Re-use of Constructions at Different Levels: Construction, Element or Material

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Abstract

The production of construction and demolition waste in the Netherlands is about 16 million tons each year. Nowadays about 90 to 95 percent of this waste are being re-used, for the main part as a road base material. The policy of the Dutch government aims at re-use of this construction and demolition waste in its own cycle, at the highest possible level. There are three different ways of re-using: re-use at construction level, re-use at element level and re-use at material level. Furthermore (building) materials can be re-used in the own cycle or in another cycle. But what is the highest possible re-use level? No models exist to answer this question.

Therefore a model will be made for comparison of these re-use options. For this comparison technological, economical and ecological aspects are very important. This model will define a degradation factor for the technical aspects. Existing models are used for the economical and ecological aspects. The degradation model describes the re-use possibilities of the construction, the elements and the materials and depends on the following items:

Construction level
- Technical state of the construction (remaining life time)
- Possibilities to improve current technical state (by repairing damages)
- Flexibility of the construction

Element level
- Technical state of the elements (remaining life time)
- Possibilities to improve current technical state (by repairing damages)
- Possibilities to deconstruct the construction into the different elements (design for deconstruction)

Material level
- Possibilities to separate and re-use building materials

The decisions, with the most effect on the re-use possibilities, are taken in the first stages of the building cycle (initiative, design and building stage). Therefore this model can also be used to help designers to choose construction methods (IDF) and materials (reusable) in order to decrease the degradation and to improve the re-use when a construction is at its end of life.

In this paper a degradation model will be described for the best re-use option for old constructions, so an answer can be given about the highest re-use level.

Keywords:
Re-use; Recycling; Environment; Construction and Demolition Waste; Sustainable Development.
INTRODUCTION

The total production of construction and demolition waste (CDW) in the European Union (EU) is about 450 million tonnes. If one excludes earth and excavated road materials the amount of ‘core’ CDW is estimated to be roughly 180 million tonnes per year; 480 kg per person each year. There is no need to say that this is an enormous amount of material. Recycling rates vary from lower than 5% until 95% in the different Member States. The question is how to improve these recycling, both quantitative as qualitative.

In most countries of the EU the problem of the CDW occurs at the time a construction has to be demolished. By changing this system into integral chain management, both quantitative as qualitative recycling can be improved. Three different ways of re-using can be recognised; re-using the construction, the elements and recycling the material. Furthermore the materials can be recycled, downcycled and upcycled.

CDW constitutes a highly significant proportion of all wastes. This waste also has a very high recovery potential. However only a small proportion of these waste streams is actually recovered in the EU as a whole. There is a big difference in recycling of CDW in the different countries of the EU. The main aspects regarding these differences are natural resources, transport distances, economic and technologic situation and the population density.

<table>
<thead>
<tr>
<th>Member State</th>
<th>Core CDW Million tonnes</th>
<th>Re-use or recycle Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>59</td>
<td>17</td>
</tr>
<tr>
<td>UK</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>France</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>Italy</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>Spain</td>
<td>13</td>
<td>&lt;5</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>11</td>
<td>90</td>
</tr>
<tr>
<td>Belgium</td>
<td>7</td>
<td>87</td>
</tr>
<tr>
<td>Austria</td>
<td>5</td>
<td>41</td>
</tr>
<tr>
<td>Portugal</td>
<td>3</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Denmark</td>
<td>3</td>
<td>81</td>
</tr>
<tr>
<td>Greece</td>
<td>2</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Finland</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Ireland</td>
<td>1</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>EU 15</td>
<td>180</td>
<td>28</td>
</tr>
</tbody>
</table>

Fig 1. Re-use in the EU

Recycling percentages vary from less than 5% (Greece, Ireland, Portugal and Spain) to more than 80% (Belgium, Denmark and the Netherlands). About 50 million tonnes of the ‘core’ CDW are being re-used or recycled. The rest, 130 million tonnes are incinerated or dumped on landfills. The total amount of core CDW and the recycling per Member State are reflected in figure 1 (Symonds, 1999).
WASTE MANAGEMENT

The methods used to manage the CDW differ from one Member State to another. Although some countries introduced a system for managing this waste, based on the waste hierarchy (paragraph 4), the waste managed by most of the Member States is, quite simply; disposal to landfill. The large number of potential sources (demolition sites) and the fact that CDW is generally inert means that it is difficult to control and creates a high risk of illegal landfilling. These illegal landfills are widespread in some Member States. Despite the recycling potential, about 75% of the ‘core’ CDW are being landfilled nowadays, only 25% are re-used.

