Construction and Demolition Waste Characteristics in Tanzania

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Abstract: *The construction industry generates a lot of construction and demolition (C&D) waste which puts some challenges to its management. For example, currently, in many towns in Tanzania, there are no landfill sites for solid waste disposal; and as a consequence open air dumping sites are used. Dumping C&D waste puts pressure for acquisition of large portions of land in order to accommodate the disposal of the growing waste generated from construction and demolition sites. Others include imposed economic burdens, social discomfort as well as sources of environmental pollution like air and water pollutants. Due to population growth and land limitation for waste disposal, the current practices will put extra pressure on C&D waste management in future as well. This paper aims to investigate the quantity and quality of C&D waste in Tanzania and the possibilities for reusing and recycling this waste in the production of building materials. The use of C&D waste for building material production can be a best option not only for waste management but also for providing alternative building material for present and future generations. Materials used in this study were cementitious rubble recovered from eight building construction and demolition sites in Dar es Salaam. Two samples from natural sources were used for comparison purposes. Secondary data from Dar es Salaam City Council was used to estimate the amount of C&D waste generated in Tanzania annually. Furthermore, the recovered C&D waste samples were crushed to get recycled aggregates that were used in laboratory analysis. The results showed that the C&D waste generation in Tanzania increased from 3.03 million tonnes to 7.9 million tonnes in the period ranging from 1994 to 2010 years. Furthermore, the results showed that the recycled aggregates were weaker than natural aggregates, however, mineralogically were not significantly different from natural aggregates. Thus, their chemical composition similarities suggest that recycled C&D waste is suitable for production of building materials in Tanzania. The recycling of C&D waste into* *building material will contribute to sustainable social, economic, and environmental improvements.*

Key words: Construction and demolition waste, quantity, quality, recycling, building material, Tanzania.

INTRODUCTION

The construction industry is a wasteful sector. According to URT (2003). construction industry is defined as 'a sector of the economy that transforms various resources into constructed physical, economic, and social infrastructure necessary for socio-economic development. It embraces the process by which the said physical infrastructure are planned, designed, procured, constructed or produced, altered, repaired, maintained and demolished'. The construction industry generates construction and demolition (C&D) waste which puts some challenges to its management. For example, Tanzanian legislations recognize C&D waste as solid waste for disposal (URT, 2004). Even though there is currently no landfill for solid waste disposal in Tanzania, open air dumping sites are used. Dumping C&D waste puts pressure for acquisition for large portions of land in order to accommodate the growing waste generation. It imposes economic burdens and social discomfort like bad odor from the dumping sites, as well as sources of environmental pollutants of air and water. Due to population growth and land limitation for waste disposal, it is envisaged that it will put extra pressure on C&D waste management in future.

In addition, the construction industry is responsible for generating construction and demolition (C&D) waste of approximately 40-50% of the total amount of waste (McDonald, 1996; Dolan *et al*., 1999; Oikonomou, 2005). The amount of C&D waste generated can be estimated from normal construction and demolition activities. A lot of C&D waste is generated by natural disasters like earthquakes (e.g. in Italy (2009). Haiti (2010). Chile (2010). New Zealand (2011). Japan (2011) etc). avalanches, hurricanes and tornadoes events (Sabai *et al.,* 2013; Sabai, 2013). According to Sabai *et al.* (2013). not only natural disasters, but also man-made causes of the C&D waste are on the increase. For example, war, bombings, and structural failures are often reported in different areas. In 2013 several buildings collapsed in different places in the world like Bangladesh (DCNCR, 2013) and Tanzania (Kizito, 2013). which were accompanied with loss of life; for example, 1000 died in Bangladesh and 36 in Tanzania, but also left a massive amount of waste on the ground.

At the turn of the century, the Directorate of Human Settlement in the Ministry of Lands and Human Settlements Development conducted a survey on the quality of the existing buildings in Dar es Salaam, Tanzania. The report showed that out of 1,084 buildings in the central area of Dar es Salaam city, only 11% were in a good condition. The report recommended that the sub-standard buildings (about 89% of the surveyed buildings) should be replaced, which has a consequence of generating more amount of C&D waste. Besides the bad condition of the surveyed buildings, town expansion and other redevelopment activities such as the International Airport expansion cause C&D waste generation as well as raw material extraction for new buildings. It is reported that about 70% of constructed buildings in Dar es Salaam are preceded by demolition of old buildings (Sabai *et al*., 2011b) which, also contributes to a lot of C&D waste generation. These facts show that the C&D waste generation in Tanzania will continue to increase. This waste generation trend is in good agreement with what Kartam (2004) reported that construction activities will never reach zero-waste status. A challenging question remains how to deal with this massive amount of waste issue. This paper aims to study the quantity and quality of the C&D waste particularly cementitious rubble and how they can fit in using them into reproduction of the new building material for building construction which satisfies the building material standard requirements in Tanzania.

Of course, this is not a first study on the quality of C&D waste, various research studies have been carried out. For example, Mueller *et al.* (2008) characterized lightweight aggregates from primary and recycled raw materials in Russia and Germany. Mueller *et al.* (2008) reported that the reuse/recycling of C&D waste depends on the quality of constituents and the products. Bianchini *et al.* (2005) analyzed chemical-mineralogical of aggregates from C&D waste in order to evaluate their chemical and mineralogical composition that will help to develop recycling strategy in Italy. After analyses using X-ray fluorescence (XRF) and X-ray diffractometry (XRD). the authors found that the waste material with grain size fraction ranging between 0.125-0.600 mm of recycled aggregates can be directly re-utilized as first order material. Besides of being expensive in crushing all rubble in the whole country to extract the grain size between 0.6-0.125 mm, the question remains, where will the residue material go? Definitely, this approach encourages the disposal of recycled aggregates which creates more financial, social, and environmental problems.

In another study, Limbachiya *et al.* (2007) reported that by using 30% of recycled coarse aggregates to replace natural aggregates, the composition of the building material had no major effect on the main three oxides (SiO_2, Al_2O_3, and CaO). although there was a decrease on SiO_2 and increase of Al_2O_3 and CaO contents when the coarse recycled aggregates content was increased in the mix. Limbachiya *et al.'s* (2007) study was limited to coarse aggregates, what the quality could be if fine aggregates were used together with coarse aggregates in replacement. Angulo *et al.* (2009) studied the chemical-mineralogical characterization of C&D recycled aggregates in Sao Paulo, Brazil, in order to increase confidence in recycling and enlarge their market (Angulo *et al*., 2009). The studies from previous researchers reported above show that characterization of recycled aggregates is not a new thing; however, the findings indicate that chemical-mineralogical composition of these recycled aggregates differ from one place to another; and, therefore, the applications of these recycled aggregates cannot be generalized.

