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Zero-waste networks in construction and demolition in Portugal

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This paper presents the results of Portuguese case studies on developing an industrial network around a construction site and three zero-waste demolition projects. The case studies analysed to what extent it is possible to achieve a significant reduction of the solid waste produced and an overall decrease in energy and water consumption. The results show that the reduction targets could be achieved by implementation of good practices in waste management and the development of networks to allow an increase in the reuse and recycling rates of wasted materials and residual water. At the construction site, overall achievement of reduction rates was additionally enforced by the substitution of inputs with strong potential impacts on the decrease of fresh water consumption and greenhouse gas emissions along the supply chain.

1. Introduction

As a consequence of the economic recession at the beginning of the twenty-first century, the construction sector has experienced a severe crisis all over Europe, particularly in countries such as Portugal and Ireland. This is significant because the construction and demolition (C&D) industry is a major contributor to individual nations' economies – it contributes 10% to the Portuguese economy and, in the UK, the construction industry employs 3 million people, generates £100 billion each year (Vadera *et al.*, 2008) and contributes 10% towards gross domestic product (GDP) (Smith *et al.*, 2002). However, this sector has relatively high environmental impacts. In Europe, the C&D sector contributes 10–33% of total waste arisings, comprising demolition waste (40–50%), renovation waste (30–50%) and construction waste (10–20%) (Balaras *et al.*, 2007). A significant amount of energy is used in the C&D industry; for example, about 10% of UK national energy consumption is used in the production and transport of construction products and materials (Environment Agency, 2011). Although most energy usage occurs during the operation of the building (Environment Agency, 2011), high energy consumption occurs during the construction phase and also during the manufacturing and processing of the materials that are to be used (Spence and Mulligen, 1995). The embodied energy of each of the materials used in construction is completely controlled by the designer and manufacturer and therefore these stages are vital when considering how to cut energy usage (Spence and Mulligen, 1995). Significant quantities of greenhouse gases (GHGs) are emitted during C&D activities such as transporting workers, crushing and transporting aggregates, and materials extraction and manufacturing. The construction of buildings consumes 16% of total water used globally (Yan *et al.*, 2009).

The economic crisis has pushed the sector to move its main focus from the construction of new buildings towards the rehabilitation of old buildings. Moreover, increases in energy and materials costs have also encouraged eco-innovation in materials, techniques and logistics, but the construction industry is a conservative sector in which changes are not readily accepted. However, due to political pressure, concerns about waste management and recycling are growing. In 2005, the Portuguese Environmental Agency estimated that 69% of C&D waste produced was illegally disposed of, 26% was landfilled and only 5% was sent for recycling (Miranda, 2009). In 2012, Pacheco Torgal (2012) reported that recycling rates in the Portuguese C&D sector were lower than 40%. However, the implementation of good practice schemes in the sector has recently been required by legislation (e.g. Decree-law no. 73/2011 demands the integration of at least 5% of recycled materials in public works where technically feasible).

In traditional demolition methods and techniques, buildings are simply pulled down, generating huge quantities of mixed wastes. This makes segregation and reuse/recycling difficult or very expensive, so most of this waste is disposed of by way of landfill. Increasing prices for landfill disposal are likely to invert this trend, making reuse and recycling more attractive and providing materials for emerging markets. However, this will also require the development of deconstruction (or selective demolition) techniques. Under existing conditions, this option is not attractive for economic reasons (Coelho and Brito, 2010).

Although, not yet common, some key actors are evolving to a different paradigm, beyond legislation. Voluntary schemes for building certification are being applied in some high-profile projects, in particular by public promoters (like the case study in Torres Vedras described later in the paper). Some producers of construction materials (e.g. cork products) are also engaged in obtaining Environment Product Declarations (EPDs) for their products, which are International Organization for Standardization (ISO) normalised declarations by the manufacturer about the environmental impacts of a product over its lifecycle.

Demolition activities, as opposed to construction works, do not use raw materials. They have significantly less negative impact on resource depletion than construction activities. However, they have a higher impact on waste generation; in fact, most C&D waste arises at demolition sites. These negative impacts may be partially counterbalanced if the high reuse and recycling potential of C&D waste is fully exploited; demolition activities may induce a positive indirect effect on resource depletion if the secondary materials resulting from C&D waste are used to substitute primary resources. In Portugal, only a small share of the total reuse and recycling potentials of C&D waste is currently used.

The project ZeroWIN (Towards zero waste in industrial networks; www.zerowin.eu), scheduled to run from 2009 to 2014, is creating innovative technologies, waste-prevention methodologies, strategies and system tools based on the vision reported by Curran and Williams (2012) and specific approaches developed during the project (den Boer and Wolf 2011; den Boer *et al.*, 2012). In this paper, the results of two case studies – the construction of a new building and three demolition projects – are presented and analysed. The first case study relates to the construction of an environmental education centre in Torres Vedras, west Portugal. The building awaits certification by the Portuguese sustainable construction scheme Lidera (an acronym for leading by environment for sustainable construction).

The overarching aim of the case studies was to build industrial networks around C&D works (including producers of materials and components, owners or promoters, architects, waste managers and other players) to demonstrate that it is possible – due to sustainable construction measures – to achieve 30% reduction of GHG emissions, 75% reduction of fresh water consumption and 70% reuse and recycling of materials.

