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Deconstruction Roles in the Construction and Demolition Waste Management in Portugal - From Design to Site Management

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1. Introduction

In the last few years, the impact of construction industry on the environment has been increasingly recognized and has become a key challenge for the sector. Construction sites activities in urban areas may cause damage to the environment, interfering in the day life of local residents, that frequently claim against dust, mud, noise, traffic delay, space intrusion, materials or waste deposition in public space, etc.. In a time where it can be seen quality improvements in construction process techniques, in materials innovation and in safety and healthy conditions, it is also necessary to take care of the environment and other sustainability related issues.

The number of new constructions in Portugal had a significant decrease on the last years. This is due to the fact that housing needs are already completely fulfilled - one dwelling per each two inhabitants. This is the result of a construction boom that took place during the 80s and 90s of the past century. But many of these buildings were made without a sustainable cost/benefit ratio and without reuse / recycling strategies, due to initial budget limitations and lack of knowledge.

In recent years, the implementation of Energetic Certification by Decree-Law 78/2006, from 4th of April, following the 2002/91/EC directive as well as new regulation on Buildings' construction waste management, Decree-Law 46/2008, from 12th of March, following the 2006/12/EC directive, conducted to relevant changes, especially regarding envelope walls, but also with repercussions on the interior layouts. There is a need of refurbishment that in some cases reflects both in the quality improvement of the construction, but also in the increase of the internal areas. The internal minimum areas have increased significantly in the last 50 years, and almost doubled, what made many buildings obsolete and not capable of fulfilling the contemporary needs of the households. Maybe this is the reason why the majority (66,9%) of the refurbishment building works taking place in Portugal in the last years correspond to extensions. Refurbishment works and rehabilitation without extensions correspond to 33,1% (INE, 2010¹).

There are still many unoccupied dwellings (11%) and a lot of buildings needing refurbishment. But in fact the number of refurbishment works is not increasing, just the opposite, it has been slightly decreasing since 1996 as the Figure 1 evidences. However, the percentage of refurbishment works has increased slightly from 2008 to 2009, in 2,2%.

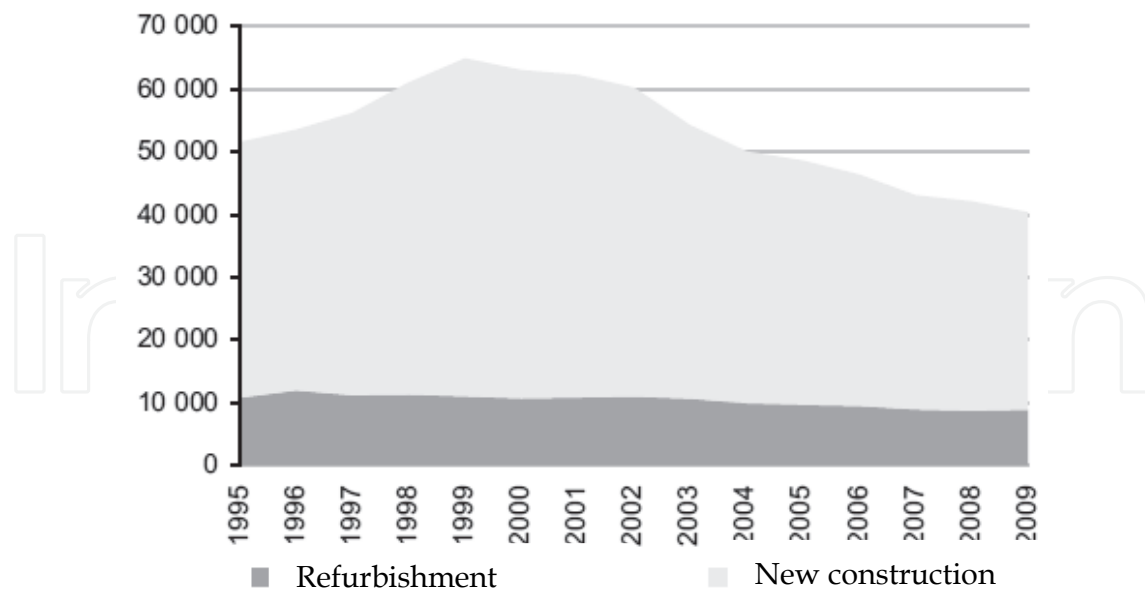


Fig. 1. Refurbished and new constructions in Portugal from 1995 to 2009. Source:(INE, 2010¹)

There is an enormous building stock in Portugal that is waiting to be refurbished. Paradoxically, very little rehabilitation takes place in Portugal – indeed. According to Euroconstruct 2008 Report in the year 2007 it was invested in refurbishment about 26% of total construction investment, whereas in other European countries it raised to about 45% (including residential, non-residential and civil engineering renovation) (Euroconstruct, 2008). The lack of interest in refurbishment underpins behaviours that limit sustainability improvement in the construction sector. The attitude is partly connected to the fact that building refurbishment involves knowledge of building materials and techniques that have been superseded. More often than not, the refurbishment of a building will stop at the preservation or restoration of the facade, disregarding the reuse of the materials inside, even though in some cases they can be recovered and employed in the new intervention. Decree-Law 46/2008 imposes since 2008 some measures in this way.

The building activity at Portuguese city centres tends to be an important waste generator because both refurbishment projects and new projects often include demolition (Couto & Couto, 2009). Surveys conducted in several countries found that the amount of waste generated by the construction and demolition activity is as high as 20–30 percent of the total waste entering landfills throughout the world and the weight of the generated demolition waste is more than twice the weight of the generated construction waste (Bossink & Brouwers, 1996). Other studies compared new construction with refurbishment, and concluded that the latter accounts with more than 80 percent of the total amount of waste produced by construction activity as a whole.

Between 2004 and 2009 Portugal generated 172 million tons of wastes mainly coming from the Transforming and the Commerce and Services Industries sector. In 2009 production decreased almost 1/4th in relation to the previous year, mainly because of the strong decrease from the Building Industry, fixing on the 24 million tons (INE, 2010²). Although an increase on the wastes generated by extractive industries could be seen, in result from the research and exploration of stone quarrying and mining industries, as well as from cement industries, thus a fact in direct strong relation with building activities.

Year	2004	2005	2006	2007	2008	2009
Construction sector (tons)	2 625 930	5 212 520	3 607 232	5 674 248	8 148 290	3 152 098
Total (tons)	24 689 088	31 096 302	31 155 301	30 240 562	31 591 727	23 659 876

Table 1. Wastes generated by the construction sector in Portugal between 2004 and 2009.
Source: (INE, 2010²)

The “mining” industry has shown a dynamic growth over the period under review, as evidenced by the average annual rate of around 30% recorded during this period, as documented in the following figure.

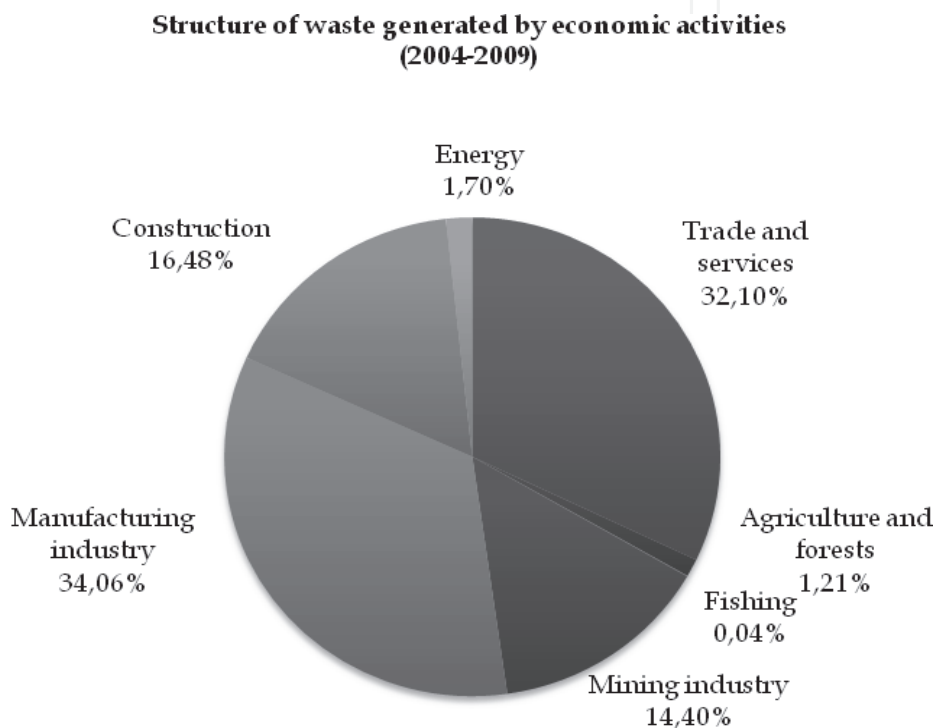


Fig. 2. Structure of waste generated by economic activities in Portugal from 2004 to 2009.
Source: (INE, 2010²)

