Construction Activity in EUROPE, Statistical Report

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technology was still in a cradle and the energy efficiency was not a priority. It has been suggested that such buildings are responsible for about 44% of Europe's total primary energy consumption and more than 30% of greenhouse gas emissions. In terms of energy consumption in the EU, building sector represents the largest share[38].

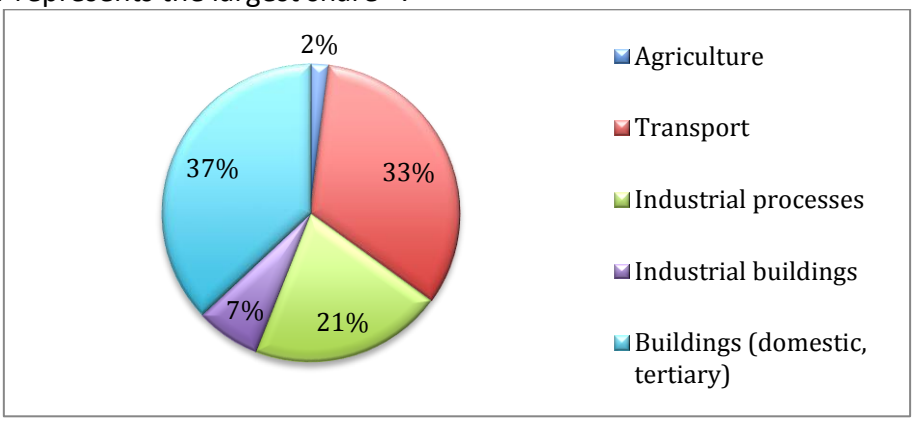

Figure 24: Distribution of total EU energy consumption

As previously mentioned, residential buildings make up the largest share in building sector and are the largest consumers of energy in the building sector. They represent about 75% of the total building stock and 63% of final energy consumption[39].

Although there are several factors contributing to energy-inefficiency such as performance of the installed heating and ventilation system, the building envelope, the climatic zone it is placed in, the behaviour of the occupants and the social conditions that relate to it, the heat losses represent the biggest share. The following figure highlights that the highest heat losses in households are through the walls.

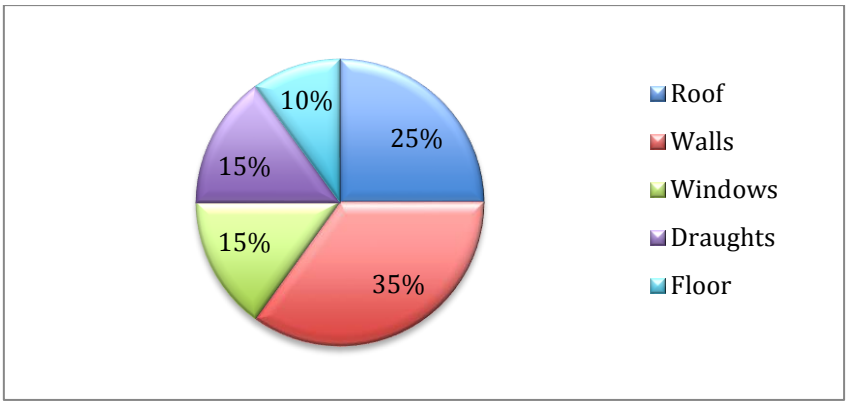

Figure 25: Typical home heat loss: Share of total40

[38] Meefs, http://www.meefs-retrofitting.eu/images/documents/meefs_policy_markets_overview.pdf
[39] http://www.buildup.eu/el/node/50689
[40] http://www.glassforeurope.com/en/issues/faq.php

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According to EuroACE, by 2050, more than 90% of existing buildings will still be standing and will be occupied[41]. Consequently, the renovation of old buildings is an inevitable activity to increase energy efficiency and to reduce CO_2 emissions in Europe. Currently, most renovation activities result only in slight energy savings. To achieve full economic and environmental potential, **renovation activities** must be effective – and **must improve the energy savings at least by 60%.**

6.2.2 Age of Buildings

Different time periods were dominated by particular construction technique trends. Such techniques play an important role in the energy consumption scheme. A considerable share of the stock in Europe is older than 50 years and is highly energy inefficient. The list of countries with the largest share of older buildings includes the UK, Denmark, Sweden, France, the Czech Republic and Bulgaria[42].

Due a boom in the construction sector in Europe during 1960s, the building stock doubled during this period. Unfortunately, the BPIE reported that "the largest energy saving potential is associated with the older building stock where in some cases buildings from the 1960s are worse than buildings from earlier decades"[43].
Existing building stock can be divided into several time periods, out of which three stand out.