A preliminary environmental impact assessment (EIA) revealed that, during demolition activities, GHG emissions are mainly produced by the demolition process itself (54%), the sorting of waste (29%) and the landfilling of inert material (10%) (Obersteiner *et al.*, 2012a). Direct energy needs on construction/demolition sites mainly refer to fuel use in machines and transportation, and special attention was therefore given to all activities requiring the use of machinery with the specific goal of achieving maximum reduction of fuel use on site. Further emphasis was set on logistical aspects concerning both material inputs (supply chain) and outputs (waste) in order to reduce the overall GHG emissions to a minimum. The preliminary EIA also showed that the main consumption of fresh water on demolition sites comes from the same three activities as for GHG emissions (Obersteiner *et al.*, 2012a). Consequently, on-site sorting of waste and avoiding landfill were deemed as priority goals.

Taking account of the economic and other interests of the stakeholders involved is crucial to the success of this type of project. The promoters of the construction projects specified their own interests as follows.

- To reduce the costs of resource consumption and waste management during construction.
- To reduce the costs of energy and water consumption by reusing water flows from other companies or activities.
- To integrate reused and recycled materials in the constructed building or using them in supporting infrastructures (e.g. in the yard and for supporting activities).
- To improve their image (municipality, construction companies, waste managers, other companies involved in the network) by reference in newspapers and other communication means to environmentally sound practices, as this was viewed as an easy and immediate way to approach future clients and other interested parties (e.g. householders).
- To increase awareness about sustainable construction and develop the experience of the staff involved.
- To disseminate good practices and show that such practices are possible to implement through targeted dissemination activities.
- To support the development of industrial networks and increase reuse and recycling activities that bring both economic and social benefits to the regions where these industries are located.
- To reduce the costs of resource consumption and waste management during demolition to promote efficiency in demolition processes.

- To increase awareness about selective demolition and materials management and to develop the experience of the staff involved.

The scope of the C&D case studies covered construction works occurring on site as well as some external activities such as the selection of input materials and the destination of output materials. In this sense, the selection of suppliers, construction techniques, support activities where applicable (e.g. site cleaning, tools maintenance, dust control, etc.) and waste management (its storage and forwarding) are inside the boundaries of the case study.

2. Methodology

Two school buildings – Escola Secundária de Paços de Ferreira (site 1) and Escola Secundária da Maia (site 2) – and industrial pavilions (site 3) were selected for the demolition case studies. Site 1 was considered a reference scenario with no intervention of the ZeroWIN team, while resource efficiency improvements were planned at site 2. The construction company Edifer – Construções Pires Coelho & Fernandes, S.A. – had been involved in the project as a stakeholder to support the implementation of construction or demolition case studies. The third project (site 3) was the demolition of industrial pavilions in Amadora, close to Lisbon; this demolition project was performed by Ambisider, Recuperações Ambientais, S.A. Potential resource exchanges were investigated in detail for mass-significant material flows and for materials with potentially higher environmental impacts (Obersteiner *et al.*, 2012a).

A detailed data collection process was carried out in order to facilitate quantitative assessment. Work package 7 of the ZeroWIN project focused on quantitative assessment and hence a data collection guideline was established to facilitate data gathering in a systematic and consistent fashion (Obersteiner *et al.*, 2012b). The data collection guideline accompanies a Microsoft Excel template that was provided to C&D partners; these documents are available by way of the project website (www.zerowin.eu).

In detail, the following steps were taken to achieve the targets mentioned earlier. Apart from a few exceptions, most of the tasks were similar for both the construction project and the demolition projects.

2.1 Development of a baseline scenario for construction/demolition projects in Portugal

The general baseline scenario was developed based on estimated averages of construction sites in Portugal, but it was necessary to adapt it to the real specificities of the case study. For demolition site 2, the baseline scenario was built empirically, based on the observation of the techniques used and material flows actually produced in site 1. For a construction site, a specific baseline scenario must be developed on the basis of the project, and the knowledge experimentally accumulated by the construction enterprise and the research team on the techniques usually applied and the average quantities of material flows that are processed in similar sites. For the case study of the construction of the environmental education centre in Torres Vedras, the municipality provided a detailed construction plan (including a list of activities) that allowed the estimation of expected material inputs.

2.2 Selection of appropriate case study sites and establishment of objectives and responsibilities with the actors involved

The main selection criterion for a site was the willingness of the owner and the construction enterprise to implement the measures suggested and supervised by the research team, within the time schedule foreseen for the implementation of construction/demolition works in the ZeroWIN project.

2.2.1 Brainstorming

Brainstorming of ideas with the involved stakeholders and the development of a guidance document for the measures implemented on site focused on the measures proposed for

- optimised management of materials and waste and industrial symbiosis in materials management
- rational management of energy and transport/logistics optimisation and industrial symbiosis in the management of energy and transport
- optimised water management and industrial symbiosis in water management.

2.3 Pre-demolition audit

Pre-demolition audits were performed based on the previous experience and know-how of the research team. Visits to the buildings to be demolished were performed in order to identify

- the type and age of the building, along with relevant specifics concerning construction techniques
- the materials present and their respective amounts
- the expected quality of arising materials.

2.4 Selective demolition plan

The selective demolition plan is a standard methodology developed by CEIFA for demolition works in Portugal. It is recognised as a helpful tool by owners, architects and construction firms (Lourenço, 2007). The goal of selective demolition is to facilitate the recovery of residual materials in order to maximise reuse/recycling and reduce the impact on landfills. Selective demolition involves sequencing the demolition activities to allow the separation and sorting of building materials.

2.5 Analysis of data

Analysis of data included the following.

