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Sustainable Approach for Recycling Construction and Demolition Waste into Building Material in Tanzania

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ABSTRACT

Because it is desired to achieve sustainability in the construction industry, the recycled products should not only be measured by production costs, but by using economic, social and environmental criteria. Knowledge on how to precisely determine the sustainability of recycled building materials is still limited because most of the available sustainability assessment tools are developed to evaluate whole building components. This paper aims at investigating the possibility of recycling the construction and demolition (C&D) waste (mainly cementitious rubble) into building material such as concrete blocks that meet the requirements for structural walls in Tanzania in a sustainable manner. A sustainability tool was applied to determine which of the recycling recipes used to produce the qualified concrete blocks was sustainable. The findings showed the recipe which used sisal fibers (i.e., 0.25% amount of cement) in 100% recycled aggregates from C&D waste for concrete block production was found to be a more sustainable recipe than the others. This condition suggests that using 100% C&D waste into building materials contributes in conservation of resource of relatively the same amount of natural aggregates for future use which is in line with the sustainable construction concept. Therefore, it is possible to recycle 100% C&D waste into building materials in Tanzania using sisal fibers which are the locally produced materials.

Keywords: Sustainable construction, recycling, C&D waste, building material, Tanzania

INTRODUCTION

The construction industry has acknowledged its environmental responsibility and the inevitability of a dematerialization. Construction industry and the environment are fundamentally linked. Ding (2005) reported that construction industry is responsible for high levels of pollution resulting from extraction, and processing and transportation of raw materials, thus has a responsibility for environmental protection.

Generally, sustainable construction practice takes into account the building's life cycle from extraction of natural resources to the end-of-life and demolition of the building. It refers to the "cradle to grave" concept (Crowther, 2001). The waste material produced during each stage of life cycle can be taken back into the system. This is emphasized by the cradle-to-cradle concept. *Cradle-to-Cradle* (MacDonough and Braungart, 2002) considers "*waste equals food"*. This means for sustainable construction, 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

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industrial metabolism and/or built environment (MacDonough and Braungart, 2002; Crowther, 2001). Sustainable construction advocates the creation and operation of a healthy built environment based on resource efficiency and ecological principles (Kibert, 2003). Building on the definition of sustainability, it can be stated that sustainable construction processes involve activities which do not undermine the capability of future generations to meet their needs. In addition, sustainability helps to decrease harmful environmental impacts and contribute to a balanced long-term resource use and is reflected in economic, social and environmental aspects (ISO 15392:2008(E)). Sustainability is a measure of how well the people are living in harmony with the environment taking into consideration the well-being of the people with respect to the needs of future generations and the environmental conservation (Young, 1997). Since this study is focused on the building construction, it suggests that sustainability advocates to the present living conditions to meet their demands without putting a threat to the future generations. This condition appeals to sustainable construction to utilize available resources holistically without imposing threats to future generation.

Since material resource base depletes as the population increase, the future material resource availability depends on the current sustainable utilization of resources in the construction industry. To deal with wastes resulting from construction and demolition activities, recovery methods such as reuse and recycle (Kibert, 2003) have been adopted in this study in order to generate new building material products for sustainable construction. One aspect which is considered to be applied as sustainable utilization of resources in construction industry is the recycling of construction and demolition (C&D) waste into building materials. Recycling is a process of reproducing waste materials and treating them as feedstock on manufacturing of new products of the same quality either in a same form or different form (Langston and Ding, 2001). Recycling contributes to the conservation of non-renewable resources by manufacture of new products from waste and avoid excessive raw material exploitation (Langston *et al.*, 2001; Meer *et al*., 2006; Tam *et al*., 2006; Banar *et al*., 2009).

Advantages of recycling are illustrated in a macro-economic model of integrated resource management and total cost of both traditional and selective demolition (see Laurizen, 1998). Laurizen, (1998) reported that by using recycled materials, economic savings in transportation of building waste and primary raw materials can be achieved. In addition to the economic saving, recycling has environmental and social benefits to be taken into account in order to achieve sustainability in construction industry.

However, for the purpose of achieving an improved sustainability in the construction industry, the international standards ISO 15392:2008 advocates that recycled products should not only be measured by production costs, but by using economic, social and environmental criteria. Knowledge on how to precisely determine the sustainability of recycled building materials is still limited because most of the available sustainability assessment tools are developed to evaluate whole building components (Seo *et al*., 2006; Dessel and Putzeys, 2007) or at project-level (Langston and Ding, 2001; Ding, 2005). This study aimed to deal with building material (i.e. concrete blocks) and not the entire building, an assessment tool was applied to determine the sustainability of the building material production from construction and demolition waste in Tanzania. The particular emphasis on Tanzania is because sustainability is a broad term which may be defined and focused according to country's priorities, technical advancements and economical capabilities. The sustainability tool was used to assess the sustainability of four concrete block production recipes.