In addition, building techniques and regulations differ from one country to another; similarly the rubble which is generated from C&D waste differs in quality from place to place. Since the quality of chemical-mineralogical composition of recycled aggregates in Tanzania is limited, the influence of C&D waste in the recycling process into building materials in Tanzania is still limited. Therefore, this paper is a pioneering contribution into this area and presents the findings on the quantity and quality characteristics of the recycled aggregates from C&D Waste in Tanzania.

MATERIALS AND METHODS

The materials were sampled from various locations in Dar es Salaam followed by comprehensive C&D waste characterization. Quantity and quality characteristics were investigated using secondary data from Dar es Salaam City Council and laboratory studies using analytical techniques such as X-ray fluorescence (XRF). X-ray diffraction (XRD). Scanning Electron Microscope (SEM). and Thermogravimetric analysis (TGA).

Materials

The rubble used to produce samples of the recycled aggregates in this study was derived from building construction and demolition sites in Dar es Salaam, Tanzania. Stratified random sampling (Kothari, 2004) was used to select C&D waste sources in Dar es Salaam city. Dar es Salaam city is made up of three municipalities, namely Temeke, Kinondoni, and Ilala. In order to get representative data, the C&D waste rubble was sampled from all three municipalities as shown in Table 1. These samples consisted of 60% demolition waste, 20% construction waste, and 20% natural sources as control (Sabai *et al*, 2013). Then all 8 C&D waste samples were combined together to form a combined C&D waste sample. The C&D waste samples were combined to form an independent sample because not always the C&D waste sample of individual either construction or demotion site found, instead, sometime it may be found a heap of waste at a collection point that contain C&D waste from different sources. That kind of waste sample needs to be recycled. Due to this fact, it was assumed in this paper that the combined C&D waste sample was formed by all 8 C&D waste samples with equal fraction.

Table 1: Material samples used in the production of concrete blocks in Tanzania

Classification of sample/material		Symbol
Demolition waste (60%)	Single storey- demolition buildings	DS1
		DS2
		DS3
	Multi-storey-demolition buildings	DM1
		DM2
		DM3
Construction waste (20%)	Single storey- construction	CS
	Multi-storey-construction	CM
Natural (20%)	Gravel (coarse aggregates)	NCA
	Sand (fine aggregates)	NFA
Combined C&D waste sample	Combined 8 C&D waste samples	100%C&D waste sample

Methods

Amount of Construction and demolition waste generation

The amount of construction and demolition (C&D) waste was estimated from the solid waste generated with respect to population. The C&D waste generation was estimated as fraction of total solid waste generated. This approach is in line with what was reported by previous researchers (McDonald, 1996; Dolan *et al*, 1999; Ekanayake and Ofori, 2000; Lichtenberg, 2006) that C&D waste as solid waste constitutes a fraction of 30 to 50% of the solid waste stream. This study adopted an average value of 40% of the waste stream. The C&D waste for each region was calculated from the fraction of 40% of the solid waste in all 30 regions in Tanzania. In addition, the population of 2002 census was used in this study. It (2002 census) was used because it was found that it is a middle (median) year for 17 years from 1994 to 2010 and hence assumed as an average population. On the other hand, the amount of solid waste generation was obtained from Dar es Salaam City Council (2010). The ratio of C&D waste with respect to population for all 30 regions using Dar es Salaam condition as reference was estimated using Equation 1.

$$CD_t = \sum_{i}^{n} \frac{m_i}{m_d} \times CD_d \quad \ldots\ldots 1$$

Where: CD_t *= total C&D waste generation, tone/year*

CD_d *= C&D waste generation at Dar es Salaam, tonnes/year*

m_i *&* m_d *= ratio of C&D waste generation with the respect to region i and Dar es Salaam region, respectively*

n = total number of regions (i.e., 30 regions in Tanzania)

Manual versa mechanical crushing methods for the recycled aggregates

The standard sieve of 2.36 mm size was used to determine the effectiveness of the recycled aggregates crushing methods used i.e., manual in relation to mechanical crushing which was obtained through aggregate crushing value (ACV). Sieve analysis was carried out according to the standard methods (TZS 58 (Parts 1–3, 1980).

Chemical-mineralogical analysis

All eight recycled and two natural aggregate samples were chemically analyzed as follows. The chemical-mineralogical composition of the C&D waste samples was determined by using X-ray diffraction (XRD). Themogravimetric analysis (TGA). and Scanning electron microscope (SEM) techniques. These chemical analyses were carried out at chemical laboratory at Technical University of Eindhoven (TU/e). the Netherlands. Sample analysis using X-ray fluorescence (XRF) spectroscopy was carried out at Deltare laboratory, Utrecht, the Netherlands. All samples were prepared into powder form as presented in Sabai (2013). The resulting powdery samples were used for all chemical composition tests and analyses such as XRF, XRD, SEM, and GTA.

(a) Chemical analysis: SEM & XRF analytical techniques

High resolution Scanning Electron Microscopy (SEM) JEOL 7500 FA was used to detect the chemical elements present in the recycled aggregates. An EDX detector coupled to a FEI Quanta 600 F E-SEM was used. Samples were firstly coated (ionized) using plutter coater EMITECH K550 before being analyzed in SEM in order to prevent charging. Metal concentrations (oxides) in this study were determined by means of automated X-ray fluorescence analyzer (ARL 9400) by Deltares laboratory, The Netherlands. Major elements identified in both recycled and natural samples included SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, CaO, MgO, Na_2O, K_2O, P_2O_5 expressed in % range (wt/wt) and trace elements including Cr, Ni, Sr, Ba, and Zr expressed in ppm. The method applied was the non-destructive analysis method. This method is applicable to all types of sediment and solid soil samples that have been incorporated into fused beads or processed into tablet according to the current XRF sample preparation[1].