(*a*) The identification of processes requiring higher energy and water inputs.
(*b*) Analysis of global materials inputs and outputs to ensure relevant items were identified and measured in mass units.
(*c*) Identification of networking potential. For network relationships to be more easily established, proposed exchanges could be performed by making use of a tool such as a web-based resource exchange platform developed within another ZeroWIN case study. However, in this particular situation, the focus was on the identification of industries in the vicinity of the site (depending on their material flows and proximity to the site). The research team (with the support of the municipality) investigated industries in the vicinity of the site with regard to the materials they processed. The municipality identified more than 2000 economic actors within 20–25 km of the construction site and divided them into sectors and kinds of activity in order to facilitate the identification of real networking potential. With this comprehensive list, CEIFA's team analysed the main materials flows of existing industries. This information was matched with the expected materials flows in the construction site in order to identify the cooperation potentials for further materials, water or energy, and to implement the respective exchanges.
(*d*) Analysis of possible substitution of input materials. Alternative solutions were investigated with the aim of substituting some of the identified materials, preferably with reusable/recycled materials or materials with lower environmental impacts. It was possible to define some substitutions for recycled, local or more sustainable materials. Possibilities to enhance networking between the actors involved in the construction works were also identified. The suggestions developed by the research team on the identified key materials and possible alternatives integrating reused or recycled materials were discussed in several meetings with the municipality architects and engineers.
(*e*) Analysis of possible improvements concerning materials outputs. The goal was to find alternative uses for the materials generated on site (e.g. instead of landfilling, search for potential uses as by-products in other industries). A plan was developed for waste materials arising from the site in order to facilitate proper segregation, reduce contamination and improve their final quality. The companies involved in the construction site were required to join an industrial network of recyclers that had achieved high recycling rates in previous years.

2.6 Development of a list of specific measures to be undertaken on site to reach the ZeroWIN goals

A set of suggestions, mainly focusing on networking potentials, substitution of input material flows and alternative destinies for outputs, was developed by the research team. The activities were judged in cooperation with the partner responsible for their environmental assessment as significant, moderate and minor with regard to the three ZeroWIN goals (see Table 1).

After discussions with stakeholders the following measures were finally accepted for implementation for the construction project.

(*a*) Use of concrete cement containing ashes from power plants or other sources as feedstock. Selected waste and by-products such as power plant ashes containing useful components such as calcium, silica, alumina and iron can be used as raw materials in kilns, replacing raw materials such as clay, shale and limestone. Because some materials have both useful mineral content and recoverable calorific value, the distinction between alternative fuels and raw materials is not always clear. For example, sewage sludge has a low but significant calorific value, and burns to give ash containing minerals useful in the clinker matrix.
(*b*) Reuse of formwork wood. Timber formwork is commonly used for the construction of cast in situ concrete structures because of its versatility and ease of handling. It may form 35–60% of the total cost of constructing a concrete structure. The reuse of formwork can thus bring about substantial cost savings to contractors. Many construction projects in Singapore utilise site-assembled timber formwork made of lumber and plywood (Ling and Leo, 2000).
(*c*) Selection of local or at least national materials, thus avoiding long-distance transportation and stimulating the regional economy. What is considered 'local' needs to be defined case by case – for the project goals, distance is linked with GHG emissions and, for the stakeholders, with transport costs. The selection of suppliers that will lead to less transport-related emissions and costs to deliver a product with a specific quality standard seems to be generally accepted as a rational decision.
(*d*) Substitution of some elements (e.g. steps, parapets and walls for filling with mounting brackets) built in single concrete by light concrete with the incorporation of recycled regranulated cork.
(*e*) Substitution of extruded polystyrene (XPS) with recycled insulation cork board (ICB)
(*f*) Substitution of aluminium external shading system (consisting of vertical profiles whose orientation determines the level of exposure to sun/shade) with a wooden system (although Nordic wood because of its resistance characteristics).

	Impact		
	Reduction of GHG emissions	Reuse and recycling of waste	Reduction of fresh water use
Reuse of components such as bricks and ceramics, insulation materials, carpet tiles, secondary components from the IT industry (switchers, diodes, etc.), secondary photovoltaic (PV) panels to provide site lighting	Significant	Significant	Significant
Use of recycled materials instead of original ones, for example ■ aggregate to replace virgin material in concrete ■ glass/ashes from power plants as feedstock in cement, concrete or ceramics ■ timber or recycled polyvinyl chloride (PVC) window frames to replace aluminium frames ■ use of electric arc furnace steel (instead of blast-furnace steel) ■ secondary wood and plastic in production of formwork ■ insulation materials with recycled fibres, etc.	Significant	Significant	Significant
Use of materials with better environmental performance instead of the ones initially specified	Significant	Significant	Significant
Undertake on-site segregation to provide clean secondary materials	Significant	Significant	Significant
Reintegration, on site, of materials/components resulting from on-site activities	Moderate	Significant for on-site activities	Minor
Reuse of temporary accommodation sites with reused installations (e.g. pipes, PV modules for power supply)	Minor	Minor	Minor
Influence suppliers to offer take-back schemes and 80–20 ordering (unused wood, bricks, sand, mortar, concrete, plasterboard, concrete)	Minor	Minor	Minor
Identify industries in the vicinity to provide used water (e.g. vegetable washing water from food industry)	n/a	n/a	Significant for on-site activities
Use of treated wastewater from municipal treatment plants or from portable plants on site Use of grey water or treated wastewater in concrete production	n/a	n/a	Significant for on-site activities

Table 1. Ranking of the potential impacts of individual measures on the overall performance

(*g*) Substitution of primary aggregates and boulders (collected from rivers or seas) with secondary aggregates (dependent on price).
(*h*) Reuse of water from a local vegetable-processing industry or wastewater treatment plant (dependent on water transport possibilities/cost–benefit evaluation) for washing, watering the concrete during curing, dust control or other purposes such as mortar preparation (although the contractor is strongly resistant to this latter use).
(*i*) Substitution of ceiling systems with equivalent systems including recycled plastic.
(*j*) Substitution of false ceiling boards with recycled fibre boards.

