Fates of end-of-life concrete and their economic implications

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Abstract
End-of-Life (EoL) concrete constitutes the largest stream of the construction and demolition waste (CDW), therefore the recycling of EoL concrete is essential to divert the CDW from landfills. Annually, around 10 million tonnes of EoL concrete arises in the Netherlands, of which 97% is recycled as aggregates for road base construction through dry process and less than 3% is recycled for concrete aggregates through wet process. Due to the renewal of the aging building stock in the Netherlands, the annual generation of EoL concrete is expected to double in the coming decade but the demand for recycled aggregates in road base will not be much different from the current level due to the saturated Dutch infrastructure system. Without technology innovation, significant amount of surplus EoL concrete will have to be recycled into concrete aggregates through expensive wet processes. The increasing expense for EoL concrete might discourage the on-site separation practice so that the EoL concrete along with other recyclables might mix together and end up in the landfills. With the breakthrough of ADR (advanced dry recovery) technology, C2CA provides an option to recycle the EoL concrete for high application as clean aggregates for concrete production and calcium-rich fines for cement production. Based on the data collected in the C2CA project, the different fates for EoL concrete are modeled and the associate economic implications are calculated.

Keywords: end-of-life concrete, construction and demolition waste, recycling, cost

Introduction
Annually, the Netherlands releases more than 24 million tonnes of construction and demolition waste (CDW), of which 95% is processed for recycling (Ingenieursbureau Amsterdam, 2011). However, this high recycling rate is realized mainly through the cheap down-cycling practice, breaking the stony CDW into road-base aggregates (RBA). According to Dutch statistics (Agentschap NL, 2010), in 2009, 96.9% of recycled CDW ended up in road-base and only 1.9% of that was recycled within the concrete industry. In the Netherlands, the end-of-life (EoL) concrete represents the largest stream of CDW. About 10.5 million tonnes of concrete debris was generated in the Netherlands in 2003 (Hofstra et al., 2006). Due to the demand from road construction, recycling EoL concrete for RBA has been profitable so far. But this situation is changing. Research of Hofstra and colleagues (2006) foresees that the release of EoL concrete will constantly increase to 22 million tonnes by the year 2025, while the demand for road construction will not be much different from the current situation. Consequently the significantly surplus of EoL concrete will need solutions other than as road base. The current processes to recycle EoL concrete into clean aggregates for concrete production are expensive. Those increasing costs might discourage the on-site separation practice so that the EoL concrete along with other recyclables might be mixed together and eventually end up in landfills. With the
state-of-the-art technology - ADR (advanced dry recovery), the FP7 C2CA project provides an innovative option which valorize the EoL concrete by liberating it into clean coarse aggregates for concrete mix and calcium-rich fines that can substitute limestone for clinker production in cement kilns. Based on the preliminary project results achieved so far, the economic implications for different fates of EoL concrete are calculated.

EoL concrete building

The building to be demolished in the framework of the C2CA project is a concrete high-rise building located on de Kempkensberg in Groningen, the Netherlands. It is made of two parts: the tower part – a roof and 14 floors and the ground part – a basement and ground floor (Figure 1). Data presented in this work come from the tower part (6,525m² of gross surface area, with a mass of 14,211 tonnes). Inventory of the tower shows that 87% by weight of the demolition materials are EoL concrete, 5% are red bricks (used in the core of the high-rise), 4% are metals and 4% are other CDW (Figure 2).

![Figure 1. Section plan of the EoL building.](image)

![Figure 2. Materials in the tower.](image)

Dismantling and demolition cost

In the Netherlands, the building demolition practice follows three steps: asbestos

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1 FP7 project of European Commission "Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste (C2CA)". Grant Agreement No 265189.
removal, dismantling and demolition. The asbestos removal has been carried out by a specialized hazard management company and it has not been taken into account in this calculation. In the C2CA case study, the cost to dismantle and demolish the concrete tower and to remove the 14,211 tonnes of CDW involved is presented below in table 1.

### Table 1. Dismantling and demolition cost and profit

<table>
<thead>
<tr>
<th>COST</th>
<th>PROFIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) dismantling</strong> per t CDW</td>
<td><strong>E) metals</strong> per t CDW</td>
</tr>
<tr>
<td>€88,200</td>
<td>€138,843</td>
</tr>
<tr>
<td>6.2 €/t</td>
<td>10 €/t</td>
</tr>
<tr>
<td>2€/t</td>
<td><strong>2) capital goods</strong></td>
</tr>
<tr>
<td>0.6€/t</td>
<td>6 €/t</td>
</tr>
<tr>
<td>3.6€/t</td>
<td><strong>3) energy</strong></td>
</tr>
<tr>
<td><strong>B) demolition</strong> per t CDW</td>
<td><strong>F) concrete</strong> x €/t * 12,357t</td>
</tr>
<tr>
<td>€186,032</td>
<td>0.9x €/t</td>
</tr>
<tr>
<td>13 €/t</td>
<td><strong>4) labour</strong></td>
</tr>
<tr>
<td>7.1€/t</td>
<td><strong>5) capital goods</strong></td>
</tr>
<tr>
<td>1.6€/t</td>
<td>7.1€/t</td>
</tr>
<tr>
<td>4.3€/t</td>
<td><strong>6) energy</strong></td>
</tr>
<tr>
<td><strong>C) waste management</strong> per t CDW</td>
<td>Total Profit</td>
</tr>
<tr>
<td>€38,499</td>
<td>€138,843 + 12,357x</td>
</tr>
<tr>
<td>3 €/t</td>
<td><strong>7) x</strong></td>
</tr>
<tr>
<td><strong>D) company management</strong> D=12%*(A+B+C) per t CDW</td>
<td>Total Cost</td>
</tr>
<tr>
<td>€37,528</td>
<td>€350,259</td>
</tr>
<tr>
<td>2.6 €/t</td>
<td>25 €/t</td>
</tr>
</tbody>
</table>

