American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Cradle-to-Cradle Production: Concrete Waste Recycling for Sustainable Construction in Tanzania

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Abstract

The construction industry world-wide has been seriously challenged to become more sustainable in terms of decreasing its damaging environmental impacts. However, in Tanzania, construction and demolition (C&D) rubble is still considered as waste, which is often dumped in one way or the other. The study objective is to investigate the applicability of the so called “Cradle-to-Cradle” (C2C) concept to achieve sustainable construction. The C2C concept rests on the philosophy that all waste can be useful as resource for another product in the same or in another industry, thereby offering an opportunity to overcome sustainability problems. In this study, C2C is defined as a cyclic system which considers C&D waste as a resource (*equals food*) for regenerating new building materials from waste rather than throwing it away or using it in low-grade applications in Tanzanian construction industry. The paper discusses the opportunities and obstacles to apply the concept in Construction by analyzing the case of concrete waste from construction and demolishment processes as input in the Tanzanian Concrete Blocks Industry (TCBI). The results are considered to serve well to support Sustainable Urbanization in other countries. The used methodology is based on the innovation theories combined with the production systems approach. The results indicate opportunities through implementation of the C2C concept. The results showed that cradle-to-cradle results to reduce waste, diminish the extraction of raw materials from origin sources, save manufacturers money, and increase benefit to the environment. Further research should be carried out on the C2C concept and the re-use of Construction waste in general. Nevertheless, widening the applicability of the C2C concept to cut back emissions, material, and energy use, to enhance the development of the Construction Industry to become more sustainable.

Keywords: Concrete waste; Cradle-to-Cradle; Sustainable Construction; Innovation; Tanzania.

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1. Introduction

The construction industry world-wide has been seriously challenged to become more sustainable in terms of decreasing its damaging environmental impacts. In Tanzania, construction and demolition (C&D) rubble is mostly considered as waste, which is often dumped in one way or the other [1]. The study objective is to investigate the applicability of the so called "Cradle-to-Cradle" (C2C) concept to achieve sustainable construction. The C2C concept rests on the philosophy that all waste can be useful as resource for another product in the same or in another industry, thereby offering an opportunity to overcome sustainability problems.

Sustainable construction practice generally takes into account the building's life cycle from extraction of natural resources to the end-of-life and demolition of the building which is referred to as "cradle to grave". In [2] was reported that sustainability in building construction involves the building reuse (i.e., reallocation), component reuse (i.e. relocation in a new building), material use in the manufacture of new component and material recycling into new products/materials. Human activities produce the waste that is dumped on the earths' surface which can lead to environmental degradation. The waste material produced during each stage of life cycle can be taken back (reused) into the system. This is emphasized by the C2Cconcept. Cradle-to-Cradle considers "waste equals food" [3].

Cradle-to-Cradle is a cyclical metabolism that enables materials to maintain their status as resources and accumulate intelligence over time [4]. Cradle-to-Cradle can be defined as the design and production of products of all types in such a way that at the end of their life, they can be truly recycled (upcycled), imitating nature's cycle with everything either recycled or returned to the earth, directly or indirectly through food, as a completely safe, nontoxic, and biodegradable nutrient [5]. According to [4], C2C deals directly with the question of maintaining or upgrading the quality and productivity of material resources. In [6] was reported that modern environmental management prescribes sustainable manufacturing practices that focus on prevention of waste and responsible care of the earth's natural resources. Resource recovery, recycling and reuse can be described as "cradle-to-cradle" resource management. Sometime, C2C can be defined as closing the supply chain loop in the product lifecycle. In this study, C2C is defined as a cyclic system in which considers C&D waste as a resource (equals food) for regenerating new building materials from waste rather than throwing it away or using it in low-grade applications in Tanzanian construction industry. This means for sustainable construction (SuCo), reusing and recycling of C&D waste instead of dumping allows waste to be consumed in construction industry as technical nutrients.

