Challenging construction industry with C&DW: opportunities and limits

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Abstract. Construction and Demolition Waste (C&DW) comprises the largest waste stream in the European Union (EU), with relatively stable amounts produced over time and high recovery rates: it is estimated at one third of total wastes generated in the EU. Although this may suggest that the construction sector is highly circular, scrutiny of waste management practices reveals that C&DW recovery is largely based on backfilling operations and low-grade recovery, such as using recycled aggregates in road sub-bases. These wastes are usually recovered as secondary raw materials after a recycling process resulting in the production of recycled sands and aggregates. Researches have been performed to show how it is possible to encourage and support the use of these recycled materials: preparation process and selection are fundamental for increasing capability of recycling. Analysis of recycled bricks and tiles sands and fine particles has also been tested as substitution product in concrete design. A quantitative analysis is proposed for five North West European (NWE) countries: Belgium, France, Germany, Luxembourg and the Netherlands, where barriers are pointed out. The construction industry will be definitively affected by C&DW recycling for promoting circular economy in the coming years.

Keywords: construction and demolition wastes, recycling, sands, aggregates, bricks, Europe.

Introduction

In 2014, the EU-28 countries produced a total amount of 2,503 million tonnes (Mt) of wastes by all economic activities and households [1]. The construction industry accounts for one third 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, including excavated soil.

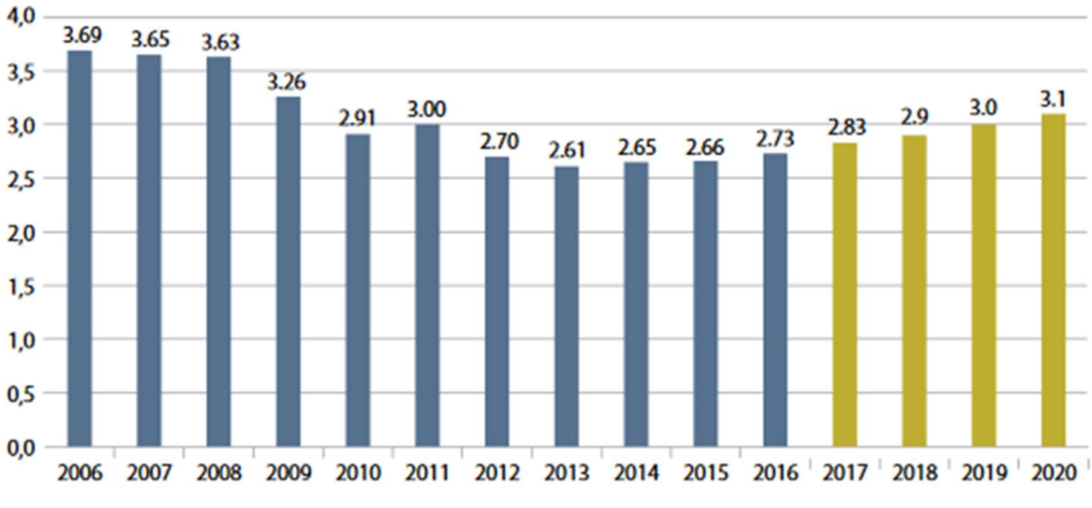

Fig. 1. Trend in total EU + EFTA Tonnages (in billions of tonnes) (UEPG, 2017) (from [2])

On the other side, the annual European demand (EU-28+EFTA) in aggregates amounted to 3,000 Mt in 2019 (Fig. 1) [2]. Driven by the recovery target of 70 % by 2020 (set by the 2008 Waste Framework Directive and defined as including all recycling and other recovery operations such as backfilling), countries report increasingly high recovery rates. Most of them already exceeded the 2020 target in 2016 [3]. However, as a result of building practices in the past and the lack of recovery of high purity materials during demolition, the material streams arising from demolition and renovation works are not suitable for reuse or closed-loop recycling (Fig. 2). This hampers the full implementation of circular economy objectives.