1) initial cost of equipment (bobcat, wire crane, sorting crane, excavator, etc.)
2) diesel consumption cost; dismantling equipment uses red diesel (1.07 €/l, tax excl.)
3) machinist 27 €/phour, dismantler 22 €/phour
4) cost for waste treatment (CDW mix 90 €/t, roofing felt 170 €/t, gypsum 55 €/t, wood 25 €/t etc.)
5) 12% of direct cost, including 2% of overhead, 5% of management and 5% of profit & loss
6) sales of recycled ferrous 200 €/t, non-ferrous 1000 €/t
7) x denotes the market value of 1 tonne of EoL concrete (12,357 t); bricks (720 t) are buried on-site for free

The cost to demolish the tower and to get rid of the generated CDW from the site is 25 €/t. 6 €/t are requested for dismantling, 13 €/t for demolition, 3 €/t for waste treatment and 2.6 €/t for other costs (demolition company management). The sale of metals compensates 10 €/t of the cost. The concrete stream from demolition used to be profitable up to a few years ago. When there is local demand for RBA, 1 tonne of EoL concrete can bring about 4 € profit. However when there is no RBA demand, the EoL concrete will have to be transported to off-site recycling center. According to the experience of the demolition company involved in the C2CA case study, the transportation and gate fee can be as high as 8 € per tonne of concrete. Therefore the current market value (denoted by x) of EoL concrete in the Netherlands ranges between -8 ~ 4 €/t. The preliminary cost analysis shows:

1. The profit driver for CDW management is metal. In the C2CA case, the metal fraction accounts for only 4% of the CDW mass but brings a profit which can compensate 40% of the dismantling and demolition costs. In contrast, concrete makes 87% of the CDW mass, but it brings only one-third of the profit from metal recycling even when there is RBA demand.
2. The dismantling cost can be covered entirely by recycling metals. In the C2CA case, the dismantling cost is only 60% of the profit created by metals recycled.

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2 According to the experience of C2CA industrial partners, the off-site disposal of EoL concrete has to bear the transportation cost 1~3 €/t, depending on transportation distance and gate fee up to 0~5 €/t.
This implies that even if EoL concrete turns to be less profitable, the good dismantling practice will continue.

3. Cost for EoL concrete recycling is much lower than that for disposing CDW mix. In the C2CA case, the disposal fee for CDW mix (90 €/t) is 10 times higher than the most expensive concrete recycling (8 €/t). This indicates that the EoL concrete will not be deliberately mixed into other wastes and will not end up in landfills even when concrete recycling becomes more costly.

Fates for EoL concrete

The above analysis shows that in future, the Dutch waste management market will likely still push the recycling of EoL concrete. The current available recycling routes are illustrated in Figure 3 as S1 – S3, and the innovative C2CA route is given as S4.

**Figure 3. The fates of EoL concrete.**

*S1: On-site breaker.* This scenario represents the situation when local demand for RBA is available. The EoL tower is dismantled to remove roofing felt, wood, plastics, gypsum, metals and other removable materials. Then the concrete structure is demolished and the EoL concrete mixed with bricks and other stony materials are sent to on-site breaker. Through the breaker process reinforcement steels are extracted and the stony materials are transformed into aggregates of 0-31.5 mm (RBA). According to the demolition company, the breaker process costs 2.5 € for 1 tonne of EoL concrete and brings 6.5 € from the sale of the products (5 € for RBA and 1.5 € for...
S2: Off-site breaker. This scenario represents the situation when local demand for RBA does not exist. The EoL concrete needs to be transported to off-site breaker and to be processed into RBA when the market demand appears. Comparing to S1, this route has an extra cost for concrete transportation. In the C2CA case, the transportation cost for 1 tonne of EoL concrete is 2.5 €, which reduces the value of EoL concrete to 1.5 €/t.

