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Reuse of Construction and Demolished Concrete Waste in Producing Strong and Affordable Concrete Blocks

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Abstract : Concrete structures have become the most universal and reliable structures, especially from the beginning of 20th centery until today. This is due not only to concrete performance under different conditions, but also to the availability of concrete components throughout the World. With current modernization and expansion of cities there are many concrete buildings being demolished and replaced by the new ones. With that demolition process, there are two problems related to the generated concrete wastes; on one hand environmental degradation caused by the activity of materials extraction and later by damped demolished wastes, and on the other hand, the irrational utilization of raw materials. The objective of this study was to assess the strength characteristics of concrete blocks made from construction & demolished (C&D) concrete wastes after recycling and reusing them in fresh concrete in search of solution to the above dual problem. The work consisted on the collection of samples of concrete wastes, which were crushed, batched and mixed with a proportion of 1:2:2 and 1:4:4. Then respective agregates were used in preparation of new concrete blocks. The results from the test with prepared blocks at 28 days showed that the maximum compressive strength was 5.13N/mm^2 for the mixing ratio 1:2:2, wich fulfills requirement of Rwanda Standards Board for hollow concrete blocks and which was 0.87 times the compressive strength of an ordinary concrete block tested under same conditions. The density and water absorption were also identified. The block was finaly found to be affordable as its cost was estimated at 15.6% less than the ordinary concrete block. It is therefore concluded that the C&D concrete wastes can be used in making strong and affordable blocks for constructions of up to one-or two-storey dwelling houses, and the checking of other mix ratios and support for recyclying Industry are recommended.

Keywords: *affordability, Compressive strength, Construction & Demolition concrete waste, Environmental protection, recycling industry*

1. Introduction

1.1. Background of the study

Sustainable environmental management has become a global topic of concern. According to Rwnda Bureau of Standards Newsletter (RSB, 2014), building materials account for about half of all materials used and about half the solid waste generated worldwide. These materials have an environmental impact at every step of the building process: extraction of raw materials, processing, manufacturing, transportation, construction, demolishion and disposal at the end of building's useful life.

The environmental protection and promotion has been among the cross cutting issues to be tackled by Rwanda until 2020 at minimum, and it was included in different Sustainable Development Goals(SDGs). The country has put a lot of efforts, enforcing measures and strategies, and allocated large budgets on environmental management programs. However, environmental degradation is still one of obstacles to green economy. One of causes for that issues is the increased growth of construction works countrywide which resulted in the consumption of a vast amount of natural aggregates used as components for bricks, blocks, asphalt and other construction materials. The rapid increase of construction works contributes not only to depletion of natural aggregates but also to difficulties in finding suitable landfills.

Concrete waste is generally found among construction waste, demolition waste, production waste and waste returned in ready-mix trucks and, therefore this amount will only grow with the development of concrete construction industry.

The reuse of concrete wastes could help not only in reduction of its landfilling problems but also in limitating the exploitation of natural concrete components. Also, authors expect that the cost related to this new building materials could be affordable.

In search of solution to the above dual problem, this research focused on assessment of strength characteristics of concrete blocks made from construction and demolished (C&D) concrete wastes after recycling and reusing them in fresh concrete, as well in establishing their affordability.

1.2. Overview of previous studies

A recent European survey showed that 25% of wastes come from the demolition of buildings and roads. 90% of it is recyclable, but only 30% is recycled. According to the U.S Environmental Protection Agency (EPA), 215 million tons of municipal solid waste is generated in the United States from C&D waste per year. This made up primarily of concrete, asphalt concrete, wood, gypsum, demolition material and asphalt shingles generated from road construction and high way maintenance, building renovation demolition of building and other structures (Khalaf and De Venny, 2004). Currently, the construction industry produces 19% of the total volume of industrial wastes (75 million tons/year), which signals a need for reuse to protect the environment. Recycling of concrete blocks, which make up 37% of construction waste, is an important issue to be promoted.

Many studies were conducted and published about the manufacturing and application of concrete blocks with the inclusion of waste materials following intensive research work in recent years (Garvin et al. , 2015; Sohoni and Sahu, 2014). Further, recycling and reusing of rubbles from demolished buildings was not also a new concept, since several countries have been using crushing's wastes to produce aggregate for a number of years. However, the produced aggregate has mainly been limited to such a low level for such construction elements as pipe bidding, site fill, sub base or as a capping layer.