For the demolition projects, the following actions were accepted for implementation.

(*k*) Implementation of a selective demolition procedure with previous and careful removal of dry elements.
(*l*) Segregation, on site, of at least the following material streams (where existing): mixed metals; mixed inert materials (for on-site crushing and use); plastics; wood;

glass; hazardous materials (separated according to their hazard type).

(*m*) Substitution of primary aggregates from stone extractions by secondary aggregates produced from C&D waste recycling (crushing); this substitution is valid for on-site uses if needed (e.g. roads) and use in new construction or refurbishment projects.

(*n*) Direct reuse of building elements (e.g. windows, doors, toilets, water taps) in new construction or refurbishment.

(*o*) Use of wood arisings in laminates, fencing, pallets, garden furniture or others.

(*p*) Use of grey water or treated wastewater for on-site dust control.

(*q*) Verification of the actual recycling rates achieved by the recyclers in the market. Companies involved were required to cooperate with recyclers achieving high recycling rates – that is they were required to choose actual recyclers instead of waste managers that receive waste, store it and then forward it to other waste managers or recyclers.

2.7 Establishment of contacts with companies for networking

After the identification of symbiosis potentials with other industries, the next step was to contact companies in order to make these networks operational. The municipality showed a preference in making the institutional contacts with the identified industries.

2.8 Managing implementation problems

In the summer of 2012, the contractor was facing insurmountable financial difficulties and work had to be stopped. With the approval of the ZeroWIN project officer, the decision was made to develop the case study at a conceptual level. In early 2013, a new contractor was found and works on the Environmental Education Center were restarted, but only part of the measures proposed could be implemented and evaluated within the ZeroWIN schedule.

2.9 Monitoring the processes implemented within the ZeroWIN schedule

Monitoring was performed by direct observations on site, verification of the documentation concerning materials substitutions and waste management, and registers on water and energy consumption.

3. Results

3.1 Construction project

From a conceptual point of view, the improvement of the construction project as related to the baseline is demonstrated in Figures 1 and 2. Every waste flow could be diverted from disposal in landfill because some materials could be reused at the site itself and others could be forwarded to companies in the vicinity of the site to be used as secondary materials. Further interesting improvements with implications on the overall impact evaluation mainly resulted from resource exchanges (inputs substitution), as described below.

The input materials identified for substitution in the construction project are listed in Table 2. The origins of the materials used in the baseline scenario are listed along with the more sustainable substations proposed for the improved scenario.

In the future, recycled ceramics should also be considered for input substitutions. From a lifecycle perspective, ceramics are very energy- and material-intensive products. Two companies that already incorporated some secondary materials into their ceramic products were found. Several research studies on input substitution in the production of ceramics have been reported (e.g. Ferreira, 2010) but, so far, such solutions have not been established at a commercial level.

With respect to outputs, improvements were suggested to provide 100% deviation of the residual materials flows from landfill to reuse and recycling. Table 3 summarises the suggestions provided by the research team. Concrete and wood could partially be reused on site. With respect to recycling, the best option could not always be selected in practice, because recycling strongly depends on the quality of the material. Thus, wherever applicable, quality tolerance and quality standards are listed in the table to indicate what requirements need to be met. To ensure confidence in the materials, it is vital that secondary materials comply with the quality criteria, which are either the same as or similar to the criteria for raw resources.

3.2 Demolition projects

In the demolition activities, the most significant materials flows in terms of quantities were inert materials (mixtures of concrete, bricks, tiles and ceramics). The pre-demolition audit for site 2 estimated this amount to be 1137 t, with the composition given in Figure 3.

Concrete represented more than 50% of the total amount of inert waste produced on this demolition site. If on-site segregation was properly completed and concrete could be delivered without the inclusion of ceramics or bricks, the recycled concrete produced could be applied in all applications, including the structural elements of a building. According to the technical specifications for the use of recycled aggregates issued by the Portuguese national laboratory for civil engineering (LNEC, 2009a, 2009b, 2009c), recycled concrete from mixed inert waste can, however, only be used in non-structural applications (e.g. road pavements and sub-layers).

Since there are no input materials flows and the on-site water and energy consumption could not be measured, the focus of

