

Construction and demolition waste: general process aspects

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1. Introduction

Building and construction is a cyclic process, as shown in figure 1. From a 'sustainable' point of view, it is clear that a closure of this cycle may be established by aiming at a near 100% recycling of construction and demolition waste. Today's Construction and Demolition Waste (CDW) is based upon building materials applied about 50-100 years ago. Although generally a major part of this CDW waste may be recycled, it is also clear that through a design and construction process based on future ease of reuse or recycling, advancements may still be made [1]-[4].

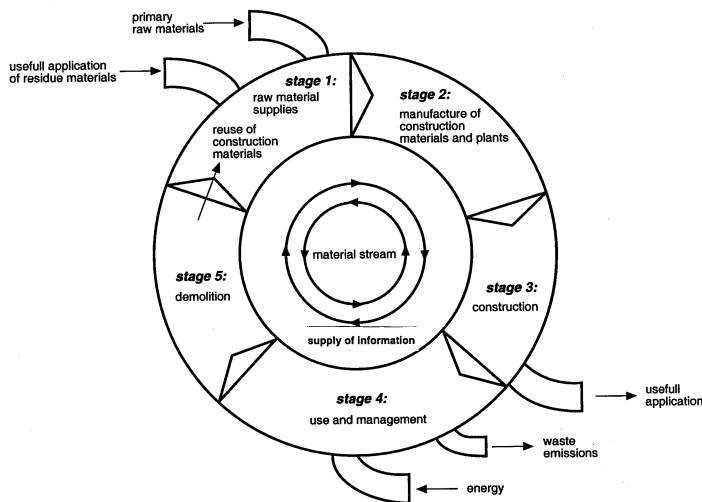


Figure 1. The Building Cycle

Worldwide, currently most C&D waste is still being landfilled. A significant quantity is being processed at a materials level or applied as e.g. road foundation. A minor part, consisting largely of plastics and old wood is being combusted. Recycling of building products remains thus far limited to plastic window frames and PVC sewer pipes. Although it is difficult to prefer one option to another, it will be clear that prevention of C&D waste is most desirable, and landfilling least desirable. The concept of integral chain management of C&D waste provides a way to address the topic more systematically [5]. In table 1 below an overview of all recycling and reuse options is provided.

Top listed options are most desirable, while options listed below should preferentially only be applied if options listed above turn out to be impossible to realize. The actual choice between options lying close together (alternatives) should preferably be made using standardised methods such as Life Cycle Assessment [6], [7].

Table 1. Recycling and reuse options according to the 'Delft ladder' concept [5]
<ol style="list-style-type: none"> 1. Prevention (extending service; life of structure) 2. Construction reuse 3. Product reuse 4. Material reuse 5. Useful application 6. Immobilisation with useful application 7. Immobilisation without useful application 8. Combust with energy recovery 9. Combustion 10. Landfill

Based on the above systematic, CDW may roughly be divided into the following types of waste:

- A. Immediately reusable if in a good condition: wood and steel.
- B. Reuse and beneficial application after processing: rubble (masonry and concrete), wood (to be subdivided into a category of initially clean and contaminated materials).
- C. Combustion: paper, fabrics, wood.
- D. Production of new materials (after processing): metals, wood for pyrolysis, glass, plastics.
- E. Useless materials, contaminated non-reusable materials (asbestos, chemical waste), or uncontaminated non-reusable materials (plaster, glass, mixed CDW).

2. CDW separation and its costs

Separation on the building site is only effective if the wastes can be processed (and eventually) sold separately. When a processing company separates wastes, substances (contamination) which impede reuse, also have to be kept apart. These include e.g. chemical wastes, products containing tar, asbestos, plaster, aerated concrete, fibre-reinforced concrete and glass. Tar and other materials containing polycyclic aromatic hydrocarbons (PAH) can be separated relatively easily by separate removal of the chimney and roofing elements.

It should be kept in mind that an increasing separation increases the selectivity, but requires more and better equipment, more time, more space, and thus higher costs. These costs should always be compared with the cost a given society makes when no separation is carried out. Of course, in this respect it is fair to include costs which may have to be made otherwise on the long term.

If a construction is to be demolished then the demolition process should aim for reuse of the C&D waste at the highest possible level. Therefore, a demolition plan is essential when a building is demolished. Although developing such a plan costs time and money, it will reduce the costs of

landfilling. Typically, dumping costs for C&D waste in Europe and the USA range between 20-50 US\$ per ton. In the Netherlands, landfilling of recyclable C&D waste is prohibited since 1997.