Some of previous published studies on application of demolished materials are brieffed bellow. some of those studies are related to crushed clay bricks, others are related to concrete wastes.

The study about Utilization of crushed clay brick in concrete industry presented a comprehensive experimental program regarding the use of recycled aggregates produced from demolition of brick buildings, and concluded that the use of recycled aggregate and dust made of clay bricks is promising in many applications where the thermal resistance, cost and environmental aspects are imperative (Aliabdo et al., 2014). Kallak (2009) carried out to study the feasibility of using crushed bricks to substitute the coarse aggregate (gravel) in concrete, and test results indicated that using crushed bricks reduced the strength of concrete. Other related studies with crushed bricks may be considered. These are among others, a direct comparison of the basic properties with those of equivalent conventional concrete (Mansur et al., 1999), using crushed clay brick as coarse aggregate in concrete (Khalaf, 2006), use of crushed clay bricks as aggregate in concrete (Otoko, 2014), etc.

Malešev et al.(2010) conducted a study about Recycled Concrete as Aggregate for Structural Concrete Production and established that recycled aggregate concrete (RAC) had a satisfactory performance, which did not differ significantly from the performance of control concrete in this experimental research. The study about an innovative study on reuse of demolished concrete waste, where sand was replaced with crushed used concrete found quite the same concrete performance (Yadhu and Aiswarya Devi, 2015). Among others studies related to concrete wastes, one can note Utilization of Demolished Concrete Waste for New Construction (Asif and Majid, 2013), recycled construction and demolition concrete waste as aggregate for structural concrete (Ashraf et al. , 2013), etc.

1.3. Status with Construction and Demolished concrete wastes in Rwanda

Reuse and recycling of concrete demolished materials conserves landfill space, reduces the environmental impact of producing new materials, creates jobs, and can reduce overall building project expenses through avoided purchase/disposal costs. The diversion of construction, renovation and demolition waste from landfill sites is an issue that has been gaining attention within both the public and private sectors. Many of our landfill sites are reaching capacity. In addition, C&D waste is sometimes illegally dumped or burned causing land, air and water pollution. The increasing costs of disposal are ultimately reflected in project costs, as contractors must incorporate anticipated disposal costs in their bid costing. While serious pollution is generated from construction activities, a comprehensive construction waste management is urgently needed on every construction site. It is of great importance to structure ways for minimizing waste generation which is seen as the most favorable solution to waste problems of any kind. Typical materials recycled from building sites include metal, lumber, asphalt, pavement (from parking lots), and concrete, roofing materials, corrugated cardboard and wallboard. One example of available C&D wastes is presented in Fig.1.

Figure1: C&D concrete wastes (RBS,2014)

Among benefits of C&D recycling, there is a decrease in production of greenhouse gas emissions and other pollutants by reducing the need for extraction of raw materials and shipment of new materials from long distances; conservation of landfill space, reduction of the need for new landfills and their associated cost (RBS, 2014).

2. Materials and Methods

To achieve the intended objective, in addition to the literature review conducted with purpose for background information on the study field, this study followed the below presented methodology.

2.1. Interview with different experts in the field of civil engineering:

Different 100 experts, including but not limited to site engineers, contractors, consultants, technicians, participated in the interview. The questionnaire checked the below information

- ✓ Survey on availability of Construction and demolished concrete wastes
- ✓ Survey on the current and potential use of C&D concrete wastes,
- ✓ Advantages and proposed area of application of C&D concrete wastes.

2.2. The new concrete blocks production: For notation, this block will be called "*new block*".

The composition of the new block: The new block was produced from C&D concrete wastes taken from the former BPR (Banque Populaire du Rwanda) headquarter, demolished for upgrading purpose. From the building site, concrete wastes were composed by big blocks and the crushing into small elements and better mixing with molding were required. The recycling of the C&D concrete wastes was conducted at TRINITAS GROUP LTD, a company specialized in producing concrete blocks with natural sand and aggregates with a mixing design of 1:2:2. The components of the new blocks were natural sand, fine aggregates from the sample of recycled concrete wastes, potable water from local Water and Sanitation corporate (WASAC), and cement from local cement producer (CIMERWA).

The crushing and sieve processes: The crushing of C&D concrete wastes was done manually at production site by use of heavy hammers as shown below (Fig.2). After the crushing, the sieve was conducted in order to get a uniform sample that would maintain the uniformity of manufactured new concrete block.