Technical nutrient is a material or product that is designed to go back into the technical cycle i.e., into industrial metabolism and/or built environment [2,3]. According to [2], reuse is more beneficial than recycling while recycling is more beneficial than disposal. So recycling becomes a strategy to control the problem of disposal of the waste which is already generated. In Tanzania, the disposal of C&D waste remains a challenge because the waste is treated as solid waste for landfilling instead of reuse and/or recycling [7,8]. Even though there is currently no landfill for solid waste disposal, open air dumping sites like Kinyamwezi-Pugu dump in Dar es Salaam are used. Due to the increase of population and demand for housing, especially in urban areas, land resource for waste disposal being limited. This situation will invariably put extra pressure on C&D waste management especially in the future. The use of C&D waste for building material production can be a good option not only for managing waste flows but also for providing an alternative source of building material. In addition, it minimizes resource utilization and hence achieves the pollution minimization and resource conservation. Recycling is important because most of the manufactured goods are not designed from the beginning for recycling as technical nutrients; instead industrial products are built-in obsolescence [3]. Steel recycling in the US for example, it was found that it contributes 74% in energy saving in the production process, 90% reduction in virgin materials use, 97% reduction in mining wastes, 88% reduction in air emissions and 76% water use reduction [3]. It was also found out that steel can be recycled and reused over and over again. Remanufacturing saves 85% of the energy needed to start from scratch [6]. This implies that recycling (remanufacturing) has significant advantages on resource conservation, energy reduction, and reduction of waste generation compared to extracting raw materials from nature (origin).

This study is limited to use the recycled aggregates which originated from construction and demolition activities that then were used as material resource for production of the concrete blocks for building construction in Tanzania. However, the research findings can be applied to any other country especially in the developing country and/or where the raw materials are scarce.

2. Methodology

Theoretically, this study makes reference to a new concept of sustainable construction, the C2C concept [3]. Cradle to cradle as a concept considers waste like cementitious waste from C&D activities as a resource (equals food) for regenerating new building materials rather than throwing it away or using it in low-grade applications. The C2C in this paper can be achieved through recycling C&D waste which has been a challenge to its disposal. Recycling contributes to sustainability in the construction industry through using C&D waste as material resource for production of building materials thereby, avoiding excessive raw material exploitation [9,10,11,12]. In this paper, recycling was defined as a process that altering original shape of C&D waste by physical, mechanical and/or chemical processes in order to produce new building material product with a quality that meet required standards and specification in the construction industry. While, the term reuse means to apply recovered C&D waste without altering its shape. In this paper, reuse is related to using a block specimen whose design of demountable building material facilitates separation at the end of the service life of the building.

The recycling process applied to this study is the same as that which is presented in [13]. In [13] was reported that ‘recycling process started from C&D waste acquisition (collected from generation sites), then the waste was transported to the recycling site, and rubble was crushed to get recycled aggregates, screened/sieved to get the required particle sizes. The recycled aggregates were then used for concrete block production whereby aggregates, cement, water and additives (if any) were mixed together, compacted, moulded and finally the concrete blocks were produced were cured in water for 28 days. After the curing process, the concrete blocks were taken to the laboratory for testing. Only the qualified, concrete blocks based on the load bearing requirements for recycled concrete blocks (i.e., structural and durability) were then ready for use. The disqualified (failed) block were taken back in the system and therefore, considered as waste resource for reproducing new recycled products. However, to ensure less waste generation during concrete blocks production, all parts in the production series were precise, as much as they can, in order to meet the quality which satisfies the load bearing requirements'.

In addition, most of the concrete blocks produced in Tanzania do not facilitate separation and reuse at the end of the service life of the building. For this reason, a solid demountable concrete block that is a dry-stacked (mortarless) interlocking blocks which can facilitate separation and reuse at the end of the service life of the building have to be used. Demounting the concrete block from the old buildings for reuse purpose, the author assumed the practice will not only reduce utilization of new materials (mostly extracted from natural sources), but will also reduce cost (economic), environmental pollutions associated with demolition, and eventually will improve human health. Therefore, using demountable concrete blocks in building construction contributes to sustainable construction and also it is in line with C2C concept [3].

