Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste

**Project Information**

IRCW

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Executive Summary:

The “Innovative Strategies for High Grade Material Recovery from Construction and Demolition Waste” (IRCOW) project has come out with some interesting results of technical and non-technical nature related to managing Construction and Demolition Waste (C&DW) as a resource of valuable materials which can be recovered for high-grade applications back in the construction sector.

C&DW represents one of the European Union’s largest waste streams, by weight and volume. Although many European Member States have undergone a strong increase in C&DW managing awareness and infrastructure, in line with the claims of the European Directive on Waste, the overall material recovery performance from C&DW in the European Union reveals that further improvement in the reuse and recycling are needed to move towards a high level of resource efficiency.

In this scenario, the main goal of the IRCOW project (2011-2014) has been to develop and validate upgraded solutions by considering a life cycle perspective, ranging from innovative approaches to cutting-edge technologies and products. IRCOW also suggests introducing some changes in the European Policy to make C&DW reuse and recycling happen more often and more effectively. By the end of the project the most promising IRCOW solutions are on a short track towards market uptake. The involvement of industrial stakeholders and national and regional authorities ensures the relevance and applicability of the project results.

One of the work lines of IRCOW has consisted in a comprehensive study of the reuse of C&D materials, with the aim to formulate improved strategies. The current reuse markets are limited to components of cultural or aesthetic value and small scale businesses aimed at private consumers and smaller companies. Important barriers hampering the reuse of C&D materials are related to costs, quality and weak market structure. Initiatives and incentive to stimulate the reuse market are needed, e.g. to include a reuse perspective in public green procurement together with increased knowledge and information on possible applications for reused materials in order to overcome current lack of confidence.

Furthermore, a demo e-platform for the reuse of elements and materials recovered from C&DW, serving as an example of how such an e-platform embracing several functions could operate, has been developed under IRCOW. The overall objective for the C&DW reuse platform is to facilitate and promote the reuse in practice. A dedicated demo stock-exchange tool is its central element. This is complemented by a wiki-area in which e.g. good practices that already exist in some countries are described. Moreover, as the e-platform has an ambition to help share knowledge and build networks of stakeholders involved in these processes, a database of agents involved in C&DW reuse is also available.

Innovative recycling technologies for C&DW recycling systems, not only for a stony fraction but also for other fractions where there is currently a strong knowledge gap, were examined in IRCOW. Advanced automated sorting techniques by colour or chemical composition were successfully researched and developed for high quality sorting of plastics, gypsum and red-grey stony fraction. Also the treatment of C&DW containing fibrous materials like asbestos, mineral and glass wool and other fibrous materials, based on Microwave Thermal Treatment (MTT) technology was developed and validated. Moreover,
multilayer composite extrusion technology (WPC) has been applied for recycling C&D mineral wool, gypsum plasterboard and mixed wooded materials with recycled plastics.

Additionally, a series of high-grade construction materials and components from recycled C&DW was developed within IRCOW. Cellular concrete C&DW was recycled into raw material for subfloors. A number of cement/chalk based mixtures were produced using recycled aggregates. Moreover, C&D gypsum waste was recycled into gypsum plasterboards and recycled ceramic aggregates were used for recycled bricks. Multilayer composite decking boards and multilayer panels for façade were also developed. An expert recycling tool assessing environmental and human health risks associated with recycling alternatives is openly available.

Five case studies at real construction or demolition sites were carried out in different parts of Europe. Each of them was focused on different practical aspects of C&DW management towards material reuse, recovery and application for high-grade construction materials and components production. The case studies provided a unique opportunity to validate which of the solutions proposed by IRCOW are technically feasible, economically viable, environmentally more appropriate (based on Life Cycle Assessment studies) and realistically applicable in market conditions.

Project Context and Objectives:
Construction and demolition waste (C&DW) represents one of the European Union’s largest waste streams, in quantitative terms by weight and volume. Directive 2008/98/EC4 on waste stresses the need to improve the material recovery efficiency of this waste stream. Although many European Member States have undergone a strong increase in C&DW recycling awareness and infrastructure, the overall material recovery performance in the European Union reveals that further improvements must be undertaken to move towards a high level of resource efficiency.

Some EU countries have attained high recycling rates for the stony fraction, but most of the derived recycled products (recycled aggregates and sands) are used in low-grade applications in civil engineering unbound applications. This market for recycled aggregates, however, is getting more and more saturated. Therefore, a shift towards more structural concrete applications is currently investigated and promoted.

The main bottleneck for incorporating recycled aggregates in higher grade uses deals with the lack of confidence in such products, due to variable properties, potentially lower strength of the aggregates, lack of purity (lightweight particles such as wood or plastics) or presence of potentially harmful components like sulphates associated with gypsum. To obtain higher quality levels for recycled aggregates, current approaches for C&DW recycling technology are focusing on the development and incorporation of more advanced sorting systems compared to traditional treatment schemes.

In general, recovery rates for the other C&DW fractions (except for metals) in the EU remain well below the 2020 target. Large amounts are still being incinerated or landfilled. The rates of reuse of construction components and materials are also low and consequently, there is a need for developing efficient strategies to favour reuse as preferable management option.

When creating a hierarchy among the end-of-life alternatives, according to environmental impact, the direct reuse of a product comes highest in the rank, followed by recycling. Moving towards reuse of
products is an ideal solution for the product end-of-life approach in order to minimize environmental impact. This is not a common practice in Europe due to the more complex construction techniques that are traditionally applied. In that sense, some reports state that it will take many years to move towards a confident, skilful and marketable industry that invests and reaps returns from the practicable and cost-effective reuse of components and materials.

The traditional recycling systems do not guarantee sufficient quality to use the derived recycled products in high grade applications. For such applications, the content of contaminants such as organic matter (wood, plastics,...) gypsum and asbestos in the recycled fractions must be minimized. In case of very heterogeneous waste streams, more rigorous separation and cleaning techniques are needed to achieve the required levels of purity. Thus, the challenge for obtaining upgraded C&D recycled materials lies in finding the right combination of inexpensive traditional separation techniques with further advanced automated sorting techniques easily adaptable to diverse generation scenarios.

