OVERCOMING TECHNICAL AND REGULATORY BARRIERS FOR A BETTER CIRCULAR ECONOMY IN CONSTRUCTION INDUSTRY

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Abstract

The availability of resources for the construction industry is becoming increasingly uncertain, while at the same time the amount of construction waste, but also of industrial and agricultural by-products, is growing. Reconciling needs and secondary resources as well as contributing to reuse is a useful and motivating scientific challenge. But legal and regulatory barriers have to be overcome in order to allow a real circular economy in the construction industry. Working locally and developing an appropriate treatment of Construction and Demolition Wastes is favouring upcycling and valorization of secondary materials for prefabricated and 3D printed concrete. Technical properties of recycled materials are analysed, and proposals are made for increasing the rate of incorporation into concrete prefabricated products. In the same time, minimum requirements are proposed for using recycled sand in 3D mortars. Final properties are compared with classical materials and durability of end products is analysed. Accelerated carbonation process seems to increase recycled sands and aggregates properties (before and/or after manufacturing concrete). But a large and systematic use of recycled materials needs to adapt regulations and requirements for specific applications: this is essential for lowering environmental impact of the construction industry.

1. Introduction

In 2020, the EU-27+UK countries produced a total amount of 2,135 million tonnes (Mt) of wastes (4815 per capita) by all economic activities and households [1]. The construction industry accounts for one third (37.5%) of all the generated wastes and consists of one of the heaviest and most voluminous waste stream in the EU. Construction and demolition wastes (C&DW) represent an amount of about 850 Mt generated every year by the EU-28 or 1.7 tonne produced per year and per EU inhabitant. Moreover, almost two-thirds (64 % or 3.1 tonnes per inhabitant) of the total waste generated in the EU in 2020 was major mineral waste.

On the other side, the annual European demand in aggregates amounted to 2,99 Mt in 2021 (Fig. 1). The European demand represents about 10% of the global demand in aggregates [2].

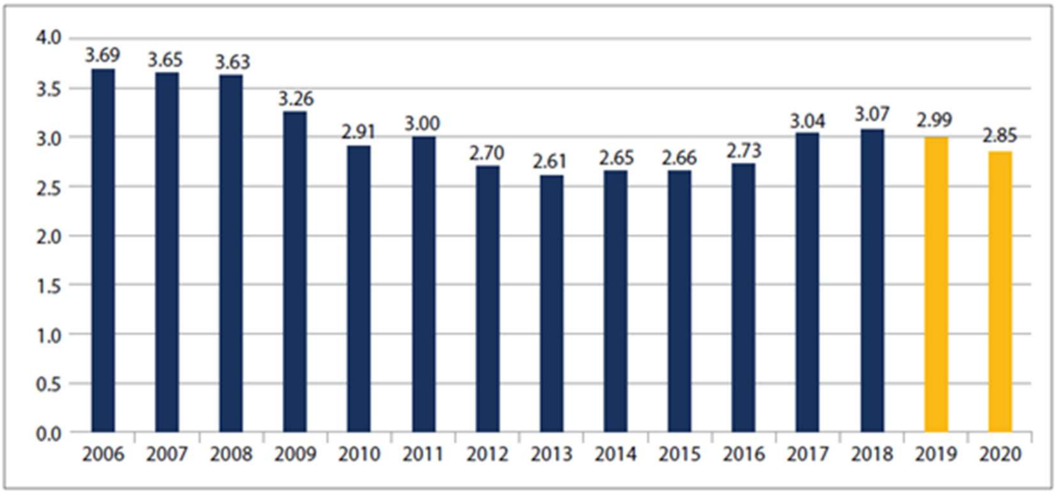


Figure 1: EU+UK+EFTA Trend in Production in Billions of Total Tons (UEPG, 2021) [2]

Aggregate and sand materials are in high demand globally for construction purposes, with an annual growth rate of around 5% while the availability of sand is decreasing. Figure 2 shows the clear increase in sand demands over the previous and coming years. The United States and China show overall the highest yearly demand of sand.