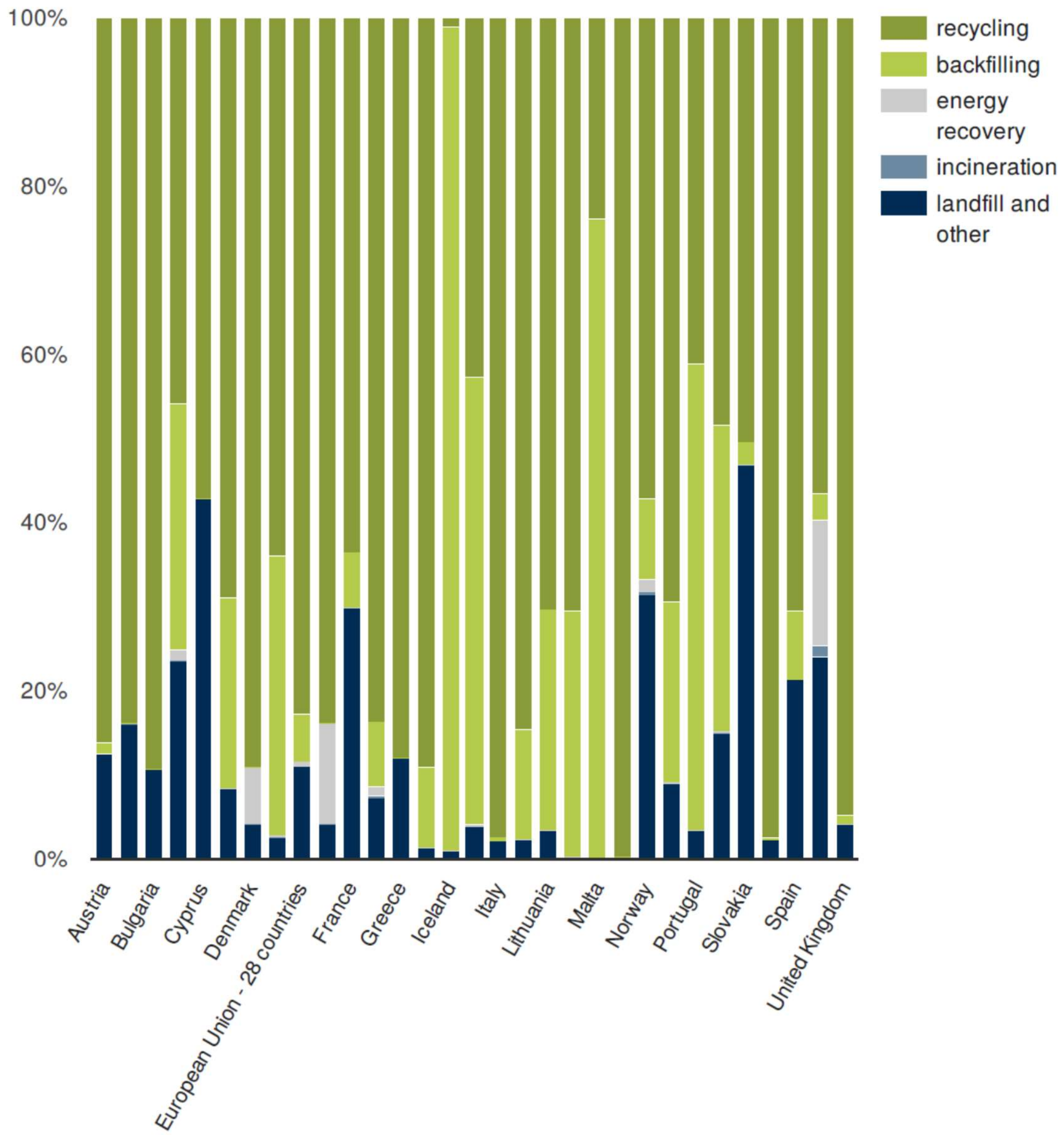

Fig. 2 Recycling, backfilling, energy recovery, incineration and landfilling of the mineral part of construction and demolition waste as percentage of total treated waste in EU (2016) [3]

Energy recovery means the energy content of waste and incineration aims only at thermal treatment of the waste

The use of recycled materials within the road industry and civil engineering has been done gradually for fifty years and has experienced a significant acceleration in the last 30 years, due to the increased demand for materials, both in quantity and in quality: if, at the outset, the waste was used mainly as backfill or aggregates, it was later used as binders and additives.

The needs of civil engineering can be indeed of four main types of materials, namely [4]:

- **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.

If the technical, economic and ecological interest appears clearly in the relationship between the supply of by-products and the needs of industry, it is also clear that the use of such products poses a certain number of difficulties:

- technical ability to enter into the composition of materials (standards);
- suitability for the use of materials using this waste;
- economic optimization of possible jobs;
- social impact on employment in companies supplying noble products;
- effects on the environment.

Therefore, beyond any technical question on the use of this or that secondary raw material, various questions must be asked:

- *How can waste find its place in an industry and, in general, in a highly standardized society?*
- *Which regularity to request and what controls should be put in place so that the waste used always remains in the ranges where it has demonstrated its capacity for use?*
- *How to observe and ensure the long-term durability of the materials used?*
- *What is the influence on the environment?*
- *What socio-economic problems can arise in conventional industrial activities?*

Recycling inert C&DW as aggregates and sands is probably the best solution for reducing waste storage [5, 6] as there is a crucial need of materials (Fig. 3).

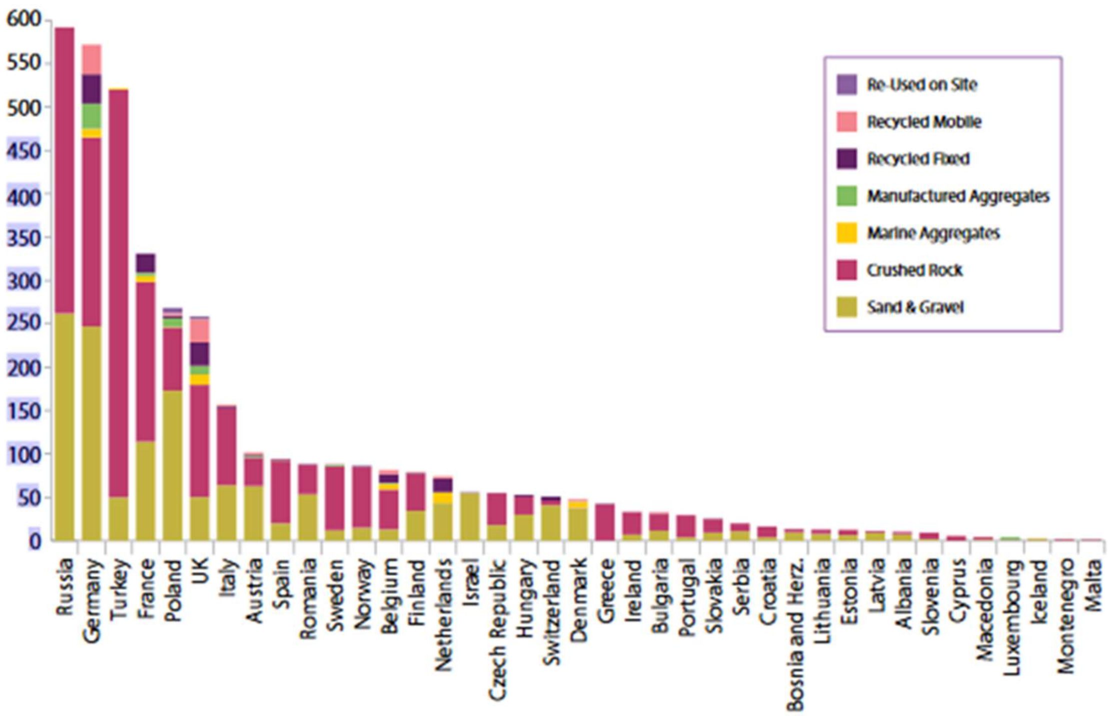

Fig. 3. 2016 aggregates production in Europe in millions of tonnes by country and type [7].