Advanced automated sorting techniques by colour (artificial vision) or chemical composition (spectrometers, lasers, X-Ray, Near Infrared,...) are successfully researched and developed for high quality sorting of plastics arising from municipal waste, in glass recycling or for non-destructive analysis of quality of horticultural products. In the field of C&DW recycling, preliminary tests have been recently carried out, at lab scale, with automatic techniques based on “Colour Sorting” and “sorting based on Dual-energy X-ray transmission”. However, further research is needed to optimize the separation of heterogeneous C&DW streams. This should result in a guaranteed supply of pure recycled materials that can be used in in high-grade construction applications. In addition, these innovative separation technologies must be fine-tuned and adapted for new emerging waste such as foamed polymers, rock and glass wool and composite materials.

The use of plastic foams for thermal insulation of house walls will even more contribute to it in the next decade. In addition, plastics occupy large volumes. In this context, it is urgent to find feasible sorting and recycling onsite solutions for C&D plastic waste. To date, there is little experience with selective collection schemes for plastic packaging from construction works. There are, however, a number of selective collection schemes for rigid plastics from construction, renovation and demolition.

Inorganic fibrous insulating materials (glass wool and stone wool) account for 60% of the current market. Such fibrous waste materials are expected to grow for the decade 2010-2020 in line with the European objectives on Energy Efficiency. The potential hazardousness for human health of these synthetic fibres is still under investigation and already cause of concern for some categories of fibres with specific chemical composition. As a consequence of the EC directives, the materials containing synthetic fibres, which are classified as potential carcinogenic/pathogenic, should be properly managed similar to asbestos-containing materials (ACM). The problems associated with the management and disposal of ACM applies also to other synthetic fibres wastes. Although there are diverse management options for fibrous waste materials, the use of microwave thermal treatments (MTT) is a promising technology to transform fibrous structures into inert compounds potentially usable in other construction applications. In terms of cost savings, it is quoted that cost of asbestos and other fibrous materials microwave thermal treatment is at the level of landfill deposition costs and even 10 times cheaper than plasma treatment also yielding an inert product that can be reused. Comparing with other management options, MTT technology reveals a large number of advantages: i) onsite treatment since the reactor can be installed on a mobile platform; ii)
derived by-products are inert; iii) possibility of treatment with toxic substances.

Furthermore, onsite recycling should be preferable to offsite recycling because of the reduction in transportation costs and environmental impacts. Currently, mobile recycling systems are mainly used to reduce the stony debris into smaller pieces and separate it in different grain size fractions. This equipment is however unfit to produce recycled materials with sufficient quality to be used in high-grade construction applications. In this sense, the challenge is to increase the technological level for C&DW onsite processing.

In line with the current European waste legislation, more and more local, regional or national public authorities are paying special attention to the efficient reuse and recycling of construction and demolition waste (C&DW). The reasons underlying this are:

• C&DW is one of the largest waste streams in the EU.
• A very large proportion of C&DW can be easily re-used or recycled within the construction sector.

In this context, the Directive 2008/98/EC on Waste, states that, by 2020, the material recovery of non-hazardous C&DW shall be increased to a minimum of 70% by weight.

Uncontaminated soil and other naturally occurring materials excavated in the course of construction activities are excluded from the scope of the Waste Directive, and hence will be excluded from the scope of this project.

• Reusing or recycling of C&DW contributes to save natural resources and energy.
• Recycled C&DW can be cheaper than using natural materials.

The main goal of the IRCOW project was to develop and validate upgraded technological solutions to achieve an efficient material recovery from C&DW by considering a life cycle perspective. Thus, the main objective can be broken down into the following ones:

• To create innovative strategies promoting the reuse of building components/products and preparing the new building solutions for reuse activities;
• To create high quality recycling systems by means of advanced solutions for C&DW sorting and processing;
• To design, test, develop high grade construction products (concrete, gypsum boards, wood-polymer composites and multilayer panels) elaborated with C&DW recycled materials: inorganic and organic ones;
• To validate new solutions developed at lab scale on real construction sites;
• To evaluate the technical, economic, environmental and human health performance of these solutions.

Additionally, the following non-technical objectives are proposed for those tasks related to dissemination, consultation and policies:

• To ensure the relevance and applicability of the project results via strong interactions with stakeholders and end-users (e.g. architects, real estate developers, C&DW processors).
• To raise awareness and build up a strong interest in C&DW mitigation among the key European level stakeholders, as an implementation potential for the IRCOW results.
• To ensure effective dissemination of the project results in order to efficiently use and share technical information among end-users and maintain strong collaborative arrangements between all the project beneficiaries of the participating countries.
• To communicate the contributions made to the European knowledge and scientific excellence, the value of collaboration between EU member states, and the benefits arising from IRCOW to European citizens in general.
• To formulate recommendations for changes in policies, where such are called for, to remove obstacles and enforce opportunities for the innovative solutions.
• To spread results towards higher education bodies.

To accomplish the above mentioned objectives, the IRCOW project is structured into seven work packages (WP) and 5 in-field case studies.

The first technological work package (WP2) focuses on generating knowledge that enable an increase in the reuse and consumption of building components, largely arising in demolition activities. For it, an analysis of supply chain for reused components and materials will be accomplished, identifying the perception of clients towards reused building products. The results derived from WP2 will be used in WP4 to optimize the eco design of new construction materials and products elaborated with C&DW recycled materials. Likewise, feedback between WP2 and WP6 will occur to optimize the operational, environmental and economic dimensions of the reuse processes.

