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INVESTIGATING THE CIRCULAR ECONOMY AS A SOLUTION FOR CONSTRUCTION WASTE: CHALLENGES AND OPPORTUNITIES

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The construction industry results in a large amount of material waste, most of which currently ends up in landfills. This study aims to find new ways to reuse waste materials captured as outputs of construction projects. First, the circular economy (CE) concept is explored. Second, the application of CE as a potential solution for minimizing material waste on construction projects is investigated. To achieve a healthy industrial metabolism, the paper illustrates how a complex industrial ecosystem is one that produces little or no waste and whose constituents can be interdependent. Output ratios from the construction industry are compared with previous literature on material waste, as a foundation to present a cycle of material reuse. Reformulating the traditional input-output system into a more circular concept presents a set of challenges; however, the opportunities and significant impacts to the material cycles and landfills have proven beneficial and some major cities are starting to employ this concept with great success.

Keywords: Ecosystem, Waste management, Demolition waste, Industrial metabolism.

1 INTRODUCTION

Although the Circular Economy (CE) concept has gained popularity recently, it actually has been a field of research and documentation for some time. Assets that are at the end of their service lives can be used for other purposes instead of being discarded. Outputs of a production process can be resources for other industries. This idea of finding a use for every waste stream can help close loops in industrial ecosystems. Stahel (2016) states CE has enormous potential in addition to existing waste minimizing concepts such as reduce, reuse, recycle (3R) and industrial parks, presenting a new economic viewpoint centered on sufficiency.

Since year 2000, the U.S. reported generating at least 136 million tons of building construction and demolition (C&D) waste each year. However, only 20 to 30 percent of this waste is recycled (Yuan *et al*. 2010). Some agencies have tried to tackle this issue; for example, the U.S. Environmental Protection Agency (EPA) provides a standard for construction waste management (U.S. EPA 2007). However, C&D waste is still a major contributor to landfills. One possible incentive to help address this problem is focusing on the economic benefits of reducing waste.

Little research focused on examining the feasibility of C&D waste management using a cost-benefit analysis approach. A systematic economically driven approach is needed to reduce construction waste. This paper aims to investigate the state of practice of waste management in construction, and explore the opportunity for CE to impact the waste resulting from the construction industry. To achieve this goal, the authors examine waste statistics from the U.S., South Korea, and the European Union. Then, construction-specific waste ratios are studied and compared, which is one key contribution of this paper. Based on the findings, the paper discusses how CE can help reduce construction waste by examining applications of CE that are economically advantageous and resulting in waste reduction in countries such as the U.K. and the Netherlands.

2 CIRCULAR ECONOMY AS A POTENTIAL SOLUTION TO WASTE

The Ellen MacArthur foundation (2015) defines a Circular Economy as one that keeps products, components, and materials at their highest value and in use. In CE, waste is considered an output and is matched with a process to which it can add value. Figure 1 shows the biological cycles of resources and materials on the left side, and the technical cycles on the right side. This paper focuses on the four technical cycles of share, reuse, refurbish, recycle.