3. Results and Discussions

This section presents the results and discussions on the importance of recycling of C&D waste and it shows how construction industry in Tanzania can become sustainable by considering waste as food.

3.1. Recycling produces the blocks for sustainable building construction

Recycled aggregates recovered from rubble collected from construction and demolition of buildings in Dar-es-Salaam. The collected aggregates were crushed manually and then sieved. Aggregates with particle sizes of 12 mm and 5 mm were used as coarse and fine aggregates, respectively to produce the concrete blocks with acceptable load bearing capacity. Different mix proportions ranged from 1:8.37 to 1:6.02 of portion of cement to aggregates were used. Out of these mix ratios, the mix proportion which incorporated 100% recycled aggregates which recovered from C&D waste was used. Since the target was to produce the concrete blocks with compressive strength of 7 N/mm^2 and water absorption ratio of 12% for load bearing block, the 100% recycled C&D waste itself did not meet this target as shown in Table 1. Therefore, additives were used. In Table 1, two additives, such as MegaFlow P4 and Sisal fibre were used. The results in Table 1 shows that the additives improved the porosity by reducing the water absorption ratio from 15.8% of 100% C&D waste to 11% and 10.4% of 100% C&D mixed with sisal fibers and MegaFlow P4 equivalent to 0.25% amount of cement, respectively. The low density and high water absorption ratios suggest that the recycled aggregates need effective compaction mechanism that will ensure denser recycled concrete block products with fewer voids. The compressive strength tests results were higher than 7 N/mm^2 however the application of additives lowered compressive strength which was different from expectation of lowering the water absorption ratio and increase the compressive strength. This assumption was in line with the density of the block which increased from 2030 kg/m^3 to 2100 kg/m^3. The lowering of compressive strength could be contributed by the fact that the additives were organics in nature and hence have impact to the compression. Regardless of what happened, the results reveal that it is possible to recycle the C&D waste into building materials which satisfy the local standards.

3.2. Recycling contributes to control the environmental degradation

Environmental degradation is largely caused by environmental pollution. Cradle-to-cradle is aimed to minimize environmental pollution like emissions to the environment. In this paper, it is assumed that by recycling C&D waste into new products instead of disposing of them to either an open dumping site or landfill, will minimize environmental pollution and therefore improve the environmental quality.

Table 1: Recycling of C&D waste into building blocks in Tanzania

Sample		100% C&D	C&D+0.25%SF	C&D+0.25%MF-P4
Cement (*C*). Kg		256	256	256
Fine aggregates (*fa*). Kg		991	991	991
Coarse aggregates (*ca*). kg		863	863	863
Aggregates (fa+ca). Kg		1854	1854	1854
Water (Designed)	*W*. kg	89.6	195	195
	W/C	0.35	0.76	0.76
Water (applied)	W_i. Kg	195	92.2	146
	W_i/C	0.76	0.36	0.57
Additive (kg)		-	0.64	0.64
fa/ca		1.1	1.1	1.1
Aggregate/cement ratio		7.24	7.24	7.24
Density (x1000 kg/m^3)		2.03	2.1	2.1
Compressive strength ($\sigma_{m)}$. N/mm^2). Nominal value is 7 N/mm^2		13.2	8.2	9.3
Water absorption ratio (WAb$_m$). %. The norminql value is 12%		15.8	11.0	10.4

Modified from [14]

