Building materials within the circular economy.

A literature study on the chances of reducing the environmental impact of building materials.

AR0531 Innovation & Sustainability
AR1B025-D3 BT Research Methodology

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Focus and restrictions – This paper focuses on the decrease of the building sector environmental impact by reducing waste with a circular material economy. It is restricted to the implementation and possible chances of application.

Abstract – With the fast growing world population and growing population with a western life style more resources are needed. The amount of resources needed in 2050 is estimated at six times the earth' size. Together with the current linear economy, dominated by a 'take – make – use – dispose' economy, a more sustainable approach is asked for. By providing a circular economy a closed cycle can be introduced. With a circular material economy improvements could be made to the environmental impact of the building materials. Focusing on the shift from linear to circular and how to create this circular material economy. With a large share of the total waste produced by the building industry, what is the chance of this closed loop system to minimize the amount of waste produced with building materials.

Key words – Circular materials economy, construction materials, building materials, environmental impact, sustainability, AR1B025-D3, AR0531

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1 Introduction

The construction industry in the Netherlands has a big share on the country's environmental impact. The total share of the transport that is due to the construction industry was 19% in 2004; the share of waste is 37% of the total weight; and in 2010 4.5% of the energy went to the construction industry (CE Delft, 2015, p. 62). At the global scale, the impact of the construction and use of buildings accounts half of the total energy consumption; and half of the extracted materials (UNEP, 2012). Furthermore, the contribution of the construction and use of building is globally liable for 50% of the greenhouse gas emissions (UNEP, 2012).

Within the more general economy of materials, the current system is based on a "take – make – use – dispose" sequence (Ashby, 2015, p. 212). With the rapid increase of the world population, estimates tell that the population with a western life-style will grow to nine billion people in 2050, the planet earth should be multiplied by six to facilitate the people's need (Durmisevic, 2015, p. 142).

The negative effects of the current linear material economy are dominant in the construction supply chain (Durmisevic, 2015). A more sustainable solution can be found in the three R's, 'Repair – Reuse – Recycle' described by Ashby (2015, p. 212). Within there is a shift from a linear economy to a circular economy. Ashby (2015, p. 216) states for the ideal circular material economy: 'an industrial system in which the consumption of materials and energy and the production of waste are minimized, and the discarded material from one product or process becomes the raw material for another'.

Within this shift from linear to circular and the relatively large impact of the materials used by the construction industry to build buildings a chance can be found. What are the chances in shifting from a linear material economy to circular material economy, that reduces its impact on the environment?

Within this literature study a definition of the circular economy is given, as well as an explanation on the shift from a linear to circular economy. Followed by the chances that can be created and obstruct this shift within the building and construction industry. In the discussion the applicability of the circular material economy to building design will be discussed. Followed by a conclusion that point out the chances of the circular material economy.

2 Methodology

The literature found is divided within the different topics of this paper. The relevant parts of the literature are designated to the different sections of this paper and combined with other sources. This for a comparable and critical view on the different sources.

The keywords used in to search in the databases are related to: circular economy, circular material economy, environmental impact, building materials, material efficiency, circular supply chain, building passport, 3D-printing, shift linear economy, deconstruction and design circular economy. These keywords are chosen because of their relevance with the subject and added or adjusted with the keywords used in the articles that were relevant.

The literature was found within multiple databases. The databases used are: library of Delft University of Technology; Scopus; and Google Scholar. Within these databases the output is judged on multiple criteria. Namely, on their relevance to the paper; the scientific order of the source; the date of the sources, so information is not out-dated.

3 Circular economy

Boulding (1966, p. 4) described the concept circular economy as 'a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs'. The deeply rooted origins cannot be traced back to a single author or date. Since the 1970's the subject has gained interested in it practical application (MacArthur, 2013, p. 26).