The portion gained from the quantities of generated wastes by Gross Domestic Product (GDP), translates the efficiency level of the economy that will be as much efficient as less is the quantity of wastes per unity of generated GDP. In generic terms, the year 2009 stands as the most efficient in environmental terms, although this result is influenced by the decrease of production in general and of building sector in particular that, in relation to 2008, generated around 5 million tons less wastes. To this fact is not indifferent the implementation of the Decree-Law 46/2008 that, among other measures, preconizes the possibility of reusing soils and stones without dangerous substances, with origin on building construction, in other works, apart from the original one, as well as on the environmental refurbishment, allowing this way to avoid the waste production and simultaneously preserving the natural resources used to identical uses (INE, 2010²). Construction industry rely nowadays on materials of a complex life-cycle, making use of many different raw materials and some with a high energy cost (in relation to its function),

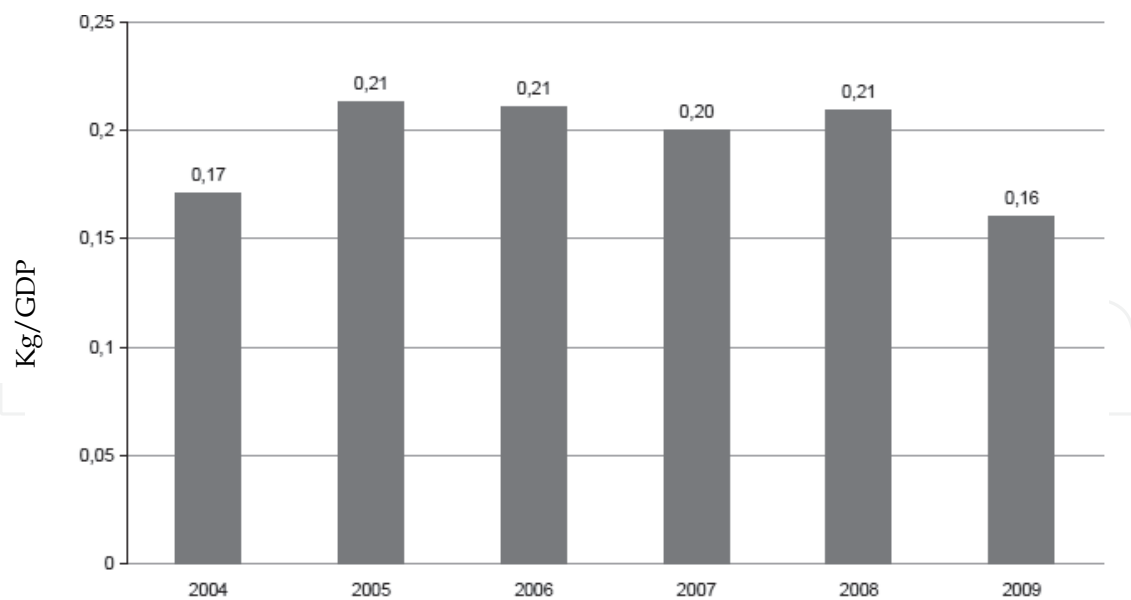


Fig. 3. Wastes generated by GDP. Source: (INE, 2010²)

in detriment from low-energy, less transformed, recycled and preferably re-used ones. The maximum use of reused materials means reduction of environmental impacts due to the extraction of prime materials, to their transformation processes and to the work yards, with reduction of the noise, dust, wastes and the consumption of energy during the construction and a proportional reduction on loss factors and on transport energy.

Berge (2000) refers: “the amount of energy that actually goes into the production of building materials is between 6 and 20% of the total energy consumption during 50 years of use, depending on the building method, climate, etc”. This is not a very relevant percentage, even if we consider the maximum, but energy cost will certainly increase in future years, and the dismantling, treatment and transport of waste materials also represents energy, especially in nowadays most common constructive system used in South European housing – concrete structure with clay hollow brick walls and pavements (Mendonca & Braganca, 2001).

Sustainability on building sector is a pluridisciplinary concept that, for its implementation, requires the cumplcity of all the involved agents, from polititians to urbanists, that have to legislate and define the planning instruments, to projectists that have to conceive efficient buildings on the resources optimization, till construtors, that should be able to construct the building in the most reasonable way.

Sustainable approach to building construction, as well as to many other areas of industry, rely on four strategies: reuse, recycling, recovery (energy) and reducing. All those points are relatively neglected in South European buildings, and specially referring the Portuguese case and, in spite of studies being made, implementation suffers a strong resistance (Mendonca & Braganca, 2001). First point focused, reuse, is usually implemented in a very limited way. Preconception about innovative materials and construction methods leads to focus the attention just on reducing environmental impact in making traditional materials for conventional buildings.

In what respects the structure and the materials used, housing constructions in South European climates are generally heavyweight. Concrete, brick or stone are used in the exterior envelope walls and structure, in order to achieve high thermal storage capacity and structural resistance. When these materials and labor are locally available (as earth, wood or stone), their

environmental cost is reduced, but the increase of the global mass of the building implies other problems, such as the increasing economical cost of an high intensive labor. Some building elements cannot be always locally made, (such as steel, concrete, glass or ceramics), and in a high density multi-storey building, the percentage of the industrial and more transformed components usually increases (Mendonca & Braganca, 2001).

2. Impact of construction industry on the environment

The Building industry is a great consumer of raw materials and energy; to whom are associated the sequent pollutant emissions, associated to extraction and production of the building materials, as well as to the use phase and eventual demolition/refurbishment. Fossil fuels burning is the most important source of pollution, associated with energy needs in the use phase as well as in the first phases of extraction, producing and transport.

To evaluate the environmental impact of a building during its life cycle, it can be considered two distinct essential components: energetic and material, that are usually associated.

The environmental impact during the construction phase constitutes a much smaller percentage in relation to the production of materials, on Portuguese present reality. This is due to the use of industrialized materials, with high specific embodied energy, as well as to a bad waste management.

A principle for future actuation should consist on a drastic reduction on the use of unprocessed raw materials. This is an important factor to be considered for the most scarce resources, but should also be considered for the most abundant.

The environmental impacts of buildings and materials do not end up in the useful life term, and can be even more significant if deconstruction strategies were not considered on the design stage. During demolition or partial dismantling, the two most significant parameters that should be considered are:

- Energy consumption and worn of equipment necessary for demolishing or dismantling, as well as hand labor;
- Transport of wastes to landfill or recycling units. The building industry in Portugal was responsible for over 8 million tons of solid wastes in 2008 (INE, 2010²).

The environmental impacts of buildings during its useful life can be represented through a diagram of "inputs" and "outputs", such as the one presented on Figure 4. In the "inputs" are included energy and materials and in "outputs" pollution and wastes.

In an open cycle (linear) system, representative of the Portuguese scenario for buildings constructed nowadays and in the past decades, environmental impacts of a building correspond to the sum of inputs and outputs from all the building life cycle phases represented on Figure 4.