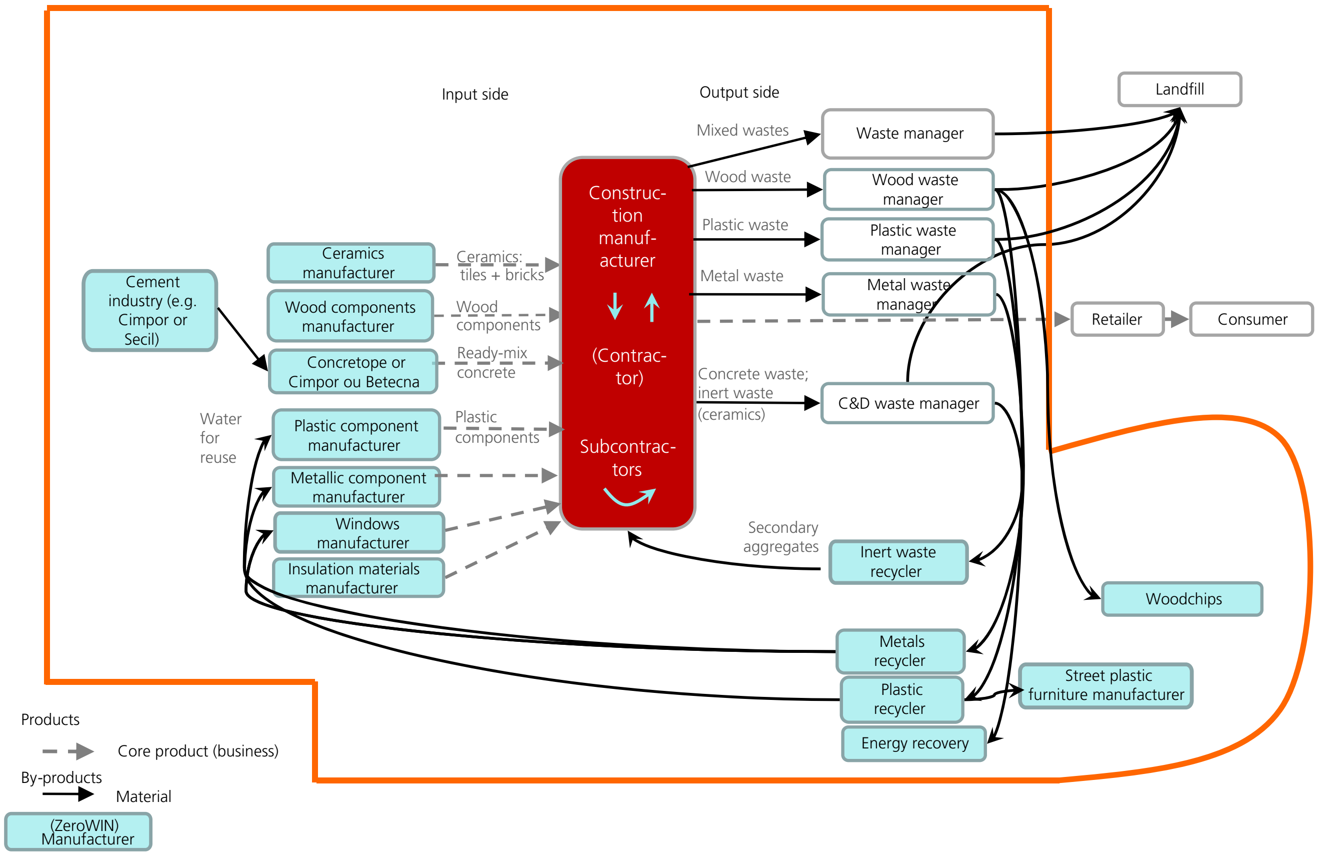

Figure 1. Baseline scenario – current status of construction works in Portugal

the analysis was on the output materials. The most important change that allowed further improvements was the implementation of selective demolition (instead of conventional demolition) techniques on sites 2 and 3 (Figures 4 and 5). Selective demolition is a process where demolition activities are sequenced in a way that allows for the separation and sorting of building materials. The act involves the removal of selective parts of a building, then the removal of portions or components of a structure. This process is used to demolish certain interior finishes without affecting the remaining structure in any way. Following this methodology on site 2, it was possible to achieve a significant improvement over the baseline established on site 1 where the total amount of solid waste produced (1136 t) went to landfill. Other than asbestos (which must go to special landfill) all other materials produced at site 2 were forwarded to recyclers. The results of the improved scenario (site 2) as opposed to baseline are summarised in Table 4.

In the demolition case study, the reduction target set for solid waste (at least 70%) was fully met. In total, 1137 t solid waste was produced in site 2 and 90% was forwarded to recyclers. Although in some situations the materials delivered for recycling were not as clean as needed (according to the information provided by recyclers, about 10% out of the recovered materials were forwarded to landfill), a recycling rate of around 89% could actually be achieved. Reuse (of lamps) contributed only insignificantly to waste reduction (less than 1%).

Based on the experience gained at sites 1 and 2, a more systematic implementation of the selective demolition procedure was applied on site 3. The results of this demolition are summarised in Table 5.

Compared to the reference scenario (site 1), important improvements could be completed at site 3. It was possible to reuse all the inert materials resulting from demolition on the site itself, while all other materials (other than asbestos) were delivered to recyclers. In reality, on-site reuse has associated costs for crushing and placement on the site (machinery movement and fuel consumption), but it is still the best option from both economic and environmental points of view. Reuse