- **Before 1945**: Materials and techniques used for construction of buildings in this period involved energy-efficiency measures to a certain extent. However, renovation of these building is not recommended, as the renovation would cost more than what is the value of the building.
- **1946 to 1980**: This period is characterized by the least energy-efficiency. Due to boom in construction sector, the amount of buildings doubled. The buildings were built fast and did not have to fulfil any energy-efficiency standards. Such buildings are the most suitable for deep renovation.
- **After 1981**: European states started to recognize the need for energy-efficiency as to reduce cost and energy consumption. After the EU ruled in EPBD (2002) energy codes standards, member states are required to comply both during renovation and during construction of new buildings.

The following graph show the age categorization of households in Europe[44].

[41] http://euroace.org/wp-content/uploads/2016/07/EuroACE-Leaflet.pdf
[42] Meefs, http://www.meefs-retrofitting.eu/images/documents/meefs_policy_markets_overview.pdf
[43] BPIE Report, 2011, http://bpie.eu/wp-content/uploads/2015/10/EU-B-under-the-mic_executive-summary.pdf
[44] https://www.researchgate.net/figure/311427966_fig4_Figure-2-Age-distribution-of-European-Housing-Stock

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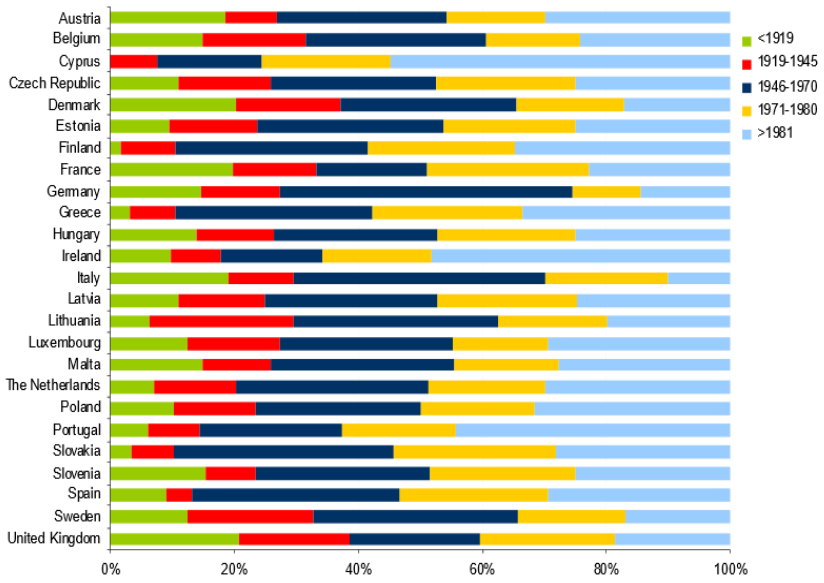

Figure 26: Age categorization of households in Europe

Table 4: Age distribution of European housing stock

	Year	<1919	1919-1945	1946-1970	1971-1980	1981-1990	1990-2000	> 2000
Austria [1 2]	2009	15.2	8.2	28.0	15.2	11.5	13.6	8.3
Belgium [3 4]	2009	17.1	24.2	24.2	13.7	20.8		
Bulgaria								
Cyprus [5 6]	2001	na	7.4	16.9	20.7	27.4	27.1	-
Czech Republic [1 5]	2005	10.5	14.2	25.4	21.8	15.8	7.9	3.4
Denmark [7]	2009	19.7	16.1	26.4	16.6	9.1	5.4	6.7
Estonia	2009	9.4	14.2	30.0	21.5	19.6	2.0	3.3
Finland [4]	2009	1.5	8.1	27.6	21.5	18.5	11.5	9.8
France [1 8]	2006	17.0	13.2	17.4	25.2	10.2	8.5	8.4
Germany [9]	2006	14.4	13.6	46.3		13.2	9.2	3.3
Greece	2001	3.1	7.2	31.8	24.5	19.1	14.4	na
Hungary [10]	2005	-	20.8	27.2	23.1	17.8	7.9	3.2
Ireland	2002	9.4	8.0	15.9	14.2	13.2	19.5	19.8
Italy [11]	2001	14.2	9.9	36.8	18.8	12.2	7.9	-
Latvia	2008	13.8	13.1	22.1	19.4	20.2	7.0	4.4
Lithuania	2002	6.2	23.3	33.1	17.6	13.5	6.3	-
Luxembourg [3]	2008	21.8	25.6	29.2	11.6	5.1	4.5	2.2
Malta [12]	2005	12.2	10.0	22.1	16.2	19.1	17.0	3.4
Netherlands [13]	2009	6.9	13.9	27.0	17.0	15.4	12.0	7.9
Poland [14]	2002	10.1	13.1	26.9	18.3	18.7	12.9	-
Portugal [3]	2008	7.4	10.0	21.9	16.1	18.8	17.7	8.1
Romania [15]	2002	3.9	11.5	37.3	23.8	14.8	7.3	1.4
Slovak Republic [1 5]	2001	3.4	6.6	35.1	25.6	21.0	6.2	0.6
Slovenia [16]	2004	15.1	7.8	27.7	23.2	16.0	6.9	3.4
Spain [17]	2001	8.9	4.2	33.5	24.1	13.6	15.7	-
Sweden	2008	12.1	14.7	37.0	16.8	9.4	5.5	4.6
United Kingdom [18]	2004/5	17.0	17.0	21.0	21.8	20.0	na	na