There are several ways to promote waste management in buildings. Part of the responsibility is in the hands of building constructor, which should act with ethic principles that should go far beyond what imposes legislation, but is also mission of the architects and engineers that design the building, to give it the maximum qualities that allow an efficient waste management. Of course it is first responsibility of politicians and technicians that assessor these, to legislate about environmental issues in building construction, in order that promoters and builders feel obliged to included these aspects as major concerns, and not only the profits (Mendonca, 2005). But, before taking any action to reduce environmental impacts of buildings, consciousness should be gained about all the factors involved, so it becomes necessary to make an LCA evaluation, already in the design phase. This LCA

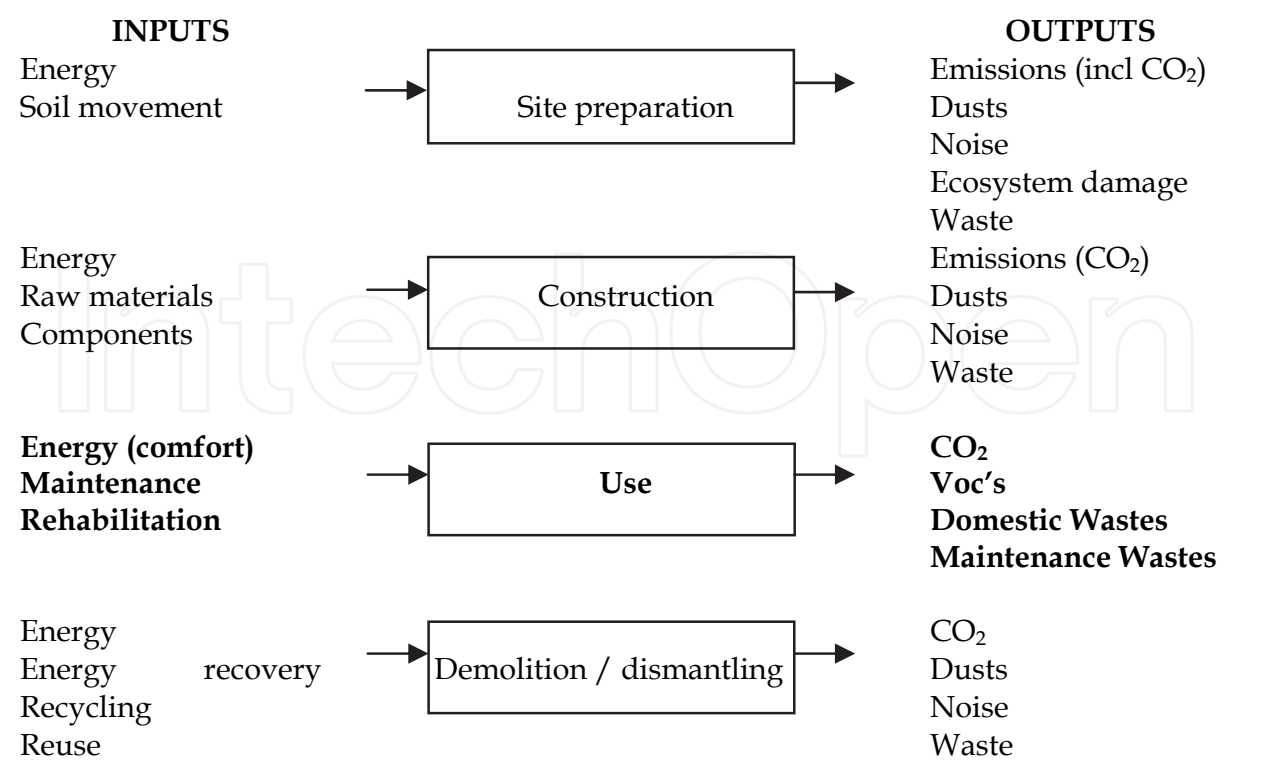


Fig. 4. Environmental Impact of buildings in its Life Cycle

evaluation should consider closed-loop systems, as represented in Figure 5. In the scheme of Figure 4 are marked in bold the inputs and outputs corresponding just to the use phase, in a close loop cycle. When building is designed for deconstruction, reuse or refurbishing beyond it's expected lifecycle, only these impacts remain present.

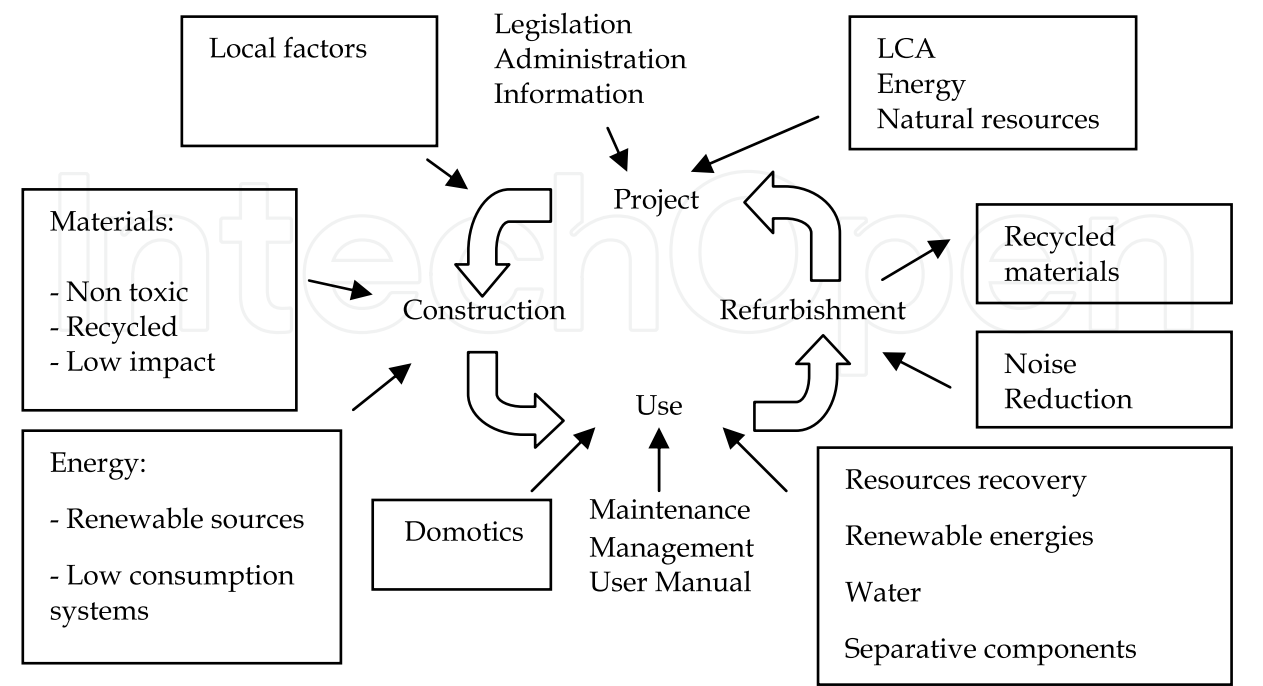


Fig. 5. Life cycle of buildings in Closed Loop – adapted from Mendonça (2005)

The impacts that building construction has on the environment can be analysed from the following points:

- Position and integration of buildings in the site;
- Influence of design in the Building behavior during its useful life;
- Influence of the equipments in the Building behavior during its useful life;
- Characteristics of the materials used - by the impact that these can produce on the environment during the processes of extraction of raw materials, manufacture, useful life and in the end of life scenarios (reuse / recycling / energy recovery).

2.1 Energy fluxes of buildings

The energy component of the building construction is not only related with the stages of extraction and production of materials and work, but continues through the use of the building and even during the demolition, so the overall environmental impact assessment of a building becomes complex. It is therefore relatively difficult to differentiate the energy component from the material component, as in virtually all phases of the building life cycle the two components are present.