Research Methods

Recycling process

The recycling process started from C&D waste acquisition (collected from generation sites), then the waste was transported to the recycling site, 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 where aggregates, cement, water and additives (if any) were mixed together, compacted, molded and finally the concrete blocks were produced that 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) are then ready for use. The disqualified (failed) are 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. Materials used to prepare a 1 m^3 concrete are presented in Table 1.

Table 1 Materials used to prepare a 1 m^3 concrete

Sample	**30% C&D replacement**	**C&D + 0.25% SF**	**C&D + 0.25% MF-P4**	**NCA + NFA (Natural)**
	Quantity, *kg*	Quantity, *kg*	Quantity, *kg*	Quantity, *kg*
Cement	256	256	256	272
Recycled aggregates	556.23	1854.10	1854.10	
Natural aggregates	1249.01			1784.30
Water	97.28	92.16	145.92	95.20
Sisal fiber		0.64		
MegaFlow P4			0.64	
Total (for 1 m^3 concrete)	2158.52	2202.90	2256.70	2151.50

Synthesis on sustainability assessment tool

To determine the sustainability of the recycling techniques/recipes, an adapted sustainability index (SI) tool that incorporated principles of different sustainability tools such as sustainability index (Ding, 2005; Langston and Ding, 2001), life cycle assessment tool (ISO 14040:2006; Goedkoop *et al*., 2010) and label for environmental, social and economic (LEnSE) buildings (Dessel and Putzeys, 2007) was used. The sustainability tool has six variables. The six variables/criteria were determined for measuring sustainability of the recycled concrete blocks that were produced from recycled aggregates (i.e., C&D waste) in Tanzania. An experts' meeting was then conducted that composed by local (Tanzanian) experts from research and development (R&D) institutes, regulators, clients, concrete block producers, contractors, and consultants to assign the weighting factor (importance) for the sustainable recipe in recycling C&D waste into building materials in Dar es salaam, Tanzania. The number of participants was limited to 18 due to financial and time constraints. Nevertheless, participants from all clusters (stakeholders) were represented as shown in Table 5. The results from experts workshop were thus deemed as fit for experimental purposes not intended to provide hard facts of the Tanzania situation.

Sustainability assessment tool applied for the recycling recipes in Tanzania

The production of building materials from construction and demolition waste is a new technology to the construction industry in Tanzania. Even a recycled product is a new product in the industry. This fact emphasizes the importance for assessing recycled product's sustainability before being applied in the industry. A credit award system (e.g. LCA) and single-dimensional approach are insufficient to evaluate the sustainability complex nature of recycling C&D waste into building materials because its diffusion into construction industry will depend on its conformity to all three pillars/legs (i.e., social, economic, and environmental) of the sustainability concept. These three sustainability pillars are further categorized into five criteria as presented in Table 2. From Table 2, the recycling of C&D waste into building materials in Tanzania is sustainable when the recycling process achieves to conserve the natural resources for future use, improve ecological quality, protect human health, ensure security for building dwellers as well as it is economically feasible.

- *Ecological quality:* it deals with the minimization of impacts of eutrophication, acidification, land use, greenhouse gases like carbon dioxide and other pollution sources in order to maintain and restore earth's vitality and ecological diversity (Goedkoop *et al.*, 2010; Dessel and Putzeys, 2007; Zah *et al.*, 2007; Ding 2005; Guinee, 2002; Hill and Bowen, 1997). In this study, ecological quality focuses on the minimization of environmental pollution like emissions to the environment. This study 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 ecological impacts and therefore improve the ecological quality. However, there are many environmental impacts that may result from the recycling process, emissions mainly of the carbon dioxide gas (CO_2) that contribute to the effects of climate change is focused in this study.

  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) using a chemical reaction presented in Equation 1.

$$CaCO_3 \rightarrow CaO + CO_2 \qquad \text{Equation 1}$$

Furthermore, estimations of CO_2 emissions in material transportation and waste disposal were done using the unit 'gram CO_2 emitted per tonne-kilometre' (Leonard *et al*[1] presents 0.13 kg CO_2 /tkm as the figure for UK) were carried out. The same unit value was adopted in this study to calculate the amount of CO_2 emissions which can be emitted during the transportation of C&D waste or natural material to the disposal or recycling/production sites, respectively. It was assumed that a 7 ton capacity truck was fully loaded in one trip and empty in another (e.g., return trip). The empty trip was considered as half a trip of the fully loaded trip. Therefore, the total CO_2 emissions were calculated by multiplying unit gram 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.

- *Resource conservation:* It deals with reduction of use of minerals like aggregates, fossil fuel, water and land as well as minimizing waste production (Goedkoop *et al.*, 2010; Dessel and Putzeys, 2007; Ding 2005; Hill and Bowen, 1997). This study describes how recycling of C&D waste into building materials in Tanzania contributes to resource conservation. Resource conservation in this study 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 requirements of load bearing capacity, 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.