The second technological work package (WP3) addresses scientific and technological breakthroughs in C&DW recycling techniques. The aim of WP3 is to establish the technological basis for new solutions in C&DW recycling. For it, advanced technologies based on NIR spectroscopy and visual spectroscopy will be researched. Also, new crushing and sieving routes will be tested for onsite recycling of stony fraction. Finally, sorting and processing technologies will be studied for C&DW plastic, wood and fibrous fractions. The output of the new separation and cleaning techniques will be continuously compared with the quality requirements for the applications developed in WP4. This will allow the partners to optimize the cleaning and separation process flows to create C&DW derived materials that can be used in high quality applications. The main outputs from WP3 will be high quality recycled products: namely, recycled aggregates, sorted granular gypsum, sorted plastics, sorted wood and by-products derived from fibrous material recycling. Interaction with WP6 will allow the project partners to optimize the technical, environmental and economic dimensions of the improved recycling techniques.

The third technological work package (WP4) deals with the design, development and optimization of high-grade construction materials and products made from recycled C&DW fractions. The main targeted products are as follows: new types of concrete elaborated with the recycled stony fraction; acoustic insulation boards manufactured with recycled gypsum; wood-polymer composites and multilayer panels composed of recycled aggregates and thermal insulations. WP3 will provide WP4 with inputs.

To acknowledge the natural, cultural and legal diversity in Europe, and to easier involve regional SME and local stakeholders, 5 case studies have been selected (WP5). Case studies will be performed in 4 different countries (Sweden, Belgium, Poland and Spain) to cover the diverse construction culture, typologies and recycling experience all over Europe. In addition, case studies encompass demolition and building works to cover the complete supply chain where C&DW could arise.

The outcomes of WP2, WP3, WP4 and WP5 will be assessed and validated from an economic and
environmental point of view, by using Life Cycle Assessment tools (WP6). Close interaction between WP3, WP4, WP5 and WP6 will allow the project partners to optimize the technical, environmental and economic dimensions of the new applications.

Finally, all results will be combined in order to formulate C&DW management strategies that take into account new development, eco-design and diversity of the C&DW market within the EU. To reach this goal close interaction with all stakeholders is fundamental. The involvement of industrial stakeholders, and national and regional authorities ensures the relevance and applicability of the project results. Moreover, the stakeholders will be involved in deriving recommendations for changes in policies aiming to remove obstacles and enforce opportunities for the innovative solutions (WP7).

Project Results:
The main scientific and technical results of IRCOW, which consist of products, technologies, tools and services, are described in this section. Intellectual Property Rights (IPR) of the partners regarding foreground of these results and their Exploitation Claims have been collected in D1.6 “Exploitation Plan”, in concordance with former consortium agreements in this field.

In the first category, regarding PRODUCTS, nine (9) products have been described. Based on:

- Recycled cellular concrete:
  1. Raw material with recycled cellular concrete for subfloors
  2. (Cement/ chalk based) mixtures using recycled aggregates of various types (mixed / concrete/EPS):
  3. Concrete mixtures with recycled granulates of the concrete type
  4. Concretes with coarse mixed recycled aggregates and recycled ceramic sand
  5. Ternary mixture with recycled crushed sand
  6. Insulating mortar with recycled expanded polystyrene
- Recycled gypsum:
  7. Gypsum plasterboard with recycled gypsum
- Multilayer extrusion (including C&D wastes)
  8. Multilayer composite decking board (WPC)
- Recycled bricks:
  9. Ceramic aggregates for bricks
- Combination of some of the developed products to obtain a façade solution:
  10. Multilayer panel for building envelope

In order to be marketable, these products in principle have comparable performance with products derived from virgin raw materials. This implies that such products have the same market perspectives of products derived from virgin raw materials. Note that there could have been some work on products that have not achieved the expected technical performance or turned out to be non-competitive. Those products are not considered exploitable and thus are not reported in the present document. That is the case of the Insulating concrete with foamed recycled polyethylene (PE).

Three TECHNOLOGICAL INNOVATIVE SOLUTIONS have been obtained within IRCOW:

- The new software for NIR (Near Infrared) Sorting Equipment provides improved recycling processes for C&DW 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:
- 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 C&DW materials or based products.

Finally, two SERVICES have been developed within IRCOW:
- An integrated service aimed at the recycle of C&D waste into high-grade applications (business model).
- Eco-design as an established approach to design new products applying secondary resources.

The environmental impacts of the developed solutions have been analyzed and assessed through Life Cycle Assessments (LCA). Three different methodologies have been used to evaluate the new products and processes; Attributional LCA, Consequential LCA and Attributional input output hybrid LCA. The focus has been on consequential LCA to capture the environmental effects of introducing the new products on the European market.

Assessed products and systems within the IRCOW LCA:

- Concrete/cement products
  - Screed with recycled cellular concrete, Cement stabilized sand with recycled cellular concrete and Insulating concrete with recycled cellular concrete developed by JACOBS, Belgium. In the products recycled cellular concrete aggregates replace parts of or all of the natural aggregates.
  - Ternary mixture with recycled crushed sand, Concrete mixtures with recycled granulates of the concrete type EE2 and EE3 developed by JACOBS and concrete including coarse mixed recycled aggregates, developed by Tecnalia, Spain. Recycled concrete aggregates are replacing parts of or all of the natural aggregates in these products.
  - Concretes with coarse mixed recycled aggregates and recycled ceramic sand; an additional concrete product developed by Tecnalia.
- Products containing gypsum and/or mineral wool
  - Gypsum plasterboard with recycled gypsum developed by Tecnalia.
  - A multilayer composite decking board or a wood plastic composite (WPC) developed by Conenor, Finland. A product including gypsum and mineral wool from construction and demolition waste.
- Insulation products containing plastics
  - Insulating mortar with recycled expanded polystyrene (EPS) developed by Tecnalia.
- Multilayer panel for building envelope
  - The IRCOW developed multiplayer panel consisting of insulating mortar, gypsum plasterboard and concrete including concretes with coarse mixed recycled aggregates and recycled ceramic sand was compared to a conventional panel that contains no recycled C&D waste.
- Treatment process systems
Off-site and on-site sorting systems for construction and demolition waste were compared in a process LCA study. This was partly developed within IRCOW and scenarios were created to show likely differences between systems.