The low percentages of recycled sands and aggregates (RS&A) in Table 1 clearly indicate a need for R&D in the NWE countries in order to improve RS&A properties and optimize recycling processes [8].

Table 1.
Estimation of total and recycled sands and aggregates production [9]

	Total production (millions of tons)	Recycled sands and aggregates (RS&A) production (millions of tons)	Percentage of RS&A vs total production (%)
Belgium	81	15	18.5
France	323	20	6.2
Germany	545	68	12.5
Ireland	28	0	0
Luxembourg	4	0	0
Netherlands	80	18	22.5
U.K.	248	52	9.5
Switzerland	*49*	*5*	*10.2*
EU28	2524	196	7.8

There is a real challenge in developing solutions to increase recycling rates and promote up-cycling of recycled wastes as secondary raw materials. This paper focuses on recycling inert C&DW, concrete, silicates and natural stones.

Market context: limits 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). 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. [10]).

A recent study [9] 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. Table 2 presents the results of a quantitative analysis carried out on key parameters that influence the market of RS&A, for the five investigated NWE counties. Attention has been paid to provide the most current available data. Some actors of the market of RS&A have also been visited, in the framework of the NWE Interreg project SeRaMCo.

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 [8]:

- 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.

Table 2. Quantitative data on the market of recycled and natural sands and aggregates in NW European countries. Abbreviations: C&DW = construction and demolition wastes; CBTC = concrete-bricks-tiles-ceramics; N/A = not applicable; RS&A = recycled sands and aggregates [3].

		Belgium				France	Germany	Luxembourg	Netherlands
		Flanders	Wallonia	Brussels	Total				
Waste production	Quantity of inert C&DW excl. soils and stones (in Mt/yr)	15	5-7	0.5	~22	64	83.5	0.5-0.6	23.2
	Quantity of inert C&DW excl. soils and stones (in t/capita)	2.3	1.4-2.0	0.4	~1.9	1.0	1.0	0.9-1.0	1.4
	Quantity of CBTC (in Mt/yr)	12.6	4.1-5.7	0.4	17.1-18.7	~38	54.6	0.25-0.3	19-20
	Quantity of CBTC (in t/capita)	2.0	1.1-1.6	0.3	1.5-1.6	~0.6	0.7	0.4-0.5	1.1-1.2
RS&A production	Quantity RS&A (in Mt/yr)	13	3.5	~0	16.5	21.4[a]	66	1.8[b]	18[c]
	Quantity RS&A (in t/capita)	2.0	1.0	~0	1.5	0.3[a]	0.8	3.1[b]	1.0[c]
	Proportion of RS&A compared to the quantity of inert C&DW (excl. soils and stones) (in %)	87	50-70		~75	33[a]	79		78[c]
	Proportion of RS&A compared to total production of sands & aggregates (in %)	46	6		18-20	7[a]	13		18-25[d]
Landfilling	Ban for inert C&DW landfilling	Yes	Yes	N/A	N/A	No	No	No	Yes
C&DW recycling plants	Number of recycling plants	~200-250	~100		~350	~400	2,073	~30	~150
	Type of facilities				80% stationary, 20% mobile			Mainly mobile	35% crushing, 20% sorting, 45% crushing & sorting
	Density of recycling plants (per 1,000 km^2)	~16	~5		~11	~0.6	~6	~12	~4
Natural aggregates and sands production	Quantity of natural aggregates and sands (in Mt/yr)	15	55-60	0	70-75	300	450	~1	55-80[d]
	Quantity of natural aggregates and sands (in t/capita)	2	15-17	0	6-7	4-5	5	~2	3-5[d]
	Number of extraction sites				~200	~2,300	~3,000	~13	~295
	Density of extraction sites (per 1,000 km^2)				~7	~4	~8	~5	~7

[a] The French production of RS&A is largely underestimated since the quantity of on-site recycled materials in not taken into account in the national statistics and is difficult to estimate accurately.
[b] The referred quantity of RS&A in Luxembourg is largely overestimated since it includes excavated soils and stones.
[c] The referred quantity of RS&A in the Netherlands is produced by BRBS's members (national federation of C&DW recyclers). This quantity could be slightly underestimated.
[d] The referred data is calculated for the regular extraction activity of natural materials in the Netherlands.

Circular economy

A survey organized by Tebbat Adams et al. [11] shows (Fig. 4) 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.