Even though there are many environmental impacts that may result from the recycling process, emissions, mainly carbon dioxide gases (CO_2) that contribute to the effects of climate change, and leachate that pollute groundwater sources are the main focus in this paper. Eight different C&D waste samples sourced in Tanzania were analyzed to determine the amount of CO_2 which could be emitted due to decomposition of C&D waste. The amount of CO_2 emissions were estimated from chemical data which was obtained from an automated X-ray fluorescence analyzer (ARL 9400) as presented in [13]. The results indicated that an average weight of CO_2 emission is 15% of heap of C&D waste in Tanzania. These emissions will be emitted if C&D waste is disposed like any other solid waste in dumping site or thrown away haphazardly. The 15% CO_2 emissions result suggests that in Tanzania situation, 1.5 million tons of CO_2 are estimated to be released to the atmosphere annually from 10 million tons C&D waste generated [14]. These amounts of CO_2 emissions contribute to the greenhouse gas causing climate change impacts like flooding and long lasting drought and therefore contributing to environmental degradation. On the other hand, if the C&D waste is recycled back into new building materials like concrete blocks, these CO_2 emissions can be prevented because the waste is used as a resource. Therefore, the recycling of C&D waste into building materials in Tanzania will minimize the CO_2 emissions results from disposal of C&D waste.

In addition, CO_2 emissions that are caused by C&D waste transportation and disposal were estimated using the unit 'gram CO_2 emitted per tonne-kilometre ([15] presents 0.13 kg CO_2 /tkm as the figure for UK). The total CO_2 emissions were calculated by multiplying unit CO_2 emitted per tonne-kilometre with truck capacity (i.e., 7 tons) together with estimated distance of a fully loaded trip one way plus half that distance for the empty trip as shown in Equation 1. The results show that by disposing of C&D waste into disposal sites and use other material from natural resources, the emissions related to transportation issues can contribute up to 94% (weight) CO_2 compared to only 6% when C&D waste is recycled into new building materials. These results suggest that recycling of C&D waste in Tanzania has a significant reduction of CO_2 emissions not only from C&D waste decomposition but also from transportation and therefore, can contribute to make the construction industry more sustainable.

$$\chi_{emission} = U_{CO_2} \times TLoad \times D_t \qquad (1)$$

Where: $\chi_{emission}$ = Total CO_2 emissions from the heap of C&D waste (kgCO_2)

U_{CO2} = unit CO_2 emitted per ton-kilometre (kg of CO_2/tkm)

$TLoad$ = truck capacity (tons)

Dt = Total distance which includes a fully loaded trip one way plus half that distance for the empty trip (km)

Leachate from decomposed C&D waste may result in groundwater contamination. Normally, leachate production depends on water availability, characteristics of final cover, characteristics of tipped waste, and the method of impermeabilization (UNIPD) [16]. The generation of leachate was estimated using the Hydraulic Evaluation of Landfill Performance (HELP) model developed by the U.S. Army Corp of Engineers [17]. According to UNIPD, leachate volume can be roughly estimated as a percentage of rainfall and as a function of waste density in landfill. In this paper, the HELP model was adopted in estimating the amount of leachate which could be released from dumping sites in the event that 10 million tons of C&D waste will be so disposed of in Tanzania. Annual average rainfall in Tanzania is around 1000 mm/yr, with other factors assumed to remain constant; the leachate volume by extrapolating is therefore estimated to be 15 m3/(ha.d). This result suggests that in Tanzania with 10 million tons of C&D waste generated annually, it needs an area for dumping site of approximately 750 ha. Aided by the HELP model, it is estimated that the disposal of 10 million tons of C&D waste on the 750 ha will release about 4.1 mil. m^3 of leachate annually. Due to poor infrastructure in developing countries like Tanzania, the released leachate may end up contaminating soil, groundwater and surface water bodies. Since a large population in Tanzania depends on the same water sources, it implies that many people and other ecosystems will be endangered from consuming the contaminated water. Water contaminants are expected to be mineral nutrients especially trace elements. This condition is in line with laboratory analysis of the recycled C&D waste.