In some Member States dangerous wastes, like asbestos and heavy metals, are not always separated from the rest of the CDW. Although their quantity is relatively small, their appearance can contaminate a significant part of the recycled materials or can contaminate landfills. The composition of CDW differs per Member State. This composition is affected by numerous factors, including the raw materials used, architectural techniques, local construction and demolition practices. The main wastes present in the CDW are soil, ballast, concrete, asphalt, bricks, tiles, plaster, masonry, wood, metals, paper and plastics.

The current management of the CDW can be described as waste management. The problem occurs at the end of the life cycle, as soon as a construction has to be demolished. A scheme for waste management is presented in figure 2 (Dorsthorst et al, 2000a).

The rules and regulations governing this waste stream in the Member States also reveal the diversity of approaches to its management. The regulations are rarely binding in most Member States. Very few countries have specific management legislation. However those, which have introduced measures to improve its management (like Denmark and the Netherlands), have achieved high levels of recycling.

The Netherlands have drawn up a national “Building site waste” plan for the period 1990-2000 comprising measures aimed at banning the landfilling of recoverable waste. Nowadays about 95% of the CDW is recovered and re-used. Since this year it is forbidden to dump reusable and burnable CDW on a landfill.
In Denmark, municipalities are responsible for the collection of the CDW. More than half of them (especially the major cities) have introduced specific regulations on sorting of that waste in order to re-use the material again.

In Germany, a voluntary agreement was concluded in 1996 between the Federal Ministry of the Environment and the federation to which most construction and demolition undertakers belong. The aim is to reduce the volume of disposed CDW to landfills by 50% between 1995 and 2005.

The southern European countries (Greece, Italy, Portugal and Spain) recycle very little of their CDW. The market for recycled materials is not highly developed in those countries. Their natural resources are of sufficient quality and quantity to meet the demand for building materials at a moderate cost.

One of the possible contributions to prohibit dumping of CDW is integral chain management; to keep the building materials as long as possible in their own cycle. Therefore action must be taken in all building stages, but two stages are very important: the design-stage and demolition-stage.

In the design-stage a dismantlable building system can be chosen, where all the elements and components can easily and directly be re-used after dismantling a building. This design-stage is called Design For Dismantling (DFD). Design For Recycling (DFR) is an other building system where during the design-stage reckoning is given with the fact what to do with the building materials after demolition. The building materials are easy to separate during the demolition process and after further processing (e.g. crushing) can be used as a raw material for the production of building materials.

In the demolition stage everything that is possible must be done in order to improve the recycling of materials and elements. This is the most common solution nowadays, because the greater part of the buildings ever built, were never built for dismantling.

INTEGRAL CHAIN MANAGEMENT

With integral chain management the recycling industry can be changed. A definition of integral chain management runs as follows: the maintenance of products and processes in such a way that all materials in a chain can perform their function as long as possible (VROM, 1993). So the degradation of materials must be kept at the lowest possible level.

Translating this definition for the building and constructing industry, it means that all actors, at all building stages must do all they possibly can to improve the use of constructions, construction elements or materials after the demolition-stage. Major issues concerning integral chain management are:
1. The level of re-use
2. The way of re-use
3. The building stages

Level of re-use
There are three different groups of re-use levels. The first group is prevention of waste, both quantitative and qualitative prevention (construction re-use, element re-use). The second group is re-use in a useful application (material re-use), and the third is the definite removement out of the building and constructing industry.

Way of re-use
CDW can be recycled, downcycled or upcycled (Hendriks 1999). When the material is used for the same function again, it is called recycling (steel scrap used for the production of steel). When the material is used for another function it is called down-cycling (mixed granulates used as a road base material) and when the recycled material is used for a better function than the original material it is called upcycling (fly ash used in cement or concrete).
Building stages

Re-use at the highest level is only possible if every actor in the building cycle is aware of the fact that the used materials are to be re-used after demolition. So at every building stage, from the initiative, design, building, use, maintenance to the demolition stage, measures must be taken to improve re-use at the highest possible level. In the following diagram (figure 3) the building stages are coupled with the material cycle. The right part of the diagram shows the building cycle, the left side the material cycle (Dorsthorst et al, 2000a).

![Diagram of building stages and material cycle]

Fig. 3 Integral chain management

All actions in the right cycle have their effects on the closure of the left cycle. So maximal efforts are needed in the building cycle to close the material cycle. A problem is the lifetime of buildings. Normally these constructions exist for about 20-250 years. So the use and maintenance stage are the longest in time. The most important decisions, about re-using materials, can be taken in the first stages (initiative, design and building stage). So to reach an optimal re-use of the construction, construction element or materials, there are a few important preconditions:

1. Design for recycling (DFR). Materials which are difficult to recycle should not be used at all, or it must be (technically) easy to separate them, before or after, demolition
2. Design for disassembly (DFD). To re-use building elements, a construction should be designed to disassemble these elements at the demolition stage’
3. Assembling and dismantling techniques. To use building elements a second time they must be dismantled carefully in order to prevent being damaged as much as possible.