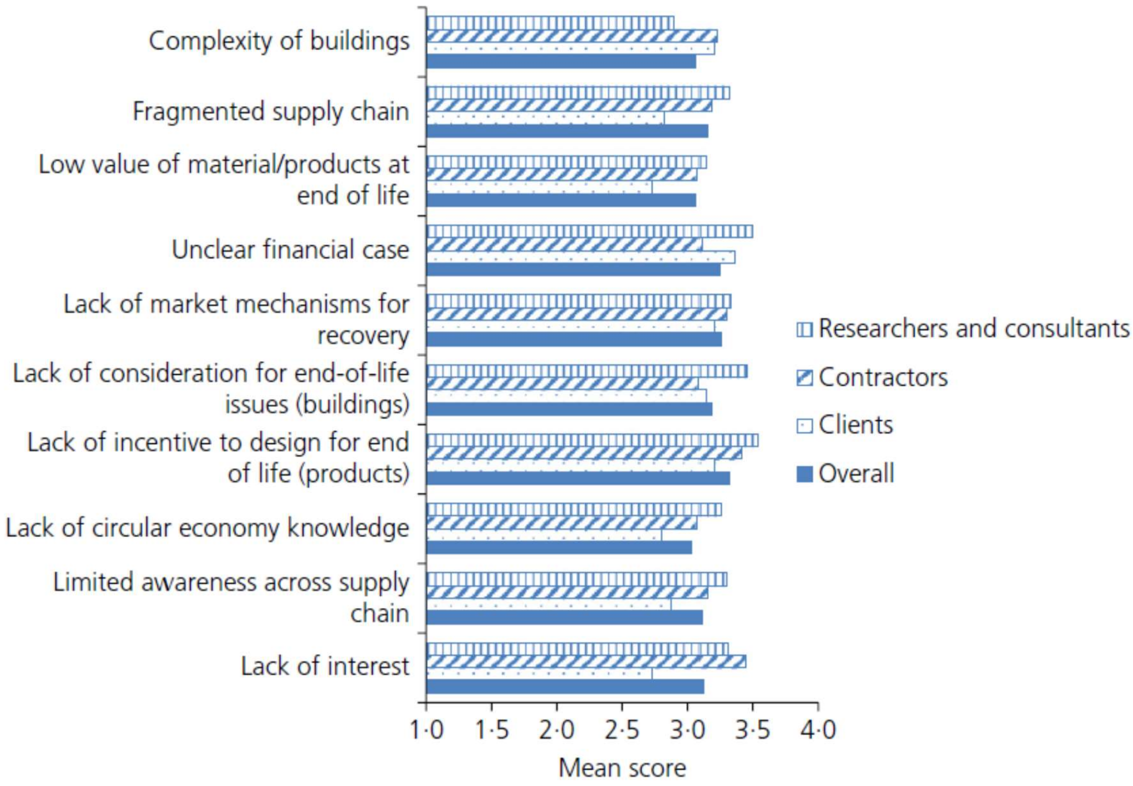

Fig. 4. The most significant challenges for implementing circular economy in industrywide [11]

As mentioned in the survey [11], "*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. 5). Cradle to cradle concept is nothing else: waste becomes a nutriment for another product. McDonough et al. [12] 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 (Fig. 6).

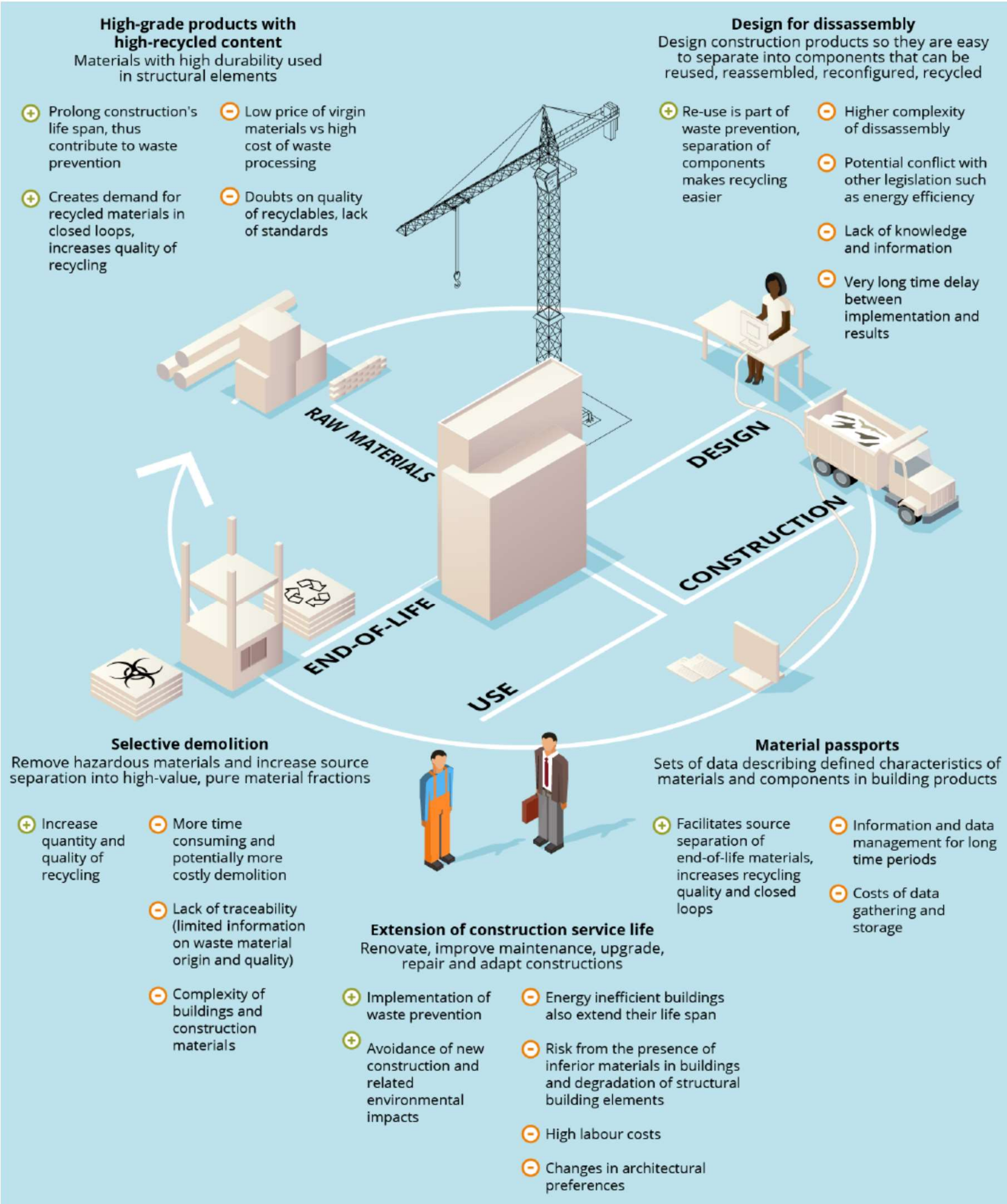

Fig. 5. Example of circular actions for improving the management of C&DW [13]