S3: Off-site wet process. This scenario represents the current situation when demand for RBA is insufficient and washing process is used to produce clean aggregate (CA) for concrete production. This route demands a good dismantling process to avoid the EoL concrete being polluted with bricks and other materials. According to the estimation of the demolition company, this procedure may increase dismantling cost of about 15% (0.9 €/t). In the C2CA case, the use of good dismantling procedure results to 60% of EoL concrete clean (away from gypsams, bricks etc.) and 40% remains in the mixed stony materials. The latter is recycled into RBA as in S2 and the clean EoL concrete is processed into CA through the process shown in Figure 4. Considering the extra dismantling cost, the concrete mixed with stony materials has a value of 0.6 €/t (=1.5 €/t-0.9 €/t). For the clean concrete, the sieving and crushing processes indicated in Figure 4 are the same as the breaker process shown in Figure 3. The cost of the washing process is assumed similar to a sedimentation basin process (9 €/t, Xing, 2004). The residue demands extra cost for de-watering process (20 €/t of dry material) and for the sludge disposal (100 €/t of dry material) (Xing, 2004). The 4-32 mm CA is assumed to be sold at a price of natural gravel (currently 11 €/t) and the 0-4 mm sieve sand is reused without charge. Therefore considering the extra costs for good dismantling, through the wet route, the concrete value on demolition site

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3 If the RBA demand will not appear for a long period, a storage cost for the EoL concrete will arise and it may be reflected into the rise of gate fee up to 5€/t.

4 Data for wet process are from literature. Field data from the C2CA partner Theo Pouw for wet process will be available in the second project year 2012.
would be -5.2 €/t (=11.2 €/t -15.5 €/t -0.9 €/t), indicating that producing CA via wet process brings negative value.

**S4: Off-site ADR process.** This scenario represents the situation when market demand is not sufficient to absorb all the recycled RBA. In this situation the innovative ADR technology provides a dry option to produce CA for concrete and cement production. Based on the product quality achieved in the first year project implementation, the coarse fraction produced by ADR is clean enough to be used in concrete production while the calcium content of the fine product is not high enough to be beneficial as filling material for clinker production. The operational cost of ADR process is around 2.5 €/t (excluding the charge for patent). Comparing to the wet route, the ADR route has lower operational cost for producing the coarse CA and has no landfill cost for the finest fraction. Because of the latter consideration it reduces the processing costs significantly. However the ADR routes has an extra cost for transporting the fines to the cement plants. Depending on the property of the fines, the cement producer might charge a gate fee or pay a purchase price for the fines. Through the ADR route, considering the extra dismantling cost (0.9 €/t), the transportation cost for fines (2.5 €/t) and assuming 0 €/t gate fee for the fines at the cement plant, the value of EoL concrete at the demolition site will be 2.6 €/t (=10.3 €/t -6.8 €/t -0.9 €/t). This indicates that a positive value of EoL concrete can be realized via ADR to produce secondary CA. Further, considering that the mobile ADR technology is being developed once it will be available, the 2.5 €/t of transportation cost for EoL concrete will be saved. Taking into account such cost reduction a value of about 5.1 €/t of EoL concrete is estimated and the fate of recycling EoL concrete into CA will be economically more attractive than processing it into RBA.

![Figure 5. ADR process in C2CA (2011).](image)

<table>
<thead>
<tr>
<th>ADR route</th>
<th>COST</th>
<th>PROFIT</th>
<th>% of throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>2.5 €/t</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Breaker</td>
<td>2.5 €/t</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>ADR</td>
<td>2.5 €/t</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>0-1mm, transport</td>
<td>2.5 €/t</td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>0-1mm, gate fee</td>
<td>0 €/t</td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>1-16mm</td>
<td>11 €/t</td>
<td></td>
<td>30%</td>
</tr>
<tr>
<td>16-32mm</td>
<td>11 €/t</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Ferrous</td>
<td>1.5 €/t</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>6.75 €/t</td>
<td>10.3 €/t</td>
<td></td>
</tr>
</tbody>
</table>

5 The first Semi-mobile ADR has been operating in the rubble recycling plant of Theo Pouw in eemshaven since September 2012.

6 Assume the transportation cost for the fines is the same as the one for concrete.
Conclusions and outlook

1. In the Netherlands, recycling EoL concrete from demolition site turns to be more and more expensive due to the decreasing demand for road base aggregate and the expensive processing cost to recycle EoL concrete into clean aggregates for concrete production through wet process.

2. The increasing processing cost for EoL concrete will probably not discourage the current good dismantling and separation practice on the Dutch sites because of the high value of the recycled metals and the extreme expensive disposal costs for mix demolition waste as well.

3. Currently the recycling of EoL concrete into clean aggregates via wet process is expensive because of the negative value due to the costly washing process and sludge disposal.

4. The ADR decreases the processing cost for clean aggregates production. The ADR has the potential to turn the costly finest fraction into a profitable material as soon as the ongoing technical improvements will allow the calcium content of the fine fraction to increase. In the near future, the development of mobile ADR technology will make recycling concrete into clean aggregate more profitable than on-site breaking it into road base aggregate.

To summarize, the economic analysis for the fates of EoL concrete shows that the C2CA technology innovation is decreasing the processing cost for recycling EoL concrete into clean aggregates. This is a key to solve the rising CDW problem in the Netherlands and probably elsewhere. The mobile ADR technology shows great economic competitiveness to turn the fate of EoL concrete from down-cycling as RBA for roads construction to secondary raw material for the concrete and cement industry.

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