From a purely economic point of view, recycling of C&D waste is only attractive when the recycled product is competitive with natural resources in relation to cost and quantity. Recycled materials will be more competitive in regions where a shortage of both raw materials and landfilling sites exists.

A simplified macro-economic model of integrated resource management and its total costs of both 'traditional' and 'selective' demolition is provided in figure 2 [6].

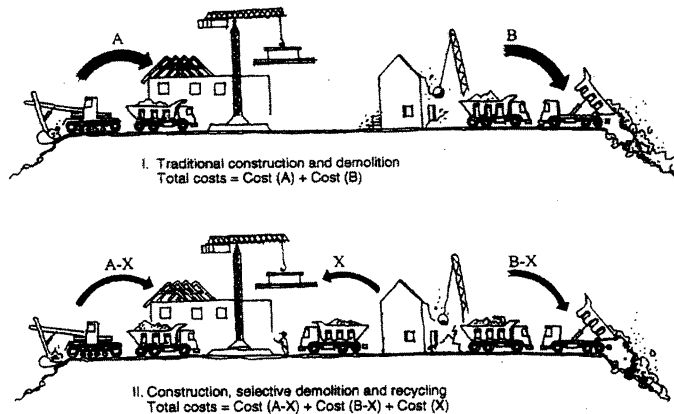


Figure 2. Macro-economic model of integrated management and total costs of traditional and selective demolition [6].

From this figure it becomes clear that with the use of recycled materials, economic savings in the transportation of building waste and primary raw materials may be achieved. Especially in larger projects, such as urban renewal, motorway renovation and clearance of war or natural disaster related damages, total project costs will be dominated by transportation costs.

The top illustration in figure 2 shows a traditional construction and demolition process, involving the use of primary raw materials (A) only, as well as landfilling of C&D waste (B). Total costs are the sum of A plus B. The illustration below shows construction, selective demolition and recycling (x), when (part of) the natural resources are substituted by recycled materials. This option saves on costs for transport, supply of natural raw materials and the landfilling of C&D waste, depending of course on a local situation.

An analysis by DEMEX [6] of the main factors affecting the prospects for successful recycling of C&D waste resulted, in order of importance, in the following three factors: Population size and density in a specific region, occurrence of and access to natural raw materials and the level of

industrialisation. Other, less predictable factors, included societies stability with respect to war and the occurrence of natural disasters, such as earthquakes, hurricanes and floods. Finally, apart from costs and local availability, also the quality of (processed) C&D waste is of prime importance. As mentioned earlier, the drafting of standard specifications is a first step here. The draft specification for recycled aggregates as published earlier by the CEN/TC 154 ad hoc group for recycled aggregates as a technical report is the most common used standard. Realistic quality control procedures are a second step.

A comprehensive separation system means that the C&D waste materials listed in table 2 should be collected separately.

Materials, ready for reuse without processing (A)	Materials, ready for reuse in another application upon processing (B)	Contaminated materials, to be cleaned or landfilled (B)	Materials to be incinerated (C)	Materials to be reused in the same application upon processing (D)	Useless materials (chemical wastes) (E)
<ul style="list-style-type: none"> - metals, sorted by type - usable wood (elements) - glass, clean, sorted on colour 	<ul style="list-style-type: none"> - rubble: clean ready for reuse; - rubble: clean, for crushing; - asphalt rubble; - soil: clean: ready for reuse. 	<ul style="list-style-type: none"> - soil: to be cleaned; - soil: contaminated, to be tripped in a controlled landfill; - soil: contaminated, to be tipped in a special landfill; - rubble: chemically contaminated. 	<ul style="list-style-type: none"> - contaminated and broken wood - plastic (unsorted) - wood 	<ul style="list-style-type: none"> - garden wastes - paper and cardboard, sorted - plastics (thermoplastics) sorted by type - metals (unsorted) - glass (unsorted) 	<ul style="list-style-type: none"> - chemical wastes, such as: - acids, alkalies, (halogenated) organic substances - solid wastes containing heavy metals, asbestos, electrical cables. - plaster - mixed CDW

3. Quantitative prevention of demolition wastes

Extending the life of buildings can reduce the volume of demolition wastes. Depending on the nature and purpose of a building the emphasis may be on extending its technical life by improving its quality and durability, or extending the functional life through flexible or multifunctional building. In both cases the measures taken in the construction stage will only have a long-term effect, when the building is demolished. When a building is demolished the materials used in it will be released. At that stage quantitative prevention is limited to avoiding the disposal of more waste than is needed. Hence, from dumping of tar waste at the demolition site has to be prevented and trucks should be loaded carefully to avoid picking up excessive amounts of soil.