*Dwellings classified by the period in which the construction of the building containing them was completed.[45]

[45] The Hague: Ministry of the Inferior and Kingdom Relations, Housing statistics in the European Union

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1 (Permanently) occupied dwellings
2 1919-1944, 1945-1970, 1991-2000
3 Estimate
4 From 1981 and onwards
5 Difference of percentage totals 100% due to unknown age of stock
6 < 1945 covers convential dwellings
7 < 1919, 1920-1945, 1945-1969, 1970-1979, 1980-1990, 1991-2000 > 2000
8 <1915, 1915-1948, 1949-1967, 1968-1981, 1982-1989, 1990-1998, >1999
9 <1919, 1919-1948, 1949-1978, 1979-1986, 1987-1990, 1991-2000, >2000
10 <1944, 1945-1969, 1970-1979, 1980-1989, 1990-1999, >2000
11 <1919, 1919-45, 1946-71, 1972-81, 1982-91, >1991
12 <1920, 1921-1950, 1951-1976, 1977-1985, 1986-1990, >1990
13 <1906, 1906-1944, 1945-1970, 1971-1980, 1981-1990, 1991-2000, >2000
14 <1918, 1918-1944, 1945-1970, 1971-1978, 1979-1988, >1988
15 <1910, 1910-1944, 1945-1970,1971-1980, 1981-1989, 1990-1999, >1999
16 Data include holiday dwellings
17 Main residences only: <1920, 1921-1940, 1941-1970, 1971-1980, 1981-1990, 1991-2001
18 <1919, 1919-1944, 1945-1964, 1965-1984, >1984

According to a report from Pike Research[46], market for retrofitting will nearly double from $80.3 billion in 2011 to $151.8 billion by 2020. Moreover, the report suggests that retrofitting is one of the most cost-effective ways to reduce operational costs. Western Europe is at the moment considered the biggest market of retrofits for energy efficiency, followed by Asia Pacific and North America.

6.2.3 Motives for retrofitting

An increasing number of buildings are implementing green retrofits. Motives to retrofit commercial and public buildings to make them more energy-efficient have many different drivers, namely, a responsibility to reduce greenhouse gases and carbon footprints, the desire to reduce operational costs by reducing energy consumption, improve productivity, reduce healthcare costs or to improve a company sustainability reports[47]. For the owners of the residential buildings, the top motive for undergoing a "green" retrofit is the energy savings which is directly linked to reduction of operational costs. In general, the investment payback was the most significant motivator for retrofits. Building appearance is also one of the triggers for starting building retrofits. Lastly, the financial incentives provided by a state contributed to a positive answer to a question whether or not to retrofit[48].

6.2.4 European legislation and retrofit sector

In the 2000, Green Paper setting forth a strategy to secure energy supply, the EU named energy efficiency as the best way to establish energy security over a longer term. One of the EU's envisioned goals is to achieve and maintain sustainability in general and to reduce CO_2 emissions in particular. To achieve this, the European Commission has a variety of directives and other legislation at hand.

Article 194 of the TFEU sets the objectives to the energy policy to:

- Ensure the function of the energy market
- Ensure security of energy supply in the Union

[46] Pike Research, Energy Efficiency Retrofits for Commercial and Public Buildings, 2012.
[47] Deloitte, The dollars and sense of green retrofits, 2008
[48] Climate Policy Initiative, Drivers of Thermal Retrofit Decisions – A Survey of German Single and Two-Family Houses, CPI Report, 2011.

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- Promote energy efficiency and energy saving and the development of new and renewable forms of energy
- Promote the interconnection of energy networks.

The Energy Performance of Buildings Directive

The European Parliament and the Council approved the Energy Performance of Buildings Directive in 2002 and came into force in 2003. The Directive was inspired by the Kyoto Protocol, which obliges the European Union to reduce CO2 emissions by 8% by 2010. A recast of the Directive took place in 2010 and made rules for member states stricter. Among those are:

- Developing a comparative methodology to calculate cost-optimality of minimum energy performance requirements for buildings
- All buildings must consider minimum energy performance during a major renovation, including retrofitting of buildings' envelope
- Member states must provide financial incentives to enable the transition towards nearly zero energy building
- Member states should enhance heating and cooling system inspection and develop a system of penalties for non-compliance.