According to Dimson (1996), buildings account for 40% of the energy consumed annually. These values were calculated for buildings located in central and northern Europe. In Portugal, the mild climate and a situation of generalized discomfort inside buildings has meant that the consumption associated with the heat and cooling needs - about 20% of total energy consumption - has not, in relative terms, nothing to do with the levels of consumption in northern Europe countries (Mendonça, 2005).

In relation to the overall percentage of energy consumption during 50 years of use, the amount of energy that actually goes into the production of construction materials in a building, is between 6 and 20% and depends on building type, climate, etc. (Berge, 2000). The intervention in reducing the embodied energy of the materials is much more significant in overall energy consumption than in countries with less favorable climate, so it can be concluded that this factor has greater importance in Portugal than in most other European countries.

Energetic consumption in the demolition and removal of building wastes constitutes in average around 10% of the total energy spent since its production (Berge, 2000), so the attitude of those who conceive the buildings should consider that energetic cost can still be amortized after the 50 years generally considered for the useful life, reusing or at least recycling as much as possible in the end of this period.

Energy use in buildings is divided between production, distribution and use of building materials, as summarized in Figure 6.

The manufacture, maintenance and renewal of materials in a housing building made of concrete blocks, for a lifetime of 50 years, require an energy consumption of 3000MJ/m². For larger buildings, in steel or reinforced concrete, the energy required is approximately 2500MJ/m² (Berge, 2000).

The embodied energy of a material corresponds to the energy used to manufacture a product. It corresponds in average to 80% of the total amount of energy associated to final product installed in the building. Embodied energy is divided as following (Berge, 2000):

- Direct energy consumption due to the extraction of raw materials and manufacturing process. It varies with the manufacturing system and the type of equipments used;
- Indirect energy consumption from the manufacturing process. It refers to the energy consumption of equipment, air conditioning and lighting in the factory, and is usually a value less significant than the direct;

- Transport energetic costs, of raw materials and semi-processed materials. The choice of transport system used is also a decisive factor. The road transport is one of the most inefficient, it implies over 400kWh/kg.Km, and this is the most used transport in the Portuguese case.

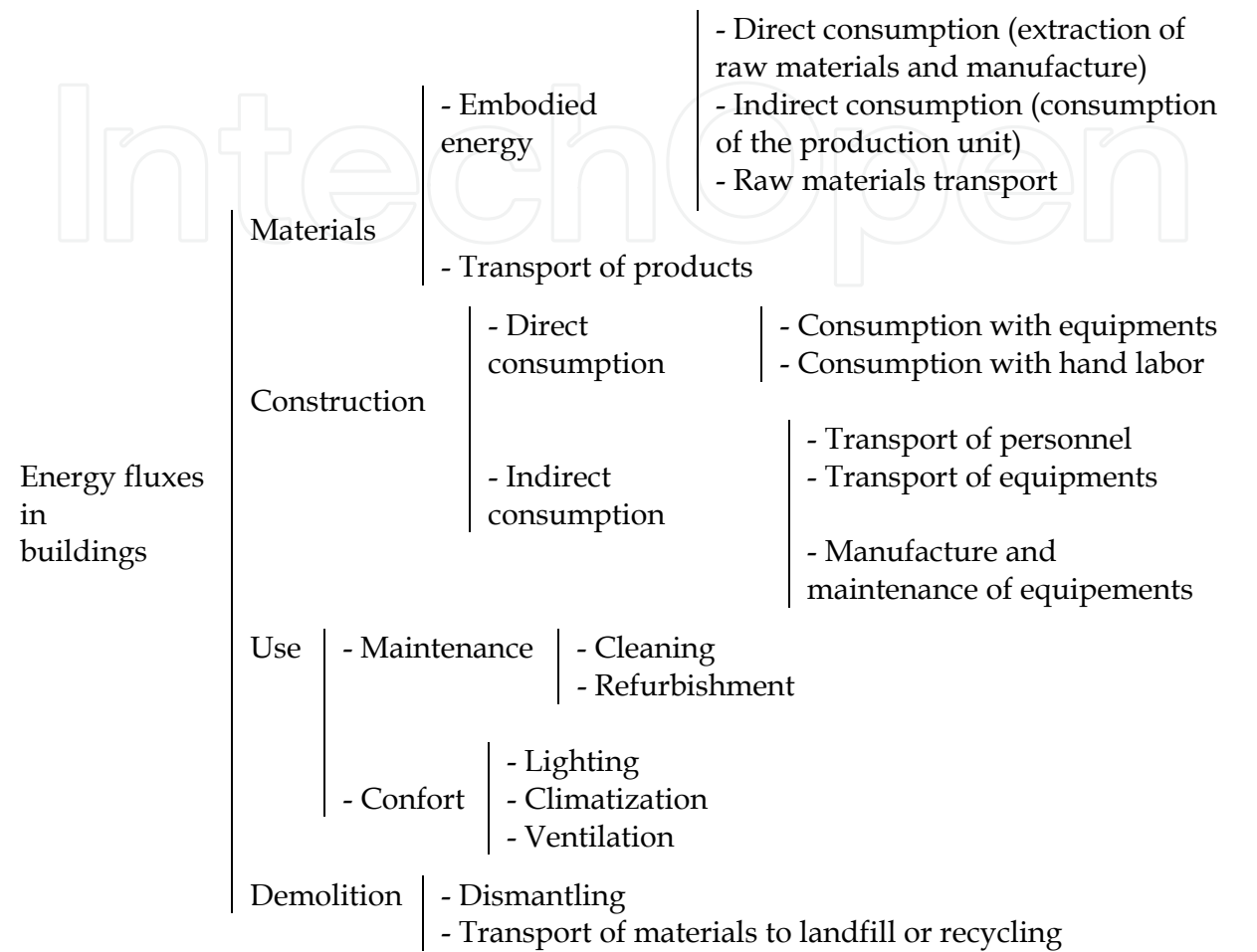


Fig. 6. Energetic fluxes in buildings – adapted from Mendonça (2005)

Massive CO₂ emissions caused by combustion engines are related with the construction industry, in large part associated to the transportation of construction materials, as well as labors. In the case of construction materials, the random location of works, the preferred mean of transport is road.

The energy pollution in the manufacturing process of a given material depends on the type and quantity of primary energy spent. Energy sources vary from country to country but in Portugal, the most commonly used types of energy are fossil fuels. The construction materials of higher embodied energy may thus contribute indirectly to the increased CO₂ and other pollutants emissions.

2.2 Material fluxes of buildings

The material environmental impact of buildings is essential due to raw materials extraction. The construction industry is the second largest consumer of raw materials in the world today, after the food industry (Berge, 2000). The building industry is responsible for consuming 25% of wood production and 40% of aggregates (stone, gravel and sand) around the world. Buildings are also responsible for 16% of water consumed annually (Dimson, 1996).

Material pollution is related mainly to pollutants in air, land and water from the material itself and from the others components of the material when in production, use and demolition. The picture becomes more complex considering that about 80,000 chemicals harmful to health, are used in the construction industry, and that their number has quadrupled since 1971 (Berge, 2000). In Table 2 are shown the types and quantity of waste associated with building materials production.

Most material environmental impacts are due to the exploration of the non-renewable raw materials resources, particularly minerals and aggregates. Quarries and opencast mines, as well as the extraction of sand, produce visual impacts on the landscape, destroy ecosystems and pollute the soil waters. The pollutants concentration percentage in the wastes resulting from demolition of buildings is relatively small; however, as the amount of waste produced is very high, this represents a substantial part of the overall environmental impacts. A great percentage of the building construction wastes in Portugal (concrete and brick) are not in general treated or selected for reuse or recycling, being only used as inert for land filling in sanitary or industrial municipal landfills.

The losses in construction are approximately 10% of the total losses in the construction industry (Berge, 2000). Each material has a loss coefficient that describes the waste during storage, transportation and installation of the final product. For many materials, increased pre-fabrication does decrease this factor, as well as the standardization of products and building design taking these factors into account.

In the construction industry, a large amount of packaging is used in the transportation and storage of products. An important aspect of packaging should be its easy recycling or even reuse.