(b) Mineralogical analysis

XRD mineralogical analysis was performed on powder samples, one determination per sample as also reported by Angulo et al (2009). in a Rigaku powder diffractometer, using CuKα radiation (40 kV and 30 mA) at an angular range of 10 to 80^0, with a 1 s/step (0.02^0).

(c) TGA-DTG analysis

TGA analysis was performed on all samples in order to correlate the mass loss at increased temperature with the presence of $CaCO_3$ in the compositions. Carbonates decompose at a higher temperature (600 °C - 800 C). liberating CO_2 as shown in Equation 2. It was expected that the mass loss would also correlate with the aggregate crushing value, because of the difference in hardness between SiO_2 and $CaCO_3$. TGA-DTG ranging between 20 ^{0}C and 1000 ^{0}C was performed with NETSZCH model STA 449F1 using 20 ml/min of N_2 as protective gas and 40 ml/40 of N_2 as purging gas with a heating rate of 10 ^{0}C/min. Powder sample was placed in an alumna crucible.

$$CaCO_3 \rightarrow CaO + CO_2$$

RESULTS AND DISCUSSIONS

Construction and demolition waste generation in Tanzania

The amount of C&D waste generated was estimated from state of solid waste generation from year 1994 to 2010. According to City Council, the solid waste generation increased from 547500 tonnes in 1994 to 1423135 tonnes in 2010. By adopting the notion that 40% of the waste stream is C&D waste, it was estimated that C&D waste generation in Tanzania ranged from 3.03 million tonnes to 7.9 million tonnes from 1994 to 2010 as presented in Figure 1. This condition shows that C&D waste generation in Tanzania like other countries (Poon *et al*, 2007; Chan *et al*, 2000) increases as the time goes.

According to Sabai et al (2013). the composition (by weight) of these C&D waste includes concrete (39.48%). cement-sand matrix apart of concrete like mortar (60.4%). Glass (0.03%). Wool (0.04%). wood (0.01%). Metal (0.01%). others such as plastic, gypsum, paper (0.03%). This composition is centrally similar with what is reported in Western Europe that C&D waste is composed of masonry (45%). concrete (40%). wood (8%). metal (4%). and plastic (3%) (Golton, 1997). This difference could be attributed by the fact that Sabai *et al* (2013) measured the composition of the recovered rubble for recycling, while the Golton (1997) perhaps measured the composition of C&D waste immediately after demolition of the

[1] *As it was reported by Deltare laboratory technologist, Utrecht, the Netherlands*

building for example, before separation (mixed waste). All in all, the findings from researchers indicate that concrete and masonry (cementitious) rubble occupy more than 85% of the C&D waste in the construction industry, regardless developing countries like Tanzania or Western Europe like the Netherlands.

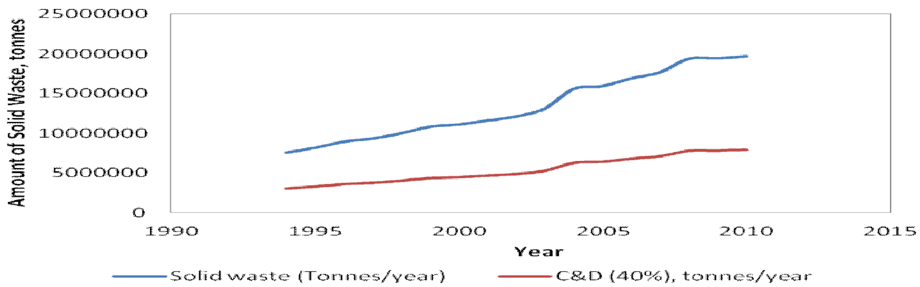

Figure 1 Amount of C&D waste generation in Tanzania

Correlation between Particle Size Distribution and Aggregate Crushing Value of recycled aggregates in Tanzania

Figure 2 presents the results of correlation between percentage (%) passing on the 2.36 mm sieve size of the particle size distribution (PSD) test and percentage (%) passes on the 2.36 mm sieve size of the aggregate crushing value (ACV) test. By comparing the results of the aggregate crushing values with the PSD of the broken materials, a few observations can be made. As expected, the materials with the highest amount of fines according to the PSD determination also had the highest crushing values. For instance, DS2 has a much higher crushing value (71.5%) than the rest of the materials (28.6-57.8%). It (DS2) is also the recycled sample found to have a highest value in PSD test for cumulative passing through the 2.36 mm sieve. The DS1 and DM2 materials, which have very similar PSDs, also have close crushing values (57.8 and 58.5%). The same observation is valid for the DS3 and DM3 materials (47.9 and 49.1%) and NCA and CM (26.8 and 30.4%). Even though there are some discrepancies in the results of the two tests, the correlation results (Figure 2) showed that they are linearly related with the correlation coefficient (R^2) of 73%. These discrepancies can be explained by the lower reproducibility of the manual crushing method which was used for obtaining all samples.

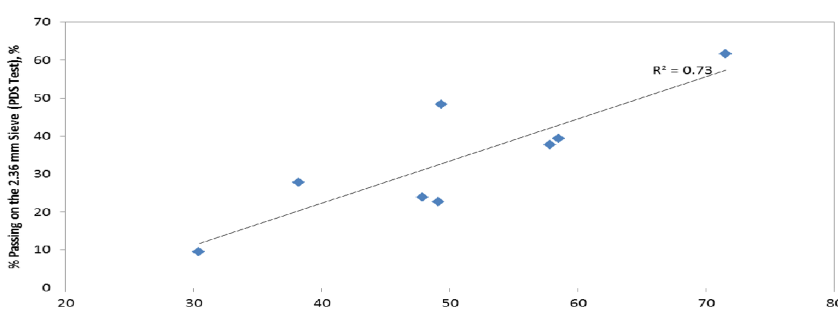

Figure 2: Relationship between % passing on 2.36 mm sieve and aggregate crushing value tests (*adopted from Sabai, 2013)*

Chemical-mineralogical characteristics of recycled aggregates in Tanzania

Scanning Electron Microscopy analysis

Scanning Electron Microscopy (SEM) was also used to detect the chemical elements present in the recycled aggregates. An EDX detector coupled to a FEI Quanta 600 F E-SEM was used. The chemical elements found in all samples were C, O, Ca, Al and Si. SEM scanned images were also taken and presented in 3 for the 8 recycled aggregates samples (*i.e., a-g*) and 2 samples sourced from natural sources (*i.e., I & j*). The images indicate that there are no significant variations of layer thickness for all samples, regardless their source of origin. These results indicate that the recycled aggregates from building construction and demolition waste are relatively close to the natural aggregates in terms of their chemical-mineralogical structures. Therefore C&D waste aggregates have no inorganic contaminants that can affect the production of the building materials, i.e., concrete blocks in Tanzania.