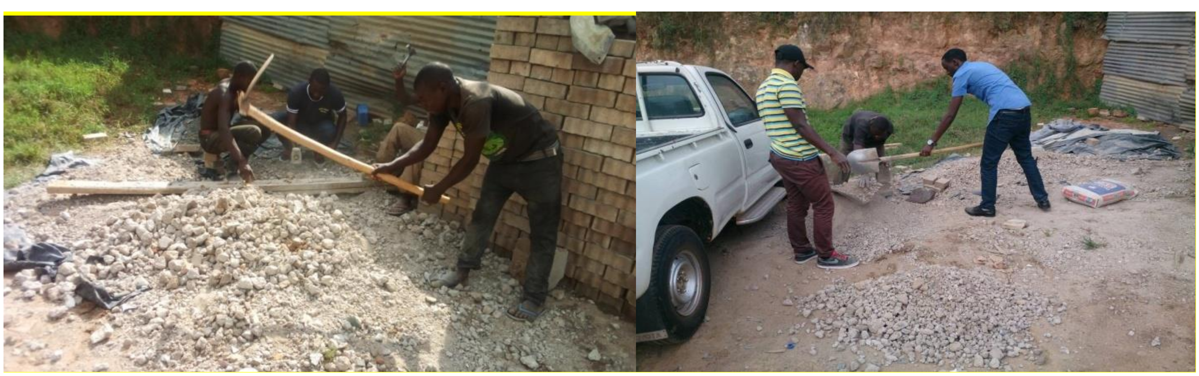


Figure 2: The crushing and sieving of C&D concrete wastes

***The used water-cement* ratio:** according to Rwandan building code, which is also in line with international practice, the water/cement ratio was taken as 0.35 (by weight).

The manufacturing of recycled concrete block: According to practice of professional concrete block producers in Rwanda, the whole mixture was subjected to the mechanical compaction machine in order to provide a later higher load bearing capacity and aesthetics to the new block. From the machine, the new blocks were covered with a plastic sheet for 24 hours to prevent rapid hardening. After 24 hours, the concrete blocks were cured in water (immersed) for 26 days. Then they were taken out of the water for surface drying for one day before the laboratory testing. The manufacturing process of the new block is presented in Fig.3.

Figure 3: Manufacturing of the new block

2.3. Materials testing

Below are different tests conducted with components of the new concrete block:

Sieve analysis of recycled C&D concrete wastes for particle size distribution.

***The density*:** Concrete block specimens were weighed by SOEHNLE-Wagebereich 0.5 bis 55 kg and the dimensions were measured by veneer caliper with 50 cm and 100 divisions. The density was calculated using equation (1) below, and for each sample type, the average of the 3 specimens was calculated:

$$D = \frac{Mass(g)}{Length\,x\,Width\,x\,Height\,(cm)} \tag{1}$$

Density test results are given in the figure 7.a

Water absorption ratio: For this test, first blocks were dried in the oven (105-1100°C) for 24 hours and then cooled at room temperature for about 4 hours and then weighed. After that, they were immersed in water for another 24 hours. Then, they were dried (surface drying, enhanced by towels - absorbent cloths) and weighed. The water absorption ratio was calculated by using the well known equation (2) below and the average results of the 3 specimens was considered

$$w = \frac{(wet\,mass - Dry\,mass)}{Dry\,mass} X\,100\% \tag{2}$$

Water absorption test results are shown in the Fig.7.b

Compressive strength**:** The concrete block specimen was placed and centered on the Platen of a compression testing machine. The compaction machine (MFL System-PRUF UND MESS) with a maximum of 3000 kN was used. Two soft sheets of plywood were placed under and above the specimen to reduce friction. The compressive strength result reported is an average over 9 specimens of three different mixing designs. The compressive strength was calculated using the formula (3) as shown below.

$$C = \frac{Crushing\,Load\,(N)}{Sectional\,\,Area\,\,(mm^2)} \tag{3}$$

There were three types of blocks specimen:

- ✓ Specimens (A) prepared using natural sand and gravel, with mixing ratio 1:2:2
- ✓ Specimen (B) from recycled concrete block, with a mixing ratio 1:2:2

✓ Specimen (C) from recycled concrete block, with a mixing ratio 1:4:4

Compression test results for all these three specimens are presented in the figure 8.c

2.4. Cost estimation of new and natural concrete blocks

This was done with purpose to check the new block affordability. It is clear that the main difference in cost would be experienced in the purchasing of cement, natural sand and coarse aggregates, and the cost of crushing and transporting C&D concrete wastes, for ordinary concrete block and recycled concrete block, respectively. The cost estimation for one block was calculated using the quantities estimation, where the unit cost of each component was considered.