MacArthur (2013, p. 22) defines the concept of circular economy as 'an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design. The term goes beyond the mechanics of production and consumption of goods and services in the areas that it seeks to redefine'. Restorative indicates the post-use material flows, which should flow back into the original economic activities, so it can be restored to the original material sources of the economic activities (Mentink, 2014, p. 14).

Multiple important characteristics of the circular economy are: the closure of material loops; the characteristics of the 'Repair – Reuse – Recycle' are part of circular economy or a strategy; the circular economy asked for a system orientated approach with system thinking (Leising, 2016).

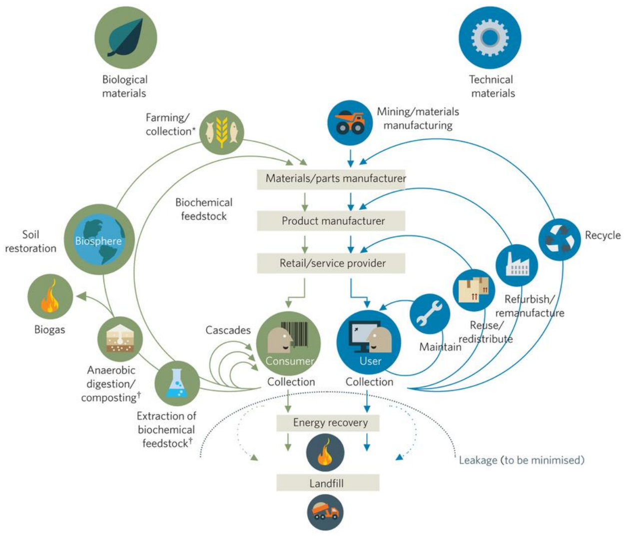

Figure 1: Schematic overview of the circular materials economy (Leising, 2016; MacArthur, 2013).

Taking into account the focus on the aspect of materials and the definition of the circular economy in general, in this report the following definition of circular economy applies: The circular economy is based on an economic system with closed material loops (as an non-disposable commodity, but as valued assets to be tracked and conserved for reuse), thereby aims for value creation (whereby financial capital invested is recovered as revenues and reinvested) (Ashby, 2015; Leising, 2016; Mentink, 2014).

4 From linear to circular

MacArthur (2013, p. 7) describes three principles of the circular economy which distinct it from the linear economy.

The aim is to 'design out' waste. Products are designed and optimized in a way that it can fit the cycle of disassembly and reuse. Compared to the linear economy, the circular economy, are set apart by the strong component-product cycles. Within disposable or and recycling a large share of the energy embedded and the labour is wasted (MacArthur, 2013, p. 7).

The circular economy proposes a strict line between the consumable and durable products. In comparison with the linear economy the consumables are largely made out of biological ingredients, which can safely be returned to the biosphere. Durable products are made of materials that cannot be return to the biosphere and should be designed from start to reuse (MacArthur, 2013, p. 7).

To increase the resilience and to become less dependent on resources the energy powering the circular economy should be renewable to nature (MacArthur, 2013, p. 7).

5 Create a circular material economy

Four sources of value creation are defined by MacArthur (2013, p. 7). These will be supported by the four strategies described by Ashby (2015, p. 225).

5.1 Power of the inner circle

The tightness of the circle, relates to the potential savings in shares of material, labour, energy, capital added to the product and external factors, i.e. reducing greenhouse gasses (MacArthur, 2013, p. 7).

A taxi is used more intensively than a private car; this is the result that the replacement of goods by services increases the use-intensity. Taking into account the circular materials economy, this would result that the ownership of products would stay at the product-maker. A product that last longer and that can be scrapped and disassembled more easily lies within the interest of the product-maker. This will increase the specifications of the design and the choice of materials which increases the life and durability of the product (Ashby, 2015, p. 231).

5.2. Power of circling longer

'Power of circling longer' refers to extending the amount of cycles of a product and the time of the product in a specific cycle (MacArthur, 2013, p. 7).