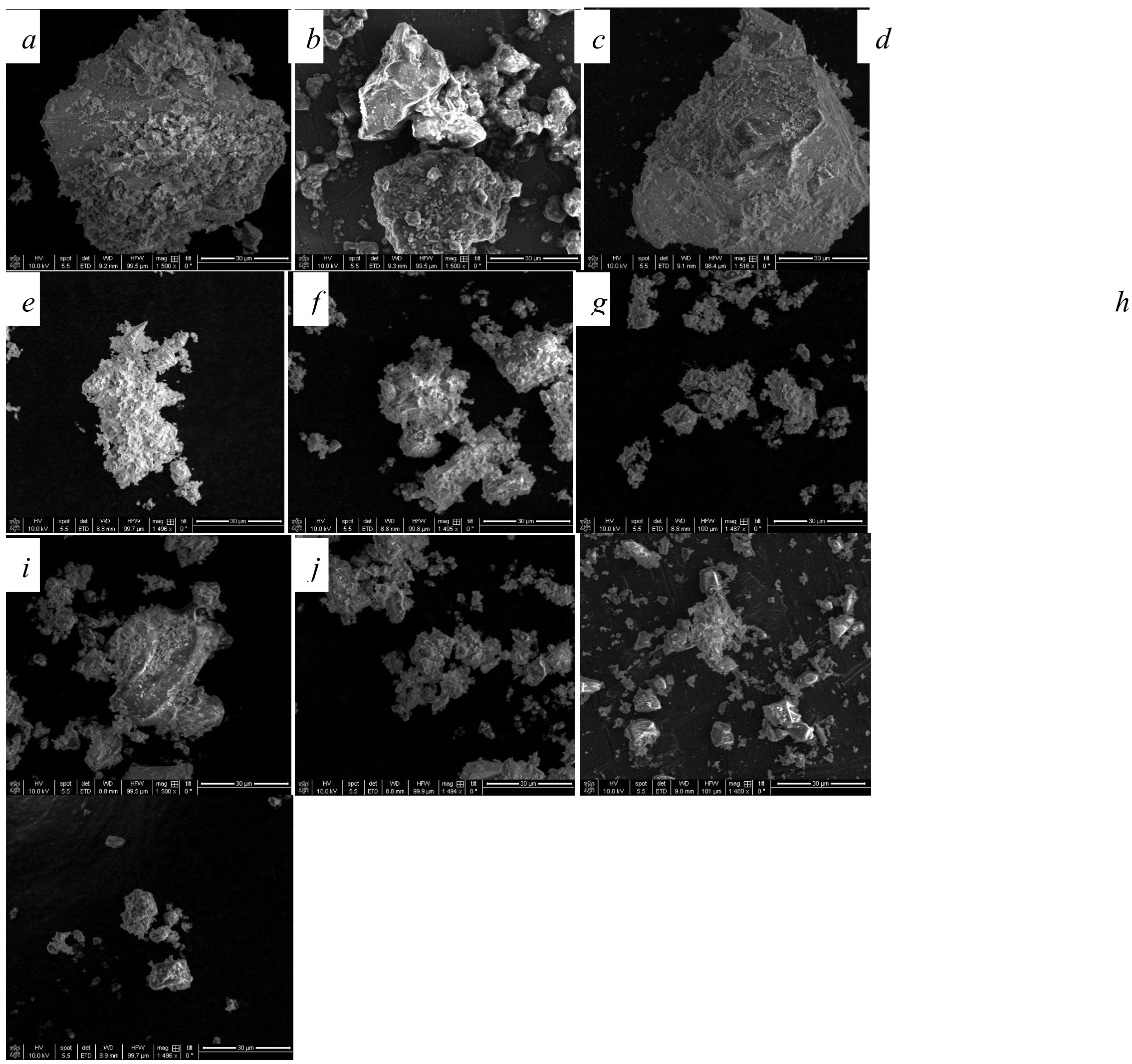

Figure 3: SEM images for 10 aggregates samples *(a = DS1, b = DM1, c = DS2, d = DM2, e = DS3, f = DM3, g = CS,h = CM, i = NFA, j = NCA)* *(adopted from Sabai, 2013)*

X-ray diffraction analysis

X-ray diffraction (XRD) was performed for all eight recycled and two natural aggregate samples to determine the mineralogical characteristics and the results as presented in Sabai *et al.*, (2011a). According to Sabai *et al.,* (2011a; 2013). the main identified phases (mineralogical composition) in all materials were SiO_2, $CaCO_3$, $Ca(OH)_2$ and various calcium aluminosilicates (C-A-S). Based on major and minor peaks observed, the DM1 and DM3 samples seem to be closer in composition to NCA while the rest of the recycled aggregates were more similar to NFA.

However, XRD results provide a qualitative analysis where the relatively high and low peaks suggest their corresponding abundances. For example, sandy-like recycled aggregates maybe composed mainly of SiO_2 while NCA-like recycled aggregates maybe composed mainly of $CaCO_3$. The XRD results showed that all eight C&D waste samples were limestones in nature (with the exception of the CM sample for which its rubble was composed of coarse aggregates sourced from granite rock). These results also suggest that mixed proportions of cementitious rubble in Tanzania contained either less amounts of carbonate cement, or more amounts of sandy ingredients used or both.

X-ray fluorescence analysis

The XRF results are presented in Table 2. The main oxides were SiO_2 (43.12-80.37%). CaO (10.42-30.0%) and Al_2O_3 (1.57-8.21%) for recycled aggregates while for natural (virgin) aggregates were SiO_2 (14.17% for NCA and 80.0% for NFA). CaO (46.64% for NCA and 18.9% for NFA) and Al_2O_3 (0.94% for NCA and 1.93% for NFA). Based on major oxides results in Table 2, almost all C&D waste samples were mainly composed of SiO_2 like natural sand (NFA). However, physical observation showed that the recycled concrete rubble was composed of limestone ($CaCO_3$) like NCA as coarse aggregates. These results suggest that either the original rubble had a lot of sand (fine aggregates) in it; less cement was used in the concrete mix or both.