3. Results and Discussion

The all study results are presented and discussed in the sub sections below.

3.1. Availability of C&D concrete wastes in Rwanda

From the local literature and survey in local construction industries, it was etablished that C&D concrete wastes were estimated at around 34% of total construction wastes. This was considered as a good quantity as it was exceeded only by bricks and blocks demolished wastes which were generated at around 49%. The graph in Fig.4 shows details.

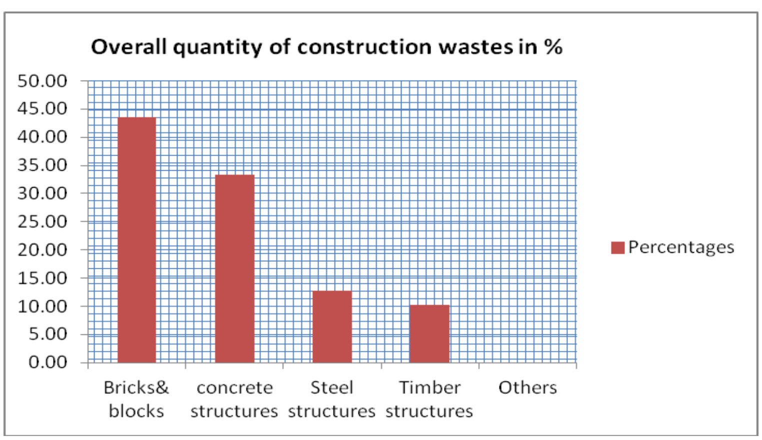


Figure 4: Quantity of Construction wastes

Even though bricks and blocks wastes represent a large quantity of demolished materials, they were not considered as dangerous as C&D wastes since they were being reused in walling construction. Therefore, only the issue of C&D concrete wastes was the most relevant.

3.2. Current use, advantages and proposed area of application of C&D concrete wastes

With regards to the current use and proposed area of application of C&D concrete wastes, the research established the findings presented in Fig.5.

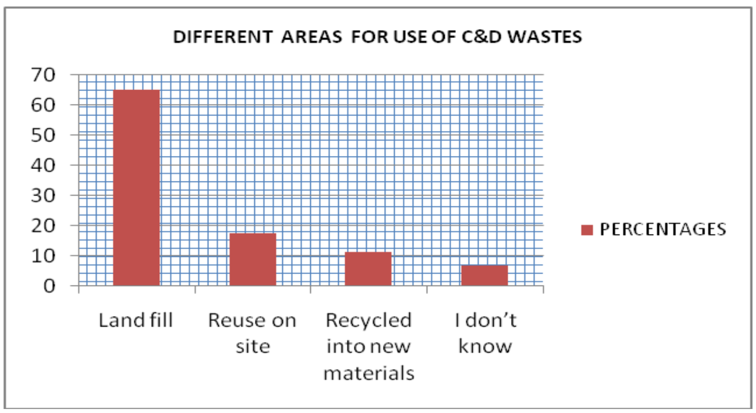


Figure 5: Use of C&D Concrete wastes

As the above graph shows, until today most of the generated concrete wastes at the rate of around 65% were taken to land fill and therefore that was contributing to environmental degradation. Regarding other potential uses, the research established that 32% of experts suggested that C&D wastes should used for preparation of new concrete blocks while 38% confirmed that these wastes should be used as wall filling materials.

Regarding the recycling advantages, the graph in Fig. 6 below presents a comparative analysis between potential advantages.