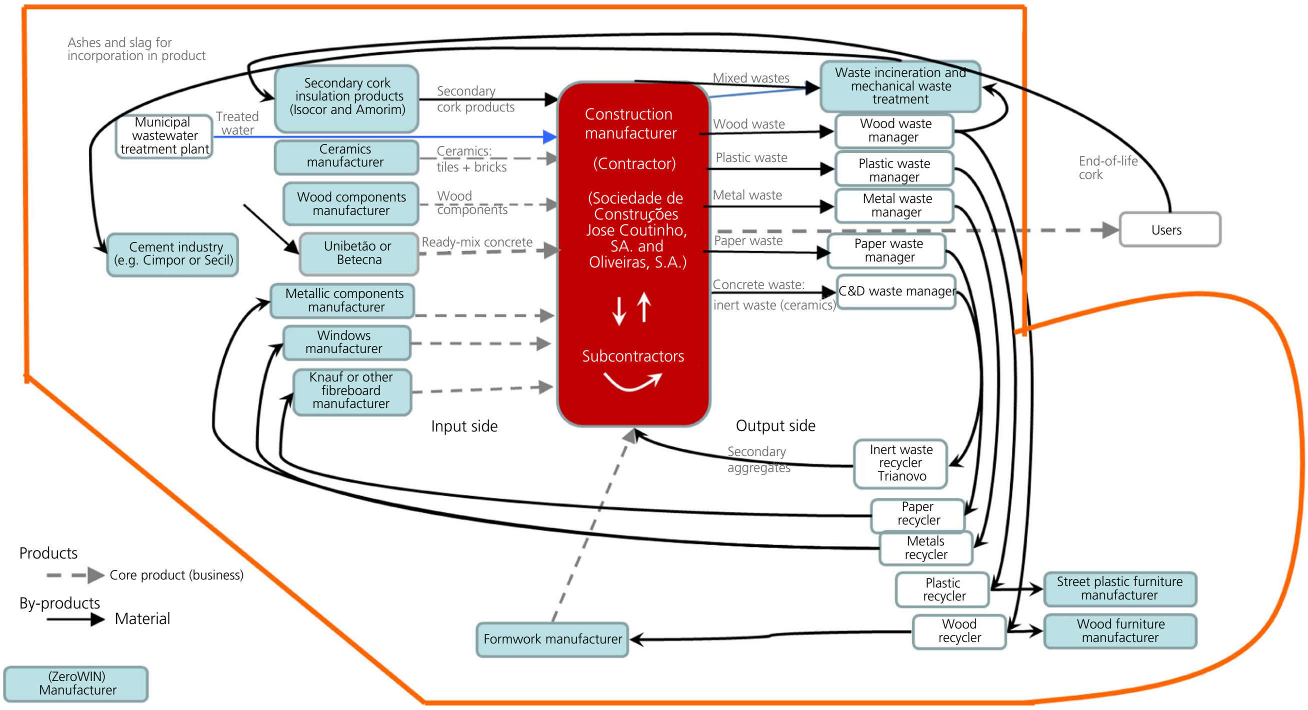

Figure 2. Simplified representation of materials flows in the industrial network developed around the construction site of the environmental education centre in Torres Vedras

outside the site was also considered for wood from the cover structure. To implement this measure, manufacturers of wood laminates and similar wood processors were identified. However, after dismantling it was found that the quality of wood was not good enough for reuse, so instead it was delivered to a recycler (Figure 6). This demonstrates that the quality protocols in place helped to select rational recovery methods for materials.

3.3 Final remarks

It is well established that the construction industry's culture and opposition to change are important barriers to effective waste minimisation (Teo and Loosemore, 2001) and that a substantial amount of construction waste originates as a result of poor design (Innes, 2004). Key factors that promote resource efficiency within the C&D sector include the use of on-site waste sorting methods (Poon *et al.*, 2001), waste auditing and assessment tools (Chen *et al.*, 2002) and waste management practices (McDonald and Smithers, 1998). Achievement of the environmental targets at the reported Portuguese sites was the result of careful preparation of the case studies and intensive communication with the stakeholders. This demonstrates the crucial importance of design, planning and facilitation for the development of industrial symbioses in C&D works.

A general barrier for the construction sector is the lack of relationship between the concept/design phase and the execution phase (Greenwood, 2003). In fact, several months – or even years – can pass between the planning and execution phases of a building. In the construction case study reported here, this meant that although the municipality was responsible for the design, some of the changes suggested by the research team were rejected because they were not foreseen at an earlier stage (e.g. the substitution of wood laminates).

For the development of industrial symbiosis, a further politically related barrier must also be mentioned. The exchange of waste materials between enterprises depends on the legal status of the materials, which is regulated at European level for each specific waste type. For example, for glass cullet, EU Commission Regulation No 1179/2012 of 10 December 2012 establishes the criteria determining when glass cullet ceases to be waste under directive 2008/98/EC of the European Parliament and of the Council and can be handled as a by-product (EC, 2012). The procedure involves administrative burdens for the producers of waste materials and these must be followed for each specific waste type (copper scrap, metal scrap, etc.).

The ongoing economic crisis was another major barrier that influenced both the selection of construction works to

Process	Origin of input material: Baseline scenario	Origin of input material: Improved scenario	Required quantity: Baseline scenario	Required quantity: Improved scenario	Comments
Construction of foundations and structure	Portland cement ready-mix concrete	Light concrete – ready-mix	685 t concrete	263 t concrete with ash 44 t granulated cork	Decrease of the amount of concrete in the improved scenario due to the substitution of Portland cement concrete with ash cement concrete with max. 35% of ash and incorporation of regranulated (recycled) cork
Construction of foundations and structure	Portland cement ready-mix concrete	Ash cement ready-mix concrete	2520 t	2520 t	Substitution of Portland cement concrete with ash cement concrete (max. 35% ash)
Construction of foundations and non-structural elements	Portland cement Ready-mix concrete	Ash cement ready-mix concrete	299 t	299 t	Substitution of Portland cement concrete with ash cement concrete (max. 35% ash)
Pavement	Aggregates from the extractive industry	Aggregates from recycler (Trianovo)	269 t	269 t	Substitution depends on the technical specifications of LNEC for use of recycled aggregates
Cover sealing 1	Imperalum Systems	Upway Systems	280 m^2	280 m^2	Imperalum Systems: several layers including polyethylene (PE) film, draining system, polypropylene (PP) filter Upway Systems: supplier includes all materials of the complete system; draining system is recycled PE
Cover sealing 2	Imperalum Systems	Upway Systems	555 m^2	555 m^2	Imperalum Systems: several layers including PE film, PP filter, XPS thermal insulation Upway Systems: supplier includes all materials of the complete system; draining system is recycled PE
Thermal and acoustic walls insulation	XPS insulation from several local retailers	XPS from local retailers; ICB from Isocor or Corticeira Amorim	8·11 t XPS	3·15 t XPS 20 t ICB	157 m^3 substituted by black cork agglomerate – ICB (insulation cork board recycled from waste cork) Applied in ETICS (external thermal insulating composite systems)
Fillings of space in the cover	Boulder from local material suppliers	Recycled aggregates from local supplier Trianovo	35 t	35 t	In the improved scenario 100% substitution of boulder with recycled aggregates