3. Waste management in building construction

In Portugal and southern Europe in general, the heavyweight building systems made of concrete structure and hollow brick, increasingly hinders reuse, in opposition to what should be expected. Interestingly, the buildings with more than 50 years, present more easily reusable components, and have an initial much lower environmental impact. In these buildings, systems were simple, often with juxtaposed stone masonry walls, timber pavement and roof structures with ceramic tiles. Even in northern Europe, more sensitive to environmental aspects, this phenomenon is a reality. Selective demolition of buildings, where a level of recycling of 90% was achieved, is only possible in old buildings, using fewer materials and well differentiated (Berge, 2000). According to Berge, it is doubtful that the level of recycling can reach even 70% in newly constructed buildings, even in northern Europe realities. This is mainly due to the extensive use of composite elements, with aggregate materials. For example, in steel reinforced concrete, where steel content can reach 20%, recycling of the metal is a relatively complex process, due to the need of separating the two elements, which can result economically unfeasible in most cases.

3.1 Implementing a waste minimisation hierarchy

Waste management can be hierarchically classified in three levels, by decreasing order of effectiveness:

- Reuse;
- Recycling;
- Energy recovery.

Material		Wastes from materials production process		Wastes from building construction/ demolition
		g/kg of product	Taken to special landfills (%)	Waste types*
Steel	100% recycled			D
	galvanized (from mineries)	601	5	D
	stainless (from mineries)			D
Chipboard	porous without bitumen	81	5	A/D
	porous with bitumen			B/E
	high density without bitumen	80		A/D
	high density with bitumen			B/E
Aluminium (50%recycled)		715	20	D
Concrete (with Portland cement)	structural	32		C
	fibre reinforced slabs	81	10	C
	mortar	17	10	C
	lightweight aggregate blocks	58	13	C
Bitumen		3		B/D
Lead (from ore)		265	5	E
Polyvinyl Chloride (PVC)				D
Copper (from ore)		2.410	84	D
Maritime counterplate		40	2	B/D
Cork				A/D
Cellulose fibre	100% recycled w/ boric salts			E
	paper 98% recycled			A/D
Carton plaster		8	10	D
Rockwool		320	5	D
Glasswool		90	5	D
Linoleum		2		B/D
Timber	non treated	25		A/D
	treated			E
	glulam			B/D
Ceramic tiles		9		C
Stone				C
Polyester (UP)				B/D
Expanded Polystyrene (EPS)				B/D
Extruded Polystyrene (XPS)				B/D
Expanded polyuretane (PUR)		486	7	B/D
Expanded perlite	with bitumen			E
	without bitumen			C
Compacted earth				C
Clay brick		87	15	C
Glass				C

* A - Burn without filtering; B - Burn with filtering; C - Landfill or inert; D - Municipal landfill; E - Special landfill.

Table 2. Wastes associated to manufacture and building industries. Source: (Berge, 2000)

The management should preferably be developed in order that materials can be returned in its original quality level and not at an inferior level - “downcycled” (Berge, 2000).

The reuse of materials after the demolition should be taken into account. The reuse depends on component useful life and refers to the use responding to the same function. An effective reuse of building components requires simplified and standardized products, which almost never happens. However, reuse of materials has been a fairly common construction practice. In coastal areas, some buildings were constructed using materials recovered from dismantled ships. The prefabricated building in timber is therefore an example of construction with a high potential for reuse. In some coastal areas of Portugal, vernacular buildings are made in this system.

Recycling, rather than manufacturing products from natural raw materials can substantially reduce their environmental impacts. A product that can easily be reused several times has advantages over lower cost products that can not be reused. In Portuguese building industry, products present high durability but low potential for recycling, but what is more problematic, there are products with low durability and great recycling potential that are not usually recycled.

Applying to few contemporary building components, but to many old building components, energy recovery is also possible as a last option. But this can only be beneficial if this energy is extracted in a site near the building, but also if the combustion process can be kept clean.

The waste minimisation hierarchy is an important guide to managing waste. It encourages the adoption of options for managing waste in the following order of priority (Morgan & Stevenson, 2005):

- Waste should be prevented or reduced at source as far as possible;
- Where waste cannot be prevented, waste materials or products should be reused directly, or refurbished before reuse;
- Waste materials should then be recycled or reprocessed into a form that allows them to be reclaimed as a secondary raw material;
- Where useful secondary materials cannot be reclaimed, the energy content of waste should be recovered and used as a substitute for non-renewable energy resources; and
- Only if waste cannot be prevented, reclaimed or recovered, it should be disposed of into the environment by landfilling, and this should only be undertaken in a controlled manner.

In Figure 7 is illustrated the waste hierarchies for demolition and construction operations.

Construction waste management should move increasingly towards the first of these options, using a framework governed by five key principles promoted by the European Union (Hurley and Hobbs, 2004):

- The proximity principle;
- Regional self sufficiency;
- The precautionary principle;
- The polluter pays; and
- Best practicable environmental option.

Clearly, the reuse of building elements should take priority over their recycling, wherever practicable, to help satisfy the first priority of waste prevention at source.

To ignore deconstruction means to create a pile of debris that cannot be viably reused. The Figure 8 attempts to depict this situation; to demolish a building without resorting to procedures that enable separation and recovery of debris and by-products.

