Sustainable use of recycled materials in building construction

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Abstract

This contribution focuses on the importance of sustainability in the building sector. The underlying idea being that sustainability and durability must be considered jointly. Different models are presented to determine the degree of sustainability, focussing on: the degradation factor, life cycle assessment, the Delft ladder of priorities, high-grade applications, design for recycling, design for disassembly, and the ecocost-value ratio. Examples are given of case studies in which these models have been applied successfully.

Introduction

The term ‘sustainability’ was introduced in the UN report Our Common Future (Brundlandt). The NEPP describes sustainable development as that which meets the needs of the current generation, without endangering the opportunities for future generations to meet their particular needs. The concept encompasses not only the environment, but also social and economic interests such as health and wellbeing, safety, care for living space, prosperity, sufficient employment and a fair distribution of resources. To ensure real sustainable development, these interests must be combined at all levels. Sustainable construction could therefore be described as a way of designing and constructing buildings that support human health (physical, psychological, and social) and which is in harmony with nature, both animate and inanimate.

For the importance of sustainability the model of factor 20 is proposed. The so-called ‘Factor 20’ is a metaphor, a guideline for sustainable development and to make specific steps forwards. The metaphor can also be used for sustainable construction. Factor 20 refers to the aim to have the environmental
impact per unit of prosperity reduced by a factor of 20, thus meeting social needs 20 times as environmentally efficiently – in this case building housing and other property. There are also a number of variants to this factor, e.g. using the less stringent factors 4 and 10. Assuming that both the population and worldwide economic developments will continue increasing, it is quite some challenge to reduce the environmental pressure. To answer the question ‘how great is the environmental load that mankind is asserting on the environmental capacity?’, the American biologist and environmental expert Barry Commoner (1972) described the environmental load using the following formula:

\[ EL = P \times PP \times E \] (1)

where:
- \( EL \) = environmental load
- \( P \) = population size
- \( PP \) = average prosperity per person
- \( E \) = environmental load per unit of prosperity

Let us assume the (not unreal) scenario that in 50 years time the world’s population will have doubled, the average prosperity per person will be fivefold (the poor countries have a lot of catching up to do), and we want to halve the total environmental pressure. This means that the environmental impact per unit of prosperity must be reduced by a factor of 20. To implement changes of this size, a number of trends will have to be reversed. However, such reductions cannot easily be achieved by (improving) existing systems and technologies. In addition to technological innovations, people’s behaviour and perceptions will also have to change. Technological solutions can only succeed if they fit in with social and cultural developments.

**What is sustainable and what is sustainable construction?**

There are many descriptions of the term ‘sustainable’, but there is no single definitive meaning. Most descriptions also provide a very limited view of the subject. We should not think that ‘sustainable’ merely focuses only on the environment. The processing industry understood this far earlier: environmental aspects should not be placed alongside or opposite other aspects or interests, but should be ‘part of the concept as a whole’, or as part of an integral approach. Here we should note that, in relation to the word ‘construction’, the term ‘sustainable’ has two meanings, i.e. both durable and sustainable.

Durable refers to the property of a material, building section or construction that can resist any unacceptable deterioration of relevant functional characteristics through specific chemical, physical and mechanical loads, over a certain period of time.

Sustainable refers to the general property of a material, building section or construction that indicates whether or not specific demands are met for affecting the air, water and soil qualities, for influencing the health and wellbeing of living
organisms, for use of raw materials and energy, and even for scenic and spatial aspects, as well as for creating waste and nuisance.

Errors often occur when only one of these meanings is taken into consideration for sustainable construction or, worse still, if one meaning has priority over the other. Such errors can and must be prevented by integrating both aspects into the development and knowledge transfer with regard to sustainability.

**Starting points**

Decisions concerning integral sustainability, which include both meanings of the term, should be based on the following three starting points.
- An integral approach to (raw) material use in the construction industry should be based durability as well as sustainability.
- The application should be optimised based on the entire life cycle, including several life cycles for reused material.
- The application should be such that recycled material is used for the next best purpose possible within the building chain. This means that these materials must be used in such a way that they can be easily recognised and separated.

**Degree of sustainability**

Various instruments have been developed to measure or calculate the sustainability of materials.