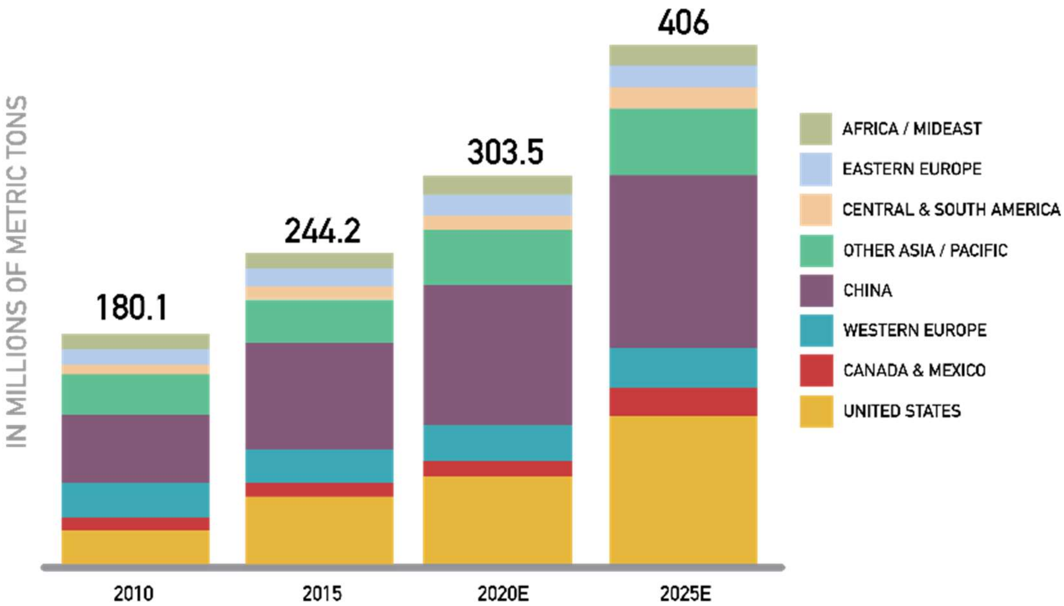


Figure 2: World sand demands in millions of metric tons.
https://iveybusinessreview.ca/6580/lafargeholcim-the-plastic-solution-to-the-global-sand-wars/graphic-2-world-sand-demand/

Figure 3 provides a synopsis of the 2019 national production tonnages categorized by country and aggregate type. Germany emerged as the leading producer, surpassing 500 million tons, followed by Russia, Turkey, France, the UK, and Poland. In contrast, smaller nations such as Malta, Montenegro, Iceland, Luxembourg, and Cyprus exhibited production levels below 5 million tons.

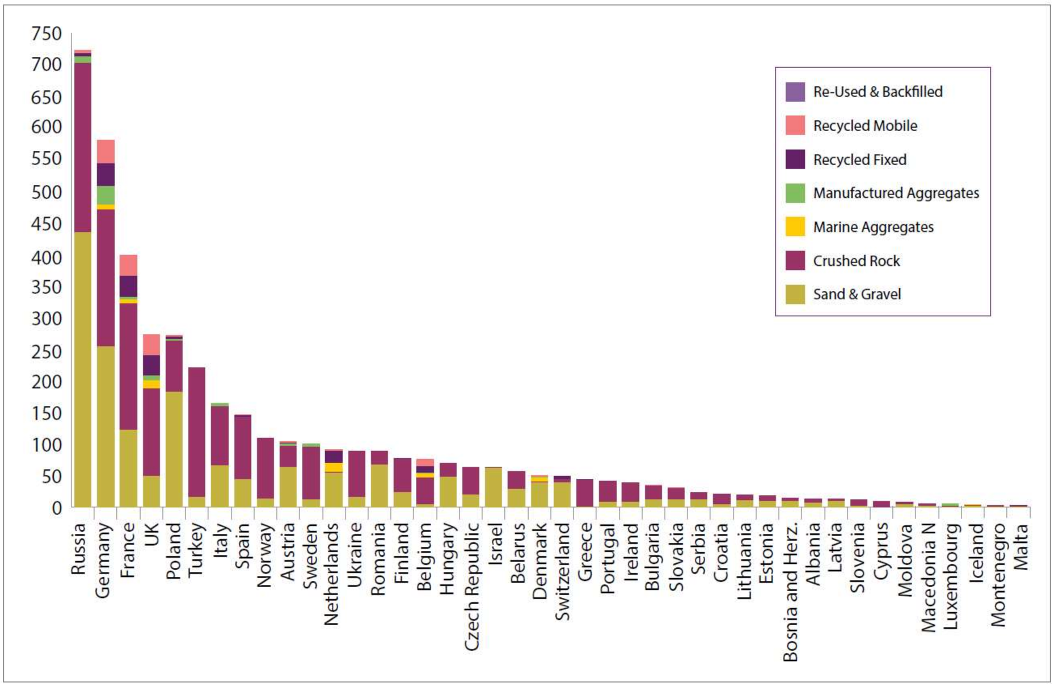


Figure 3: 2019 aggregates production in Europe (UEPG, 2021)

National tonnages depend not only on economic strength, but also on geological availability of and access to deposits, national ambient climate, ruggedness of the terrain and local building traditions.