Circular economy in construction industry is clearly a need and a wonderful opportunity [13], 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.

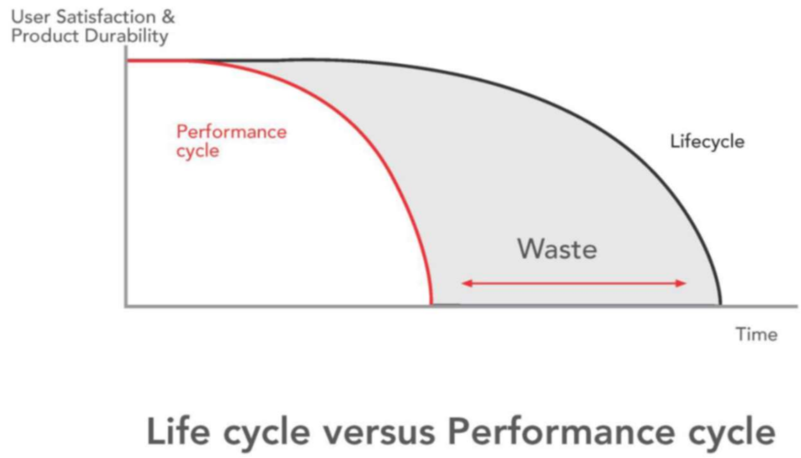

Fig. 6. Life cycle and performance cycle: distortion inducing waste production (from [12])

C&DW up-scaling

Recent research performed at UEE GeMMe Building Materials laboratory show that quality of recycled product preparation and proper design are critical for up-scaling secondary resources into civil engineering and architectural applications.

Crushing and grinding operations

C&DW recycling plants are quite similar to natural aggregates production plants. They use various crushers, screens, transfer equipment, filtering devices to produce granular material of a specific granular fraction. Several studies have shown that increasing the number of crushing stages led to decreasing adherent hardened cement paste content [14-16] but the influence of the crushing method itself has not been thoroughly studied. In the study of Hubert et al. [17], laboratory made concretes have been crushed with two different types of mechanical crushers to study the influence of the crushing method on the properties of recycled concrete aggregates (RCA). Studies have also shown the influence of the parent concrete on RCA properties [16; 18] but most of those linked the adherent hardened cement paste content to the compressive strength of the parent concrete. A lot of other factors in the parent concrete composition could impact the properties of the RCA which is why it has been chosen to consider five different compositions where the type of cement, the nature of the aggregates, the cement quantity and the water to cement (W/C) ratio differ from the reference one.

The reference concrete has been designed with limestone aggregates of granular fractions 2/7, 7/14 and 14/20 mm, crushed calcareous sand of granular fraction 0/4 mm. The composition for the reference composition has been determined according to the standard EN 480-1 which has led to the following proportions: 35% of sand 0/4 mm, 20% of aggregates 2/7 mm, 20% of aggregates 7/14 mm and 25% of aggregates 14/20 mm, by mass. 400 kg/m^3 of CEM I 52.5 N cement are used and the W/C ratio is fixed at 0.56. The other compositions differ from the reference by one parameter: the second composition uses CEM III/A 52.5, the third uses sandstone aggregates, the fourth reduces the quantity of cement to 320 kg and the fifth has a W/C ratio of 0.46. For each composition, 120 liters (corresponding to ~280 kg) of concrete were manufactured. Cubes (15 x 15 x 15 cm) were produced and stored in humid atmosphere for 90 days before being crushed (temperature of 20 ± 2°C and relative humidity of 90 ± 5%) in accordance with EN 206.

About 240 kg of each composition has been crushed using the two most common crushers for inert waste recycling: jaw crusher and impact crusher. After crushing, the RCA obtained have been characterized. Specifically, their particle size distribution, morphology, hardened cement paste content and water absorption of RCA have been measured and analyzed.

The experimental campaign conducted showed that impact crushers produce aggregates with better morphologic characteristics but with a more extended grain size range and higher fine content than jaw crushers. The crushing method does not, however, appear to have any influence on the hardened cement paste content nor on the water absorption of RCA for the studied concretes [17]. Another interesting result of this study is that the flakiness index, the shape indexes, hardened cement paste content and water absorption of RCA all decrease with increasing granular fraction (Fig. 7). This would tend to indicate that bigger recycled aggregates present a much better liberation rate. It is also notable that minimal value of the water absorption (thus by correlation of the cement paste content) and morphology indicators of the recycled aggregates produced with the jaw crusher are obtained for granular fraction close to the maximum diameter of natural aggregate of the parent concrete. This could be linked to the breakage mechanism of the jaw crusher which is not breaking the natural aggregates contrary to the impact crusher.