The life of a product can be defined by: physical, functional, technical, legal, and the desirability life (Ashby, 2015, p. 222; Woodward, 1997). According to Ashby (2015, p. 223) the design should start with analysing the lifetime that is dominant for the products life. Besides, i.e. when the technology is advancing rapidly and energy consumption is reduces, replacement at an early stage can be more efficient then a longer life (Ashby, 2015, p. 225).

The added value of design and manufacturing of the product is always higher than the value of the materials it consists of. Within the proposed 'reuse - repair- recycle' of circular economy the value is respectively decreasing, but in all three cases the materials stays part of the active stock (Ashby, 2015, p. 225).

5.3 Power of cascaded use

'Power of cascaded use' indicates the possibilities of reusing a certain product. For example cotton clothing, it can be used first at a second hand store; secondly, it can be used as filler of fabrics in the furniture industry; thirdly, it can be shredded and used as insulation of buildings; and at last it can safely be reintroduced to the biosphere (MacArthur, 2013, p. 7).

A form of non-destructive recycling is reuse. Within reuse the function of the product may change but the materials stay in service (Ashby, 2015, pp. 225-226).

5.4 Power of pure circles

'Power of pure circles' refers to the use of uncontaminated materials. According to MacArthur (2013, p. 7) this would increase the efficiency of collection and redistribution while the quality is maintained. This will eventually extend the product longevity and therefor increase the material productivity. This can be achieved by different ways.

An economy where labour is less expensive than materials it makes sense to repair or remanufacture a product, however in most developed economies the labour is more expensive than the materials. In an economy with a slowly advancing technology remanufacturing works for products that are approaching the end of their life cycle. Nevertheless, remanufacturing has some disadvantages. The design asks for easy access and separation; easy identification of components; easy verification of conditions. Plus, that the difficulty in automation of remanufacturing is raising the costs (Ashby, 2015, p. 226).

The advantage of recycling over reuse is that the material is re-entering the primary production process, which allows it to be used in other systems. Problems are found in the separation and recognition. Tagging the components with stamps or barcodes could help, but only if the products are disassembled before they are shredded (Ashby, 2015, p. 226).

Improving the material extraction and yield. The potential of improving the efficiency and yield lies in the offer of new processes (Ashby, 2015, p. 222).

5.5 Human behaviour

Ashby (2015, p. 234) describes: 'Breaking the link between status and possessions brings a drop in material consumption'. In rich economies people consume more than necessary. A lot of things are seen as necessities rather than luxuries. And in a lot of communities the wealth is linked to status, of which the possessions are the physical representation of (Ashby, 2015, p. 234).

5.6 Savings

The possibilities of material efficiency are not specifically short-term solutions. The opportunity lies within the long-term change of material intake (MacArthur, 2013, p. 7). Figure 2 shows the advantages of the circular model compares to the current linear model.

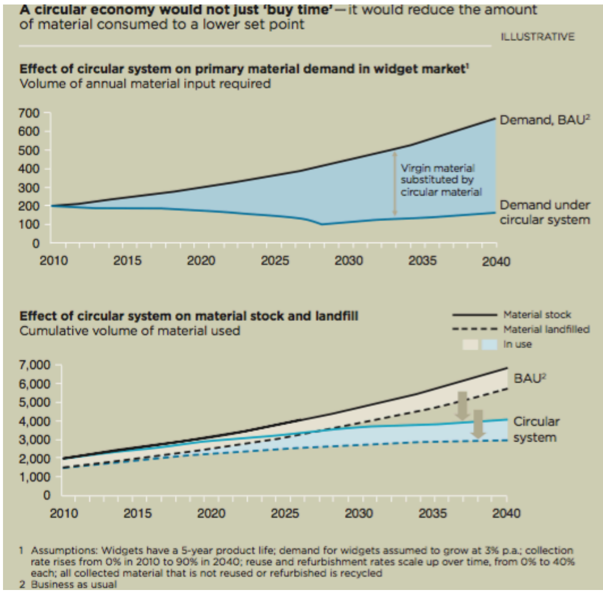

Figure 2: Schematic overview of the circular materials economy (MacArthur, 2013, p. 34).