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[1] *Leonardi, J., Rizet, C., Browne, M., Allen, J., Pérez-Martínez, P. J., and Worth , R. (Unknown), Improving energy efficiency in road freight transport sector: the application of a vehicle approach, viewed from http://www.greenlogistics.org/SiteResources/7d476c2c-2574-4890-ae4a-97484b9a443_LRN%20vehicle%20approach.pdf*

- *Economic Effect:* Mostly, economic in any project is defined in terms of cost-benefit ratio (CBR) of the project (Ding, 2005). However, CBR often ignores or underestimates the environmental values (Ding, 2005, Tisdell, 1993). According to Kartam *et al* (2004), in recycling sector, the economic is viewed in relation to the production cost. Based on this recycling scenario, the current study defined the economic effect in terms of production cost. In this study, economic effect was defined in terms of *project cost* (refer Table 2). Project cost is defined as the cost which consist of material and production costs. Production costs consisted of labour, energy and equipment costs.

- *Health*: Since C&D waste is categorized and handled as normal solid waste in Tanzania (URT, 2004), so, its improper disposal may endanger human health and put it into risk (Zah *et al.,* 2007; Al-Yaqout and Hamoda, 2003). These health risks include cancer due to carcinogenic substances and respiratory effects (Goedkoop *et al.,* 2010). So, it is assumed that by recycling of the C&D waste into new building material instead of landfilling or throwing it away will minimize these human health risks.

- *Employment:* Recycling processes help to create more employment opportunities in which people get more income that enables them to meet their daily needs. These employment opportunities include collection, transportation and processing C&D rubble into aggregates as well as using the recycled aggregates to fabricate the precast the concrete blocks and other concrete products. Therefore, recycling of C&D waste into building materials became source of income and hence regarded as a valuable resource rather than throw it away or dump into dumping sites.

- *Safety:* Dessel and Putzeys (2007) defined security as protection of building and surroundings against crime. Crime can be anything that harms building as well as inhabitants. Since C&D waste is regarded as waste for thrown away in Tanzania (Sabai, 2013; Sabai *et al.*, 2011); so its reuse should ensure protection of the inhabitants and surroundings against accident risks like building collapse. Normally, buildings collapse due application of poor building material quality which do not satisfy the building material specifications and standards. Therefore, security may defined as safeguarding inhabitants and the surroundings by constructing the building with recycled building materials from C&D waste that meet the building material specifications and standards.

Table 2 Sustainability criteria and their attributes

Sustainability Pillars	Criteria	Indicator	Goal	Measuring units
Environmental effect	Ecological quality	Greenhouse gas (CO_2) and leachate	Minimize pollution that cause climatic change and water and groundwater contamination that affects ecosystem.	% of reduction
	Resource conservation	Amount of recycled materials that replaced natural materials	Reduce use of generic materials i.e. energy, water, materials and land as well as minimize waste production	kg
Economic effect	Project cost	Material and production costs	Minimize the material purchasing and processing costs, concrete block production cost, and transportation costs	$
Social effect	Health	Improve human health	Reduce factors that cause health risk such that carcinogenic and respiratory effects may results due to mismanagement of C&D waste	Expert judgment
	Employment	Reduce level of unemployment	Recycling skill will stimulate entrepreneurship in the field of C&D waste recycling in Tanzania and hence create more employment opportunities	Expert judgment
	Safety	Quality of the recycled products	Use of recycled C&D waste into building material production that meets the required standards	The quality model score

Since the measuring units from Table 2 are different for almost each individual criteria, so, in order to determine the homogeneous (i.e., dimensionless) unit values, the calculated/determined value of each criterion was normalized in order to obtain the homogeneous overall score. Normalization in this study was expressed as division of value of individual recipe to sum of the value of total values of all recipes. Then the dimensionless values were multiplied by weighting factors to determine the sustainability index (SI) value of the respective criteria with respect to recipes (which we can call them as alternatives). The dimensionless values were then multiplied by weighting factors to determine SI score of each criterion first for all four recipes and then to six criteria. The results of total scores for each recipe were compared to others in order to determine which recipe with higher score value than others. The higher the score value will imply the more sustainable the recipe is (Ding 2005). Furthermore, the recipe which was obtained here was used to compare with the results of the recipe that was obtained from the developed Quality Assessment Model (QAM) (Sabai, 2013).

The sustainability model developed by Ding (2005), which is a multi-dimensional model that incorporates environmental, material utilization, social and economic aspects, was adopted in this study. The Ding's sustainability model results were used to make the decision regarding which development option is the best that considering environmental values from planning phase. The model seeks to maximize the revenue and social benefits and minimize the material utilization and environmental impacts of the project. However, the existing sustainability model which developed by Ding (2005), deals with the selection of the best project in the planning phase among the alternatives, but, in this study, the model's principles were applied to assess the sustainability of concrete blocks products that were produced from C&D waste in Tanzania. The previous sustainability model did not include the quality of the produced products which is important for recycled products. Given that this study deals with recycling building material from C&D waste, it was assumed that the quality aspect should be considered as an independent sustainability criterion in analyzing the sustainability of recycling C&D waste into building materials as shown in Table 3.