The Energy Efficiency Directive

The Energy Efficiency Directive sets rules and obligations to help the EU reach its 2020 energy efficiency targets. The European Union has identified energy efficiency as a crucial element in ensuring the sustainability and it set an aim to reduce energy use by 20% by 2020. A couple of Directive's highlights concerns buildings; these are:

- Member states must commit to renovation of 3% of buildings owned and occupied by the authorities such as government.
- Moreover, buildings occupied by public authorities and buildings frequently visited by the public should set an example by showing that environmental and energy considerations are being taken into account and therefore those buildings should be subject to energy certification on a regular basis.
- Member states are required to present a plan, which will make the entire building sector more energy efficient by 2050.

The EU Heating and Cooling Strategy

The European Union has set a strategy to optimize buildings' industries' heating and cooling systems. A part of the strategy relevant to buildings aims to develop a way to make renovation of buildings easier. It should be done so by:

- Developing of a toolbox of measures to ease the renovation of multi-apartment buildings
- Promoting proven energy efficiency models
- Strengthening reliability of energy performance certificates.

Green Public Procurement

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Public sector's spending accounts for 17% of EU GDP and publicly owned or occupied buildings represent about 12% by area of the EU building stock[49]. The largest share of the residential stock is held in private ownership while 20% is allocated to 'pure' public ownership. A stronger emphasis on energy efficiency in the public sector is crucial, covering public purchasing, the refurbishment of public buildings and the encouragement of higher building standards in cities and communities.

According to the EU Commission, the public sector can create new markets for energy-efficient technologies, services and business models. As envisaged by the draft **Energy Efficiency Directive**, public sector is anticipated to take a leading role in the renovation revolution. Public sector should kick start the market for renovation and help bring costs down for private households and businesses[50].

6.2.5 Requirements and renovation policies in EU Member States

Many EU Member States have already envisioned ideas for improving their building sectors. In Denmark (2012), there was a wide political support for measures such as building retrofitting. The target of Denmark is to eliminate fossil fuel as energy source as well as for transport by 2050. France set a goal to reduce energy consumption in existing building stock by 38% by 2020. In Germany, a proposal to reach almost climate neutral building stock by 2050 was approved. Environmental quality objectives, including a good build environment, which describes the state of environment, takes place in Sweden[51]. The following table briefly summarizes policies and requirements for renovation in member states – data are taken over from the BPIE report[52].

Country	Policies and Requirements for Renovation
Austria	• No national obligatory requirements for renovating buildings • "Theoretical" requirements related to the maximum heating energy demand of renovated buildings and the maximum externally induced cooling demand • Major renovations should achieve at least the B rating (less than 50kWh) – it should be expected to change to A+ rating (less than 10kWh) by 2020 • Financial subsidies are provided for measures improving thermal insulation

[49] European Commission, Energy Efficiency Plan 2011
[50] European Commission, The European construction sector – A global partner, 2016.
[51] BPIE (2013), Boosting building renovation. An overview of good practices, http://bpie.eu/wp-content/uploads/2015/10/Boosting_building_renovation_-_Good_practices_BPIE_2013_small.pdf
[52] Ibid

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Belgium	• Specific component requirements such as maximum U-value • All buildings that undergo major renovation should comply with the very low energy standard • Buildings bigger than 800m^3, maximum R-values or minimum U-values are expected • A standard for roof insulation has been set
Bulgaria	• Regulations requiring performance-based standards of existing buildings and buildings after renovation • New and renovated building have the same requirements
Cyprus	• Minimum energy performance requirements (class A or B) for buildings over 1000m^2 undergoing major renovation
Czech Republic	• Requirements for renovations of building larger than 1000m^2 • New and renovated building have the same requirements • Building envelope must fulfil minimum requirements • Requirements for major renovation of residential buildings (U-value thermal bridging limits, thermal stability of the room, minimum efficiency of boilers
Denmark	• Minimum energy requirements for building components (all energy upgrading measures must be economically feasible • In case of external walls, the minimum energy performance requirement applies regardless of cost-effectiveness
Estonia	• All types of building, which undergo renovations have to fulfil specific requirements • Values for renovated buildings are around 25-38% higher than new build requirements
Finland	• Minimum requirements for energy efficiency regarding renovations <u>Instruments:</u> a) Improving the heat retaining capacity b) Improving energy efficiency c) Reducing the building's E-number by reducing energy consumption