Furthermore, results on trace elements showed that Cr ranged from 7.6-53.7 ppm for recycled aggregates while 5.0-14.5 ppm for natural aggregates, Ni (2.3-51.8 ppm for recycled aggregates while 5.8 ppm for NCA and < 2.0 ppm for NFA). Sr (192.0-501.6 ppm for recycled aggregates while 349.9 ppm for NCA and 195.2 ppm for NFA). Ba (70.2-498.6 ppm for recycled aggregates while 40.2 ppm for NCA and 91.5 ppm for NFA) and Zr (222.2-437.4 ppm for recycled aggregates while 106.2 ppm for NCA and 384.8 ppm for NFA). The trace elements results showed that generally, the amount (concentration) of trace elements is higher than those found in natural aggregates. The source of these elements could be cement paste, paints or any other mixed materials found in the rubble of C&D waste. These results suggest that if these recycled aggregates were disposed of in dumping sites and decompose, they would mostly likely endanger ecosystems, especially plants, animals and human beings. The opposite of that, if these recycled aggregates were used for the production of new products, then the health risks associated with the disposing of the recycled aggregates would be controlled, which is in line with this study.

Results in Table of recycled aggregates (DSs, DMs, CM and CS) are in firm agreement with the results presented by Limbachiya *et al.*, (2007) in UK on recycled aggregates for both percentage (%) weight (for main elements) and ppm (for trace elements) regardless of their difference in locations of origin. However, there was a slight difference in CaO amounts (2.4-13.9%) for the study conducted in Sao Paulo, Brazil by Angulo *et al*. (2009). These results suggest that the chemical composition of C&D waste may be similar in geographical locations. The difference noticed in CaO may be attributed to the difference of rock origin of recycled aggregates under the particular study. In this study, recycled aggregates mainly originated from limestone (with high amounts of CaO). but probably in Sao Paulo recycled aggregates originated from granite rock. These results suggest that recycled aggregates are not significantly different chemically and mineralogically from one country to another; except where the difference may be attributed to the original rocks used ~~to~~ in the production of the aggregates. The other reason could be the difference of the original concrete mix used that targets a certain quality of the concrete products, which are mostly influenced by the specific chemical requirements for such concrete products or available technologies. These original concrete mixes may have impacts ~~to~~ on the physical and mechanical characteristics of the recycled aggregates and hence affect the quality and chemistry of the recycled products.

In addition, chemical composition of a combine C&D waste sample was estimated using the Equation 3. Percentage (%) composition of individual sample *'i'* in a combined C&D waste (R) value in this study was assumed to be of equal fraction for 8 C&D waste samples, thus, R = 12.5%. The results of chemical composition of combined C&D waste (100% C&D waste) sample are presented in Table showed that all common and trace elements lie within the range of the individual C&D waste sample for all elements. These results suggest that it is possible to recycle C&D waste, however, the quality of the recycled product is not expected to have higher values than individual samples, and instead it is expected to lie between them. Nevertheless, question remains how it can be recycled to obtain higher values. The appropriate technique should be investigated; but this is beyond the scope of this paper.

$$100\%\text{C \& D waste composition} = \sum_{i}^{N} G_i * \frac{R_i}{100} \qquad i=1,2,3,\ldots,N-1,N \qquad (3)$$

Where: χ = *Content of chemical composition of individual C&D waste sample 'i'.*
R = Percentage (%) composition of individual sample 'i' in a combined C&D waste sample

Furthermore, three abundant major oxides of all 8 recycled aggregates as well as natural (virgin) aggregates were plotted in the ternary phase diagram as shown in Figure 4. The results in Figure 4 were normalized in order to get a total composition of 100% for three oxides out of the oxides presented in Table 2. The results showed that the CM as well as DM1, DM2 and DM3 samples seem to be closer in chemical–mineralogical composition to NCA (natural coarse aggregates) while the rest of the recycled aggregates of single storey buildings are more similar to NFA (natural sand).

Table 2: Chemical composition of recycled C&D waste and natural aggregates obtained by use of XRF

	C&D waste samples	100% C&D sample	*Natural samples*
Major elements (%weight)			

	DS1	DS2	DS3	DM1	DM2	DM3	CM	CS	100 %C&D waste	*NCA*	*NFA*
SiO_2	71.81	80.37	60.54	43.12	58.04	64.52	54.56	70.67	62.95	*14.17*	*80.00*
Al_2O_3	1.60	1.57	2.32	3.16	2.35	1.92	8.21	1.72	2.86	*0.94*	*1.93*
TiO_2	0.25	0.35	0.26	0.25	0.24	0.30	0.62	0.32	0.32	*0.06*	*0.35*
Fe_2O_3	0.45	0.48	0.26	0.81	0.64	0.58	4.07	0.51	0.98	*0.35*	*0.57*
MnO	0.02	0.02	0.03	0.04	0.02	0.03	0.10	0.02	0.04	*0.02*	*0.02*
CaO	15.43	10.42	21.36	30.00	26.46	15.45	18.10	16.64	19.23	*46.64*	*18.90*
MgO	0.23	0.15	0.28	0.43	0.43	0.28	2.25	0.18	0.53	*0.68*	*0.21*
Na_2O	0.17	0.15	0.31	0.48	0.19	0.31	1.63	0.10	0.42	*0.09*	*0.12*
K_2O	0.2	0.27	0.45	0.65	0.71	0.27	0.82	0.17	0.45	*0.11*	*0.19*

	6										
P_2O_5	0.02	0.02	0.04	0.04	0.06	0.03	0.12	0.01	0.04	*0.08*	*0.02*
Trace elements (ppm)											
Cr	41.3	26.2	10.0	10.2	11.9	7.6	53.7	10.1	21.38	*5.0*	*14.5*
Ni	51.8	40.9	4.6	10.0	3.6	7.5	15.8	2.3	17.06	*5.8*	*<2.0*
Sr	238.2	227.7	228.4	364.1	414.6	378.8	501.6	192.0	318.18	*349.9*	*195.2*
Ba	124.4	135.4	202.8	305.8	290.2	119.3	498.6	70.2	218.34	*40.2*	*91.5*
Zr	272.4	347.9	248.0	437.4	347.4	343.7	222.2	338.0	319.63	*106.2*	*384.8*
R (%)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5			