Advantages of integral chain management

Integral chain management helps with the following items:

1. Less waste is produced because most of the waste will be used again after a construction is demolished
2. By closing the material cycle, the need for raw materials will be reduced, due to secondary materials. Therefore the ‘scenic’ deterioration is less.
3. By using more secondary material, there is saving on the use of space for landfills.
The effects of integral chain management on the environment are both positive and negative. Producing a qualitatively good secondary material out of CDW takes energy and transportation, and causes emissions. On the other hand, due to the production of fewer raw materials, there are savings in energy, transportation and emissions. These environmental advantages and disadvantages of integral chain management can and must be calculated.

WASTE MANAGEMENT HIERARCHY

In its Community Strategy for Waste Management (COM, 1996), the European Commission describes the hierarchy in waste management. This is a three step hierarchy with prevention of waste as first priority, followed by the recovery of waste, with the disposal of waste is the last option. In some Member States this hierarchy has more steps. The Dutch government introduced a seven step hierarchy (SDU, 1980), called the Ladder of Lansink (figure 4).

A disadvantage of such order is that it is a fixed top-down approach. The first option is always better than the second and so on. Nowadays there are more sophisticated models that calculate the best results from economic and ecological standpoints, so this fixed order should become flexible. The Delft Ladder (Hendriks, 2000) is a new, flexible model. It has more rungs, because more waste treatment options have been developed. The order can change thanks to the results of calculation methods like Life Cycle Analysis (Heijungs, 1992), Eco-cost Value Ratio (Vogtländer, 2000) and the degradation model (paragraph 5). The Delft ladder is presented in figure 5.

DEGRADATION MODEL

The options of the Delft Ladder must be compared to each other, on financial, technical and environmental aspects. Lots of models are available to compare the financial aspects, but comparison of the environmental and technological aspects are much more complicated. Therefore a new model has to be developed. This model, called the ‘degradation model’, makes a comparison possible for technological and ecological aspects. All the 10 steps from the Delft ladder can be compared to each other from these aspects.

The model has five steps (figure 6).

1. Data collection
2. Delft Ladder
3. Environment
4. Prevention
5. Construction reuse
6. Element reuse
7. Material reuse
8. Useful application
9. Immobilisation with useful application
10. Immobilisation
11. Incineration with energy recovery
12. Incineration
13. Landfill

Fig 5 Delft Ladder
4. Comparison
5. Degradation factor

![Degradation model diagram]

**Fig 6. Degradation model**

**Step 1 Data collection.**
In order to re-use an old construction (on each level) the construction has to be examined. The quality of the construction on its own, the elements used and the material must be secured. Therefore parameters like strength, elasticity mode, frost-resistance, stiffness, remaining lifetime and so on, must be examined. If the construction or elements fulfill certain standards, a second life time can be served, otherwise the construction can be re-used at material level.

**Step 2 Delft Ladder**
The Delft Ladder generates 10 different re-use options. Not every option is possible in each case. The feasibility of these options depend on various aspects. One aspect is in the field of technology. It must be possible to renovate the construction for object re-use, or for element re-use the building must be dismantled. Furthermore there must be a user for a renovated construction, and the regained elements must be used in another project (within certain distance). So in this step the Delft Ladder must be scanned for usable re-use options.

**Step 3 Environment**
The production of secondary building materials or parts is different from that of primary ones, and the recovery of these materials is often much more complicated. So the environmental aspects differ from the production of primary products, and the environmental aspects (like emissions, energy use, material use, transportation and so on) must be calculated for every option. These calculations can be done with the Life Cycle Assessment method. Programs like EcoQuantum and Greencalc are specially developed for these calculations.

**Step 4 Comparison**
Two comparisons must be made. The first is the comparison between products with primary (virgin) materials and products with secondary materials, on each step of the Delft Ladder. A second comparison has to be made between the steps of the Delft ladder. Both compare on economic and environmental aspects.
Step 5  Degradation factor
An order can be given about the (calculated) steps of the Delft ladder. The steps can change! Or a second option is to start all over again at step 1 with the newly built construction as input. Then the result of this model is an advice of how to use CDW, in such a way that the materials can be used time after time after time.