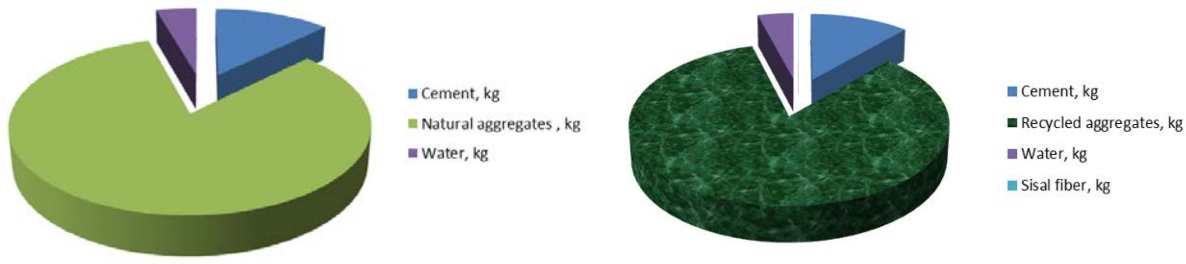
Generally, the C&D waste like other mineral aggregates is composed of, among other things, chemical elements both common and trace elements. Based on laboratory analysis in this study, the trace elements identified included Chromium (Cr), Nickel (Ni), strontium (Sr), Barium (Ba), and Zirconium (Zr). These trace elements are carcinogenic when they are consumed either in water, air or food. The contamination of trace elements are expected to occur when the C&D waste is either thrown away, randomly disposed of, or dumped on open dumping site, or even in the landfill if the leachate will not be well collected and treated before ultimate disposal. This contamination eventually will cause health problems like carcinogenic diseases and respiratory diseases. To control these health problems which may be caused by improper treatment of C&D waste in Tanzania, it was assumed that recycling the C&D waste into building materials will enhance the use of C&D waste which is composed of these trace elements and therefore, instead of being a source of health problems, it will become a valuable resource for building material production. In this study, it postulated that there will be no material erosion during the life time of the building which is built with recycled concrete blocks nor are trace elements causing in-door air pollution.

3.3. Recycling contributes to material conservation

Material conservation in this paper refers to the reduction in the use of minerals like aggregates from natural resources and in turn using recycled C&D waste instead. Since the aim is to recycle C&D waste (i.e., cementitious rubble) into building material that satisfy building material standards, it was therefore assumed that the amount of recycled aggregates that were used for production of the concrete blocks are equivalent to a resource saved for future use. Materials used to prepare a 1 m3 concrete are presented in Figure 1. The results in Figure 1 indicate that using recycled aggregates by 100% (i.e., 1854 kg) mixed together with 0.25% sisal fiber (SF) (as weight of cement), it is possible to replace natural aggregates by 100% in concrete blocks production. Further analysis showed that the amount of cement was reduced by 6% (i.e. from 272 kg for Natural aggregates to 256 kg for recycled aggregates with sisal fibres admixtures). These results suggest that it is possible to use the recycled aggregates to substitute the natural aggregates in production of concrete blocks with satisfactory load bearing capacity in Tanzania and also to reduce the needed amount of cement as well. This reduction of consumption of the natural resources and amount of cement in new building materials fulfils the aim of conserving the natural resources for future use which is in line with the sustainable construction concept.

3.4. Recycling contributes to sustainable utilization of land resource

The recycling of C&D waste into valuable building material helps to conserve and manage the land resource. According to [18], demolition work is estimated to produce 1.5 tons/m^2 of waste while construction work generation rate is 45 kg/m^2. It can be estimated that the C&D waste generation rate is about 0.75 ton per m^2 for both construction and demolition activities. For more than 10 million tons of C&D waste in Tanzania which may be disposed of to an open-air dumping site, it is estimated to occupy plot of land of approximately 7.5 million m^2 (750 ha). This land (750 ha) will be saved by opting for the recycling C&D waste into building material instead of disposing in to dumping site or landfill. The recycling therefore, will not only save the land resource, but also maintain indigenous flora and fauna ecosystems for present and future use.



a) NCA+NFA (Natural aggregates) recipe *b) C&D +0.25%SF recipe*

Figure 1: Reduction of using the generic material by using the recycled C&D waste in Tanzania (adopted from [14])

3.5. Recycling C&D waste contributes to improve economy

Recycled aggregates acquisition: Costs for recycled aggregates were estimated from C&D waste acquisition, transportation to recycling site, crushing and screening/sieving (separate between coarse and fine aggregates). The costs of production of the recycled aggregates from C&D waste in Tanzania were estimated to be US$0.026/kg in 2010[a]. On the other hand, natural coarse and fine (sand) aggregates acquisition was estimated to cost US$0.04/kg. This cost is twice as much compared to the cost for recycled aggregates in Tanzania.