Figure 4: Aggregate type percentages

The composition of aggregate types (Fig. 4) in the EU27+UK+EFTA countries in 2019 revealed that crushed stone accounted for 46.9% of all production, while sand and gravel constituted

39.7%. Aggregate production from recycled and reused materials contributed 9.3%, with marine and manufactured aggregates comprising the remaining 4%.

2. Market analysis and barriers

The market of recycled sands and aggregates (RS&A) needs to be healthy at country scale to foster member states to reach the target defined in the Waste Framework Directive (2008/98/EC) [3]. The most cited drivers that can boost C&DW recycling are: Green Public Procurement, taxation on C&DW landfilling, taxation on natural sands and aggregates, availability and cost of natural sands and aggregates, quality certification of RS&A, better public perception and increased consumer acceptance and low distance with C&DW recycling plants (e.g. [4]).

A recent study [5] has pointed out the three main key parameters that influence the market of recycled materials: the landfill of inert C&DW, the challenge with primary raw materials and the availability of inert C&DW recycling plants. The market context was investigated in five NWE countries (Belgium, France, Germany, Luxembourg and the Netherlands) towards a quantitative analysis of the generation of C&DW, the production of natural and RS&A, the density of recycling plants, the density of extraction sites for natural materials, and C&DW landfilling legislation.

Results point out that the market of recycled sands and aggregates is more developed and more suitable in the Netherlands and in Flanders (North of Belgium) where all the three investigated key variables are considered as drivers. These regions are characterized by a lack of available local and good quality natural rocky materials, a developed framework of recycling plants for inert C&DW and a favourable legislation that push the waste flux to sorting and recycling. The market in Wallonia (South of Belgium), France, Germany and Luxembourg is challenged by primary raw materials where resources are locally abundant. The French market of recycled materials is furthermore disadvantaged by a lack of incentives that foster sorting and recycling, including landfilling.

A proactive policy of support for the recycling of C&DW therefore implies stopping the disposal of waste in landfills, the setting up of adequate recycling techniques, in particular through the installation of complete sorting centres and the networking of these recycling centres sufficiently dense, so as to reduce the impact of transport. There is a great opportunity for increasing the part recycled products on the NWE market of aggregates. More generally, the following recommendations can be formulated [6]:

- Enhance public procurement through the introduction of mandatory percentages of recycled aggregates in large civil engineering projects;
- Develop reuse/reclaimed products programme of support and promotion (e.g. reuse percentage target);
- Introduce end-of-waste criteria for recycled products;
- Develop standards for recycled materials for various utilization for waste that did not meet end-of-waste criteria;
- Facilitate material content traceability;
- Introduce applications for recycled non-aggregates;
- Encourage the construction products and materials supply chain to have much greater provision for taking back and incorporating recycled materials into new products;
- Deploy financial incentive to use recycled aggregates.

3. Circular economy in construction industry

A survey organized by Tebbat Adams et al. [7] shows (Fig. 5) that the most significant challenge which was highly ranked by all the stakeholders, is the lack of incentive to design for the end-of-life issues for construction products. The low value of products at end-of-life is also an important economic challenge. The construction industry's structure is also viewed to be a significant challenge in the form of a fragmented supply chain [8].