The purpose of life cycle assessment (LCA) was to assess the environmental impacts from all relevant stages in the life of a product or a process. In order to calculate the environmental impact of the life cycle, detailed information on the flows to and from every part of the life cycle was included.

The results from the studies show various impacts from the different products and impact categories (such as global warming potential).

The best performing products from an overall environmental perspective:

- **Insulating concrete with recycled cellular concrete**
  - The insulating concrete was compared to aerated concrete with a similar strength, conductivity and density and performed at least 80% better in all impact categories. This means that there is a good potential for improved environmental performance if aerated concrete is replaced by the IRCOW insulating concrete.

- **Multilayer composite decking board or Wood plastic composite (WPC)**
  - The IRCOW WPC was compared to conventional WPC with similar technical performance and performed more than 40% better for global warming and better or similar for other impact categories.

- **Gypsum plasterboard with recycled gypsum**
  - The IRCOW developed Gypsum plasterboard with 5% recycled gypsum from C&D waste performed more than 25% better for all impact categories (except Acidification, which was similar) than the conventional gypsum plasterboard.

- **Ternary mixture with recycled crushed sand**
  - The IRCOW ternary mixture showed environmental improvements by up to 70% compared to the conventional product. This product is however connected to higher uncertainties regarding environmental performance than the above mentioned products.

Remaining IRCOW products from the stony fraction of C&D waste, with the exception of cement stabilized sand, perform slightly worse but similar to their reference products for environmental performance. This is because the developed products contain replacements for aggregates rather than replacements for concrete.

An important conclusion from the IRCOW project is that from an environmental perspective it is generally preferred to replace natural aggregates with recycled aggregates if and only if the use of cement is equal or lower than in the conventional product and if an environmentally similar or better cement is used.

This is especially clear in the case of the IRCOW product cement stabilized sand where a higher amount of CEM 1 is used in the recycled product and a lower amount of CEM 3 is used in the conventional product, which results in a significantly higher environmental impact from the recycled product.

The multilayer panel developed within IRCOW proved to perform better than the conventional product for all impact categories, but not for the use of primary energy.

The comparison of demolition and sorting of demolition waste showed that the combination of a selective
demolition and off-site sorting gave the highest environmental benefit.

Policy recommendations

Finally, the policy modifications worked out in the IRCOW project refer to:
• standardization of recycled concretes based on the definition of a series of recycled aggregate categories linked to their composition and purity;
• promotion of selective demolition processes i.e. separation at source, for which compulsory demolition inventory towards reuse and recycling prior to demolition is implemented;
• regulation of demolition as waste management activity by considering the building-to-be-demolished in the „waste“ list of the corresponding Directive and the adaptation of gate fees in C&DW treatment facilities attracting clean waste fractions;
• initiating regional pilot projects demonstrating feasibility of reuse activities related to C&DW recovered materials;
• application of green public procurement favouring end-of-life design to improve reusability in the future.

Potential Impact:

IRCOW expected impact mainly focuses on the increase of material recovery rates from C&DW, due to both the activation of reuse practices and the improvement in recycling. These changes lay on, and also foster, the paradigm shift deemed necessary for converting Europe in a recycling society, in which an integrated approach based on closed materials loops is targeted, a life cycle perspective is assumed in the design of buildings and other civil works, and construction products are both (partially) recycled and (totally) recyclable.

In the following paragraphs the potential socio-economic impacts and the wider societal implications of the IRCOW project are reported.

Recycled materials based on C&DW

IRCOW has explored recycling technologies regarding not only the stony fraction of the waste but also gypsum, mineral wool, etc, as explained in the Main S&T results/foregrounds section. Moreover, these products were validated in real case studies and assessed from the environmental and economic point of view. All in all, the introduction of these solutions in the European level would noticeably improve current material recovery rates.

For instance, in the case of cellular concrete waste, a voluntary collaboration agreement for the Flanders region was signed on October 2014 within IRCOW Final Conference, involving demolition sector, collection-recycling sector, producers, sellers and construction sector. The agreement aims for a chain management of cellular concrete, closing the loop of the material. It is estimated that between 50.000 and 100.000 tons of cellular concrete waste are generated per year in this region, of which 30.000 tons are expected to be recycled in 2014. Flanders expects becoming a European leader in the recycling of cellular concrete by 2020. The manufacturing costs of the recycled IRCOW products made of cellular concrete are, at least, 40% cheaper than the products made of raw materials.
In the case of the stony fraction of the C&DW (accounting for ca. 80% of the total C&DW), efforts have been made both in improving recycling processes as well as developing a number of recycled concretes. More in detail, concretes including coarse (> 5 mm) recycled aggregates of the concrete type and of a mixed composition (based on concrete and ceramics) have been studied. IRCOW has provided recommendations regarding the use of those recycled coarse aggregates in concrete, based on: the compositional requirements of the recycled coarse aggregates; the limitations on the use in different exposure conditions; and the maximum strength concrete class definition.

Moreover, three aggregate types have been defined for the use in recycled concretes. In the case of a strigent “high-grade concrete aggregate”, which would stimulate the confidence of consumers/users, all exposure classes would be allowed, in various substitution percentages (up to 50 w%), depending on the exposure. In the case of (low impurity content) coarse mixed recycled aggregates of a determined composition (maximum ceramic content of 30 w%), 100% of substitution is allowed for concretes of C20/25 compressive strength class, i.e. non-structural concrete (of lower responsibility though very common). In the countries where the use of ceramics such as tiles and hollow bricks is more extended (Mediterranean countries), the mixed recycled aggregates represent almost 70 w% of the recycled aggregates.