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France	• For major renovations (>1000 m2): the overall energy performance target for renovated buildings built after 1948 is in the range 80-165 kWh/m2/year • For renovations <1000 m2: element-based requirements for replacement or renovation of elements (for heating, insulation, hot-water production, cooling and ventilation equipment) Goals: • Renovate 400,000 housing units per year • Renovate the 800,000 most energy-consuming social housing units by 2020 Undertake work on energy efficiency in public and private tertiary sector buildings between 2012 and 2020.
Germany	• Germany wishes to achieve climate neutral building stock by 2050 • Minimum efficiency for buildings for renovations • Building surface components must not be changed in a way that decreases the energy performance of the building • Requirement of cost-effective renovation for insulation of hot water pipes and top floor ceilings, retrofit of HVAC systems and replacement of electrical heat storage systems
Greece	• Building envelope must fulfil minimum requirements in the renovated building • Minimum thermal resistance defined for different types of building components and different efficiency of systems • Thermal bridges are being considered
Hungary	• Residential buildings, offices and educational buildings must fulfil performance-based requirements • New and renovated building have the same requirements • Primary energy consumption must comply with the requirement
Italy	• Energy performance requirements for major renovations • Requirements for the installation of RES systems for heating and PV • Minimum energy efficiency requirements for boilers • Requirements for specific regions (e.g. in Bolzano, owners of building will be allowed to expand the building's surface only if the building can achieve heating consumption below 70kWh/m^2 per year) • New and renovated building have the same requirements
Latvia	• Requirements on different elements

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Lithuania	• Building larger than 1000m^2 must achieve the energy performance standard of a class D (less than 110kWh/m^2 per year) when being renovated • Building envelope and systems in buildings must fulfil minimum requirements depending on renovation
Malta	• U-value requirements for building renovation
Netherlands	• Insulation requirements apply for skylight windows or renovation of existing ones • Requirements for the energy performance of major renovations of existing buildings • New and renovated building have the same requirements • All material and product used for renovation must have an approved label
Poland	• New and renovated building have the same requirements
Portugal	• Requirements for buildings over 1000m2 and over a specified energy cost threshold • A mandatory energy efficiency plan must be prepared and implemented (payback of less than 8 years) for a major renovation • Minimum requirements for thermal resistance for different types of buildings • Building should achieve a healthy indoor climate • Thermal bridges should be avoided • Minimum insulation levels for the building envelope
Romania	• The actual energy performance of a building is compared with a "reference building" which is a virtual building having the same geometry as the actual building but the energy performance of a new one – concerning individual parts of the building envelope and systems
Slovakia	• In case of a major renovation, requirements to improve the thermal performance by at least 20% • There are minimum requirements in term of energy use and energy performance (U-value, insulation of heat and hot water systems, thermal comfort and indoor quality)
Slovenia	• Minimum requirements apply to major renovations, in case at least 25% of the envelope is renovated • The requirements apply to all buildings • Minimum requirements for heating systems

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Spain	• If a building (over 1000m^2) undergoes a major renovation, it must comply with the same requirements as new buildings • Energy efficiency, heating and lighting systems, minimum solar-thermal contribution requirements
Sweden	• Depending on the size of the renovation, it has to fulfil energy requirements for new buildings • In case of major renovation, the minimum energy efficiency requirements may be extended also to other parts of the building
United Kingdom	• In case of thermal element renovation, the element should improve U-value of the building • Renovation should be technically, functionally and economically feasible • In case of roof renovation, thermal efficiency must fulfil regulations • From April 2018, private rented properties must be brought up to a minimum energy efficiency rating of E

Article 4(2) of the EPDB 2010/31/EU is setting five target strategies to be dealt with by member states, and through which member states can be examined on cooperation with national legislation and policy-making on the topic of renovation and retrofitting of buildings across the EU.

The following strategies are Overview of the National Building Stock - Art 4 (a), Cost-effectiveness approaches of renovations - Art 4 (b), Policies and measures to stimulate cost-effective deep renovations of building - Art 4 (c), Forward-looking perspective to guide investment decisions - Art 4 (d), and Evidence-based estimate of expected energy savings and wider benefits - Art 4 (e). The ranking of the member state compliance with the article on a national level is measured in the report "Synthesis Report on the assessment of Member States" building renovation strategies" from 2016, which is policy report, produced in 2016 for the European Commission.

The grading was given separately for each topic, on a scale of 0 to 5.

- 0 meaning that the topic is not dealt with in national level
- 1 that the topic is addressed in a non-satisfactory level
- 2 the topic dealt with but inadequately
- 3 the topic dealt with adequately
- 4 the topic is described well, and the grade is "good"
- 5 the topic is covered completely.

The following table summarizes the evaluation of Member States according to the report[53], only 10 countries fully comply with the Article 4(2) of the EPDB.