"<" means less than detection limit

The result reveals that almost all recycled samples were rich in SiO_2 followed by CaO. The same result was observed with natural sand (NFA) but, for natural coarse aggregates (NCA). the results showed that CaO was richer than SiO_2. These results suggest that the original concrete mix of rubble particularly from single-storey buildings was mainly composed of sandy material and/or less cement material, while NCA (coarse aggregates) samples were sourced from limestone quarry site sources. Based on the results of C&D waste composition (Sabai *et al.*, 2013). the concrete, which also contains cement–sand matrix like mortar comprises about 39% of C&D waste recycled in Tanzania; the rest is almost cement–sand matrix waste. These results suggest that the original rubble was dominated by sandy materials (fine aggregates) and/or less cement was used in the concrete mix.

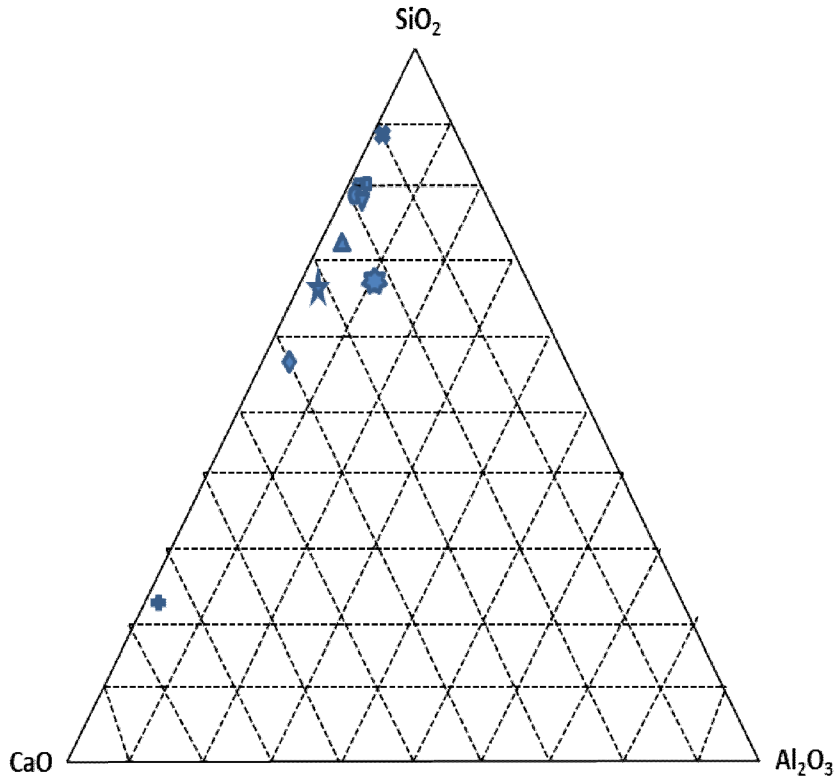

Figure 4: Ternary diagram (*redrawn*) for the abundant oxides such that SiO_2-CaO-Al_2O_3 (●= CS, ▲=DS3, ■= DS1, ♦= DM1, ✖=DS2, ⬢= NFA, ★ =DM2, ✹ = CM, ✚= NCA, ▼ =DM3) *(adopted from Sabai, 2013)*

Thermogravimetric analysis

Thermogravimetric analysis (TGA) was performed on all samples in order to correlate the mass loss at increased temperature with the presence of $CaCO_3$ in the compositions. Carbonates decompose at a higher temperatures (600 °C – 800 °C). releasing CO_2 (Sabai *et al*, 2011a; Angulo *et al*., 2009). It was expected that the mass loss would also correlate with the aggregate crushing value, because of the difference in hardness between SiO_2 and $CaCO_3$ (Sabai *et al.*, 2011a). According to Sabai *et al* (2011a). the mass loss of all considered 10 samples between 23 ^{0}C and 1000 ^{0}C were including 12%, 8%, 16%, 23%, 13%, 19%, 11%, 12%, 37%, and 0.2% for DS1, DS2, DS3, DM1, DM2, DM3, CM, CS, NCA, and NFA samples, respectively. The results showed that the NCA sample had the highest mass loss, suggesting the highest $CaCO_3$ content. This correlates also very well with the lowest crushing value that the NCA had of all samples (

Figure **5**). When comparing this correlation remains valid for all materials with DS2 having the lowest mass loss (Figure 5). Again, the DS3 and DM3 samples gave very similar results.

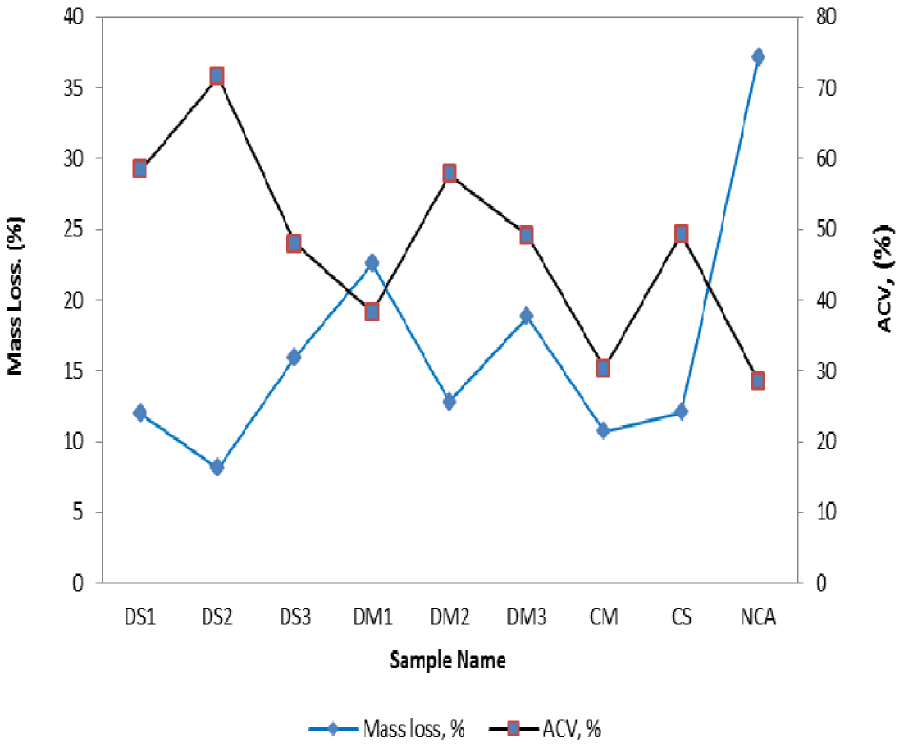

Figure 5: Relation between mass loss and aggregates crushing value (ACV) *(adopted from Sabai, 2013)*