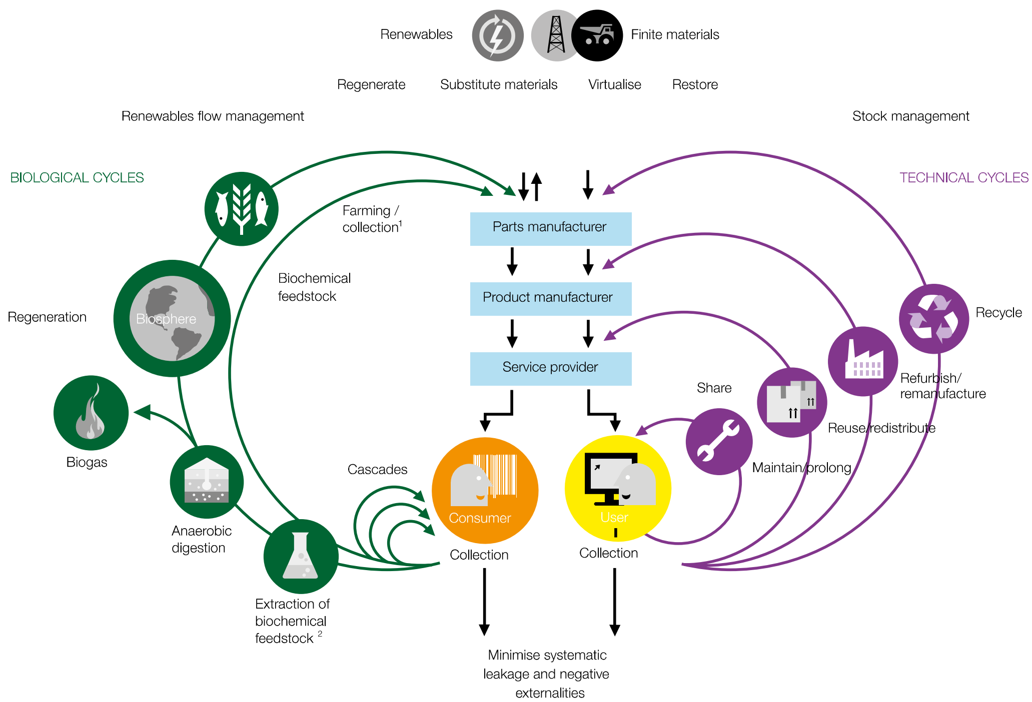

Figure 1. Cycles of the Circular Economy (adapted from Ellen MacArthur Foundation 2015).

ARUP (2016) defines *sharing and maintaining* as maximizing goods utilization and prolonging their life, as well as optimizing an asset's performance. This cycle is preferred when compared with the other cycles due to its least use of new resources. An example in construction is simply reusing existing buildings and spaces as opposed to demolishing and rebuilding a new facility. Next in the figure is *reuse/redistribution* cycle, which means minimizing production and reusing long life components of a system on another structure. One example is modular design in construction. The third cycle is *refurbish and remanufacture*, where components are remanufactured, expending little resources to add considerable value. Finally, recycling is the last and least preferred technical cycle if all others are not possible. One example in construction is crushed concrete, once compliant with earthwork requirements, it can be used as satisfactory soil for fill or sub base. Keeping the resources in closed cycles is key for a successful CE. All technical cycles take part of a model that highlights regenerating and restoring capital, aiming to maintain the resilience of ecosystems.

3 THE CONSTRUCTION INDUSTRY HAS A LOT TO BENEFIT FROM A CIRCULAR ECONOMY

In order to attain and benefit from a CE, the construction industry would require a transformation from its current linear production-consumption pattern, which would first entail a study of how construction material flows are organized. Ness and Atkinson (2001) state that construction material inputs into buildings are growing at an alarming rate. This fact is an indicator of a growing C&D waste problem down the line. Table 1 shows C&D waste ratios of 34.7% and 47.7% for the European Union and South Korea, respectively, based on data from the South Korean Ministry of the Environment (2014) and Eurostat (2017). The table shows that C&D are responsible for a very large portion of total waste. In order to perform a more detailed analysis, Table 2 uses data from the same sources to present C&D waste statistics in these two regions and indicate potential opportunities in C&D waste management. When looking at the 868.5 tons of total C&D waste, the EU recycles 36.20 percent of it while South Korea recycles an enormous 97.88 percent of total construction waste. In the EU, about half of the C&D waste (411.67 million tons per year) still goes to landfills. In a study that investigates the different types of materials existing in demolition debris and construction waste in the United States (U.S. EPA 2007), the numbers put concrete in the first place (by weights) with about 70% of the total C&D waste. Table 3 shows the breakdown of the top C&D waste materials in the U.S.

Table 1. C&D waste ratios in the E.U. and South Korea (2014).

	European Union	**South Korea**
C&D Waste (million tons)	868.5	67.7
Total Waste (million tons)	2,502.9	141.7
Portion of C&D from total (%)	**34.7**	**47.7**

Table 2. Waste management statistics for C&D in E.U. and South Korea (2014).