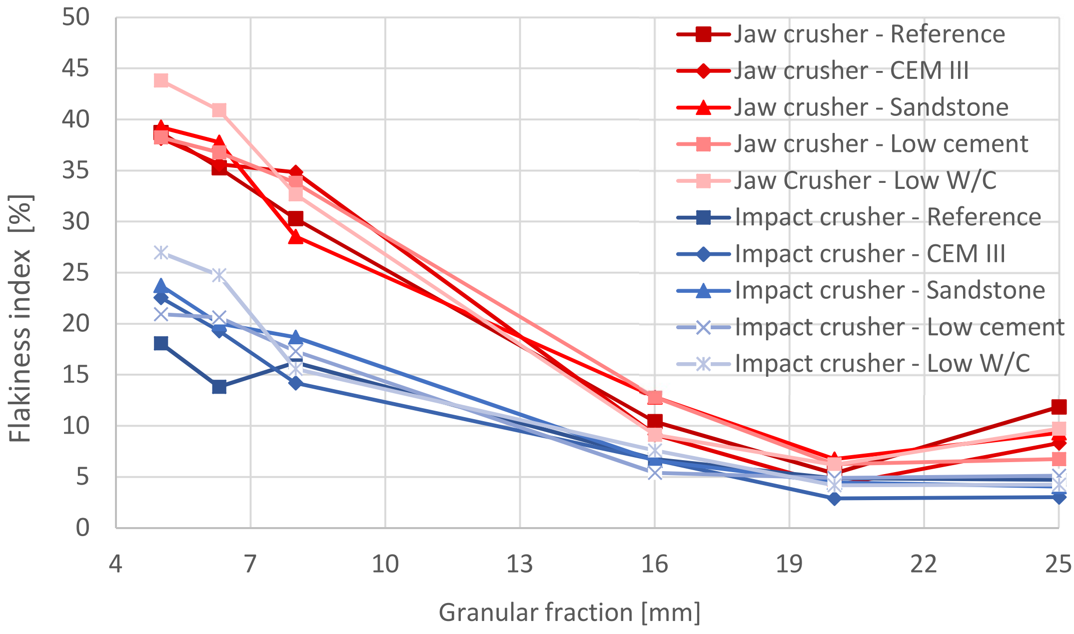

Fig. 7. Flakiness index of concrete aggregates crushed by jaw and impact crushers [17].

Recycling concrete block by-products in the new concrete blocks

The feasible use of recycled aggregates from C&DW in the production of concrete blocks has recently attracted more research interest [19-20]. However, most existing studies were based on laboratory test experience and used RCA from the C&DW recycling facility. They focused principally on the mechanical properties and specific durability of concrete blocks. Knowledge from industrial scale experiences remains limited. In the study of Zhao et al. [5], the feasibility of using RCA obtained from precast concrete block by-products in industrial scale production of precast concrete blocks has been investigated. Moreover, the environmental impact of industrial concrete blocks with RCA via a life cycle assessment has also been conducted.

The concrete block by-products (concrete block wastes: C8/10) from a Belgian precast company were crushed using an industrial scale impact crusher and the different fractions of produced RCA were characterized. Three concrete building blocks with different substitution rates of natural aggregates (NA, 0%, 30% and 100%) by the same volume fraction of RCA were manufactured in the precast factory. Only the fraction 2/6.3 mm was used for the manufacture of precast concrete building blocks in real industrial conditions (dimension 39 cm × 14 cm × 19 cm with two holes). CEM III/A 42.5 cement and a water/cement ratio of 0.5 were used for block production. The air-dried recycled aggregates were used for the concrete blocks production. The absorbed water of natural and recycled aggregates was adjusted according to the water content of the aggregates and their water absorption in the mixer.

The results showed that the hardened density and compressive strength of concrete building blocks slightly decreased with an increase in the RCA content (Fig. 8). The compressive strength of concrete blocks produced with 100% RCA at 28 days decreased up to 16.5% compared to the reference block and up to 6.0% for the concrete block with 30% RCA. However, the compressive strength of concrete blocks made with 100% RCA could even reach 11.1 MPa after 28 days, which is within the Belgian code requirements for this type of block.

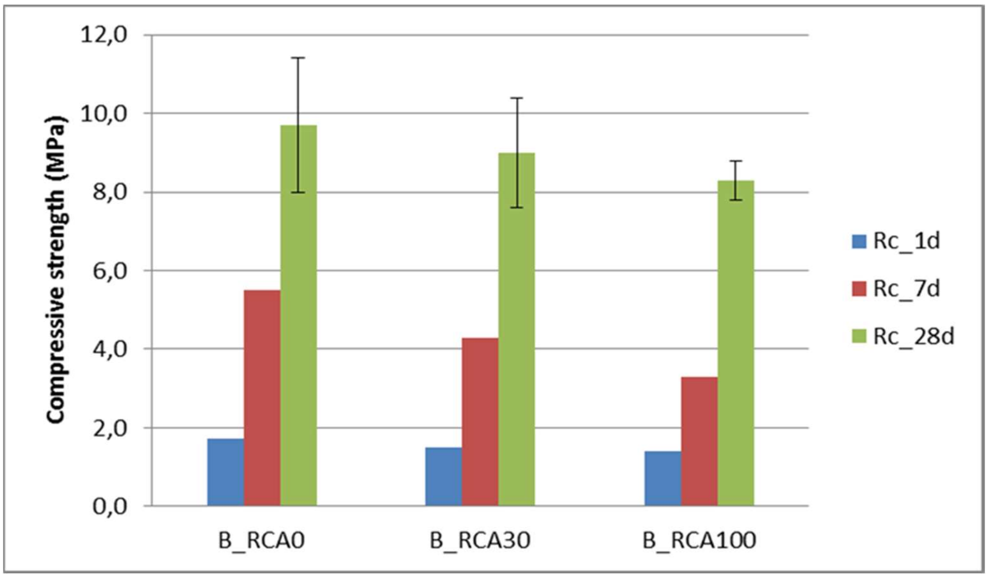

Fig. 8. Compressive strengths of concretes with RCA [5].