MacArthur (2013, p. 7) states therefor that is could have substantial cumulative advantages compared with the linear material economy.

6 Chances in implementation in the build environment

6.1 Deconstruction

Untouched potentials cause a large loss of materials and value within this industry, these are found within these products with a long life span, such as buildings and infrastructure (MacArthur, 2013, p. 37).

Lund and Yost (1997) state that by deconstructing instead of demolishing American 1950's and 1960's houses 76% of the rubble would be saved from the landfill. This would save the linked landfill costs and enable the valuable building components and materials to be recycled or reused.

Deconstruction shows forms of social benefits too, in terms of the requirements of labour (Kibert, Chini, & Languell, 2000), creating local jobs and improve the employment condition and educational opportunities (MacArthur, 2013, p. 37). In his research Milani (2005, p. 186) shows that if deconstruction was fully adopted to the demolition industry in the Unites States of the 200,000 houses taken down, it would create 200,000 jobs.

6.2 3D-printing

Being beneficial for the circular material economy is the evolving additive manufacturing techniques. These techniques increase the productivity of materials by eliminating waste compared to the traditional subtractive techniques (Cohen, Sargeant, & Somers, 2014).

Van Wijk and van Wijk (2015, pp. 57-68) compare a conventional townhouse with a 3D printed townhouse. The respectively made out of concrete and PLA, concrete and sand. The embodied energy of the traditional townhouse is lower compared to the 3D-printed one. But the CO_2 emissions of the 3D printed one are lower. Besides, the PLA can be made out of sugarbeets, a natural product, which afterward could be reintroduced to the biosphere.

6.3 Building passport

For an overview of materials in use and for the reuse or recycling of building materials a building passport could be used. This building passport, in combination with a Building Information Model, helps with the recognition and separation of components and materials. A couple factors apply to the building passport. All actors in the supply chain should provide information that forms the content of the passport, and this should be updated regularly. All data should be stored in centralized on-house servers that can be accessed from any location. Important is the consistency and recentness of the information stored in the passport. This should be taken into consideration carefully (Damen, 2012).

7 Discussions

Within this paper the general objectives of a circular material economy are touched. These objectives cannot only be applied to the building industry itself, nevertheless it can be applied to other practices as well, i.e. the car industry or the phone industry. The relevance of this subject with architecture lies within the industry's large share in the waste produced. The building industry consists compared to i.e. the phone industry out of large components that make a product. Therefore it can be easier to make a difference in the environmental impact to apply a circular sequence to the building industry.

8 Conclusions

The circular materials economy is defined by it closed material loop. Materials are tracked, conserved, reused and recycled, at the point where materials re-entre the cycle as raw materials.

The shift from a linear to a circular material economy can be distinguished from a 'take – make – use – dispose' sequence to a 'repair – reuse – recycling' sequence. Three principles are described: 'design out' waste; strict distinction between consumable and durable products; and powered by renewable energy.

Applying a circular material economy can be powered by four powers of added value. *Power of the inner circle*, which introduces the potential of the linear economy and shift from ownership to service. *Power of circling longer,* refers to the amount of cycles a material is making, like first reusing and recycling afterwards. Besides adapting the design to its shortest life cycle. *Power of cascaded use,* indicates the possibilities of re-entering a material to the cycle and keep the materials in service. *Power of pure circles*, pure materials enable a more efficient and affordable opportunity to reuse or recycle products. Identification, recognition and separation are important for materials to re-enter the cycle.

The possibilities to create a circular materials economy within the building industry can inter alia be found within deconstruction, 3D printing or building passports. These applications respectively give the opportunity to reuse or recycle a large part of the materials; provide a method the minimize the waste product with subtractive manufacturing and the use of bio-based materials; and, give the opportunity to track, identify, recognize the materials within building so it can be reused or recycled.

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