[53] Castellazzi L., Zangheri P., Paci D.; Synthesis Report on the assessment of Member States' building renovation strategies; EUR 27722 EN

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Member State	Overview of building stock – 4(a)	Identification of cost-effective approach to renovation – 4(b)	Policies to stimulate cost-effective renovation – 4(c)	Forward-looking perspective to guide investment decisions – 4(d)	Estimate of expected energy saving and wider benefits – 4(e)
Austria	4	3	2	1	1
Belgium (BCR)	4	4	4	3	2
Belgium (Flanders)	3	1	2	1	2
Belgium (Wallonia)	1	1	1	0	0
Bulgaria	1	2	2	2	0
Croatia	4	4	3	4	2
Cyprus	3	3	3	2	3
Czech	3	3	4	4	4
Denmark	3	3	4	2	2
Estonia	2	3	2	3	3
Finland	4	2	4	3	4
France	4	4	4	3	3
Germany	4	1	3	2	3
Greece	4	3	4	5	4
Hungary	4	3	3	3	3
Ireland	4	3	4	3	3
Italy	3	2	3	2	3
Latvia	4	2	3	3	3
Lithuania	3	3	3	3	4
Luxembourg	4	2	4	2	3
Malta	3	3	4	3	2
Netherlands	4	3	3	2	3
Poland	3	1	3	1	2
Portugal	1	0	2	1	0
Romania	4	3	4	4	4
Slovakia	4	2	3	3	3
Slovenia	4	3	4	3	4
Spain	5	4	4	4	4
Sweden	4	2	3	1	2

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United Kingdom	**5**	**4**	**4**	**3**	**3**

RED – non-compliant strategy
ORANGE – strategy not fully compliant
BLUE – strategy almost fully compliant
GREEN – strategy fully compliant

Table 5: Member states' performance grading

6.2.6 Opportunities for RE^4 project outcomes

The existing building stock in Europe is dominated by energy-ineffective buildings, which contribute largely to energy and heat losses. From the environmental point of view, the reconstruction of this building stock is inevitable. Also, according to a Pike Research[54], Europe offers the biggest market for retrofitting. As RE^4 project is focused on the application within Europe, it is safe to claim that the market potential is immense. Moreover, the European legislation is in favour of energy efficient renovation solutions and thus is assumed to positively contribute to end-users' acceptance. So far only 10 countries (Czech, France, Greece, Hungary, Ireland, Lithuania, Romania, Slovenia, Spain and the UK) fully comply with the Article 4(2) of the EPDB 2010/31/EU which sets regulation regarding renovation and retrofitting. These states should be RE^4 target group.

It has been suggested that to fully achieve both European goals and economic potential, the retrofit must improve the energy savings at least by 60%. The developers of RE^4 project products should bear this in mind and should ensure that the RE^4 fully prefabricated building will meet this target. There are other factors to take into account. Those are:

- Excellent ROI
- Appearance
- Financial incentives
- Reduction of greenhouse gases and carbon footprints.

6.3 European prefabricated construction market

A prefabricated building is a building that is manufactured and constructed using prefabrication components and technology. It includes factory-made components or units that are transported and assembled on-site to form the complete building. As these buildings are built in parts, a house owner can easily add additional room or other components to the building. In the past few years, there has been an increase in the use of "green" materials in the construction of prefabricated houses.

The most common prefabricated component of a prefabricated building is a concrete panel. Concrete panels represent a solid but moveable wall or face, which is produced in a precast plant.

[54] Pike Research, Energy Efficiency Retrofits for Commercial and Public Buildings, 2012.

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As panels are produced in controlled environment, the curing, demoulding and monitoring of the concrete can be conducted properly. In many cases, weather delays occur on site, however, in case of precast concrete panel, which is produced in a precast plant such delays are omitted. Another key characteristic of precast concrete is its energy efficiency. Due to panels' high thermal mass, which enables them to store and then release significant amounts of heat, precast concrete allows for energy savings. Precast concrete has another cost-related benefit; the forms used in a precast plant can be reused hundreds to thousands of times before they must be replaced, while the ones on site usually do not have long lifespan. Panels can be produced in various shapes and sizes and therefore architects and designers do not have to limit themselves in creative design. The reason general contractors tent to choose such panels is often due to concrete's fire resistance, which is rather high. Another advantage of prefabricated houses is a fact that the constriction time period is significantly shorter compared to traditional construction. Last but not least, it has been suggested that the use of prefabricated elements results in lower amount of waste generation (up to 50%)[55].

The prefabricated construction market has been growing in accordance with the global construction industry, after the economic slowdown between 2007 and 2009. The global prefab construction market is projected to reach USD 208.79 billion by 2020, at a CAGR of 6.50% between 2015 and 2020. According to global shipments of Prefabricated Housing, approximately 1.1 million units of modular homes are expected to be sold by 2020. Lower construction costs, improved functionality, superior aesthetics and weather-resistance are key benefits driving demand for high performance manufactured houses. In particular states, demand is driven by a fact that prefabricated buildings are resistant to harsh weather including earthquakes.