IRCOW has also been working on the recycling of the C&DW gypsum into plasterboards. Within the product’s industrial validation with Knauf, a low percentage of substitution of conventional gypsum by C&DW gypsum was made (< 10%). Nevertheless, technical viability of much higher substitution rates is promising. Setting feasible scenarios and supply chains for the recovery of this stream seems to be the main pending issue for the establishment of this product.

The successful multilayer extrusion of certain C&DW streams, for which disposal is the common practice, has been demonstrated also in IRCOW, namely the mineral wool and gypsum plasterboard (for which another recycling solution was presented above). Also the wood can be introduced in the composite, but it must be 100% hard metals free. These C&DW materials would be ca. 60% w% in the composite composition. These composites (WPC) are used in applications such as decking, fencing, other indoor applications such as window and door frames, etc.

According to market projections, worldwide WPC production will rise from 2.43 million tons in 2012 to 3.83 million tons in 2015. North-America is today the world’s leading producer with 1.1 million tons ahead of China, which produces some 900,000 tons (estimate), and Europe, which produces 260,000 tones. It is expected that European production will particularly grow by around 10% per year, reaching 350,000 tonnes in 2015.

Policy recommendations from IRCOW

IRCOW Policy recommendations are considered to be of high potential, as explained in the following section. They have been developed based on the comprehensive diagnosis and assessment of the reuse practices throughtout Europe, on the techno economically validated solutions such as the recycled concretes, and on the conclusions regarding the influence of demolition practices and waste policies on
the feasibility of the establishment of markets for both reused and mainly recycled products.

At first sight these policy briefs might seem to be rather independent issues, but there is a common underlying factor in all of them: a more efficient material recovery from C&DW, which requires coordinated actions from different actors involved and from each of the phases as they are intimately related:

• A common and homogeneous framework for recycled products such as recycled concretes (i.e. their standardization) is desirable for creating a demand for products that otherwise might not find the trust from the purchasers. IRCOW recommends that a series of recycled aggregate categories (linked to their composition and purity) is established. Likewise, the exposure class and maximum replacement rate for the recycled concretes made of these aggregates should be defined, as well as the compressive strength class. The idea of “the right aggregate for the right application” lays behind it.

• Obtaining high-grade recycled products in an efficient and economically durable regime requires that high-grade recycled materials are generated from C&DW, which is necessarily connected with the optimisation of construction and mostly demolition practices, and the subsequent recycling treatments of the generated waste. This, in short, leads to the preferable practice of selective demolition, as the demolition method determines, up to a great extent, the characteristics of the wastes that will be generated and hence their recyclability. IRCOW recommends that the building or structure at the end of its life is included in the “waste” list and consequently, that the demolition activity is considered to be waste management.

• Selective demolition requires an adequate planning, regarding both the identification of reusable elements and materials recyclability. Hence, IRCOW recommends the compulsory demolition inventory prior to the demolition (which will focus both on reusable elements and in recyclable materials).

• Regarding current reuse market, IRCOW suggests that public administration, most possibly at regional level, could activate the present reuse market, by initiating regional pilot projects demonstrating that designers have the possibility to include reused components in their design of conventional construction.

• In relation to reuse and recycling in the future, the need of a change towards end-of-life design is claimed, as could radically decouple waste generation from demolition activity in the future. IRCOW recommends public procurement favouring it.

Arising awareness and challenging perception of reuse

Regarding the comprehensive diagnosis of reuse activity and and assessment of potential markets in IRCOW, it was pointed out that even in an ideal reuse supply situation, where other prerequisites like quality assurance, supply availability, etc. has been fulfilled, a negative perception of reused material, either from construction professionals or the final customers, would constitute a major drawback that must be overcome. Moreover, it was concluded that, in order to avoid missing reuse opportunities, both public and professional’s awareness of reuse need to be improved.
In the framework of IRCOW a number of actions were taken to arise awareness and challenge perception of reuse. In the case of the professional sector, workshops devoted to reuse were organized both in Spain and in Sweden, and also reuse was included in the agendas of the three Stakeholder Panel Meetings. Moreover, a Stock Exchange demo tool has been developed and made available on IRCOW webpage for the general public.

Out of the project scope, IRCOW study suggests that more massive diffusive actions could be made as to improve the awareness of the general public, such as TV programmes about construction including reuse cases, or reuse practices publicized as good practice in emblematic constructions undertaken by public administrations. Similarly, it was concluded that there might be a so-called “cultural feature” or “custom” in different countries, related to the practices that are common there and that leads to a more positive or negative perception of the reusable elements. Moreover, it was learnt from some experiences in Sweden and Belgium that actively working on improving the perception of reused elements can be effective.

Likewise, the training of skilled professionals, with knowledge in reuse, should be considered within the education plans of such students.

Efforts to involve other actors and spread awareness

Within IRCOW project a number of dissemination activities were made, as reported in detail in the following section. Principally the involvement of agents from C&DW management sector, construction and demolition firms, recycling companies, producers of bulding components and materials, designers/architechs and public administrations was targeted in the public IRCOW events. The awareness and perception of the professional sector is deemed to be crucial in the implementation of closed material loops. In this line, collaborations and agreements within the supply chain, such as the one signed in connection with cellular concrete, in a win-win basis, would be desirable for achieving a better reality regarding material recovery from C&DW in Europe. Moreover, it is expected that the administration drive this innovation by means of green public procurement, as well as fine-tunning policies.

The awareness and training of the future professional has been addressed. There has been interaction of IRCOW with a number of Universities in this line (see table with dissemination activities), and in addition, information is available online in IRCOW website, such as explanatory videos, recorded presentations from IRCOW events or the wiki-area, which could be potentially used for educational purposes.

IRCOW has also connections with other research initiatives in the European scientific community, such as the project Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste (C2CA project in short, www.c2ca.eu) and GtG “Gypsum to gypsum” project (http://gypsumtogypsum.org/).