Incorporating the quality of the product in the assessment model will influence the ease of acceptability of the recycled products into the building construction industry in Tanzania. For this reason, the quality aspect was incorporated as a variable (criterion) in assessing the sustainability of the recycled products as shown in Equation 2. In this study, the quality attribute falls into social theme of sustainability because people (inhabitants) should be protected against building hazard like building collapse that results because of applying poor building materials. Oliveira de Paula and Negrao Cavalcant (2000) classified quality of the product as a social aspect as well. Therefore, the sustainability index model that developed by Ding (2005) was adapted to suit the sustainability assessment of the recycled products in Tanzania. The adapted model has six criteria which include the economic effect, resources conservation and ecological quality. Others are Health and Employment (i.e. improve human health and reduce level of unemployment) as well as safety (quality of recycled products) criteria together as shown in Equation 3 and Equation 4 as well as Table 3. Thus, analysis of sustainability score for 6 criteria that presented in Equation 2 applied to 4 different production recipes in this study is illustrated in matrix table as shown in Table 2.

$$e_{ij} = f\{EQ, RC, PC, HH, EMT, ST\} \quad \text{Equation 2}$$

Where: e_{ij} *= value of criteria, i for the recipe j;*
EQ = Ecological quality;
RC = Resource conservation;
PC = Project cost;
HH = Health;
EMT = Employment;
ST = safety (quality of the recycled product).

Table 3 Matrix of sustainability criteria with respect to recycling techniques (recipes)

		Recipe, j *(j=1, 2, 3, 4)*								**Weighting factor of criterion *I* (W_i)**
		30% C&D replacement, *(j=1)*		C&D+0.25%SF, *(j=2)*		C&D+0.25%MF-P4, *(j=3)*		NCA+NFA (Natural), *(j=4)*		
		e_{ij}	SI_{ij}	e_{ij}	SI_{ij2}	e_{ij}	SI_{ij}	e_{ij}	SI_{ij}	
Criteria, I *(i=1, 2, …, 6)*	*Ecological quality (EQ), (i=1)*	e_{11}	$e_{11}*W_1*W_1$	e_{12}	$e_{12}*W_2*W_1$	e_{13}	$e_{13}*W_3*W_1$	e_{14}	$e_{14}*W_4*W_1$	W_1
	Resource conservation (RC), (i=2)	e_{21}	$e_{21}*W_1*W_2$	e_{22}	$e_{22}*W_2*W_2$	e_{23}	$e_{23}*W_3*W_2$	e_{24}	$e_{24}*W_4*W_2$	W_2
	Project cost (PC), (i=3)	e_{31}	$e_{31}*W_1*W_3$	e_{32}	$e_{32}*W_2*W_3$	e_{33}	$e_{33}*W_3*W_3$	e_{34}	$e_{34}*W_4*W_3$	W_3
	Health (HH), (i=4)	e_{41}	$e_{41}*W_1*W_4$	e_{42}	$e_{42}*W_2*W_4$	e_{43}	$e_{43}*W_3*W_4$	e_{44}	$e_{44}*W_4*W_4$	W_4
	Employment (EMT), (i=5)	e_{51}	$e_{51}*W_1*W_5$	e_{52}	$e_{52}*W_2*W_5$	e_{53}	$e_{53}*W_3*W_5$	e_{54}	$e_{54}*W_4*W_5$	W_5
	ST = safety, (i=6)	e_{61}	$e_{61}*W_1*W_6$	e_{62}	$e_{62}*W_2*W_6$	e_{63}	$e_{63}*W_3*W_6$	e_{64}	$e_{64}*W_4*W_6$	W_6
Weighting factor of recipe *j* (W_j)		W_1		W_2		W_3		W_4		
Overall SI			Equation 3		Equation 3		Equation 3		Equation 3	

$$\text{Sustainability score (index) (SI) of recipe j for the criterion i} = e_{ij} * W_j * W_i \qquad \text{Equation 3}$$

$$\text{Overall sustainability score (SI) value of 6 criteria for recipe j} = \sum_{i=1}^{6} e_{ij} * W_j * W_i \qquad \text{Equation 3}$$

Where: e_{ij} = *score of criteria I for the recipe j;*

W_i =*weighting factor of the criterion i;*

W_j = *Weighting factor of the recipe j;*

SI_{ij} = *Sustainability score (index) of recipe j for the criterion i*

Analysis of sustainability scores for the building material production recipes

The six sustainability criteria which are presented in Table 2 are used to determine the overall sustainability score by using Equation 4 as shown in Table 3. Then, the sustainability score of four concrete blocks production recipes/techniques from C&D waste were evaluated. The recipes that satisfied the building material requirements: both structural (i.e. compressive strength) and durability (i.e. water absorption ratio were established. These requirements are the ones which used to classify the concrete blocks with load bearing capacity in Tanzania (Sabai, 2013). From the study of 27 different recipes tested, it showed that 12 out 27 recipes studied were able to produce the concrete blocks with good quality (Sabai, 2013). The good quality product in this study is the one which met both structural and durability requirement as presented in Table 4.. However, out of these 12 recipes, 4 of them were selected for sustainability analysis because are the ones utilized less amount of cement and additives which are identified as expensive materials in block production.