Water and cement: Water for block production was costed at US$7.46x10-4/kg of water. In addition, cost incurred for purchasing cement was Tshs 16000 (US$11) per 50 kg bag of cement. This cost is equivalent to US$0.22/kg of cement.

Cost of additives: The cost of sisal fiber (SF) in Tanzania is approximately US$ 1.2/kg. This cost is much higher compared to Brazil where it was sold at US$ 0.53/kg-FOB [19]. The high cost may be triggered by the fact that most of the sisal fiber produced in Tanzania is exported. However, it is assumed that costs may be lowered if sisal production will increase and the domestic demand stabilizes. In addition The MegaFlow P4 plasticizer [20] was approximately sold at US$ 2.7/kg in Dar-es-Salaam. It is an imported chemical material from the United Arab Emirates (UAE). It is also a synthetic and industrial material.

Block production cost: Since labour based (manual) technology was used in production of concrete block in this study, three un-skilled and at least one skilled (technical) worker (labourers) were hired. The labour cost for concrete blocks production in every 1 m^3 concrete mixes is estimated to be US$ 11. Furthermore, 1 m^3 concrete mix can produce about 70 blocks of average weight 33 kg per block. This labour cost (US$ 11) is equivalent to US$ $4.76x10^{-3}$/kg of concrete block. Analysis based on recipes used, it was found to be technically feasible to produce the concrete blocks that comply with building material standards using recipe of C&D + 0.25% SF,

[a] *United States Dollar (US$) 1 was equivalent to Tanzania shillings (Tshs) 1500/=*

C&D + 0.25% MF-P4, and natural aggregates (NCA + NFA) used as control. It was found that the recipe with the lowest cost is C&D + 0.25% SF of which 100% C&D waste is used to mix with 0.25% of sisal fibres an additive. This recipe reached the production cost of US$ 123.27 per 1 m^3 of concrete. Other recipes had total costs of US$124.53, and 160.06 per 1 m^3 of concrete mix for C&D + 0.25% MF-P4, and natural aggregates (NCA + NFA) recipes, respectively. Furthermore, treatment and disposal charges in Tanzania for 1 kg of C&D waste are estimated to be US$ 0.01/kg. This cost is eliminated in recycling of C&D waste, but considered when using natural aggregates (i.e., 100% natural (NCA + NFA) aggregates. These results suggest that C&D + 0.25% SF recipe are a feasible and affordable recipe for the Tanzanian construction industry. On the other hand, the results showed that it is more expensive to use natural aggregates only. From these results, it can be demonstrated that there is a possibility to recycle C&D waste into building material without imposing economic burden to users compared to other recipes in Tanzania. In addition, recycling of C&D waste contributes to the reduction of unemployment in Tanzania which was estimated to be 10.7% in 2011 [21].

Energy saving: Energy is required for almost every process of C&D waste recycling, that is, from demolition, transportation of rubble and crushing to get the recycled aggregates. After having aggregates, before their application, they need to be tested in the laboratory in order to understand their quality and how best they can suit to the intended use. Laboratory analysis also consumes energy. Then aggregates undergo certain production processes in order to produce the concrete block products. These production processes also need energy. From aforementioned activities, it shows that energy is required for almost every step in the recycling process. However, amount of energy which is required for recycled and natural material production may differ. These differences may be caused by the fact that C&D waste is an artificial rock; it is composed of old aggregates and cement paste while natural materials (aggregates) are not. The artificial condition of C&D waste makes it to be weaker than natural ones and therefore, energy used for crushing C&D waste becomes lower than that used for natural ones. This phenomena is supported by aggregate results for example, aggregate crushing value (ACV) and ten percent fines value (TFV) which showed that the recycled aggregates were weaker than natural aggregates [1,14]. Since the production technology used in this paper was manual, it was difficult to measure energy that was used.