**Degradation factor (DF)**

Using the design specifications as starting point and taking into account (variants for) material use and the required lifespan, including repair and maintenance scenarios, an image can be formed of the expected degradation, as a function of time and conditions of application. This is also important in the decision-making process when considering possible variants for reuse and recycling once the end of the lifespan has been reached.

**Life-cycle thinking (LCA method)**

Life cycle thinking is based on the fact that decisions taken in one phase (design, implementation, management, maintenance, demolition and reuse) should always be set against the background of the consequences for the following phases. The intention is to minimise the environmental interventions over the entire life cycle. The most suitable method for this is the life-cycle analysis (LCA), which has now received both national and international (ISO: International Organisation for Standardisation) recognition.
Table 1: Overview of environmental problems in the LCA method

<table>
<thead>
<tr>
<th>Depletion</th>
<th>Pollution</th>
<th>Deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depletion of raw materials</td>
<td>Greenhouse effect</td>
<td>Deterioration of landscape</td>
</tr>
<tr>
<td>Abiotic and biotic depletion</td>
<td>Deterioration of ozone layer</td>
<td>Deterioration of ecosystems</td>
</tr>
<tr>
<td></td>
<td>Human toxicity</td>
<td>Deterioration of habitats</td>
</tr>
<tr>
<td></td>
<td>Ecotoxicity</td>
<td>Victims</td>
</tr>
<tr>
<td></td>
<td>Smog</td>
<td>Dehydration</td>
</tr>
<tr>
<td></td>
<td>Acidification</td>
<td>Fragmentation</td>
</tr>
<tr>
<td></td>
<td>Eutrophication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rejected heat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Odour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Noise</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working conditions</td>
<td></td>
</tr>
</tbody>
</table>

Waste management

Until recently, the Dutch approach was based on the so-called ‘Lansink’s ladder’, i.e. prevention – reuse of building elements – reuse of materials, incineration with energy recovery – incineration – disposal.

Lansink’s ladder dates back to the end of the 1970s, when the legislation concerning waste products was first being written. However, looking back with hindsight, we notice several things. Firstly, the number of opportunities has increased, i.e. the scale of these opportunities (construction, building elements and materials) and there are new insights regarding immobilisation (using chemical or physical methods to prevent the spread of contaminants). Secondly, Lansink’s ladder includes a clear order of preference. Methods are now available concerning life-cycle analysis (LCA), eco-costs (costs of ensuring a system or process meets sustainability criteria, including the so-called hidden costs) and value assessment. In particular, the results of the LCA methods and the EVR (eco-costs/value ratio) are applicable for making the best choice as to which rung on the ladder should be used in a specific situation. The result is thus an ‘eco-ladder’ or ‘sustainability ladder’ for the building sector, in which the order up the steps is ‘tailor made’. This new dynamic ladder is depicted below, under the name ‘Delft’s ladder’.
Table 2: The ‘Delft’s ladder’

<table>
<thead>
<tr>
<th>The 10 steps</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention</td>
<td>‘Design for recycling’ (DFR), recovery, based on remaining lifespan (technical and economic)</td>
</tr>
<tr>
<td>Reuse of constructions</td>
<td>DFR, oversizing, selective dismantling, remaining lifespan</td>
</tr>
<tr>
<td>Reuse of building elements</td>
<td>DFR, selective dismantling, reprocessing, return system</td>
</tr>
<tr>
<td>Reuse of materials</td>
<td>DFR, selective dismantling, reprocessing, return system, leaching and content of contaminants</td>
</tr>
<tr>
<td>Useful application as residue</td>
<td>Quality equal to reference (with regard to leaching)</td>
</tr>
<tr>
<td>Immobilisation with useful application</td>
<td>Leaching and content of contaminants</td>
</tr>
<tr>
<td>Immobilisation without useful application</td>
<td>Dumping conditions</td>
</tr>
<tr>
<td>Incineration with energy generation</td>
<td>Emission limitation</td>
</tr>
<tr>
<td>Incineration</td>
<td>Emission limitation</td>
</tr>
<tr>
<td>Dumping</td>
<td>Dumping conditions</td>
</tr>
</tbody>
</table>

The return system refers to building elements or building materials that are returned to the original supplier and are processed (cleaned, repaired etc.), thus allowing them to be reused for the same purpose.