In addition, analysis was carried out to determine the relationship between mass loss and contents of SiO_2 and CaO oxides as per XRF analysis (Table 4) for all samples and the results are presented in Figure 6 and Figure 7, respectively. Results in Figure 6 show that mass loss is inversely proportional to the amount of SiO_2 present to the aggregate sample. Once again, the DS3 and DM3 samples gave similar results. For Figure 7, the relationship between mass loss and CaO shows that mass loss has good agreement with the amount of CaO present in the aggregate sample.

The lower amount of CaO content in recycled aggregates samples (for example, the DS2 sample) observed as compared to NCA (i.e., sample normally used as coarse aggregates in Tanzania). suggests that the original concrete mix of the rubble had limited amounts of coarse aggregates (i.e., NCA) as well as cement content which in turn resulted in the production of rubble that was weak. The weak recycled aggregates were then expected to produce a weak recycled product. So, to use the same recycled aggregates for the production of building materials with higher value, appropriate techniques are required to be further investigated. This is within the scope of this study even though it will be presented as an independent paper.

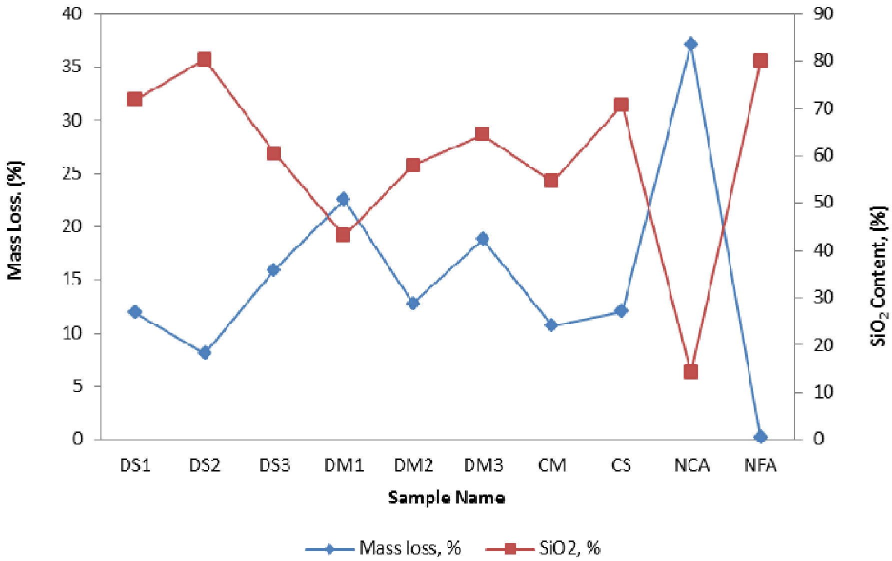

Figure 6: The relationship between mass loss and aggregates SiO_2 content *(adopted from Sabai, 2013)*

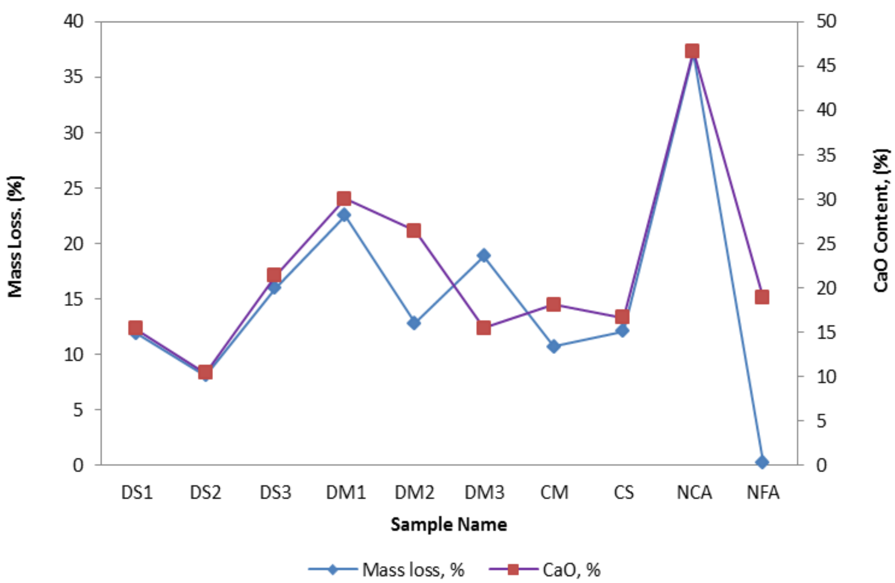

Figure 7: The relationship between mass loss and aggregates CaO content *(adopted from Sabai, 2013)*

Results of the chemical composition from Table 2 were further analyzed using Equation 2 to understand the amounts of $CaCO_3$ and SiO_2 phases present in both recycled and natural aggregates. TGA (Mass loss) was analyzed as well and the results are presented in Table 3. The results showed that the aggregates of DM1 sample were almost similar to NCA which were mainly composed of $CaCO_3$, while the rest were composed of SiO_2. Based on physical observation made during the crushing process, only the CM sample was a construction waste (rubble) that was composed of granite stones. The rest were composed of limestone aggregates. As it is known that limestone is mainly composed of $CaCO_3$, it was therefore anticipated that most of the recycled aggregates have higher amounts of $CaCO_3$ than SiO_2.