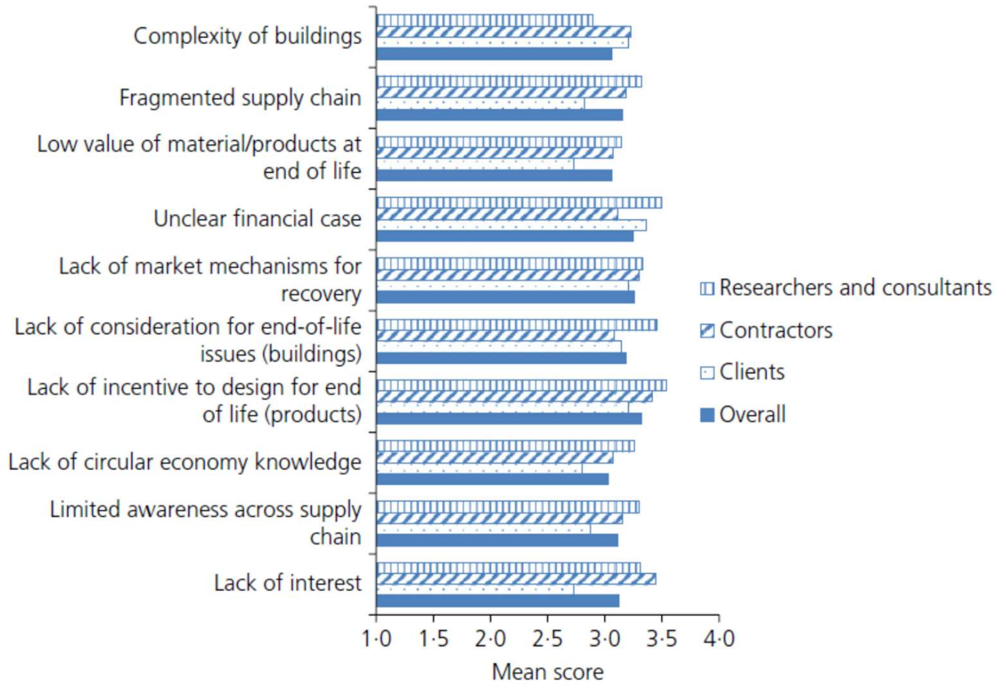


Figure 5: The most significant challenges for implementing circular economy in industrywide [7]

As mentioned in the survey [7], "*a larger obstacle is the existing stock of buildings and infrastructure where circularity principles have not been adopted*". However, many opportunities to advance the circular economy exist. A better recovery of material by means of viable take-back schemes and higher value markets as well as assurance schemes for reused materials are promising (Fig. 6). Cradle to cradle concept is nothing else: waste becomes a nutriment for another product. McDonough et al. [9] promote the idea that biological and mineral cycles have to be separate for favouring reuse and recycling. But also that we must design materials in such a way the end of life and end of use are timely corresponding: because the waste is induce by this discordance of time.

Circular economy in construction industry is clearly a need and a wonderful opportunity [10], regarding the huge amount of C&DW versus the demand of granular materials: compatibility between deposit and market should contribute to change the paradigm and transform the wastes into secondary resources. Coming challenges in this area are longer-lasting materials, repairable products, prefabrication and off-site construction, banks of materials, circular material supply chain, design for adaptation and deconstruction, …

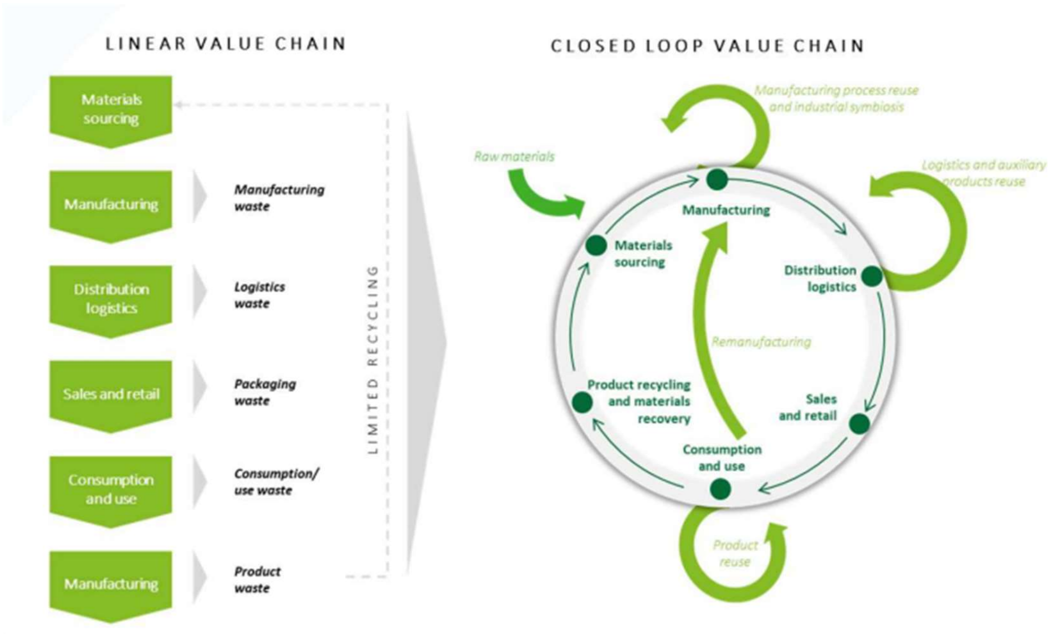


Figure 6: Comparison between linear and circular economy (from [10])