The Dutch Building Materials Decree specifies acceptable compositions and leaching, while the Dumping Decree defines the regime with which dumping sites must comply. Immobilisation means that the dosage rate for leaching (leaching rate) must be drastically reduced once the material has been treated (thermally, chemically or by adding a binder).

High-grade
The term ‘high-grade reuse’ is becoming clearer. It is often said that, although a lot of construction and demolition waste is reused, this is mostly low-grade waste that is only suitable for building roads. High-grade therefore means reuse in concrete or other building products, as the economic return is much higher for roads than for concrete buildings.

Based on the Delft’s ladder, and with the exception of the most desired option, how can the high-grade level be defined? The key can be found by answering the following 10 questions as accurately as possible. By performing this exercise for all recycling options, the results can be easily compared. However, just as when using the life-cycle analysis to select a material, we see that none of the options receive a perfect score, but weighing the criteria further usually leads to the desired choice.
Table 3: High-grade levels for reuse

<table>
<thead>
<tr>
<th>High-grade applications: definition of the functional unit as per the LCA</th>
<th>Choices or actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-grade applications: definition of the functional unit as per the LCA</td>
<td>Choices or actions</td>
</tr>
<tr>
<td>Applications meet all existing requirements, according to both private and public law</td>
<td>Yes or no</td>
</tr>
<tr>
<td>Technical lifespan is greater than economic lifespan</td>
<td>Yes or no</td>
</tr>
<tr>
<td>Applications require little maintenance</td>
<td>Express in mass quantities of maintenance materials per functional unit</td>
</tr>
<tr>
<td>Maximum potential for future reuse</td>
<td>State the various opportunities for reuse</td>
</tr>
<tr>
<td>Minimum degradation during the usage phase</td>
<td>No longer usable due to degradation</td>
</tr>
<tr>
<td>Applications are material-extensive</td>
<td>Materials required per functional unit</td>
</tr>
<tr>
<td>Applications are energy efficient</td>
<td>Energy required per functional unit</td>
</tr>
<tr>
<td>Applications have minimum harmful emissions</td>
<td>Emissions per functional unit</td>
</tr>
<tr>
<td>Applications have minimum non-reusable residual waste</td>
<td>Amount of unusable waste in kg per functional unit</td>
</tr>
<tr>
<td>Applications conform to market standards</td>
<td>Yes or no</td>
</tr>
</tbody>
</table>

**Design for recycling (DFR)**

Most primary raw materials are natural substances and are homogeneous, e.g. sand, gravel, clay, oil (including the production of plastics), wool, cotton and wood (for various applications in the building sector, but also for paper), and ores (for metal production). This homogeneity often makes it possible, with relatively simple preparation, to use these raw materials in the production process.

However, this is not true for secondary raw materials, i.e. mainly discarded products, mostly material conglomerates the composition of which is often so complex that reuse is only possible after extensive processing.

Recycling secondary raw materials generally requires a series of processes, of which recognition, sorting, size reduction, and separating are the most important. Housing or construction demolition rubble must first have the iron, wood, mastic, bitumen, cardboard, chipboard, plastics, aluminium, zinc, copper etc. removed before the aggregate from the rubble crushe is suitable for use as secondary material. Asphalt and concrete from broken-up road pavings is also contaminated with road dirt, salt and oil residues etc. that must be removed before the recycling process can begin.

During the past decades, mechanical 'reprocessing' systems have largely replaced manual processes, primarily in the metal sector but also for construction and demolition waste (CDW), so that CDW can now be used on a large scale in the construction sector.

Not only the recycling sector, but also the government, came under increasing pressure to implement 'design for recycling' (DFR), i.e. designing items in such a way that they can be recycled. DFR means:
- using fewer materials;
- using parts that can be easily dismantled;
- marking all the plastic parts used so that they can be readily identified during dismantling and can be easily separated for further processing.

Governments, both in the Netherlands and elsewhere, are promoting DFR through certification, subsidies, 'return to supplier' obligations and levies on non-recyclable materials or scarce primary raw materials.