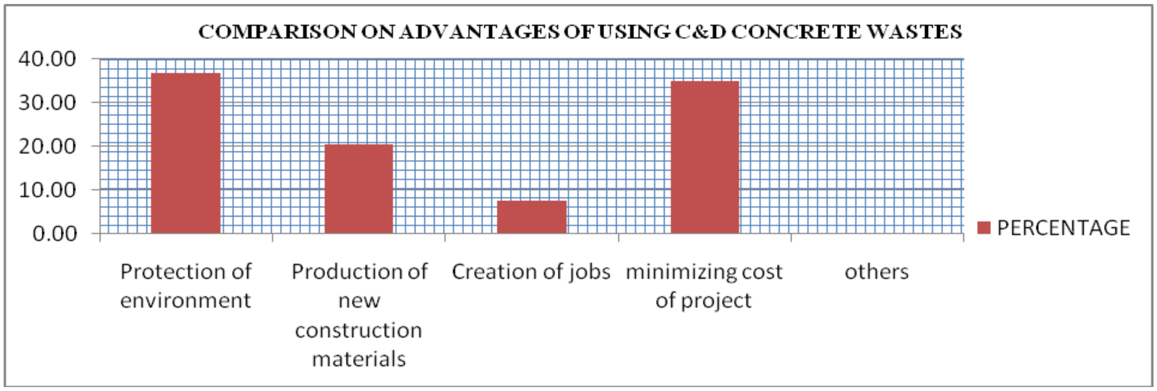


Figure 6. Advantages of using C&D concrete wastes

From the above graph with details about the feedback from participants in the survey places the recycling of C&D concrete wastes as very important for the following application: around 35% for environment protection, around 20% as a source of new building materials, and 32.5% for construction cost reduction.

3.3. Material Testing results

The sieve analysis results are presented under the graph in Fig.7 below.

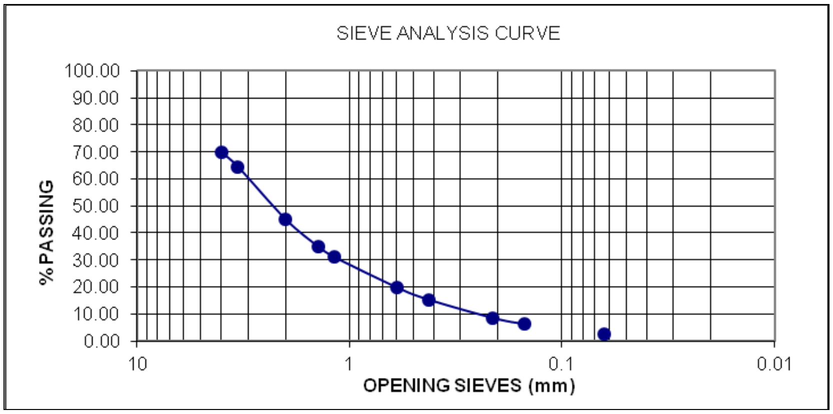
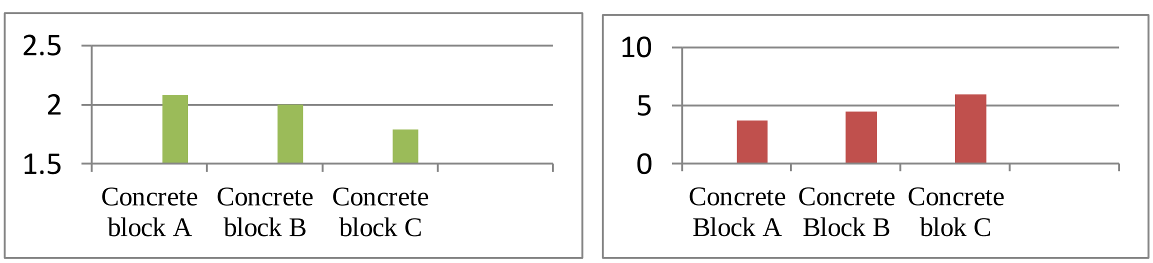


Figure 7: Particle size distribution of recycled concrete block

According to USCS (Unified Soil Classification System), the sieve analysis established that the used C&D concrete wastes were made of 55% of fine gravels and 45% of sand.

For test with the new block, after the 28 days of controlled conditions curing, all concrete block specimens were taken to the National laboratory for testing. The density, water absorption ratio and compressive strength were tested. The analysis was carried out according to the standard methods which are specified in Rwandan standards. The test results are shown in Figure 7. These results showed that the compressive strength of recycled concrete wastes block ranged from 4.07 to 5.25 N/mm^2 but blocks produced by natural sand aggregates had a compressive strength ranging between 5.67 and 6 N/mm^2. The mean compressive strength of new block under specimen (B) was found to be 5.13 N/mm^2, while the mean compressive strength for new block under specimen (C) was equal to 4.15 N/mm^2. For the concrete blocks made with natural sand and gravel under specimen (A), the mean compressive strength was found to be 5.87 N/mm^2.