Table 4 Recipes that met load bearing capacity for the production of the recycled concrete blocks

Recipe/technique	Definition	Why selected
30% C&D replacement	30% C&D replacement means 30% construction and demolition (C&D) waste was replacing natural aggregates (both fine and coarse aggregates) in concrete blocks production and the rest (i.e., 70%) were aggregates from natural (virgin) sources	Achieved the load bearing requirements
C&D + 0.25% SF	C&D + 0.25% SF means 100% aggregates (both fine and coarse aggregates) used was C&D waste, and 0.25% Sisal fiber (SF) (i.e., %weight of amount of cement) was added in the concrete mix for the production of concrete block	• Achieved the load bearing requirements • Used less amount of cement • Used a low dosage (i.e., 0.25% of amount of cement content) of additives
C&D + 0.25% MF-P4	C&D + 0.25% MF-P4 means 100% aggregates (both fine and coarse aggregates) used was C&D waste, and 0.25% MegaFlow P4 (MF-P4) (i.e., %weight of amount of cement) was added in the concrete mix for the production of concrete block	• Achieved the load bearing requirements • Used less amount of cement • Used a low dosage (i.e., 0.25% of amount of cement content) of additives
NCA + NFA (Natural)	NCA + NFA means 100% natural (virgin) coarse and fine aggregates used in concrete block production	As control.

Weighting factors determination

As shown in Equation 4 the sustainability index (value) is a function of value of criteria with respect to recipe (e_{ij}) and weighting factor (W). Weighting is a process that involves the community to make a decision for the things which affect them as well as helps to understand the client motives and community requirements (Ding, 2005). The motivation for employing weighting is usually based on the desire to determine impact of the assessment output (Schmidt and Sullivan, 2002). There are many and different weighting techniques which include paired comparison, raking, rating and public participation (Ding, 2005; Hobbs and Meier, 2000; Saaty, 1994). Out of these aforementioned weighting approaches, public (stakeholder) participation was adopted. Experts (stakeholders) workshop was conducted in Tanzania in order to explore the local expert's opinions on the sustainability aspects of recycling the C&D waste into building material products in Tanzania. Sustainability criteria were individually weighted (Ding, 2005), and then the sum of their weighting factors was equal to 100% as reported by Goedkoop *et al* (2010) and www.lehigh.edu[2]. Therefore, the weighting of criteria as well as recipes was carried out in order to determine the local stakeholders' (community) perceptions and requirements in recycling C&D waste into building material such that concrete blocks in Tanzania.

The experts (stakeholders) workshop was conducted in Tanzania in order to explore the local expert's opinions on the sustainability aspects of recycling the C&D waste into building material products in Tanzania. The Tanzanian experts' were asked to assign the weighting factor (importance) in each sustainability criteria using a structured questionnaire for each recycling recipe of recycling C&D waste into building materials in Dar es salaam, Tanzania. 18 participants from *academic and research institutions* (i.e., University of Dar es Salaam (UDSM), Ardhi University (ARU), and National Housing and Building Research Agency (NHBRA)), *regulators* (i.e., Tanzania Bureau of Standards (TBS) and National Construction Council (NCC)) and *concrete block producer* were attended as presented in Table 5. Others included *consultants*, *contractors*, as well as *clients*. Since the workshop composition was diverse, similar perspective would be difficult to be given. In order to get the representative information from each stakeholder, the following were carried out before weighting factor assignment was conducted. An overview of the research problem and objectives were presented. The detail descriptions on the following were presented:

- Sustainability criteria and their preliminary findings
- Factors that should be taken into account included (*improved from www.lehigh.edu*):

a. Is a recipe/factor critical?
b. How important is it in recycling?
c. What is the impact to recycling outcome (*i.e., bigger positive impact implied larger weight and vice versa*)?
d. How significant do you consider the impact?
e. Who is affected from it and to what extent?

Discussion and clarification on the matters presented as well as those raised by stakeholders (experts) followed. After everything was clear for everyone, then experts were asked to assign weighting value for each sustainability criterion as well as accompanied factors based on their expertise *(without being influenced).* In assigning the weightings, it was emphasized that cumulatively, the weightings of individual criterion or factor must be equal to 100%. To simplify this approach and make exercise precise, participants termed it as '*giving marks'*. For them, assigning weightings and marking scripts (in exams) were considered to be similar. After filling the questionnaire, the average value of weighting factor from all 18 participants was obtained.