Potential impact on employment

A qualitative assessment of the potential impact on employment related to IRCOW results (products, technologies, tools and services) was made within the project. The impact on employment is considered to be neutral or slightly positive if one considers the value chain that is aimed at the production of the
assessed IRCOW products, which involves demolition, transportation, secondary raw material processing (as compared to primary raw material processing) and product manufacture. Also a potential positive effect is foreseen for the application of some innovative technologies (new software for NIR sorting equipment and on-site microwave energy thermal treatment for inorganic fibrous material), tools (stock-exchange tool) and services (integrated service aimed at the recycle of C&D waste into high-grade applications); while no effect is foreseen for the implantation of the multilayer composite extrusion technology nor for the expert tool or the services based on the eco-design recommendations.

Another major societal impact of the IRCOW project would be related to the enhancement of workers’ skills in relation to C&DW recycling, especially in those countries in which the recycling infrastructure is less developed. In other countries, such as Belgium (with focus to Flanders), also due to the low availability of natural resources in terms of quarrying resources, this impact would be less relevant as there are already several processing centres and high recycling ratios for C&DW (over 90%) are already achieved, including (though in a percentage that could be higher according to IRCOW results) some high-grade applications. In Spain for instance recycled aggregates are yet mostly used for low-grade applications (such as backfilling), meaning that new workers’ skills will have to be developed in order to upgrade application of C&DW.

Occupational/health risks associated to manufacture/production

Some potential risks, associated both to the recycling processes and/or the manufacture of recycled products have been identified, such as the dust generation in certain processes. Limit values are not exceed and personal protective equipment should be compulsory in certain processes.

MAIN DISSEMINATION ACTIVITIES

The dissemination efforts undertaken within the IRCOW project were aimed first of all at ensuring the relevance and applicability of the project results via strong interactions with stakeholders especially representing construction and demolition sector as well as to demonstrate in a convincing way that there are innovative, efficient approaches that can make a change in the way C&DW is handled nowadays especially in terms of closing material loops in construction sector and preventing waste generation by reuse practices. Dissemination activities were deployed at tow levels: consortium/project level as well as by individual project partners using their own dissemination channels and networking relationships. Below the main dissemination channels and respective activities developed and deployed within the IRCOW project and the achieved results are presented.

Network of end-users and stakeholders

As a two way communication channel to provide transfer of project results, their discussion and direct feedback from the end-users and interested stakeholders a database of stakeholders from all over Europe a network of end users and stakeholders was created at the beginning of the project and then continuously supplemented throughout its duration, ending up a with a database of 260 records of companies, organisations and other actors of C&DW value chain from all over Europe. On the top of that, each Case Study created its own network of stakeholders, of regional or local origin. The value of these networks was
extremely high for the success of IRCOW efforts as it allowed demonstrating the applicability of IRCOW solutions to address very specific C&DW related issues in different local/regional settings, depending on the Case Study location. This resource of stakeholders created for IRCOW project was used to disseminate information on project events, requests for specific deliverables of IRCOW project that stakeholders might be interested, distribution of project newsletter etc at the project level. For regular feedback and consultation a panel of stakeholder organisations was established including the following:

- European Demolition Association (EDA)
- Spanish Association of Demolition Contractors (AEDED)
- Spanish Housing and Land Public Promoters (AVS)
- Public Environmental Performance Body of the Environment Department of the Basque Government (IHOBE)
- Natural Resources Service of the Flemish Government
- Public Waste Agency of Flanders (OVAM)
- European Construction Technology Platform (ECTP)
- E2B (Energy Efficient Buildings association)
- Belgian Building Research Institute (BBRI) - Sustainable development and renovation
- The Royal Institute of Technology / Ragn Sells - Industrial Ecology / Raw Materials
- PEAB
- Architectural Construction and Technology Department- Polytechnic University of Madrid
- Gamla Mursten
- ROTOR
- European Aggregates Association (UEPG)
- Dealin Oy, Finland
- Gamle Mursten ApS, DK
- RAGN Sells, SE
- KOMPANIONEN NORDEN AB, SE
- LAFARGE
- KHBO

Among the most prominent achievements of stakeholder’s interaction are two agreements to which IRCOW efforts and outputs contributed: a voluntary cooperation agreement closed by Flemish OVAM with some representatives of demolition and construction sector of Flandria to close the material cycle of cellular concrete. The ceremony took part during the Final IRCOW Project Conference in Brussels. The second initiative has been launched December last year by IHOBE the Public Environmental Performance Body of the Environment Department of the Basque Government, aiming to set feasible scenarios to close the loops for gypsum recovered from C&DW streamin the Basque Country. Another value coming out from the interaction with stakeholders are the policy briefs and recommendations concerning improvements in the current scenarios of C&DW management in the areas of reuse, recycling but also market uptake of innovative products based on resources recovered from C&DW.

Project web site and mailings

IRCOW project web site ([www.ircow.eu](http://www.ircow.eu)) was created as a primary source of information about the project activities and its key outputs. All visual materials have been presented there including:
- public IRCOW deliverables
- information on project Case Studies and their results
- movie clips from Case studies and the IRCOW project movie
- presentations from project events
- access to tools developed in IRCOW (expert tool for risk assessment and ICT platform facilitating reuse incl. Demo StockExchange, WikiArea, C&DW AgentsDatabase)
- IRCOW product innovations ( product sheets)

Mailings as a dissemination channel were used to invite stakeholders to IRCOW events, distribute IRCOW public deliverables e.g. newsletters etc. The total number of visitors of the IRCOW website was 22,091.

Restricted access zone of the web site

To ensure that proper dissemination of project outcomes takes place amongst project partners a restricted access zone was created within the IRCOW web site. All key documents, restricted access deliverables and working presentations were uploaded therefore internal consortium use.