3.6. Demountable blocks for Cradle-to-Cradle

The traditional concrete blocks produced in Tanzania do not facilitate separation after the end of life of the building; instead, they are bonded using mortar. This means that they are constructed to last endlessly. But in practice, buildings have an intended [22]. So, when a building reaches the end of its life, the traditional concrete blocks encourage the demolition condition. The demolition normally turns all old building materials into waste. This condition makes it difficult to recover the blocks which can be technically, environmentally, economically, and socially useful. It also impedes the separation of materials. This condition imposes challenges to use the building block that facilitates the separation (demountability) at the end of the service life of the building. The demountability condition of the block enables the block product to be recovered with its original shape for reuse. This condition enhances the cycle of the building block in the construction industry. The recovery of the demountable block for reuse purpose in building construction is in line with sustainable building construction concept.

4. Conclusions

It is possible to recycle C&D waste into building materials in Tanzania and therefore, construction industry can achieve the sustainable construction concepts. Recycling C&D waste reduces CO_2 emissions and leachate to the ecological environment. It prevents health risks which are associated with dumping C&D waste which include leachate contamination to the water bodies like groundwater. It conserves land and aggregates (non-renewable) resources for future use through using the C&D waste which for a long time has been perceived as waste to be thrown away. It is also found that the recycling cost is far low compared to acquiring natural aggregates to produce the building block which satisfies the material standard in Tanzania. It enhances economy growth because it reduces costs for building materials i.e., aggregate. The recycled building materials found that they are cheaper, reliable and affordable to many people in Tanzania. To recycle C&D waste into the building material to be applied into construction industry in Tanzania and also to reuse the recovered concrete blocks at the end of service life of the building, it enables the closing cycle of the material flow in the construction industry and therefore it is line with the cradle-to-cradle. It is therefore concluded that by applying cradle-to-cradle theory, it is possible to reduce useless waste, instead waste becomes resource for reuse, save manufacturers money in valuable materials over time, diminish the extraction of raw materials from origin because nutrients for new products are constantly circulated and therefore resulting to enormous benefit to the environment. It is recommended that C&D waste to be used in Tanzania for production of the building materials such as concrete and sandcrete blocks in order to achieve the sustainable construction in Tanzania. However, further study is required to investigate the impact of the additive when using recycled aggregates in block production.

Acknowledgement

Many thanks go to the sponsor, NUFFIC-NFP for funding this study; training institution, the Technical University of Eindhoven (TU/e); and employer, Ardhi University. Many thanks go also to my promoter Prof. Dr. ir Jos Lichtenberg, Dr. ir. E.L.C. van Egmond, Dr R R.A.M. Mato, ir M.G.D.M. Cox and many others to mentor me during conducting this research work at Technical University of Eindhoven (TU/e), the Netherlands.

References

[1] M.M. Sabai, M.G.D.M. Cox, R.R. Mato., E.L.C. Egmond and J.J.N. Lichtenberg. “Concrete block production from construction and demolition waste in Tanzania” Resources, Conservation and Recycling, vol. 72,pp. 9-19, March 2013.

[2] P. Crowther. “Developing an inclusive model for design for deconstruction” in Proceedings of the CIB Task Group 39 – Deconstruction Meeting, CIB World Building Congress April, 2001.

[3] W. MacDonough, and M. Braungart. Cradle to Cradle: Remarking the Way we Make Things, China: Douglas & McIntyre Ltd, 2002.