Waste Management Method	**European Union**		**South Korea**	
	Million tons	**Percentage**	**Million tons**	**Percentage**
Landfill	411.67	47.40	1.08	1.59
Incineration	13.03	1.50	0.36	0.53
Recycle	314.40	36.20	66.23	97.88
ETC (Energy and Backfilling)	129.41	14.90	N/A	
Total C&D Waste amount	**868.50**	**100.00**	**67.67**	**100.00**

Table 3. C&D waste materials in the U.S. in million tons (2014).

Materials	**Demolition debris**	**Construction waste**	**Total**	**Percentage**
Concrete	353.6	21.7	375.3	70.3%
Asphalt concrete	76.6	0	76.6	14.3%
Wood products	35.8	2.9	38.7	7.2%
Asphalt shingles	12.7	0.8	13.5	2.5%
Brick and clay tile	11.8	0.2	12	2.2%
Drywall and plasters	10.3	3.3	13.6	2.5%
Steel	4.3	0	4.3	0.8%
Total	**505.1**	**28.9**	**534**	**100.0%**

In the case of concrete, the U.S. numbers present an excellent opportunity since South Korea showed almost 100% recycling for demolished concrete and asphalt concrete. Traditionally wasted materials can be reused or recycled and used as inputs to the construction industry as well as other industries. The next section illustrates additional opportunities by highlighting current CE applications in the construction industry.

4 CURRENT APPLICATIONS OF CIRCULAR ECONOMY

Circular economy concepts are being used around the world, leading to positive results. For example, a multi-story modular housing block in Stoke Newington, London, UK is adapting the concept of design for disassembly. Modular construction using 3D printing and additive manufacturing could reduce structural waste and construction times, delivering a benefit of over 800 million U.K. pounds per year (ARUP 2016). Another example is Denmark, which is mandating new requirements and presenting new standards for material waste management. As politically encouraged, the total cost of ownership (TCO) of each type of material needs to be comprehensively studied for each product. Waste containers, for instance, are made from one plastic polymer type that is highly recyclable. Reprocessing of worn out plastic containers, by the producer, saves around 80% of the fossil fuel used for manufacturing of virgin plastics. Furthermore, plastic reprocessing saves on average 1.15 tons of CO_2 per ton of plastics in this small example alone (Nielsen 2014). Another example is Japan, which implemented the "reduce, reuse, recycle" (3R) concept in 2005 and presented several regulations including fundamental construction material recycling laws. Incineration in Japan is the highest compared to other countries (Ministerial Conference on the 3R Initiative Website 2005) and data show a growth in incineration from around 20% in 1955 to 75% in 2000. With the introduction of the new regulations, the byproducts of incineration were included in a circular economy cycle instead of being wasted: Gas emissions were controlled through a strict maintenance of incineration temperatures, and the exhaust heat is used for power generation.

In addition to applications in the construction industry, CE concepts are being applied in industries directly related to construction, such as mining. Construction material flows often start with mining. There are opportunities with mining, by capturing byproducts. One example is zinc, used for galvanizing construction materials. Zinc can be captured while processing iron and steel scrap. Another example is Phosphate mining, which allows for a possible recovery of both gypsum and fluorine at the same time. This synergy reduces both the waste disposal from the phosphate mining as well as the mining process of fluorine and gypsum (Ayres and Ayres 1997).

Gypsum is another major construction material. More than 4 million tons of gypsum scrap was recycled in the United States in 2015 alone. Gypsum is primarily used for wallboard, but markets for this particular mineral include athletic fields, cement production, grease absorption, water treatment, and agricultue. The U.S. produced 11.5 million metric tons of gypsum in 2015, making it the largest mine producers of gypsum (U.S. Geological Survey 2016). Recycling C&D gypsum waste can help close the loop and offer a stable supply to the construction market, especially at a time when both U.S. imports of gypsum and mine production are increasing.

5 CHALLENGES AND FINANCIAL OPPORTUNITIES OF CIRCULAR ECONOMY IN THE CONSTRUCTION INDUSTRY

In a survey about waste management, Tam (2007) showed that in construction, cost is still often considered as the major decision factor, while harm to the environment is less important. Financial incentives must be clear in order to attract cross-industrial partnerships within a broader goal of reaching a circular economy. Therefore, the authors analyzed available waste data in an attempt to assign a monetary value to it.