4. Selective demolition

The objective of qualitative prevention is to improve the quality and composition of the demolition wastes to facilitate reuse. This means that buildings have to be demolished selectively. There are a number of reasons why selective demolition is not used. Firstly, the accessibility of the materials to be removed is important. The accessibility depends on the design of the structure to be demolished. Furthermore, selective demolition is only effective if wastes are also collected separately, which requires more space at the demolition site. In urban areas there is often insufficient space for anything other than separating rubble and other materials.

Time constraints are also important. In urban areas, the local authorities may restrict the duration of the demolition activities. This may be related to nuisance, opportunities for vandalism, and traffic obstruction. The client will also generally want the site to be cleared as soon as possible.

Costs are also important factor. In the past simply knocking down the structure as quickly as possible was the most common approach and also the cheapest. The demolition wastes were then removed in the state in which they arose, fully mixed. Only materials for which there was a ready market were removed from the building first.

This approach is slowly changing due to the new charges for the disposal of CDW. If recycling companies charge more for processing mixed demolition wastes than processing separated rubble then there is a financial incentive for selective demolition and separate disposal of the rubble.

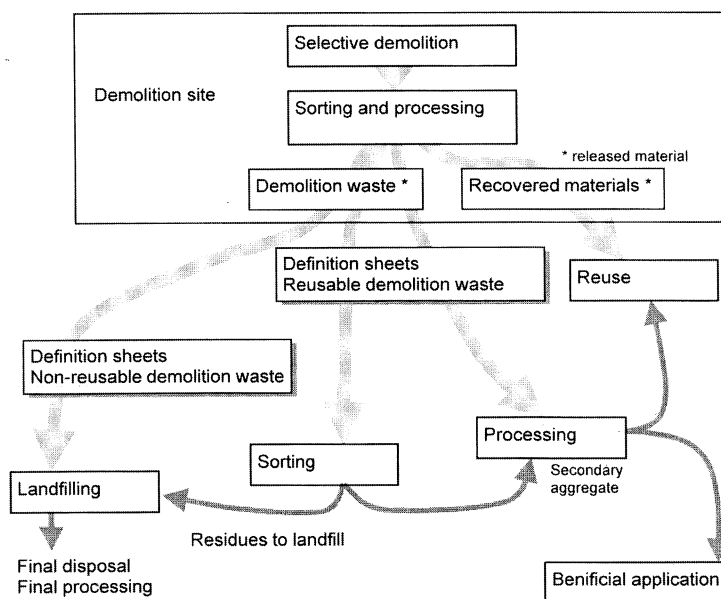


Figure 3. Disposal of materials released by selective demolition

After sorting and processing the materials are divided into the following streams:

- useless demolition wastes;
- reusable demolition wastes;
- recovered materials.

This division greatly facilitates the recovery of building materials and other resources and is an important condition in creating facilities for high level reuse, such as life cycle management.

5. The demolition process

If demolition of a building is taken as an example, first adequately trained professionals should investigate it, if the building contains any hazardous substances such as asbestos. If there are any such materials then a specialist contractor should be engaged to remove them. Asbestos stripping in particular requires extensive safety measures. After completion of this investigation an architectural reclamation (salvage) company should make an inventory of the building for any components which can be reused entirely. Such materials may include leaded glass, marble fireplaces, precious woods such as walnut and oak, central heating boilers, water heaters and radiators. Demolition contractors prefer it if these components are removed first, as this saves them work and their sales provide revenues.

Demolition contractors divide buildings into the following types:

1. Buildings constructed of brickwork with wooden floors, wooden roof structures, flat roofs with bitumen roofing or roof tiles.
2. Buildings with concrete skeleton frames, which may also include prestressed concrete elements.
3. Buildings with steel frames.

Generally, all three building types are treated as follows:

First, the buildings are stripped of unusual or reusable components such as leaded glass, traditional sanitary ware, etc., mentioned above. Next, floor coverings and ceilings (plaster) are removed. Burnable and nonburnable materials are separated. Glass is removed from the window frames. Building services installations are removed. Metals are removed. Piping is generally removed before the real demolition work starts. Roof tiles are removed. Roofing is removed and landfilled. The roofing gravel may be contaminated with PAH (polycyclic aromatic hydrocarbons) and should be treated as dangerous waste. The gravel can be washed and reused. The question arises if gravel could then be reused on roofs without washing as this simply moves the chemical contamination rather eliminating it.