The incorporation of RCA slightly impaired the durability of concrete blocks in terms of drying shrinkage and freeze-thaw resistance. The drying shrinkage of the blocks increased with an increase of RCA but remained under the limit ($\leqslant$ 0.06%) regardless of the type of block. Freeze-thaw resistance results clearly confirmed that all concrete blocks satisfy the requirements. A cradle-to-gate life cycle assessment of the production of concrete blocks including RCA did not show significant gain in most of the impact categories because the element with the most impact in the blocks is cement. The substitution of NA by RCA showed a very limited gain in most categories, except in the land use category, especially with a level of 100% of substitution (up to 53.1% of gain). Globally, from a circular economy perspective, substituting NA with RCA recycled from concrete blocks, combined with externally importing RCA, is an interesting development route to decrease the environmental impact of producing concrete building blocks.

Concrete products made with recycled sands

The coarse fraction of RCA (CRCA), essentially composed of natural gravel, possesses satisfying properties for the reuse as concrete aggregates. Lots of research works have been dedicated to the study of properties of concrete containing CRCA. However, the fine fraction of RCA (FRCA), essentially composed of mortar and hardened cement paste, possesses a large water demand which makes it harder to recycle into concrete compared to coarser RCA [21-22]. In this study of Zhao et al. [23], the influence of the fine recycled concrete aggregates (FRCA, or also called recycled sands) on the mechanical and durability properties of concrete has been investigated. The concretes with different substitutions (0%, 30% and 100%) of natural sand by the FRCA were produced and fresh properties, mechanical properties, and durability properties of these concretes were tested.

The results showed that the compressive strength of concrete decreased as the substitution of FRCA increased. The compressive strength of concrete made with 100% FRCA deceased in the range of 48.2% comparing with the reference concrete, while the concrete made with 30% FRCA decreased up to 15.9% comparing with the reference concrete. However, the compressive strength of concrete made with 100% FRCA could reach 35MPa after 28 days. Durability of concrete could be strongly influenced by the high porosity and water absorption of recycled concrete aggregates. The durability properties of concrete made with 30% FRCA were comparable to the reference concrete, especially for capillary absorption and carbonation. Therefore, the use of FRCA in concrete structures can be envisaged depending on their class of exposure and the concrete grade requirement (for example the concrete C25/30 with no risk of corrosion or attack). Substitution rate of natural sand up to 30% is acceptable, while for the substitution rate higher than 30%, mechanical properties of concrete should be checked while the effects on durability should be also monitored for specific applications.

Using waste brick powder as supplementary cementitious materials (SCMs)

The fired clay brick waste generally presents some pozzolanic activity, which could react with calcium hydroxide and form compounds with enhanced strength and durability. Therefore, the waste brick powder (WBP) might be used in cement based materials to decrease the amounts of waste which have to be disposed in landfill and the CO_2 emissions [24]. Recently, the use of WBP as a partial substitution of Portland cement in the concrete has been received much attention during the past decades. In the study of Zhao et al. [25], the possibility of substituting the limestone filler by WBP in self-compacting mortar has been analysed. The properties of mortars including rheological properties, mechanical properties (compressive and flexural strengths), drying shrinkage, and durability properties (carbonation resistance, chloride ion diffusion and sulphate resistance) have been investigated.

The results showed that when the substitution rate of limestone filler by WBP increased, the compressive strength of mortars slightly decreased after 7 days. After 28 days, the compressive strength of mortars with WBP was equivalent to reference mortar with limestone filler; the decreasing trend seems to be compensated by the pozzolanic activity of WBP and this effect should be enhanced after 90 days. According to the results obtained in this research, self-compacting mortars in which 50% and 100% of WBP as substituting limestone filler, showed good service properties in comparison with reference mortars.

The incorporation of WBP induced a reduction of the drying shrinkage. The substitution of limestone filler by WBP however increased the carbonation depth of mortars. Therefore, the substitution of limestone filler by WBP didn't seem to impair the behavior of mortars in case of sulphate and chloride ions. The use of WBP as an alternative to limestone fillers seems to be a good opportunity for recycling waste brick and reducing natural resource depletion. Fresh and hardened properties of mortars globally fulfil the requirements for self-compacting mortars. Particular attention should be paid to the use of these materials in the case of the presence of reinforcements and the risks associated with carbonation.

A specific study was performed with 3 types of brick fines [26]: B1 (D_{50} = 3.2 μm), B2 (D_{50} = 20.7 μm), B3 (D_{50} = 180 μm). A greater change in the porosity of microstructure is noted with coarser B3 fines, versus finer B1 and B2 fines. The pore size distributions for the samples are shown in Fig. 9. At 90 days, a refinement of the distribution of pores was observed.