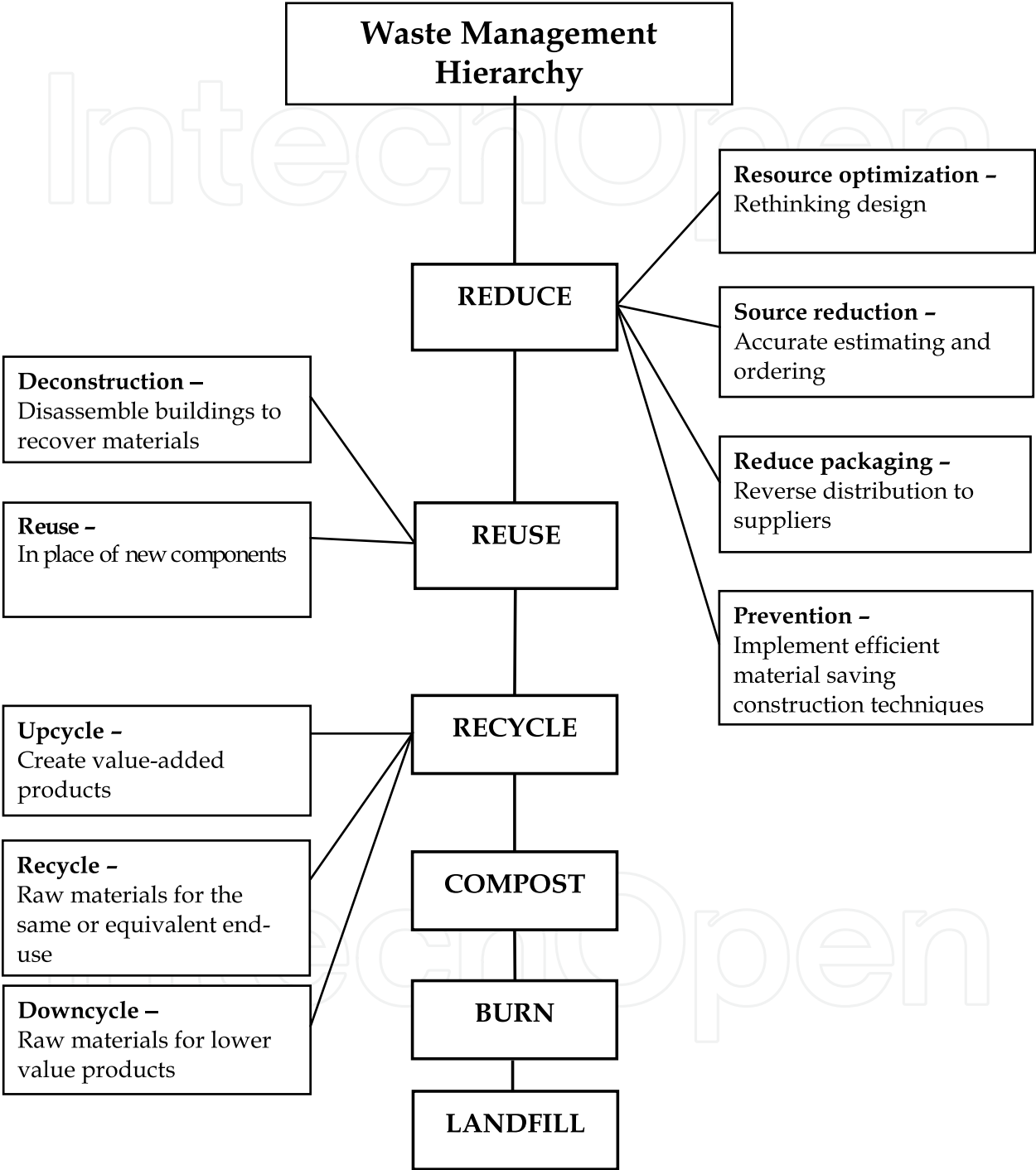


Fig. 7. Hierarchies for demolition and construction operations. Source: Adopted directly from (kibert & Chini, 2000)



Fig. 8. Sample of an undifferentiated demolition. Source: (Pinto, 2000)

The Figure 9 attempts to depict that deconstruction permits the resorting to procedures that enable separation and recovery of debris and by-products.



Fig. 9. Sorted broken concrete and steel stockpiled separately (Public Fill Committee, 2004)

The benefits from reuse are significant. The main benefits of building reuse include sustainability, direct and indirect monetary savings, an accelerated construction schedule, and decreased liability exposure (Fig. 10).

Although the reuse can benefit all projects, the situation more clearly advantageous for the reuse of construction is in urban environments, because the construction sites can be close to existing buildings and cause negative impacts on surrounding ((Chapman et al., 2003) cited by (Laefer & Manke, 2008)).

Building deconstruction supports the waste management hierarchy in its sequence of preferred options for the management of generated C&D waste materials (see Figure 7). If a building is still structurally sound, durable and flexible enough to be adapted for a different use (either in situ or by relocation), then waste can be *reduced* by *reusing* the whole building. If components and materials of a building can be *recovered* in high quality condition,

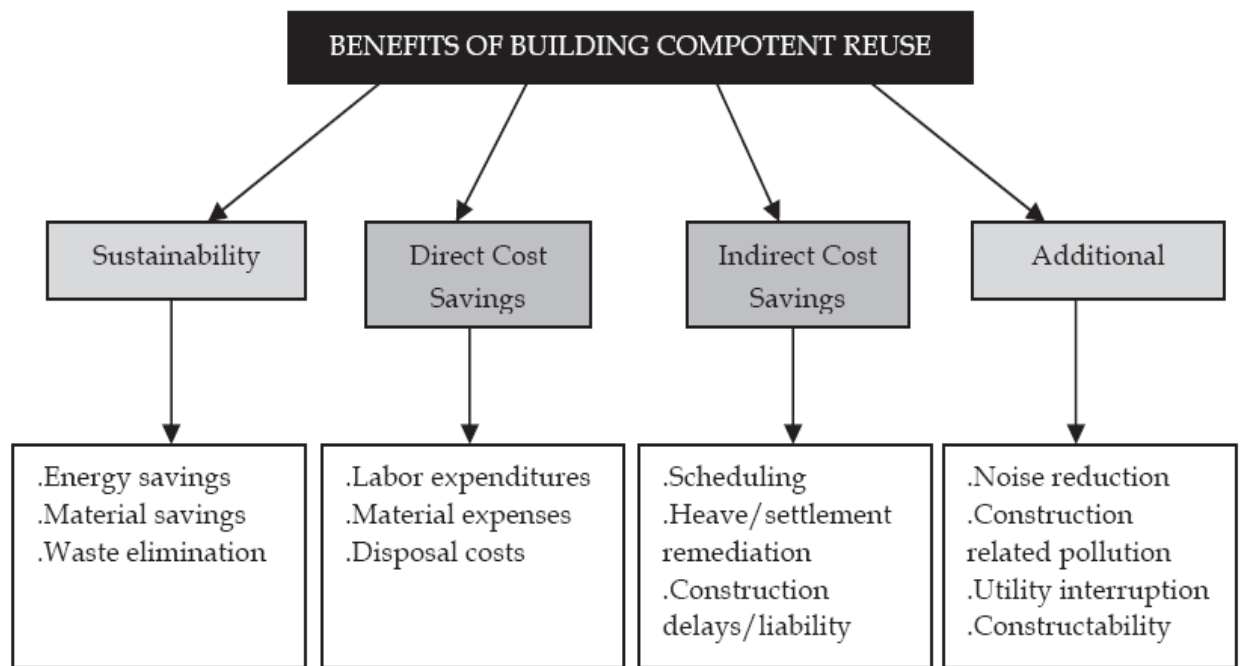


Fig. 10. Benefits of building component reuse. Source: Adopted directly from (Laefer & Manke, 2008)

then they can be *reused*. If the building materials are not immediately reusable, they can be used as secondary feedstock in the manufacture of other products, *i.e.*, *recycled*. The aim is to ensure that the amount of waste that is destined for *landfill* is reduced to an absolute minimum. This approach closes the loop in material flow thereby contributing to resource efficiency.

4. Deconstruction as alternative to traditional demolition process

4.1 Barriers and advantages of deconstruction

There are a number of areas where the authorities may influence design and planning strategies at an early stage. These include fiscal incentives such as the maintenance of a fixed price for recovered products or increased costs for waste disposal through the landfill tax. Incorporation of deconstruction techniques into material specifications and design codes on both a National and European level would focus the minds of designers and manufacturers. Education on the long-term benefits of deconstruction techniques for regulators and major clients, would provide the necessary incentive for the initial feasibility stage. Design for deconstruction is not, however, solely an issue for the designers of buildings. The development of suitable tools for the safe and economic removal of structural elements is an essential pre-requisite for a more widespread adoption in deconstruction (Couto & Couto, 2007).

A study carried out by BRE (Building Research Establishment) (Hurley et al., 2001) has shown what the industry has known for decades; that there are keys factors that affect the choice of the demolition method and particular barriers to reuse and recycling of components and materials of the structures. The most factors are physical in terms of the nature and design of the building along with external factors such as time and safety. Future factors to consider should well include the fate of the components, the culture of the

demolition contractor and the 'true cost' of the process. For the latter, barriers to uptake include the perception of planners and developers, time and money, availability of quality information about the structure, prohibitively expensive health and safety measures, infrastructure, markets quality of components, codes and standards, location, client perception and risk.

According to Hurley and Hobbs (2004), the main barriers (in the UK) to the increased use of deconstruction methods within construction include:

- Lack of information, skills and tools on how to deconstruct;
- Lack of information, skills and tools on how to design for deconstruction;
- Lack of a large enough established market for deconstructed products;
- Lack of design. Products are not designed with deconstruction in mind;
- Reluctance of manufactures, which always prefer to purchase a new product rather than to reuse an existing one;
- Composite products. Many modern products are composites which can lead to contamination if not properly deconstructed or handled;
- Joints between components are often designed to be hidden (and therefore inaccessible) and permanent.

Although the market for products from deconstruction is poorly developed in Portugal, can be noted that the interest in low volume, high value, rare, unique or antique architectural components is much higher than the interest in materials that have high volume, low value, such as concrete.

Even though there are significant advantages to deconstruction as an option for building removal, there are still more challenges faced by this alternative:

- Deconstruction requires additional time. Time constraints and financial pressure to clear the site quickly, due to lost time resulting from delays in getting a demolition, or removal permit, may detract from the viability of deconstruction as a business alternative;
- Deconstruction is a labor-intensive effort, using standard hand tools in the majority of cases. Specialized tools designed for deconstructing buildings often do not exist;
- The proper removal of asbestos-containing materials and lead-based paints, often encountered in older buildings that are candidates for deconstruction, requires special training, handling, and equipment;
- Re-certification of used materials is not always possible, and building codes often do not address the reuse of building components.