Stripping a building produces a number of waste streams and a range of different materials. These are transported to a sorting plant where they are separated in burnable and nonburnable materials. The burnable fraction is incinerated in a waste incineration plant and the nonburnable fraction is landfilled.

Buildings constructed of brickwork with wooden floors, wooden roof structures, flat roofs with bitumen or roof tiles

When only the brickwork and floors are left the building is taken down floor by floor. Joists (beams) and wooden floors are removed from the building using a crane and equaliser beam. The nails in joists and planks are removed by punching. The punching unit pushes the wood around the nail down and then extracts the nail by its head. There is currently a good market for second-hand wood. That is often used for floors and has the advantage that it is fully seasoned - it will not shrink. Wood cannot be reused as planks or beams is transported for the production of chipboard.

Brickwork is cut into sections and taken to a crusher plant. Occasionally, the client intends to build a new building using the bricks from the old building. However, the mortar used after the Second World War is so strong that the bricks will break before the mortar does. In that case, the bricks are carefully removed one by one. This is mostly relevant in renovation projects when dealing with unusual and rare types of brick.

Buildings with concrete skeleton frames, which may also include prestressed concrete elements

The roof, which is generally covered with bituminous material, is removed first. The gravel is removed from the roof. The wooden roof structure is removed with a crane and equaliser beam. The wood is sold on the second-hand market or to the chipboard industry. The concrete structure is cut up using breaker shears and taken to a crusher. In the past, the rubble was reduced in size and the steel (reinforcement) was removed from it. However, current crusher plants can handle large sections (2 m x 2 m) and it is more economical for demolition contractors not to break up larger sections. If the rubble fits in to a truck then the crusher can handle it. Hence, the maximum dimensions are what fits into a truck.

Prestressed concrete structures pose special problems. Often, nobody knows that there are prestressed elements. If it is suspected that a structure may be prestressed, then a section is cut away to investigate this. If it is indeed found to be prestressed the terminations are first cut away at the ends of the structure, which will often lead to its collapse. Structures with unexpected prestressed section can be dangerous, because the structure may suddenly liberate the stress and the concrete may fly around.

Buildings with steel frames

If the beams can be reused then the structure is disassembled. Otherwise, the steel structure is cut up and sent to a steelworks. Occasionally, structures such as steel bridges are sold as a whole and shipped overseas.

Further demolition activities for all three types of buildings

The foundations (masonry or concrete) are broken up, like rest of the building, and removed by diggers or they are pulled out of the ground. If the foundations include a deep basement then it may be necessary to create an excavation in which the work is carried out. Groundwater lowering will then be necessary to work in the dry. Clearly, this will be very expensive. It is difficult to remove wooden piles in situ as they tend to break. However, they can be broken up at some depth below the surface. In contrast, precast concrete piles can be successfully removed through simultaneous vibration and pulling.

Trends and developments

If a building contains both brickwork and concrete then these materials are normally not separated. However, crushed concrete secondary aggregate is stronger than crushed masonry secondary aggregate and is therefore easier to sell. As a result, the crushing companies are left with the crushed concrete aggregate to produce mixed crushed secondary aggregate. This material is mostly sold to the road construction industry.

Selective demolition is actually nothing new in this industry. It was only in the period from 1970 to 1985 that demolition was not done selectively. At that time the capacity of the machines has developed so much that it was possible to demolish buildings quickly and it was assumed that our resources were inexhaustible.

Balling, knocking down a building with a heavy steel ball, is no longer widely used. It has a major impact on the surrounding area through noise and vibration. The most difficult aspect of balling is aiming the ball accurately. A limited jib movement develops the large pendulum movement of the ball and this takes a great deal of experience.

Demolition by blasting is only used when a building has to be brought down very quickly, for example if it is close to a major road and there is not enough space to screen the demolition site. Generally, buildings will only be demolished by blasting if local authority or the client requires this.

As the economic life of buildings is getting shorter it is expected that there will be more demolition activities. Another development is that buildings are stripped, but not demolished in their entirety. In itself stripping is not a new development as all buildings are stripped before demolition. When a building is stripped and the structure should therefore remain intact, smaller equipment is used, which can move inside the buildings. These smaller diggers and cranes are more compact which allows them to work on intermediate floor and they are light enough to be supported by normal floors.

Conclusion

It is more and more common that the demolition of building is executed in such a way that the resulting CDW, after crushing, sieving and cleaning is reused as aggregate. The most realised applications are found in unbound layers for road constructions and as aggregate for concrete.

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