ICT platform based communication service - WikiArea

The ICT platform facilitating reuse one key component has been developed which serves dissemination purposes: it is the WikiArea and its special section dedicated to good practices in reuse. Articles included in the WikiArea are related to project findings and results obtained from the Case Studies and from stakeholders.

Workshops

Three IRCOW workshops were organised:
- 1st workshop: Unlocking the resource potential of Construction and Demolition Waste: Is reuse an alternative for construction now or in the future? on 24th January 2012 at BUDMA International Construction Fair in Poznań, Poland
- 2nd workshop: Advanced recycling systems for Construction and Demolition Waste on 22nd October 2012 in Madrid Spain,
- 3rd workshop: High-Grade building applications using recycled Construction and Demolition Waste materials in Europe, on 14th June 2013 in Antwerp, Belgium.

With the active participation of stakeholders, relevant target groups, technical experts and project consortium they aimed at discussing the project outcomes and obtaining feedback related to the relevance and applicability of IRCOW outcomes as future solutions to meet different C&DW challenges. For each workshop a dedicated e-brochure has been developed and distributed before the event as invitations. These events managed to gather an audience of 143 participants in total and all were successful in terms of organisation and feedback received.

Stakeholder Panel meetings
Three Stakeholder Panel meetings were conducted. They were organised in conjunction to project meetings organised at BUDMA fair in Poznań, Poland (25th January 2012) in Gothenburg, Sweden (25th May 2012) and the Final Project Conference in Brussels (24th October 2013). They served to obtain feedback from the stakeholders on project results at different stages of project development. Reports from the meetings were developed and consolidated as one deliverable submitted to the Commission. These reports were also further explored to focus project activities and outcomes on observations provided by stakeholders and to develop policy briefs and recommendations. Prior to the meetings Stakeholders were invited to submit request for some specific deliverables of restricted access which might be of interest as basis for discussions. A total of 54 stakeholders (other than project scientists) attended these meetings.

Final project conference

Final Project Conference was organised on 24th October 2013 (project month 34) in Brussels Belgium. The aim of this conference was to present and discuss with all interested parties the results of technical and non-technical nature obtained within the IRCOW project and to get their feedback on the policy recommendations to facilitate the uptake of innovative high grade strategies to C&DW management. The conference was attended by 66 participants from 12 countries. A video coverage was made from the event including all presentations delivered. To broaden the impact of the IRCOW final outputs to audiences who were not able to take part in the event, a video coverage of the conference was made. The coverage and the accompanying presentations were uploaded to project web site for promotion and accessibility to general audience.

Communication towards higher technical schools and universities

To communicate the project outcomes for didactic purposes to higher education centres IRCOW partners delivered the lectures/courses to students using the outputs of IRCOW: Seminar at KULeuven: “Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste, Belgium (VITO), LCA in construction and demolition waste management at Lund University (IVL) and a University course, HCU (HafenCity University Hamburg), internal MSc program “resource efficient architecture and planning”, course “technologies for sustainable material cycles” (TRINIUS).

In addition to that, in order to create a repository of materials for use by higher education a dedicated zone has been created within the IRCOW web site. It includes selected presentations and description of technical outputs in a form of product sheets. Higher technical schools and universities identified by IRCOW consortium as stakeholders were notified by mails about the availability of these materials and rules of their use.

Participation at conferences, seminars, workshops etc outside the project framework

IRCOW consortium members took part in 27 events organised outside the project framework organised in different parts of Europe, also in countries that were not covered by the IRCOW project. List of these events in included in annex A2. The form of IRCOW communication included presentations, distribution of IRCOW materials and direct contacts with representatives of the project target groups/audiences. Already
after project completion, IRCOW project has been selected by DG Environment as a case to be presented during the EcoAP Forum entitled Towards circular economy in cities, organised in the days of 7-8 April 2014 in Hanover during the Hanover Fair event.

IRCOW Dissemination materials

A lot of effort within the project has been involved to produce materials that could reach the broadest range of stakeholders including both experts, students but also general audience and present the project and its outcomes in an attractive and understandable way. A project two pager followed by a project brochure, project corporate presentation and project poster were produced as background introductory materials for use and distribution at events attended by IRCOW partners. Every year a project newsletter was prepared to demonstrate the progress of work and the key achievements accomplished within a project year. A lot of multimedia materials were also produced to give the stakeholders but also the general audience a better understanding of IRCOW approaches. These include: a series of movie clips presenting the project and the individual Case Studies: CS 1 and SC5 as well as relations with stakeholders, the content of the Final Conference, animations as instructions to use the StockExchange and the AgentsDatabase tool. Beside materials produced as planned IRCOW activities, partners produced 10 articles dedicated to general audience and 7 articles published on-line. In recognition of ecoinnovative approaches worked out in the project, IRCOW was also presented in a form of an interview at the web sites of the DG Environment dedicated to the implementation of Ecoinnovation Action Plan. Innovative products

Peer-reviewed publications

The articles “Upgrading the quality of mixed recycled aggregates from construction and demolition waste by using near-infrared sorting technology” (Iñigo Vegas, Kris Broos, Peter Nielsen, Oliver Lambertz, Amaia Lisbona) is undergoing the review process in the “Construction and Demolition Waste” indexed journal. Moreover, the article “Recycling of autoclaved aerated concrete in stabilized sand” (Peter Nielsen, Kris Broos, Jef Bergmans, Johanna Freden, Kurt Jacobs, Mieke Quaghebeur, Wolfram Trinius) is under development, as further scientific results are needed beyond IRCOW.

Additional scientific papers are expected to be submitted to indexed journal after the reporting period (before the end of 2014). Authors will accordingly acknowledge the FP7 for the support to this research and development line.

A summary of dissemination efforts is presented in table in Annex 2 of the attachment.

EXPLOITATION OF RESULTS

Within the IRCOW project, a number of exploitable results have been achieved, being those results recycled construction products, both recycling or (recycled) product manufacturing technologies, as well as tools and services supporting upgraded management of C&DW. These results are described in detail in the section “Description of the main S&T results/foregrounds”.