[2]*Source:* *http://www.lehigh.edu/~inhro/documents/GPS_Weighting Factors_Handout.pdf [viewed October, 2012]*

Table 5 Participants for the Local experts' (stakeholders) workshop

Expertise	**Participants**	
	Expected	Participated
Consultants	3	3
Contractors	3	2
Researcher	6	8
Regulators	2	2
Clients	3	2
Concrete block producers	3	1
Total	20	18

RESULTS AND DISCUSSIONS

The quality of the building blocks produced from recycled aggregates of C&D waste

The building (concrete) blocks were produced from recycled fine and coarse aggregates processed from C&D waste in Tanzania as presented in Section 2.1. The blocks that achieved the building material standard requirements (TZS 283:2002E; NEN-EN 772-1 (en):2000E) were selected to assess their sustainability performance. Four different recycling recipes (see Section 2.4) were selected and assessed in this paper used sustainability tool as presented in Section 2.3. These recipes are those met the compressive strength of 7 N/mm^2, which is traditionally used to define the minimum requirement of load bearing capacity (Sabai *et al*., 2013; Soutsos *et al*., 2004; TZS 283:2002(E); Poon, *et al.*, 2002,; Neville, 1995; Jackson and Dhir, 1988) as well as water absorption ratio of 12% (Sabai, 2013, Boehme, 2000). These building material standard values of greater than or equals to 7 N/mm^2 (compressive strength) and less than or equals to 12% (water absorption ratio) are termed as 'requirements' in Figure 1. The results of four recipes are presented in Figure 1. Figure 1 shows that 30%C&D replacement recipe was achieved to produce blocks with 18.5 N/mm^2 and 6.9% for compressive strength and water absorption ratio, respectively; C&D+0.25%SF recipe was achieved to produce blocks with 8.2 N/mm^2 and 11% for compressive strength and water absorption ratio, respectively. Others include C&D+0.25%MF-P4 recipe which was achieved to produce the concrete blocks with 9.3 N/mm^2 and 10.4% for compressive strength and water absorption ratio, respectively; and NCA+NFA recipe that achieved the compressive strength of 18.9 N/mm^2 and water absorption ratio of 5.2% for concrete blocks produced and tested in the laboratory. These results showed that all four recipes are within the concrete blocks requirements for load bearing wall construction. However, assessment for which recipe is more sustainable in Tanzania compared to others were required. In this paper, the improved sustainability index was used to estimate which recipe is sustainable as presented in subsequent sections.

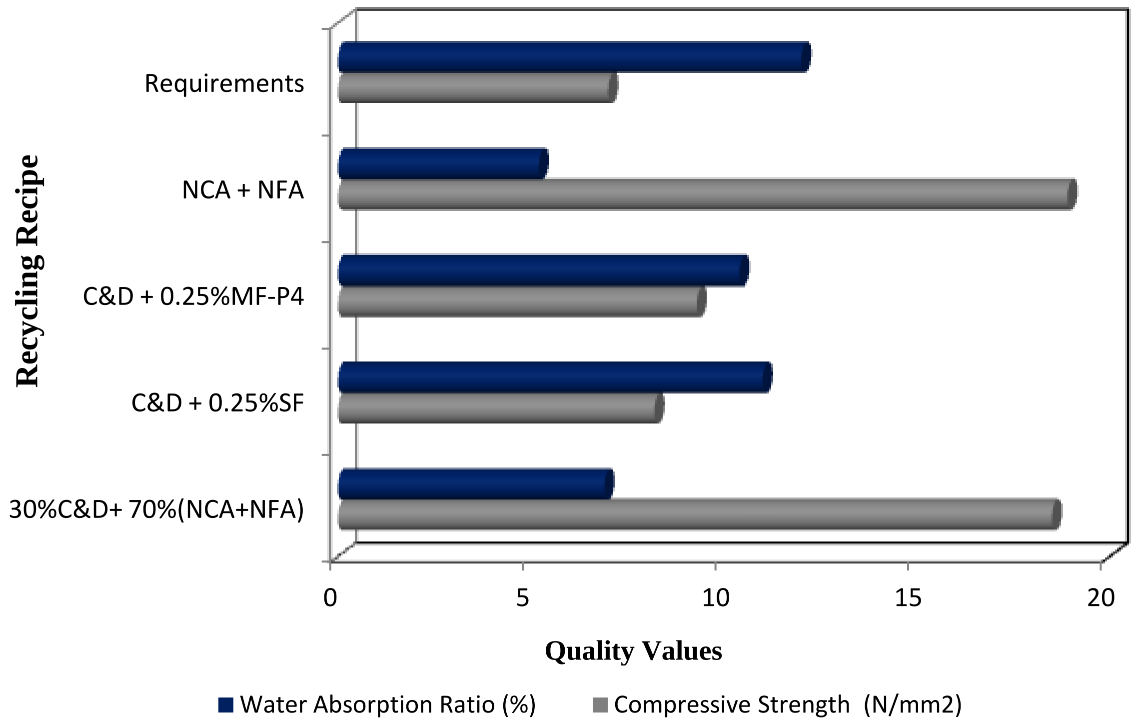

Figure 1 Recycling recipes and their concrete blocks quality produced from recycled C&D waste in Tanzania

Determination of importance of the recipes used in sustainability study based on Tanzanian (local) expert's opinions