Details about new block tests results are presented in Fig.8.



(a) (b)

Figure 8. Concrete Block Density in g/cm^3 (a) & Water absorption in % (b)

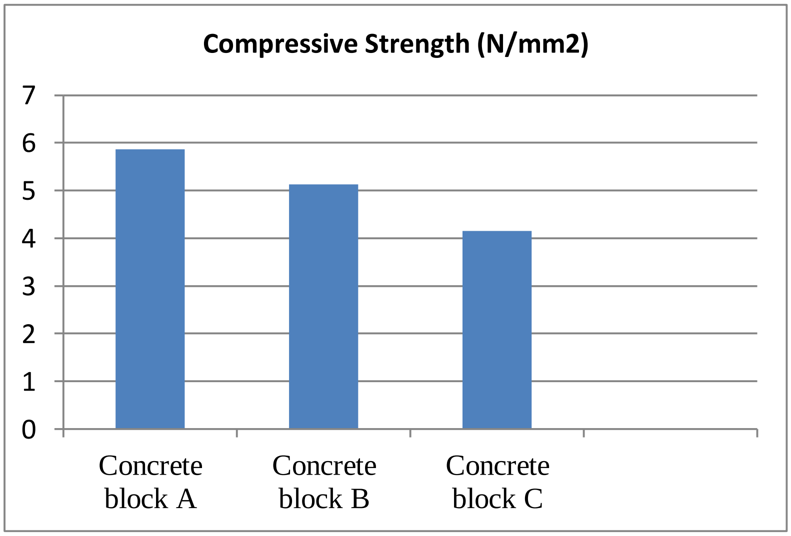


Figure 8.c: Concrete Block compressive strength

3.4. Results discussion

The sieve analysis results for which the maximum sizes of recycled C&D concrete wastes were 4.74 mm, shows that the obtained materials components were classified as fine aggregates, and were therefore suitable for cements blocks.

The results of the concrete blocks presented in Figure 8 above showed that the denser concrete blocks were, the stronger they were. Concrete block A with density 2.083g/m^3 have a compressive strength of 5.5N/mm^2 while for C that had a lower density of 1.788 g/cm^3 than others, has a lower compressive strength (4.15 N/mm^2). These results are generally in agreement with Fuller's theory stating that the higher the density, the higher the strength. Specifically to this study, it is established that the compressive strength of the new block is only slightly smaller than the one for normal concrete; this also is in agreement with previous studies' results (Malešev, 2010; Yadhu, 2015; Asif, 2013)

The new block under specimen (B) with mix ratio of 1:2:2 and a compressive strength of 5.13 N/mm^2 meet requirements for Rwanda Standards and, as a hollow block should be suitable for the wall of any building not exceeding three storey in height.

3.5. Cost effectiveness of recycled concrete block against ordinary concrete block

After it was established that the C&D concrete wastes are available and the respective new concrete block showed the accepted compressive strength, it became useful to establish its affordability comparing with the ordinary concrete block made with natural aggregates. It was established that one unit of recycled concrete block would costs around 339.2 Rwf (0.4USD), while the ordinary block costs 401.7 Rwf (0.5USD).

4. Conclusion and Recommendation

Through the manufacturing and laboratory testing of recycled concrete block, it was established that the compressive strength of recycled concrete block falls in the accepted range of Rwandan standards, and the block can be used easily in building construction.

The re-utilization of concrete wastes into building materials could help in solving the problems of C&D concrete waste disposal in Rwanda, and also to become an alternative source for the production of new building materials; and this would contribute to the conservation of natural resources as well as to the environment protection.

Finaly, based on the cost estimation, it was clearly established that recycled concrete block made of C&D concrete wastes was affordable since it can save 62.5 Rwf which is 15.56% of cost for one concrete block. It is believed that the cost of 339.2 Rwf can be decreased even more if a crushing machine is used during crushing of C&D concrete wastes, instead of the manual crushing method used in this study.

It is recommended that a detailed and regular study on availability and quantity of C&D concrete wastes through the whole country should be done so that an eventual recycling industry is developed and supported accordingly. Also, the checking of other mix ratios is encouraged.

As advantages of recycling C&D concrete wastes, in addition to the environment protection and building materials cost reduction, this would increase employment opportunities and improve the country and population economic well being.

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