The main opportunities which require development include:

- The design of joints to facilitate deconstruction;
- The development of methodologies to assess, test and certify deconstructed elements for strength and durability, etc.;
- The development of techniques for reusing such elements;
- The identification of demonstration projects to illustrate the potential of the different methods.

Modern materials such plywood and composite boards are difficult to remove from structures. Moreover, new building techniques such as gluing floorboards and usage of high-tech fasteners inhibit deconstruction. Thus, buildings constructed before 1950 should be ideally targeted for deconstruction (Moussiopoulos et al., 2007). In Portugal, it is expected a substantial increase in the investment on refurbishment of buildings. The deconstruction should have a relevant contribution in this process.

The greatest benefit will be achieved by incorporating deconstruction issues into the design and feasibility stage for all new construction. Each case can then be judged on its merits in terms of the potential cost of recovery and recycling or reclamation and reuse of construction materials.

4.2 Deconstruction benefits

Deconstruction seeks to close the resource loop, in order that existing materials are kept in use for as long as possible and the deployment of new resources in construction projects is diminished. The benefits from deconstruction are considerable. Deconstruction offers historical, social, economic and environmental benefits. Older buildings often contain craftsmanship which have significant historical value. Deconstruction can carefully salvage these important historical architectural features, because materials are preserved during removal. Deconstruction is more time consuming and requires more skill than simply demolishing a structure. Although the extra time required could act as a detriment, deconstruction provides training for the construction industry and also has the potential to create more jobs in both the demolition and the associated recovered materials industry. Deconstruction provides a market for labour and sales of salvaged material. More important, deconstruction puts back into circulation items which may be directly used in other building applications. Environmental benefits of deconstruction are essentially two fold. Primary, resource use is reduced through a decreased demand on new materials for building. This means that climate change gas emissions, environmental impact, pollution (air, land and water) and energy use are all reduced. Deconstruction also means that less waste goes to landfill because materials are salvaged for reuse. This means fewer new landfills or incinerators need to be built which reduces the environmental and social impact of such facilities, and environmental impact of existing landfills is reduced. Currently there are few incentives to break the historical practice of landfilling debris. The occasionally higher cost of selected demolition can be offset by the increased income from salvaged materials, decreased disposal costs, and decreased costs from avoided time and expense needed to bring heavy equipment to a job site (Couto & Couto, 2007).

Based on the review of international literature it is possible to categorize the main benefits of deconstruction as follows:

- Reuse and recycle materials: materials salvaged in a deconstruction project can be reused, remanufactured or recycled (turning damaged wood into mulch or cement into aggregate for new foundations) (Hagen, 2008);
- Foster the growth of a new market – used materials: recovered materials can be sold to a salvaging company. The market value for salvaged materials from deconstruction is greater than from demolition due to the care that is taken in removing the materials in the deconstruction process;
- Environmental benefits: salvaging materials through deconstruction helps reducing the burden on landfills, which have already reached their capacity in many localities. By focusing on the reuse and recycling of existing materials, deconstruction preserves the invested embodied energy in materials, eliminating the need to expend additional energy to process new materials. By reducing the use of new materials, deconstruction also helps reducing the environmental effects, such as air, water and ground pollution resulting from the processes of extracting the raw materials used in those new construction materials. Deconstruction results in much less damage to the local site, including soil and vegetation, and generates less dust and noise than demolition;

- Create jobs: deconstruction is a labour-intensive process, involving a significant amount of work, removing materials that can be salvaged, taking apart buildings, and preparing, sorting, and hauling the salvaged materials.

Other less obvious benefits may also come from the deconstruction, but that depend on the specific characteristics of countries and regions.

4.3 Cost of deconstruction

Deconstruction, as an environmentally-sound business practice, is not necessarily more costly than traditional demolition. Buildings can be often deconstructed more cost-efficiently than they can be demolished. There are many different factors involved, including the type of construction and the value of the materials that can be recovered. But overall, deconstruction can be more cost-effective than demolition. Not only can buildings be deconstructed more cheaply than they can be demolished, but deconstruction provides construction companies with low-cost materials for reuse in their own building projects. Deconstruction is also an ideal training ground for the construction trades. Preliminary results from pilot projects carried out in different parts of the USA by the US Environmental Protection Agency (EPA) have indicated that deconstruction may cost 30 to 50% less than demolition (CEPA, 2001).

Deconstruction is labor-intensive, involving a higher level of manual work than there would be in a demolition project. But the higher labor cost can be offset by lower costs for equipment rent and energy usage, cost savings in the form of lower transportation and landfill tipping charges, and the revenues from sales of the salvaged material.

Research shows that the market value for salvaged material is greater when deconstruction occurs instead of demolition, because of the care taken in removing materials. Money made through salvaging can be used to offset other redevelopment costs. Lastly, disposal costs are lower with deconstruction because the process reduces the amount of waste produced by up to 75 percent.

Different studies carried out in Germany on deconstruction methods have showed that optimized deconstruction combining manual and machine dismantling can reduce the required time by a factor of 2 with a recovery rate of 97% (Kibert, 2000). In the Oslo region, Norway, it is estimated that between 25% and 50% of C&D waste stream is recycled or reused (Kibert, 2000).

In Portugal the construction waste management is now beginning its first steps, so, its outcomes are not yet completely known.

Previous research analysis point out that from the clients' perspective the following are sound economic reasons for using deconstruction (Couto & Couto, 2009):

- To increase the flexible use and adaptation of property at minimal future cost;
- To reduce the whole-life environmental impact of a project;
- To maximise the value of a building, or its elements, when it is only required for a short time;
- To reduce the quantity of materials going to landfill;
- To reduce a future liability to pay higher landfill taxes;
- To reduce the risk of financial penalties in the future, due to changing legislation, through easily replaceable building elements;
- To minimise maintenance and upgrading costs incurred by replacement requirements.

A key economic benefit of design for deconstruction is the ability for a client to "future proof" their building, both in terms of maintenance and any necessary upgrading, with

minimum disruption and cost. The wider economic benefits to society include minimising waste costs at all levels.

Numerous projects have been costed, and while some have come in on budget, others have not. Much depends on the canniness of the design team and contractor, from the outset, with cost savings to be viewed as bonus rather than a given. Design for deconstruction should always be adopted for its wider economic, social and environmental benefits rather than any initial cost saving.

Current economic barriers to design for deconstruction and reuse of reclaimed materials and products include: the additional time involved for deconstruction and the difficulty of costing this against reused materials which will be used on a different project, the damage caused by poorly designed assemblies and connectors, as well as the limited flexibility of reclaimed elements. Reuse is not subsidised in the same way that manufacture is in terms of energy, infrastructure, transportation, and economies of scale, all of which have hidden environmental costs.

5. Designing for deconstruction

In the concept of construction management, building towards a future scenario of deconstruction is an important factor. With this concept, the different components can be easily separated during the demolition, separating the components of each type for reuse, but also facilitating recycling and energy recovery (Berge, 2000).

Addis & Schouten (2004) synthesized the following deconstruction design strategies to facilitate reuse and recycle:

- Use materials that can easily be recycled;
- Use materials for which, when recycled, a viable market exists;
- Whenever possible design products or elements that can be separated easily into units made of one material;
- Whenever possible design products or elements whose materials all decay at the same rate, so they reach their end of the life simultaneously;
- Ensure that materials, once deconstructed and separated, are clean and free from contamination and paint – this will maximize their reusability or recyclability, although it may compromise their durability;
- Use alternatives to chemical bonding (adhesives) in favour of bolts, clips, etc.

A summary of strategies that can adapt to the Portuguese and thus allow to complete a draft prepared for the deconstruction consists in:

- Using totally separated systems;
- Possibility to separate components in each system;
- Using standardized and homogeneous materials.