Using the South Korean waste statistics discussed earlier, even though recycling percentages are 98%, additional construction materials can still be included in the waste management plan, such as glass, tiles and ceramics, textile, wallpaper, surface coating materials, and panels. The assumptions for these remaining materials are:

- Construction demolished Soil: $30.62 per 50 lb ($1.35 per Kg)
- Glasses: $26.95 per 2 lb ($24.3 per Kg)
- Tiles & ceramics: $1 per 0.25 kg ($4 per Kg)
- Textile: $350 per ton ($0.35 per Kg)
- Wallpaper: $35 per Kg
- Surface coating board & panel: $200,000 per day
- Sludge, brick & block, wood, resins, and mixed construction materials are negligible

Adding these up for South Korea results in an additional U.S. $1.48 million in benefits per day, or U.S. $532 million per year that can be saved if applying CE succeeds. Recent reports agree that there is a strong economic case for CE. One example is a study on the Indian market, which estimates that applying CE in the construction sector could lead to an annual benefit of 76 US $billion by 2050 (Sukhdev *et al.* 2016). Another example is described by the London Waste and Recycling Board (2015). London consumes more than 20 million tons of construction material per year and produces 10 million tons of construction waste. The latest estimates for the potential benefit from CE opportunities in the built environment in London adds £3 to 5 billion annually to the UK GDP by 2036. Strategies include designing for effective building disassembly, material management and re-use management of building materials.

Moreover, the Ellen MacArthur Foundation (2015) estimates that moving to a circular economy in the EU alone can capture benefits amounting to €1.8 trillion by 2030, with a growth of 3% annually in resource production. Similarly, Japan instituted new regulations for both generators of industrial waste and waste management firms to support the current implementation of the 3Rs concept and ultimately circular economy (Japanese Ministerial Conference 2005).

6 DISCUSSION OF RESULTS

The data presented in this paper showed significant potential of implementing CE in the construction industry. Since monetary benefits constitute key incentives for stakeholders involved in the CE process; this section interprets the results introduced earlier and further discusses their impacts, specifically when it comes to the EU.

In the previous section of this paper, a benefit of $532 Million per year was calculated as the possible result of implementing CE in South Korea, even though its recycling percentages were already at a very high 98% rate. That remaining 2% of C&D waste in South Korea represents about 1.35 million tons of material waste. Dividing $532 Million by 1.35 million tons results in a value of $394 Million for every million ton of material waste. While the EU recycles only 36.20% of their C&D waste, 63.8% (554 million tons) go mostly to landfills, and in smaller shares to incineration and ETC. Assuming the same monetary values of South Korea’s materials ($394 Million per million ton of waste) for the sake of computing an estimate for this study, if the EU proceeds to recycle its remaining waste, they could benefit from about $220 Billion per year.

Moreover, ARUP (2016) showed recycling as the least favorite cycle, whereas sharing, maintaining, reusing, and remanufacturing were all preferred venues. Therefore, financial advantages and environmental benefits from preferred cycles can be even greater than the numbers shown here for recycling. In summary, CE can be viewed as a cost-driven concept. The most efficient way of implementing CE is by keeping the products at the end user level and reducing the need for manufacturing new products using new raw materials. Instead, making good use of the large amount of available C&D materials currently being wasted, is a sizeable opportunity for our industry.

7 CONCLUSION

This paper quantified construction and demolition material waste and contrasted it in the EU, South Korea, and the U.S. It proposed circular economy as a solution for construction waste, while presenting a strong case for CE based on current best practices and existing financial opportunities. The opportunities offered by applying a circular economy are contingent on strong partnerships. Moving towards CE requires a cross-industry, cross-performance and multidisciplinary approach in order to find a diverse enough pool of "buyers" so that every product and byproduct finds a home. In the construction industry, there is certainly a need to understand C&D material waste flows in order to identify potential uses and reduce C&D landfill waste. A limitation of this paper is the number of countries for which data was available. Future work will expand the list of countries investigated, and map the material flows out of construction projects to develop a comprehensive set of strategies needed to embed the construction industry in a circular economy.

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