Table 2. Input materials of the construction case study – material exchanges foreseen in improved scenario in relation to baseline (continued on next page)

	Origin of input material		Required quantity		
Process	Baseline scenario	Improved scenario	Baseline scenario	Improved scenario	Comments
Walls and roof coatings	Plasterboard from generic local material supplier	Knauf local supplier	12·74 t		Improved scenario (Knauf plasterboard with around 80% recycled gypsum and 100% recycled paper) could not be implemented for economic reasons; instead, a Portuguese producer (Gyptec) was identified that supplies fibreboards with some content of recycled materials
External shading system	Aluminium profiles from local material supplier	Nordic pine	1·80 t aluminium	5·7 t wood	In the improved scenario, aluminium profiles substituted by wood profiles
Carpentry (divisors and doors)	High-pressure laminate elements from local material suppliers	Recycled plastic elements from Reciplast or Extruplas	$16\ m^2 + 6{\cdot}5\ m^2$ Around 0·17 t		Substitution of high-pressure laminate for recycled plastic

Table 2. Continued

Output material or component	Process	Quantities produced at site: t	Quantities and destination of material		Quality standards and specifications for the material
			Baseline scenario	Improved scenario	
Concrete	Structure and foundations	71·98	Waste manager	Delivery to supplier for recycling/reuse	For recycling into aggregates, concrete should be clean inert material, with no organics (wood, plastics) or others. It may have metal contaminants because shredders usually have metal segregation incorporated
Insulation materials	Insulation	0·37	Waste manager for further recycling	Cork supplier (the cork) Waste manager for further recycling	Around half XPS and cork For recycling, materials need to be segregated
Wood	4·58/formwork and packaging	10·8	Contractor for reuse Waste manager	Contractor for reuse Waste manager Materials suppliers for reuse (packaging)	Wood from formwork is usually reused until it is too broken or warped Wood contaminated with release agents usually landfilled Material suppliers receive entire wooden pallets for further reuse Wood for recycling should be free of releasing agents
Other C&D containing dangerous substances		0·43	Landfill	Waste manager	Hazardous materials need to be properly segregated and in containers for forwarding to treatment or disposal
Mixed packaging: low-density polyethylene (LDPE); paper and cardboard	All processes except structure	Around 0·95 paper and 0·35 LDPE	Waste manager (for segregation and further recycling)	Recycler (segregation on site)	For recycling, materials need to be segregated and free of contaminants (although plastic may be washed before the recycling process)

Table 3. Quantities and destiny changes foreseen for output materials in improved construction scenario in relation to baseline construction scenario

participate in this research project and the involvement of stakeholders in the concept of zero waste. A further economic barrier detected was the low landfill taxes in Portugal, which do not support the diversion of recoverable materials from landfill.

Among the technical barriers, the most important is lack of confidence in the technical quality of alternative sustainable materials and fear of their failure as construction materials (e.g. the use of recycled cement for some non-structural applications was not always well accepted). A way to overcome the general resistance to the use of secondary materials in construction probably requires the implementation of policy measures such as regulations that stimulate/oblige designers to consider input substitution with by-products or recycled

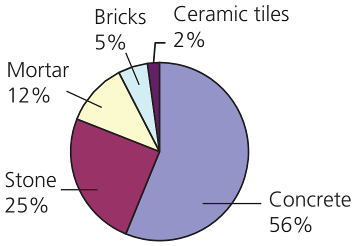

Figure 3. Composition of inert demolition materials at site 2

materials, promote less consuming processes and use materials whose by-products have a high reuse potential in other processes. Finally, aesthetics and architectural concepts were found to present a barrier to some proposed networking solutions. For example, the use of reused wood or recycled materials in public and visible spaces (e.g. wooden shading system, stone pavement) was declined by the architects. Eco-design and the inclusion of recycled or reused materials as criteria for the evaluation/licensing of buildings or constructions would create an important incentive for project professionals to consider these aspects at the design stage (Greenwood, 2003).

In spite of all difficulties met, the case studies have shown that it is possible to achieve zero-waste goals on C&D sites by exploring nearby industrial networking potentials. A prerequisite for the success of industrial networking and increasing resource efficiency is the implementation of accurate waste management logistics at the site to ensure proper separation of different types of materials.

4. Conclusion

The reported case studies show that implementation of the general framework set for the ZeroWIN project was challenging in the construction sector. Several recommendations have

Figure 4. Hand removal of dry elements in site 2

Figure 5. Careful removal of asbestos in site 3

been developed to support industrial networking around a construction site, and it seems to be easier to establish an industrial network when an external agent acts as a facilitator. The main tasks of a facilitator are to identify industrial network potentials and analyse materials flows in order to detect possibilities for materials exchange and substitution with other economic activities in the surroundings. In addition, the facilitator promotes contacts, resolves problems or conflicts and evaluates project progression. In this case study, the research team played this role. Owners and promoters that are aware of the importance of industrial networks to achieve better environmental performance in construction projects understand the relevance of a network facilitator. Intensive awareness-raising is needed in the construction sector in order to build up favourable framework conditions to spread this concept.