5.1 Separated building constructive systems

A building is composed of various building components, forming systems (structure, facades, fittings, partitions, furniture, etc.). The structural system has to last the entire lifetime of the building, while interior partitions are often rearranged in short periods of time, for functional or more futile reasons.

In Portuguese contemporary buildings of conventional construction, the different systems are almost always permanently fixed, forming an inseparable unit, which causes that

components with short useful life may condition components with long useful life, which is unwise when the smaller durability component is for example the structure. It becomes common, for example, to demolish buildings where facilities are integrated in the structure and thus it became difficult to maintain or replace. A fundamental principle for efficient reuse of building components is the differentiation of the systems. Figure 11 presents examples of three types of connection between wall and structure: the image (a) show the connection between walls and structure, which was the common situation in the buildings in Portugal until about 50 years; the image (b) show the common situation today with brick masonry walls and reinforced concrete structure; and image (c) show the situation in separate systems, whose materials can be of the same quality or not, but always easily separable.

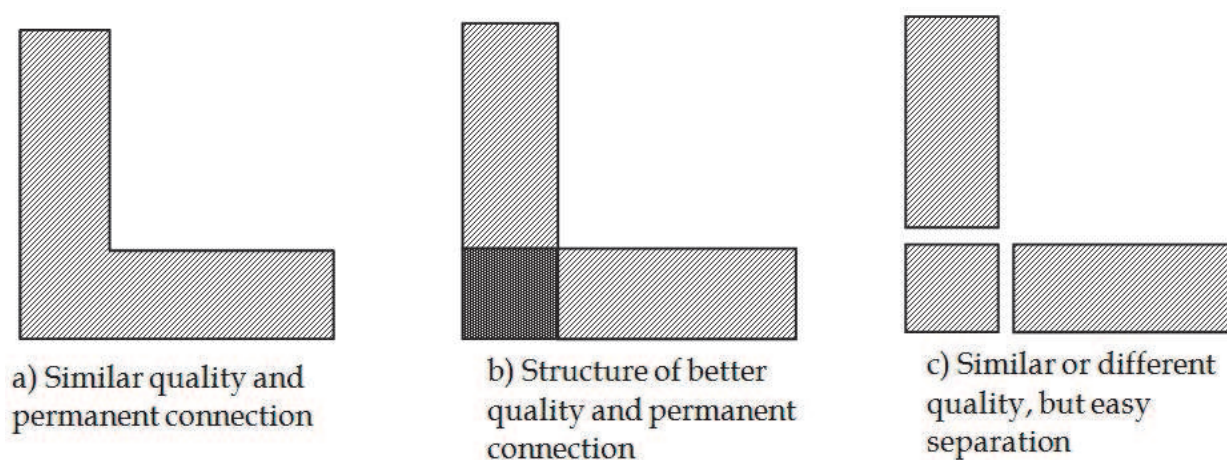


Fig. 11. Connections between structural and wall systems. Adapted from Berge (2000)

Easily dismantling building systems should comprise components prepared to be loose fitted together during assembly and are commonly known as prefabricated. The prefabricated lightweight systems present as a main advantage to be easily transported in cargo volume and small weight, potentially making them easier to move over large distances. In places with difficult access to large transport vehicles, these represent a constructive solution economically more feasible than the conventional heavyweight one. It starts to be common in Portugal, mainly for single family houses, and marketed by companies that normally are responsible for their design and assembly. The most common material used is timber, although metal frames and sheets are also common options.

5.2 Durability and possibility to separate the systems' components

From the standpoint of material resources, there is always a clear advantage in using more durable materials for buildings, allowing the longest lifetime possible (Berge, 2000). The use of durable materials allows reducing the raw materials used, since ensuring durability equal to all components of the same building system, so as not to compromise the durability of materials by the existence of lower durability. If it is impractical to use materials of equal durability, the type of material, then the replacement of less durable materials should be easier. The building layers model of Brand (1995) allows to understand and manage the different components in relation to its durability.

Durability depends from diverse factors, such as:

- The material in itself, by its physical and chymical structure;
- Building and execution, where and how the material is placed;
- Local environment exposure - sunlight, raining, pollutants and other conditions.

Components of each system should be easily divided into units for easy handling, allowing reuse and recycling. Separation allows easy substitution of elements with greater wear; easy replacement of elements after repair; and reuse elements in areas of less visual exposure in exchange for the elements with less wear. It also allows the easy transport of components within the building itself and outside it.

5.3 Standardized and homogeneous materials

Many building components are composed of different materials combined in a new material with different and increased properties, often called composite. But the reuse or recycling of composite materials is often impossible or very difficult. On the other hand, different degrees of durability of the materials present within the same component can result in a material that can reach the loss of its useful life, while others are still valid, but it is no longer possible to use the component for that reason (Berge, 2000).

The use of homogeneous materials, such as hardwood timber in a floor or natural stone in a wall, allows re-use later, fulfilling the same purpose, something not possible with the use of most composites. For example, between an outer coating in corrugated iron or a plastic composite sandwich panel, the last one is unlikely to be reused and recycled while in the first case any of these hypothesis is feasible.

6. Conclusion

All around the world, the deconstruction of buildings has gained more and more attraction in recent years as an important waste management tool. Deconstructing a building consists on the careful dismantling of their components, so as to make possible the recovery of materials, promoting reuse and recycling. The concept arose as a consequence of the rapid increase in the number of demolished buildings and the evolution of environmental concerns within society at large. In fact, demolition is one of the main construction activities in what concerns to the production of waste. The deconstruction is an unusual process in Portugal; as traditional demolition is yet the preferred method when it is necessary to dismantling a building. In addition to the general lack of awareness about the overall benefits of deconstruction, there are many barriers to deconstruction in Portugal. The barriers have many sources that include not only technical and market issues, but also issues related with social and educational factors. The barriers to the implementation of deconstruction were disclosed as well as its opportunities.

Strategies and actions that could be implemented in Portugal by impelling the deconstruction process were discussed in order to improve waste construction management. The focus was on easy to implement design for deconstruction strategies, having in view the prediction of future scenarios of deconstruction. To achieve this goal, the different components should be easily separated during demolition, allowing its reuse, and if this is not possible, at least allowing the recycling or even the energy recovery.

Various factors allow achieving a deconstruction effective project, such as: using totally separated systems; Possibility to separate the components in each system; Using

standardized and homogeneous materials; Using mechanical or dry joints; Use lightweight materials and components. These strategies can make handling easier, quicker, and less costly, thereby making reuse a more attractive option.

In Portugal, recent legislation about waste management in construction has come into force, but is still giving its first steps and there are still many difficulties to overcome. There are some good examples but these are still insufficient.

Therefore, a greater engagement and a new attitude from all practitioners is absolutely necessary in order to implement new and more adequate waste management rules and new selection demolition processes so as to increase the results of the construction waste management.

It is very important that National authorities and construction practitioners understand the benefits of the deconstruction process and look at it as an advantageous way to improve waste management, thus following other European countries' practices.

7. Acknowledgment

The authors are grateful for all the resources provided by Territory, Environment and Construction Centre/University of Minho.

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Integrated Waste Management - Volume I

Edited by Mr. Sunil Kumar

ISBN 978-953-307-469-6

Hard cover, 538 pages

Publisher InTech

Published online 23, August, 2011

Published in print edition August, 2011

This book reports research on policy and legal issues, anaerobic digestion of solid waste under processing aspects, industrial waste, application of GIS and LCA in waste management, and a couple of research papers relating to leachate and odour management.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

João Pedro Couto and Paulo Mendonça (2011). Deconstruction Roles in the Construction and Demolition Waste Management in Portugal - From Design to Site Management, Integrated Waste Management - Volume I, Mr. Sunil Kumar (Ed.), ISBN: 978-953-307-469-6, InTech, Available from:
<http://www.intechopen.com/books/integrated-waste-management-volume-i/deconstruction-roles-in-the-construction-and-demolition-waste-management-in-portugal-from-design-to->

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