Products
As mentioned before, the main IRCOW construction products, including different C&DW recycled materials, are the products based on:

- **Recycled cellular concrete:**
  1. Raw material with recycled cellular concrete for subfloors
  2. (Cement/ chalk based) mixtures using recycled aggregates of various types (mixed / concrete/ expanded polystyrene EPS):
  3. Concrete mixtures with recycled granulates of the concrete type
  4. Concretes with coarse mixed recycled aggregates and recycled ceramic sand
  5. Ternary mixture with recycled crushed sand
  6. Insulating mortar with recycled expanded polystyrene

- **Recycled gypsum:**
  6. Gypsum plasterboard with recycled gypsum

- **Multilayer extrusion (including C&D wastes):**
  7. Multilayer composite decking board (WPC)

- **Ceramic aggregates:**
  8. Ceramic aggregates for bricks

- **Combination of some of the developed products to obtain a façade solution:**
  9. Multilayer panel for building envelope

In the case of the research organizations (TECNALIA, VITO, IVL) future use of the generated knowledge for other developments is intended. On the other hand, construction/ demolition companies (ACCIONA Infraestructuras S.A. DERRIBOS PETRALANDA), plan the manufacturing of the IRCOW products in their forthcoming works, as well as future research in the same topic (ACCIONA Infraestructuras S.A.) and eventual licensing to third parties (DERRIBOS PETRALANDA). BRIJSSE MINERALS & RECYCLING, as a service company for the recycling and construction industry, retrieves manufacturing, further development and licensing for the corresponding products. Development company CONENOR, for its part, intends using the knowledge on multilayer extrusion with C&DW for future research and eventual licensing to its clients. Finally JACOBS, concrete manufacturer, is already producing some of these IRCOW products and plans the introduction of some others in the near future, also depending on the influence that IRCOW results might have on the certification bodies about the regulation of some of them. In addition to the manufacturing, Jacobs also envisages future developments and potential licensing.

The main risks associated to the exploitation of these products (i.e. their manufacturing fundamentally) are related to resource availability (as in many cases the supplying routes from demolition works to the manufacturing step are not yet well-developed), purity of the waste, market acceptance risks (image, tough competition with non recycled products, etc.), as well as product permit risks (which lead in general to significant- high, very high- risk to the exploitation) are reported. In the case of cellular concrete, also potential sulphate leaching is considered. Two of the products also present grave risk due to the issue of their recycling at the end of life.

**Technologies**

Three technological innovative solutions have been obtained within IRCOW:
The new software for NIR (Near Infrared) Sorting Equipment provides improved recycling processes for C&DW recycling plants, with the main objective of high-grading recycled aggregates and their use. This development is owned by TOMRA Sorting project partner, expert of sorting advanced technologies, and the future manufacturing and further development of this technology are envisaged. The spread of advanced recycling technologies to countries in which C&DW is still mainly landfilled is expected.

On-site microwave energy thermal treatment is a technology owned by ATON project partner, which allows the disintegration of asbestos and other mineral fibres. The manufacturing associated to the sale of the equipment, and the further development and licensing of this output are planned by ATON. Exploitation is planned toward the treatment of asbestos and/or other mineral fibres containing waste in the construction sector, being permit difficulties the main risk associated to this exploitation. Moreover exploitation toward the treatment of after-production waste from mineral wool production is also a promising opportunity.

In IRCOW multilayer composite extrusion technology was validated for the extrusion of products with high contents of wastes, including C&DW. The multilayer extrusion technology produces two differentiated layers (with their corresponding formulations), and some of the requirements applying to the outer layer (e.g. appearance) do not apply for the core layer (where eventually higher contents of waste can be recycled). Hence, this technology allows optimising both the performance of the products and their cost. Development company CONENOR plans further research on this technology and eventual licensing.

Tools

Two tools have been developed within IRCOW:

Stock-Exchange tool is a demo dedicated e-commerce portal for sale and purchase of C&DW recovered materials and elements, being IETU the main foreground generative partner. The development of the demo version into a full system version to be offered as a service to interested users or subject to system licensing is planned by IETU Institute for Ecology of Industrial Areas.

The Human Health and Environmental Risk Indicator (HERI) is a computer based tool which can be used by the building or recycling industry to indicate the potential risks (to human health and the environment) due to the use of recycled construction and demolition waste (C&DW) materials or of products based on recycled materials prior to the start of a project. It has been developed by VITO within IRCOW and it is conceived as a free tool, available online here.

Services

Two services have been developed within IRCOW:

An integrated service aimed at the recycle of C&D waste into high-grade applications has been developed by ACCIONA Infraestructuras S.A.in close cooperation with several other actors (both IRCOW partners as well as external players) along with the capability to manage the whole supply chain that is necessary for
the purpose. Within this framework, ACCIONA Infraestructuras S.A. will be able to increase its internal recycling targets and to offer highly specialized / qualified engineering and construction services to environmentally conscious customers in the construction sector.

Eco-design is an established approach to design processes. Eco-design can address sustainability aspects, as the concept can embrace a wide range of aspects and parameters, and it can address these aspects from all along the product’s life cycle. While eco-design usually is applied in product improvement or refinement processes, the IRCOW perspective was on the design of new products applying secondary resources. While the eco-design analysis of the presented products can not directly be generalized or transferred to other products, the service developed by Ingenieurbuero TRINIUS is the way of application of the eco-design concept, the analysis of eco-design parameters, and the illustrative and easy to understand presentation of adverse and beneficial trends resulting from the exercise.

List of Websites:

IRCOW project web site (www.ircow.eu) was created as a primary source of information about the project activities and its key outputs. All visual materials have been presented there including:
- public IRCOW deliverables
- information on project Case Studies and their results
- movie clips from Case studies and the IRCOW project movie
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- IRCOW product innovations ( product sheets)

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