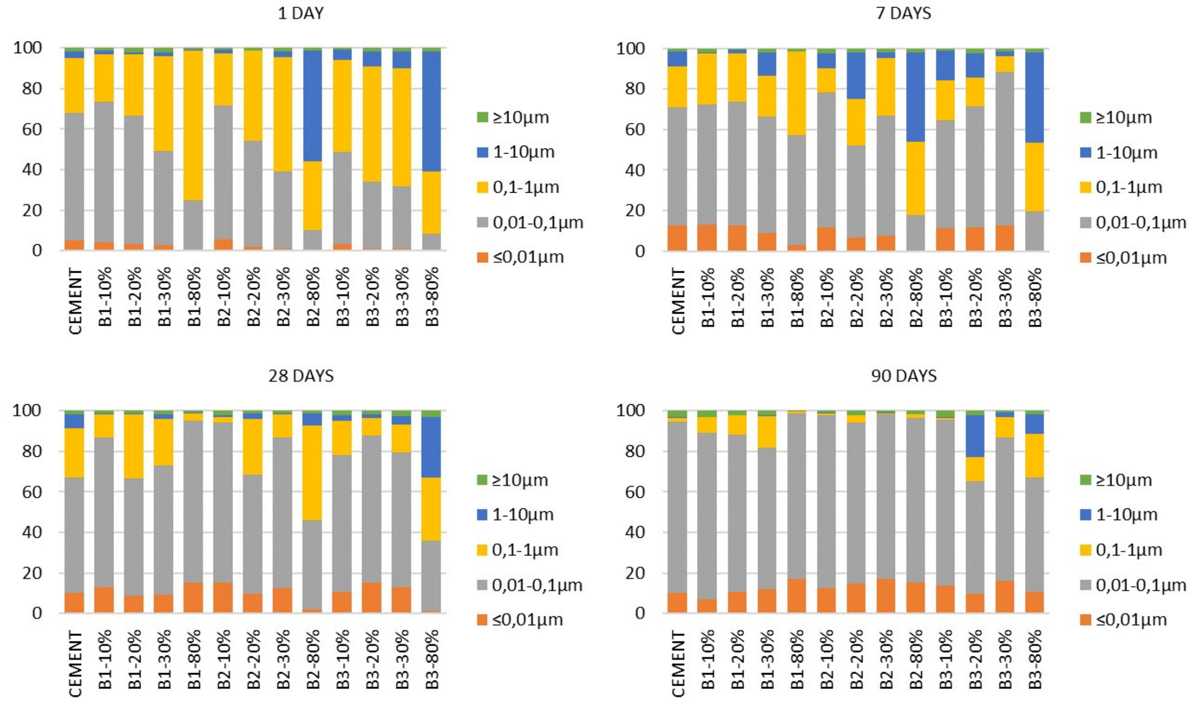

Fig. 9. MIP analyses for B1, B2 and B3 mixes at 1, 7, 28 and 90 days [26].

A finer microstructure was noted with lower fines substitution rates. Mixtures with B3 were characterized by a more spread pore size distribution. After 90 days, B2 fines presented the best microstructure with more than 90% of the porosity consisting of pores with a diameter of less than 1 µm for all mixtures. While B1 fines, despite their great fineness, preserved some coarser pores in microstructure probably due to agglomeration of the brick fines.

New concepts for using recycled materials

Another approach to increase the reuse of C&DW is to broaden their market potential. In the framework of the SeRaMCo project, several pre-cast products have been designed to be produced with RCA. Some of those products are quite common but, if proven efficient, cover large market shares. These includes hollow core floor slabs or concrete insulated wall for example.

Others have been specifically designed to take advantage of the specific properties of RCA. One of the most interesting examples is water permeable concrete pavement. These combine a specific design with the RCA higher porosity, water absorption and water permeability to drain and retain water delaying runoff peak and decreasing the risk of flooding. The design includes slots in between pavements to increase the drainage.

A second interesting example (Fig. 10) is sound absorbing retaining wall which are also taking advantage of the higher porosity of RCA. Using RCA in the structural part of the wall as well as in the sound absorbing layer of concrete significantly improves its efficiency.

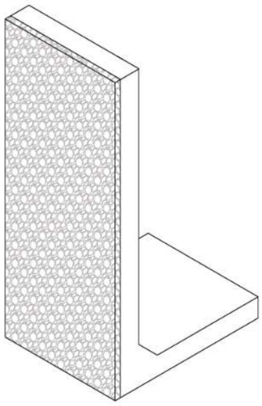

Fig. 10. SeRaMCo sound absorbing retaining wall made with RCA.

Another possibility is to use RCA in lower grade applications such as rammed concrete. Rammed concrete is the contemporary update of the traditional rammed earth construction method (Fig. 11). Rammed concrete presents many advantages such as low water and cement requirement making it an ecological alternative to classical masonry. It is also a quite easy method to implement and as such it is a good fit for self-building. Moreover, it can be of architectural interest for projects looking for a more artisanal and rustic look.

Fig. 11 Rammed concrete wall [27]

Rammed concrete constitutes a viable way of recycling RCA with smaller grain size. As highlighted during the study on the influence of the crushing method, adherent cement paste content increases with decreasing grain size distribution making smaller RCA less desirable candidates for precast concrete/higher grade applications. RCA rammed concrete samples have been produced to test the feasibility of this method. Results have been very promising with cubes demoulded after 24h presenting a clean and sharp appearance (Fig. 12). They have, then, been conserved for 28 days in a humid atmosphere before being tested. Mean compressive strength of 5.26 MPa has been measured for a 80 % - 10 % -10% in mass mix of aggregates - water - cement. Those values are in accordance, and even a bit better, with the traditional rammed earth method.

Fig. 12. Rammed concrete cube made with RCA.

Conclusions

There is no choice: changing "*the way we are making things*" [12] is the solution as well as an opportunity. Technical progresses in sorting and preparing recycled materials (specifically recycled aggregates and sands) allows higher rates of substitution of natural aggregates and sands by recycled concrete and/or silicates. Countries with low availability of natural resources clearly confirm this is possible. But the main remaining challenge resides in the capacity to change the perspectives of leaders in the construction industry and decision makers in the public authorities who oversee regulation and normalization. Standards or technical requirements are of course a security for the users but are also a barrier for new experiences and innovation in the construction industry sector. A technological transfer is today needed from laboratories and research centres to companies and administrations to preserve resources and to expand circular economy in civil engineering and housing development.

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