[4], M. Braungart, W. McDonough and A. Bollinger. “Cradle-to-cradle design: creating healthy emissions – a

strategy for eco-effective product and system design" Journal of Cleaner Production, vol. 15, pp. 1337-1348, 2007.

[5] http://link.springer.com/referenceworkentry/10.1007/978-3-642-28036-8_165, [May 2015].

[6] Kumar, S., and Putnam, V., Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors, Int. J. Production Economy;115,305-315; 2008.

[7] United Republic of Tanzania (URT). Construction Industry Policy (Tanzania), Dar es Salaam: Ministry of Works, 2003.

[8] United Republic of Tanzania (URT), Environmental Management Act (EMA), Dar es Salaam: Vice President Office, 2014.

[9] C.A. Langston and G.K.C Ding. Sustainable practices in the built environment, 2nd Edition, Oxford: Butterworth Heinemann, 2001.

[10] S.E. Meer, A.R. Pereira Roders and P. A. Erkelens. "Minimizing C&D waste through rehabilitation, Adaptables 2006". in International Conference on Adaptable Building Structures, July 2006.

[11] V.W.Y. Tam, and C.M Tam. "A review on the viable technology for Construction waste recycling". Resources Conservation & Recycling, vol. 47, pp. 209-221, 2006.

[12] M. Banar, Z. Cokaygil and A. Ozkan. "Life cycle assessment of solid waste management options for Eskisehir, Turkey". Waste Management, vol. 29, pp. 54–62, 2009.

[13] S.M.M. Sabai, J.J.N. Lichtenberg, M.G.D.M. Cox, R. R. Mato and E.L.C. Egmond. "Sustainable approach for recycling construction and demolition waste into building materials in Tanzania". Journal of Building Development and Settlement, Special Issue, pp. 80-93, Nov. 2014.

[14] M.M. Sabai. "Construction and demolition waste recycling into innovative building materials for sustainable construction in Tanzania". PhD Thesis, Technical University of Eindhoven, The Netherlands, 2013.

[15] J. Leonardi, C. Rizet, M. Browne, J. Allen, P. J. Pérez-Martínez and and R. Worth. "Improving energy efficiency in road freight transport sector: the application of a vehicle approach". http://www.greenlogistics.org/SiteResources/7d476c2c-2574-4890-ae4a-997484b9a443_LRN%20vehicle%20approach.pdf [Nov. 2012].

[16] University of Padua, Image Department (UNIPD).

http://www.image.unipd.it/tetrawama/index_file/page0027.htm, [Sept. 2012].

[17] P. R. Schroeder, N. M. Aziz, C. M. Lloyd and P. A. Zappi. "The Hydrologic Evaluation of Landfill

Performance (HELP) Model: User's Guide for Version 3 (EPA/600/R-94/168a)". Washington DC: U.S. Environmental Protection Agency Office of Research and Development, Sept. 1994.

[18] N. Kartam, N. Al-Mutairi, I. Al-Ghusain and J. Al-Humoud. "Environmental management of construction and demolition waste in Kuwait". Waste Management, vol. 24, pp. 1049-1059, 2004.

[19] H. Savastano and V. Agopyan. "Transition zone studies of vegetable fiber-cement paste composites". Cement and Concrete Composite, vol. 21, pp. 49-57, 1999.

[20] Conmix Ltd, MegaFlow P4 Technical Datasheet, CC/MF02/Ver2/08/07, Construction Chemicals [Oct. 2011].

[21] National Bureau of Statistics (NBS). "Unemployment estimates for the year 2011" http://www.nbs.go.tz/index.php?option=com_content&view=article&id=186:unemployment-estimates-for-the-year-2011&catid=100:labour-force-and-ees&Itemid=135, [July 2013].

[22] J.M. Post and M.H.P.M. Willems. "The XX-project: saving 45% on resource depletion". In Perspectives on Innovation in Architecture, Engineering and Construction, C.J. Anumba, C Egbu & A. Thorpe (Eds.), (pp. 681-689). U.K: Loughborough University, 2001.