For a definite DFR design the following categories of materials must be capable of being recycled and separated.

**Concrete**
- according to VBT concrete specifications (meets national standards)
- non-standard compositions (for use in concrete)

**Masonry**
- bricks, sand-lime brick and concrete brick with mortar (for use in roads or concrete)
- aerated concrete
- crushed brick used as such or in brick (without mortar)
- crushed sand-lime brick for use in sand-lime brick
- crushed concrete brick for use in concrete brick

**Bituminous materials**
- asphalt without modified binders
- asphalt with modified binders
- roofing materials

**Wood**
- hardwood
- unpreserved wood
- preserved wood

**Plastics**
- thermosetting and thermoplastic agents should be used separately

**Design for disassembly (DFD)**
When using constructions and materials the criterion applies that, regardless of whether or not materials can be disassembled in an economic fashion, they can be separated for later reuse, if necessary. The following provides a basis for this strategy.
- Inspection and sampling.
- Specifications.
- Maintenance inventory.
- Conditions of use.

Some elements and materials should have been previously removed: flue pipes, gypsum blocks, gypsum walls, aerated concrete, bituminous roofing.
containing tar, asbestos and materials mixed with dangerous waste. Mixing with (contaminated) soil should be avoided where possible.

With regard to the various categories of materials that should be recycled and separated, the comments in the section ‘Design for recycling (DFR)’ concerning concrete, masonry, metals and wood, also apply here. Glass should be separated independently or in combination with concrete or masonry. Plastics should be split into thermosetting and thermoplastic agents. When demolishing roads and hydraulic engineering constructions the DFD method is fairly simple as the various materials are usually applied in layers.

Eco-costs/Value Ratio (the EVR model)
This model describes ‘sustainability’ (in the ecological sense) from a management systems approach, in which sustainability means the strive for eco-efficiency, as defined by the World Council for Sustainable Development: ‘the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity through the life cycle, to a level at least in line with earth’s estimated carrying capacity’ (WTCSD, 1993).

This business-oriented definition connects the thinking of the modern manager (‘the delivery of competitively priced goods and services .... ... quality of life’) to the need for a sustainable society (‘while progressively reducing .... ... to ... ... earth’s carrying capacity’). But what does this definition mean in practice for managers and designers, with regard to the many decisions taken daily? This is why a numeric model has been designed that is based on this definition, whereby well-founded choices can be made during the design phase with respect to the sustainability of the design, which is then used as a basis for setting out an entrepreneurial strategy.

The first section of the definition describes the ‘value’ of a product, the second section describes the impact on the environment, or ‘eco-costs’. The basic idea behind the model is to couple the ‘value chain’ (Porter, 1985) to the ‘product chain’ as defined in the life cycle assessment. The added value and the costs are defined in the value chain for every step (from raw material to client, the usage phase and the ‘end-of-life’ phase). The environmental impact is also defined in monetary terms for each step in the chain, i.e. the eco-costs. If the usage phase and ‘end-of-life’ phase are also added to the chain, this gives the ‘Total Costs of Ownership’ (this approach is common in the car industry and for structural and civil-engineering and civil projects). The ‘Total Eco-costs of Ownership’ are therefore defined in a similar way in the model.

The eco-costs are ‘virtual’ costs, i.e. the hidden costs required to manufacture and use a product in a sustainable manner, or ‘in line with earth’s carrying capacity’. These costs are estimated based on the costs of technical measures to prevent undesired emissions and based on depletion of fossil energy and raw materials. As our society is nowhere near sustainable, the eco-costs are ‘virtual’, or not yet integrated into existing costs of the product chain (the existing life cycle costs). The eco-costs therefore consist of costs that have yet to be made to reduce the environmental impact (emissions and depletion) to a sustainable level.
The eco-costs/value ratio (EVR) is defined as: EVR=eco-costs/value. The composition of eco-costs, costs and value is shown in Figure 1.

A low EVR means that a product is suitable for a future sustainable society. A high EVR means that the economic value/cost ratio will worsen along the road to a sustainable society (and may even drop below 1.0) due to the required prevention measures, so that there will be no market for these goods in a future sustainable society.