Experts were asked to evaluate the recipes based on their potential in contributing to sustainable construction through recycling of C&D waste into building materials in Tanzania. The scale used was as follows: 1 *(10% score*) = poor; 2 *(40% score)* = less potential; 3 *(70% score)* = potential; 4 *(100% score)* = most potential. The average results from the expert respondents are presented in Table 6. These results showed that using 100% C&D waste without incorporating any additive in the recycling production of C&D waste into concrete blocks was considered as the most potential recipe to improve the sustainable construction in Tanzania. This was followed by using sisal fiber (SF) in the concrete block production from recycled C&D waste aggregates. In addition, the recipe that used super-plasticizer (i.e., MegaFlow (MF) P4) was evaluated as having the same potential as with using natural aggregates. The reason of for this may be attributed to the fact that the MF-P4 admixture is a synthetic and imported material product. These results suggest that construction industry experts in Tanzania were curious to seek alternative sources for obtaining materials for the production of building materials instead of depending on the traditional sources (raw material) which are depleting.

Table 6 Potential for sustainable construction in Tanzania

Recipes	Potential for sustainable construction	
	Scale	Performance (%)
C&D waste replacement *(Considers 100% C&D replacement)*	4	100
C&D + use of sisal fiber (SF)	3	70
C&D + use of MegaFlow P4 Plasticizer	2	40
Use of natural aggregates (NCA + NFA) only	2	40

Overall score of sustainability index for all recipes in Tanzania

After obtaining the value of criterion *i* for recipe *j* (see Table 3) and weighting factor of the respective recipe and/or criteria (see Section 2.5); the sustainability score (index) was estimated using Equation 3. The determination of the sustainability score (SI_j) of the recipe *j* from each sustainability criterion *i* was carried out using Equation 4Equation 3. After sustainability score (SI_j) of the recipe *j* for criterion i (SI_j), was obtained, it was multiplied by weight factor of the respective criterion (see Table 7). Then sum of all 6 criteria was carried out as shown in Equation 3 and the results are presented in Table 7. According to Langston and Ding (2001) and Ding (2005), the higher the sustainability index (SI) value implies the more sustainable the recipe is. The same principle has adopted to be applied in this study. The results in Table 7 showed that the sustainability score for each criterion showed that out of six sustainability criteria studied, the *C&D+0.25%SF* recipe had high sustainability score for four of them such as ecological quality, resource conservation, project costs and health with the score value of 0.045, 0.033, 0.256, and 0.072, respectively. Highest value for employment was found to the 30%C&D waste replacement recipe, while NCA+NFA (natural) recipe had higher sustainability score on safety. Furthermore, sensitivity analysis was carried out by assumed that one of criterion (parameter) contributes nothing (equals to zero), the results showed by varying ecological quality, resource conservation and economical effect (costs), the overall sustainability score was dropped significantly compared to when health, employment and safety criteria used. These results suggest that environmental and economic parameters are sensitive recycling C&D waste water in Tanzania even other developing countries at large.

Furthermore, the results presented in Figure 2 showed that A *C&D+0.25%SF* recipe was found to have a higher sustainability index value of 0.472 compared to 0.460, 0.363, and 0.277 of *30%C&D replacement*, *C&D+0.25%MF+P4*, and using natural *(NCA+NFA)* aggregates recipes, respectively. However, it (C&D+0.25%SF recipe) had a lowest performance in safety criterion with the sustainability score of 0.006. Since it reached an acceptable performance which is a 'higher values' score, this achievement indicates that the lowest score value in this criterion among four recipes does not affect its sustainability performance or have effects to human life (building dwellers) and other ecosystems and thus does not require a further remediation before use. Therefore, the use of sisal fibers (i.e., 0.25% amount of cement) in 100% recycled aggregates from C&D waste was found to produce a more sustainable recipe than the others (i.e., 3) recipes. Therefore, the optimum dose of 0.25% as percentage of cement content is recommended to be applied in the Tanzanian construction industry. This is because it is within the dose of organic additive (i.e., 0.5% of amount of cement) that is allowed in concrete production in Tanzania as recommended in TZS 727(Part 1):2002. It is also less than 0.75% content as reported by Prabakar and Srindhar (2002). Moreover, this 0.25% SF dose, which is equivalent to 0.64 kg in a 1 m3 concrete, also which lies within the dosage of 1 kg/m3 of fibers that recommended in CEMEX3 mortars. These results reveal that it is possible to recycle 100%C&D waste into building materials which meet standard requirements in Tanzania using low dose (amount) of sisal fibers.