MAASSLUIJS

Project description
Currently there is a re-use project going on in the Componistenbuurt in Maassluis, the Netherlands. It is a project where six apartment buildings will be re-used. Two apartment buildings have been renovated and an extra floor has been added. On three apartment buildings, the top floors have been removed and the remaining part of the building will be redesigned to become single-family dwellings. The sixth apartment building has been demolished and only the foundation will be re-used for single-family dwellings. Between the two renovated apartment buildings a new apartment tower will rise.

Degradation model

Step 1  Data Collection
The first step of the degradation model is to investigate the usability of the construction. The apartment buildings were built about 30 years ago, with a technical lifetime of about 75 years. So there was no technical reason to demolish these constructions (Dorsthorst nd Kowalczyk, 2000b). The only reasons to reconstruct this area are social reasons.

Step 2  Delft Ladder
The second step is to investigate which steps of the Delft Ladder are useful options. Prevention is something that must be done during the design stage of a construction, so this is not helpful for the existing construction, only for newly built constructions. Object renovation is a possible solution. Two apartment buildings have already been renovated. Old apartments were put together (horizontally) to improve the size of the new apartments, and an extra floor was put on top of the apartments (figure 7 and 8).

Fig 7. Old apartment

Fig 8. Renovated apartment
At the beginning of the project the new single family dwellings, in between the old apartment buildings, were to be constructed with the existing old elements of the top floors (element re-use). But thanks to a few difficulties during the deconstruction and storage problems (logistics) these materials haven’t be used at element level. The remaining of the three apartment buildings (the bottom two floors) are reconstructed into single-family dwellings. Therefore two old apartments are put together (vertically). A new roof will be put on top. A part of the floors between the first and the second floor have to be removed because a stair must be added (figure 9). Another example of element re-use is the re-use of the foundation of one apartment building for single family dwellings (figure 10).

The rest of the material (the deconstructed top floors) are being re-used at the material level, for (temporary) construction roads on site. Therefore all the material will be crushed with a mobile crushing plant on site (figure 11).

**Step 3 Environment**

The reconstruction of this neighborhood has lots of environmental aspects like emissions, energy use, dust, noise and so on. After the data collection, it can be calculated with life cycle assessment programs. These data must be compared with the same environmental data from completely new buildings. In this case new buildings, single family dwellings, will be built between the old re-used apartment buildings. So the data can be available to compare these new houses with the re-used apartment buildings. A third comparison can be with the (new) houses built on the old foundation. All these three types of buildings can be compared on their environmental impacts. Very important in this comparison is that the production of primary materials, transportation of primary building materials and CDW and the processing of this CDW.
Step 4 Comparison

This project is a demonstration project. It wants to show the technical possibilities for re-use of building materials for these kind of constructions. About 2 million of these apartments have been built in the Netherlands and more of these buildings have the same problems as here in Maassluis, so it is also a learning project. The degradation model wasn’t developed before the start of this project, so all the data has been collected afterwards. That is one of the reasons that no environmental comparison can be given at this moment.

Re-using the construction instead of building totally new houses gave a profit for the smaller dwellings of $2,250 and for the bigger $5,500. So far, for the first apartment building the extra costs for dismantling were about $45,000, that is per dwelling $2,800. There has to be said that the extra time for deconstruction and building hasn’t been calculated in these figures.

CONCLUSIONS

CDW is one of the biggest waste streams in the Netherlands and the EU. Therefor the government wants to reduce the total amount of CDW. This is one of the reasons for the ban on dumping reusable (and burnable) waste on a landfill in the Netherlands. Re-use at material level, mostly as a road base material, is common practice nowadays. But the material has more potential.

The Ladder of Lansink has been renewed with more options and has become flexible. Methods like life cycle assessment and the degradation model make it possible for the rungs of the ladder to change.

The reconstruction of the Componistenbuurt in Maassluis has been studied. Object renovation, element re-use and material re-use have been calculated and compared. Financially there will be a little profit. The new houses are a little bit cheaper, but the deconstruction and construction will take more time. The environmental aspects are not yet available, so nothing can be said about that point at this moment.

A lot of houses in the Netherlands are built in the same way as in the Componistenbuurt in Maassluis. Therefore this is a kind of pilot project to show what is technically possible. The idea was that re-use of (parts of) the old building is a better solution than just demolish it and built completely new ones. There was no scientific foundation for this opinion. These scientific base can (or won’t) be given with the calculations of the degradation model.

The highest possible re-use option, one of the options of the Delft Ladder, can be calculated with this degradation model. So a decision can be taken about re-use of constructions at construction, element or material level.

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