The demolition projects demonstrated progressive improvement – site 1 represented 'business as usual', site 2 was a trial to implement a selective demolition plan (not fully implemented) and site 3 showed the best results in selective demolition. Detailed planning of the methodology and close contact with the involved stakeholders proved to be very important. In general, the targets of the ZeroWIN project and the objectives of the case study were achieved. The deviation of waste streams from landfill to recyclers normally induces cost advantages, and the stakeholders thus generally accepted the measures proposed unless additional costs were associated with their implementation. Industrial networking directly involving manufacturing industries (direct reuse of materials/resource exchange) was shown to be difficult in demolition projects, due to both the degradation stage of materials and the resistance of the actors involved.

Output material or component	Process	Quantity: t	Destination: Baseline scenario (site 1)	Destination: Improved scenario (site 2)	Quality standards/specification for material	Comments
Mixtures of concrete, bricks, tiles and ceramics	Demolition of structure	1136·6	Landfill	Site reuse as aggregates after crushing (site roads, etc.)	Contaminated with wood, glass and plastics	Composition estimated in the pre-demolition audit (see Figure 1)
Iron (mixed with all other metals)	Window removal	0·470	Recycling after separation	Recycler (Metais Jaime Dias, SA)	Segregated iron, not in original shape and corroded by years of use	Cut into smaller pieces and sent to Siderurgia Nacional (steel and iron manufacturer) for integration in new products
Steel (mixed with all other metals)	Structure demolition	10·65	Recycling after separation	Recycler (Metais Jaime Dias, SA)	Steel in pieces from being cut during demolition	
Copper (mixed with other metals)		0·335	Recycling after separation	— (see Comment)	In pieces after demolition, and contaminated with mortar	Delivered by informal activity to a recycler
Wood	Dry elements removal	5·82	Waste manager – around 30% for recycling and 70% for landfill	Recycler (Jomar)	Wood with treatment layers such as varnish and broken into pieces	Recycled into pellets, wood aggregates/laminates or waste-derived fuel (WDF) (WDF most likely in this case, because of varnishes)
Glass	Window removal	0·215	Landfill	Recycler (Metais Jaime Dias, SA)	Window glass sometimes broken, segregated from all other materials	To be sent to Vidrologic to be recycled for shell of glass or calcined for application on glass containers, flat glass, glazed tiles (pads) resin-based flooring, surfaces of recycled material (silestone)
Plastic – polyethylene from cover	Cover removal	0·4	Landfill	Recycler (Metais Jaime Dias, SA)	Hard polyethylene tiles	Sent for Extrusal, S.A. and recycled – heating followed by grinding and moulding or extrusion; further used in urban furniture

Table 4. Improved resource management as a result of the demolition case study (site 2)

Output material or component	Process	Quantities produced at site	Destination		Quality standards/specification for material	Comment
			Baseline scenario	Improved scenario		
Concrete Mortar Ceramic bricks Ceramic bricks (from ventilation grids)	Demolition of structure and foundations	437·5 t 65·7 t 217 t 1·6 t	Landfill (in mixtures)	Site reuse as aggregate, after crushing	Broken/crushed secondary aggregates	Reuse on site after crushing Possible reuse by construction company at other sites
Concrete (from prefabricated beams)	Demolition of cover structure	20 beams (19·87 t concrete, 0·223 t steel)	Landfill (in mixtures)	Site reuse as aggregate, after crushing	Reinforced prestressed concrete beams	Possible reuse to be considered
Soils and rocks (stones)	Demolition of foundations	587 t	Landfill (in mixtures)	Site reuse as aggregate	Multi-sized stone used on continuous foundations	
Glass	Window removal	Not relevant	Landfill	Site reuse as aggregate, after crushing		Not viable conditions for segregation of broken glass from windows
Wood	Dry elements and cover removal	9·3 t from wooden structure, 0·135 t from old windows	Waste manager – around 30% for recycling and 70% for landfill	Recycler/shredding	Pitch pine in apparently good condition (in reality was degraded by age)	Recycled into pellets, wood aggregates/laminates Suggested reuse not possible due to poor quality of wood after dismantling
Plastic – polyethylene from cover	Cover removal	0·285 t	Landfill	Recycler (SGR)	Hard polyethylene tiles	To be sent for Extrusal, S.A. and recycled – heating followed by grinding and moulding or extrusion – further used in urban furniture
Materials containing asbestos	Asbestos removal	n/a	Landfill	Landfill in Chamusca – Ribtejo		Mandatory by law to be sent to landfill
Fluorescent lamps	Previous dismantling	0·02 t (144 units)	Landfill	Stored for reuse on the yard	Entire and functional lamps	Non-functional lamps to be forwarded to recycler Ambicare for crushing, removal of hazardous materials and separation of all other materials

Table 5. Resource exchanges for output materials from demolition site 3 in reference to baseline (established by site 1)

Figure 6. Segregated wood for recycling at site 3

In the construction sector, further research is needed with regard to the manufacture of construction materials incorporating secondary materials (ceramics, steel, glass, cement, concrete, etc.) without compromising product quality. Standards and regulations need to be established for materials with recycled content. Research needs specifically related to demolition were also detected – these are mainly related to the incorporation of secondary materials in new products (both for construction products or other sectors) and the direct incorporation of demolition by-products on construction works.

Mechanisms to simplify the procedures related to the certification of secondary materials and recognition of by-products should be developed and tested.

Alternative demolition processes must be better studied. Selective demolition requires special techniques and, at the moment, the best standards are achieved with labour-intensive approaches. New technical developments are needed to reduce the time and costs involved in selective demolition so that it becomes more attractive to both owners/promoters and contractors.

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