6.3.1 Opportunities for RE^4 project outcomes

The aim of the Project is to construct fully prefabricated energy efficient building. As shown, the prefabricated construction market is expected to grow and thus provide an opportunity for RE^4 products to be placed on an expanding market. The main drivers for prefabricated buildings are:

- Low construction cost
- Improved functionality
- Superior aesthetics
- Weather resistance
- Flexibility to add another component
- Energy efficiency
- Shorter period of construction (compared to traditional one)
- Flexibility in sizes.

[55] L. Jaillon, C.S. Poon, Y.H. Chiang *Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong* Waste Management, Volume 29, Issue 1, January 2009, Pages 309–320

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7. TARGET AUDIENCE

RE^4 project outcomes revolve around the prefabricated energy efficient building components made of CDW. The target audience this project addresses are house owners who wish to retrofit, those who are aiming to own a house, construction companies and demolition companies. The following paragraphs will identify what are the reasons and motives for purchasing prefabricated construction components and what parameters are taken into consideration while choosing specific type. The focus will be placed on target audience as well as on designers and architects.

As previously mentioned, the drivers for prefabricated construction material include:

- Low construction cost
- Improved functionality
- Superior aesthetics
- Weather resistance
- Flexibility to add another component
- Energy efficiency
- Shorter period of construction (compared to traditional one)
- Flexibility in sizes.

Looking at the preferences of customers, in most cases, the price is the determining factor. As the project is still in its early stages, it rather difficult to compare its costs at the moment. Nevertheless, the preliminary ROI calculations seem more than positive. As the goal of the RE^4 project is to construct fully prefabricated energy efficient building, the energy efficiency is also known to reduce the energy bills of a building owner. The higher the efficiency, the less it will cost to operate. Although the difference in annual energy cost between two buildings might be small, in the long range, the difference adds up[56]. RE^4 also aims to develop a product with low maintenance costs.

Simultaneously, the increasing demand for sustainable products has been noted worldwide in general and in Europe in particular. Over the span of one year, the willingness to pay more for environmentally friendly products has increased from 55% in 2014 to 72% in 2015[57]. According to a recent study, "green building" continues to double every three years as customers demand sustainability for both energy-efficiency and occupant benefit. Researches[58] also show that the factor of "health" and "safety" are equally important aspects.

Regarding the architects and construction companies demands, the weather resistance and durability are crucial for buildings. For this reason, RE^4 project commits to examine and develop a product with high anti-seismic performance. The designers, on the other hand, wish to have

[56] Selecting a home heating system. https://www.energydepot.com/RPUres/library/homeheating.asp

[57] The Nielsen Company, *Green Generation: Millennials Say Sustainability is a Shopping Priority*, The Nielsen Company (Nov. 5, 2015).

[58] An Analysis of Residential Customers' Preferences for Household Energy Systems.

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prefabricated materials in various sizes and shapes, meaning have possibilities to create various building layouts, placing their drivers on the aesthetics.

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8. MARKET DRIVERS AND BARRIERS

The previous chapters explored the options on the current European markets, the preferences of the end-users as well as the CDW situation in the EU. Based on those findings, this chapter aims to summarize what are the positive and negative forces compelling the target audience to either purchase a product or discourage from buying.

8.1 Market Drivers

Market Driver	*How does RE^4 address it?*
A need for sorting system that can recycle at least 80% of CDW	Although the competitors' analysis showed that there is a number of existing sorting systems, there is none that would sort more than 75% of CDW and especially not at the European market.
Currently, there are barely any prefabricated components made of CDW. Recovered CDW is used for low-grade application.	RE^4 aims to produce high quality prefabricated components made of recovered CDW applicable for direct construction of buildings.
Construction components must be suitable for all parts of Europe, taking into account anti-seismic performance	One of the objectives of RE^4 is to examine and excel in anti-seismic performance.
Easy installation	RE^4 products are expected to be characterized by easy installation, disassembly and reuse.
Recyclability	Positive LCA of RE^4 project is expected.
Excellent ROI	Preliminary calculations show ROI of 2 years for prefabricated elements production.
Energy efficiency	The ultimate goal of the project is to construct fully prefabricated energy efficient building.
A need for a solution how to utilize CDW	RE^4 prefabricated components will be made mainly from CDW
A favourable regulatory environment	The EU legislation plays a key role in the construction and renovation sector. As RE^4 technology is a "green" technology

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	and contributes to deal with the excessive CDW in Europe, the legislation is favourable.
Building stock is expected to expand	RE^4 technology is suitable for both newly constructed buildings and those that are to be renovated
Renovation and retrofitting is inevitable	
Appearance	The developers of prefabricated components should bear in mind the aesthetics and availability of the products in various shapes and sizes
Financial incentives	Is yet to be investigated
Cost reduction	The long-term cost saving is expected due to energy efficiency of RE^4-prefabricated building
Indoor air quality	Is yet to be examined
Durability	Is yet to be examined