4. Upcycling of Construction and Demolition Wastes

The needs of civil engineering can be indeed of four main types of materials, namely [11]:

- **Filling materials**, on which there are low requirements and consumed in large quantities, for embankments but transportable over short distances due to costs;
- **Aggregates**, which must meet various specifications depending on the place they will occupy in the structures and the treatment techniques used. The quality requirements can at this level become high, even severe for the surface layers, to lead to finished products of quality identical to that of traditional materials;
- **Binders**, which must meet very precise specifications and whose properties must remain constant over time. Employed in small quantities and competitive with expensive products (cement & bitumen), they may experience pre-employment packaging and bear higher transportation costs;
- **Activators**, which will be used in small quantities, which can cause problems of collection, storage, distribution and regularity.

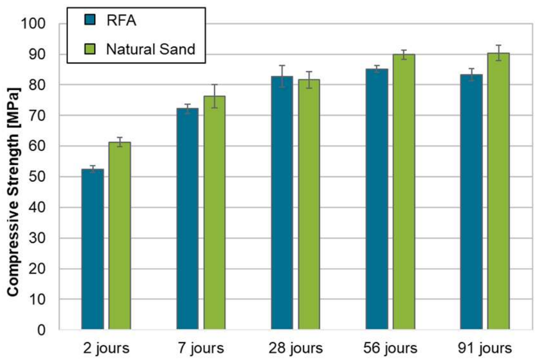
Specific sorting and grinding process [12], original applications [13], incorporation of production waste into the final product [14], prefabricated products [15] tend to increase needed performances and upcycling of C&DW.

5. Example: 3D printing with recycled fine aggregates

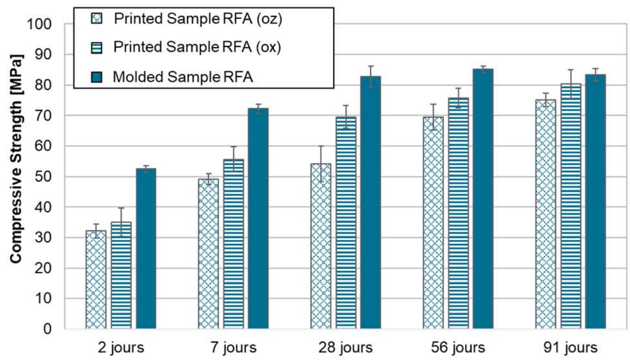
Concrete 3D printing is an innovative technique allowing for the quick production of easily customizable elements. Yet, it is also facing a lot of criticism targeted in part to its environmental impact. To address it, the entirety of the granular skeleton has been replaced with washed concrete Recycled Fine Aggregates (RFA).

The research [16] investigates the influence of RFA on the mechanical and durability performances of 3D printing mortars. This investigation involves a comparison of mortar samples produced using two types of fine aggregates: virgin fine aggregates and recycled fine aggregates (RFA). The aim is to determine how the incorporation of recycled fine aggregates affects the properties of the mortar. Additionally, the study assesses the impact of the 3D printing process itself on mortar properties. To do this, the performance of mortar samples that were 3D printed are compared with those of samples that were cast using conventional methods.

A battery of tests is conducted to assess various mechanical and durability properties, including compressive strength, tensile strength, flexural strength, porosity, water absorption, and resistance to environmental factors like freeze-thaw cycles. Direct tensile tests have also been used to assess if the cracking pattern followed the interface between two printed layers which would indicate the existence of a structural weak point in the material.



(a)



(b)

Figure 7: Influence of the use of RFA (a) and of the printing process (b) on the compressive strength of mortars

The research findings indicate that substituting natural sand with RFA does not lead to significant alterations in either the mechanical properties (cf. Figure 1(a)), or the durability aspects, such as resistance to freeze-thaw cycles and carbonation, in the context of 3D printing mortars. However, elements produced through 3D printing exhibit lower mechanical strength compared to samples cast using traditional methods which is assumed to be caused by poor curing conditions during the first 48 hours. Moreover, these 3D-printed samples display anisotropic properties. Specifically, when a load is applied parallel to the printed layers (as shown by "oz" in Figure 1(b)), the resistance is lower compared to when the load is applied perpendicular to the layers (indicated by "ox" in Figure 1(b)). This finding is somewhat counterintuitive because it challenges the assumption that the interface between layers in 3D printing is typically weaker than other parts of the material. These results are supported by the direct tension test, which indicates that the failure plane never corresponds to the interface between two layers. These collective findings suggest that there may not be a pronounced weak point at the interface between layers in 3D-printed mortar elements.

Acknowledgments

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