[3]*CEMEX mortars, Experts in Mortar-Educational guide to admixtures, additives and water, www.cemex.co.uk/mortar [viewed April 2011]*

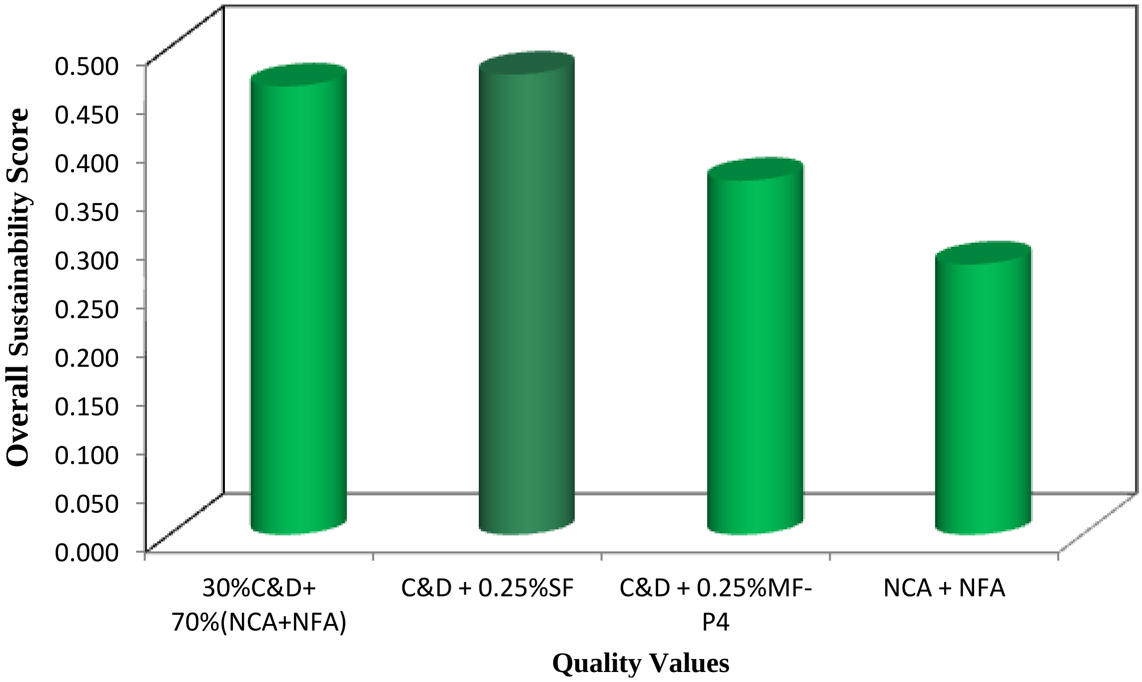

Figure 2 Overall sustainability score using the Improved Sustainability Index method in Tanzania

Table 7 The overall sustainability index (score) value for six criteria and 4 recipes in Tanzania

Sustainability pillar	Criteria, *i*	Weighting Factors, W_i (i.e., i= 1, 2, …, 6)	Recipe, *j (i.e., j= 1, 2, 3, 4)*							
			30% C&D replacement (j_1)		C&D + 0.25% SF (j_2)		C&D + 0.25% MF-P4 (j_3)		100% (NCA + NFA) (j_4)	
			$(e_{ji}*W_j)$	$(e_{ji}*W_j)*W_i$	$(e_{ji}*W_j)$	$(e_{ji}*W_j)*W_i$	$(e_{ji}*W_j)$	$(e_{ji}*W_j)*W_i$	$(e_{ji}*W_j)$	$(e_{ji}*W_j)*W_i$
Environmental	Ecological quality *(i_1)*	27	0.063	0.017	0.167	0.045	0.056	0.015	0.004	0.001
	Resource conservation *(i_2)*	24	0.054	0.013	0.137	0.033	0.083	0.020	0	0.000
Economic	Project costs *(i_3)*	19	1.063	0.202	1.347	0.256	1.063	0.202	0.621	0.118
Social	Health *(i_4)*	9	0.733	0.066	0.800	0.072	0.689	0.062	0.356	0.032
	Employment *(i_5)*	8	1.025	0.082	0.750	0.060	0.688	0.055	0.362	0.029
	Safety *(i_6)*	13	0.615	0.080	0.046	0.006	0.069	0.009	0.746	0.097
Overall sustainability score=$\sum(e_{ji}*W_j)W_i)$				**0.460**		**0.472**		**0.363**		**0.277**

= *High sustainability score;* = *Moderate sustainability score;* = *Low sustainability score;* = *Least sustainability score.*

$(e_{ji}*W_j)$= Sustainability score of recipe j for the criterion i as presented in Table 3

CONCLUSIONS

This paper demonstrates that by using C&D waste as a resource (*equals food*); it is possible to recycle C&D waste into building material, suitable for sustainable construction in developing countries like Tanzania. Concrete blocks produced from 100% recycled aggregates with incorporating sisal fibers as additive was found to be more sustainable than concrete blocks produced from aggregates extracted from natural (virgin) sources in Tanzania. Since sisal fiber is a natural and locally available material, its use will contribute to the acceptance and application of the recycled concrete block developed in this study. Other benefits include reduction the importation of synthetic admixtures; sisal plantation may grow and hence increase production, employment, income and overall wellbeing of people and nation at large. In addition, recycle C&D waste into building material results to minimize environmental, economical, as well social impacts. This is in line with the sustainable construction concept. Therefore, recycling of C&D waste into building material with load bearing capacity is recommended in Tanzania in order to achieve sustainable construction.

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