8.2 Barriers

Barriers
• **Despite numerous benefits offered by offsite construction, the lack of consumer awareness remains a major challenge that prefab home manufacturers across the globe continue to face**
• **Penetration in the European building sector has been slow in recent year thanks to low construction rate of new building (1,3%) and renovation rate around 1,5%.**
• **The initial investment into RE^4 technology might be high**
• **Lack of user's experience with products made of CDW**
• **User's confidence – There are perceptions that waste should not be used as raw material**
• **Certification and standardization are yet to be dealt with**
• **Durability and indoor air quality are yet to be verified**

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9. EVALUATION OF RE^4 PRODUCT PROSPECT POSITION ON A MARKET

The previous chapter identified the market drivers and barriers of the project products. This chapter aims to evaluate, based on the market drivers and barriers, RE^4 packages prospect market position. The evaluation will be conducted in form of the SWOT analysis.

Strengths
• **Easy installation, maintenance, reuse**
• **RE^4 sorting system can recycle up to 95% of CDW**
• **Green technology which is in line with EU strategies**
• **High recyclability potential**
• **High replication potential**
• **Excellent ROI**
• **The use of the RE^4 technology contributes to energy saving**
• **Positive LCA**
• **Long-term cost saving**

Weaknesses
• **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, examining and verifying is still needed**

Opportunities
• **Minimal competition on the European market**
• **A favourable regulatory environment**
• **Reduced consumption of raw materials**
• **Entire components can be reused**
• **Energy efficiency**
• **RE^4 technology contributes to solving the issue with excessive CDW**
• **Market potential is large with existing and growing need for energy-efficiency**

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Threats
• **Public acceptance**
• **Certification and standardization**
• **Ongoing similarly oriented projects**
• **New low-energy buildings might reduce demand for RE^4 technology**

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10. CONCLUSION

The present document constitutes the first version of the market assessment of the RE[4] project. The Deliverable will be updated along the project development and serve as basis for the business plans, models and strategies tailored for the RE[4] project outcomes. It is important to note that the project is in its early stages and thus important data are yet to be examined, testes and verified. Such data will be crucial for the comparison of the RE[4] project outcomes and their competition.

The goal of the Deliverable was to map the RE[4] relevant markets – construction, retrofit, and prefabricated construction European markets. The following observations were made.

- The European construction sector is projected to remain stable with increasing number of new dwellings. The construction of new residential buildings was particularly visible in Hungary, Spain, Croatia and Portugal and thus those states would be highly suitable for the RE[4] project results. Other EU Member States can be targeted as well – all Member States are expected to recover from the financial crisis and are expected to expand their building stock. Simultaneously, the EU legislation regulates the construction of new buildings from the environmental point of view.
- The existing building stock in Europe is dominated by energy-ineffective buildings, which contribute largely to energy and heat losses. From the environmental point of view, the reconstruction of this building stock is inevitable. Also, according to a Pike Research[59], Europe offers the biggest market for retrofitting. Moreover, the European legislation is in favour of energy efficient renovation solutions and thus is assumed to positively contribute to end-users' acceptance.
- The aim of the Project is to construct fully prefabricated energy efficient building. The prefabricated construction market is expected to grow and thus provide an opportunity for RE[4] products to be placed on an expanding market.
- European legislation and strategies are favourable for the RE[4] technology. The excessive amounts of CDW are overburdening Europe and this project offers a solution.

Based on the examination of the markets, CDW status in Europe, and target audience preferences, market drivers and barriers were identified. The overall evaluation of the project outcomes was conducted in the previous chapter through the creation of the SWOT analysis. One can note that the strengths and opportunities exceed the weaknesses and threats.

Undoubtedly, RE[4] project outcomes have a huge potential across the Europe, bringing various benefits such as introduction of a solution to a problem of excessive CDW in Europe, enhanced energy efficiency, long-term cost reduction, recyclability, easy installation, reuse of entire components and easy maintenance. The identification of market drivers and their application on

[59] Pike Research, Energy Efficiency Retrofits for Commercial and Public Buildings, 2012.

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RE^4 products seem to have optimistic conclusions as the vast majority of market drivers are positively addressed by the project outcomes.

On the other hand, there are also few barriers that might humper the smooth introduction on a market such as:

- Lack of user's experience with products made of CDW
- User's confidence
- Certification and standardization
- Low construction and renovation rates

The developers of the RE^4 project products should also bear in mind to thoroughly examine parameters such as indoor air quality, durability, and overall safety to promote public awareness. Simultaneously, it would be fruitful to pursue certification and standardization processes as well as to lobby for public financial incentives to support CDW management through RE^4 products.

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