However, the outcome was different because more recycled aggregate samples were composed of SiO_2 phase. This condition may be attributed to the fact that the original concrete mixes of the recycled concrete rubbles were mainly composed of sandy material than other materials like cement and coarse aggregates. This may in turn result in the production of poor cement paste (e.g. concrete blocks) due to the low cement quality used which influences the weak particles bonding (hardening) condition. This condition is more likely to prevail in Tanzania because according to field survey conducted on local concrete block producers; it was found that there were concrete blocks produced in Tanzania having the compressive strength of 2.1 N/mm^2 which is too low compared to specified standards of 3.5 N/mm^2 of infill blocks or 7 N/mm^2 for load bearing capacity standards of (Sabai *et al*, 2013; Soutsos *et al*, 2004; TZS 283:2002(E); Neville, 1995; Jackson and Dhir, 1988). Therefore, origin rubble was mainly composed of sandy material than coarse material as well as cement contents. This condition suggests that the original concrete mix in Tanzania was weak and has impact to the recycled aggregates.

Table 3: Chemical analysis of recycled and natural aggregates in Tanzania

Sample name	SiO_2	CaO	$*CaCO_3$	Mass loss (%)
	%wt.	%wt.	%wt.	%wt.
DS1	71.81	15.43	27.55	11.95
DS2	80.37	10.42	18.61	8.13
DS3	60.54	21.36	38.14	15.98
DM1	43.12	30.00	53.57	22.55
DM2	58.04	26.46	47.25	12.81
DM3	64.52	15.45	27.59	18.87
CM	54.56	18.10	32.32	10.71
CS	70.67	16.64	29.71	12.09
NCA	14.17	46.64	83.29	37.16
NFA	80.00	18.90	33.75	0.20

**Refer to Equation 2*

Furthermore, the relationship between SiO_2 and CaO contents were analyzed and the results are presented in Figure 8. The results showed that SiO2 contents decrease as CaO content increase regardless of the different sample sources used. These results suggest that in order to produce a stable recycled product with low mass loss (i.e. thermal decomposition); the addition of the materials (e.g., mineral material) with rich SiO_2 composition should be focused rather than those rich in CaO composition. This fact puts a challenge to the recycling of the C&D waste with high CaO composition than SiO_2 into new products with a higher quality value. This is the situation which is facing the Tanzanian recycling sector because 80% of recovered C&D waste for recycling originates from limestone (CaO). Even though the chemical composition presented in Table showed that the recycled aggregates in Tanzania is mainly composed of SiO_2, this is due to the fact that the original concrete mix of cementitious rubble contained large amounts of sand-cement paste which gave the impression of a composition of high amounts of SiO_2 (quartz).

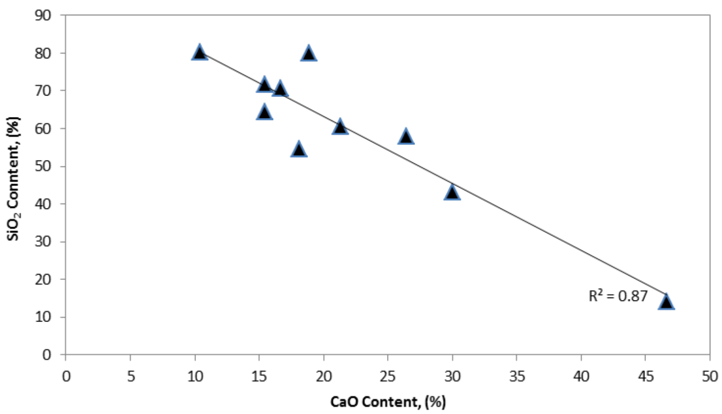

Figure 8: The Relationship between SiO_2 and CaO contents of the recycled aggregates in Tanzania *(adopted from Sabai, 2013)*

CONCLUSIONS

The results showed that C&D waste generation in Tanzania increased from 3.03 million tonnes to 7.9 million tonnes in the period ranging from 1994 to 2010 years. This condition shows that C&D waste generation in Tanzania, like in other countries, is increasing as the time goes. Therefore, recycling of this C&D waste is essential. The recycling of C&D waste generated annually in Tanzania may reduce, by almost the same amount, the amount of natural (virgin) materials (i.e., mineral source for aggregates) used in building materials, like in concrete blocks production. This practice will, therefore, contribute to conserve available natural resources for future use as well as reduce the waste disposal burden to the environment.

The results from chemical–mineralogical investigations reveal that chemically, the recycled aggregates from building construction and demolition waste in Tanzania have no significant differences in inorganic contaminants which may affect the building materials quality produced from these aggregates. This condition shows that the recycled C&D waste are suitable for use in new concrete block production in Tanzania. Furthermore, the similarities and differences in chemical–mineralogical composition between recycled aggregates and those from natural sources indicate that low amounts of cement were used in the original concrete waste.

It can be also concluded that recycled aggregates are weaker than natural aggregates not because of undesirable chemical-mineralogical elements; instead it is attributed to the poor cement paste due to the poor original concrete mix of the recycled aggregates. The use of recycled C&D waste into building material will contribute to social, economic, and environmental improvements for sustainable construction. However, investigation of advanced recycling technology to recycle C&D waste into building materials i.e., concrete block with load bearing capacity in Tanzania needs an independent study.

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REFERENCES

Angulo, S.C., Ulsen, C., John, V.M., Kahn, H. and Cincotto, M.A. (2009). Chemical–mineralogical characterization of C&D waste recycled aggregates from São Paulo, Brazil, *Waste Management*, 29, 721-730.

Bianchini, G., Marrocchino, E., Tassinari, R. and Vaccaro, C. (2005). Recycling of construction and demolition waste materials: A chemical–mineralogical appraisal. *Waste Management*, 5, 149–59.

Boyle, J. (2012). Dar es Salaam: Africa's next megacity?, BBC News, Dar es Salaam. http://www.bbc.co.uk/news/magazine-18655647; [Viewed December 2012].

Chan, C., Banthia, N. and Sakai, K. (2000). Use of recycled aggregates. In: Shortcrete, Concrete Technology for a Sustainable Development in 21st Century, Edited by Odd E. Gjorv and Koji Sakai, E&FN Spon, New York, USA.

Daily Commercial News and Construction Records (DCNCR, 2013). Government probe faults construction materials for Bangladesh building collapse. The Associated Press, Online at: http://dcnonl.com/cgi-bin/dcnhome.pl?rm=print_story&story_id=55515&source=article [Accessed on May 2013].

Dolan, P. J., Lampo, R. G. and Dearborn, J. C. (1999). Concepts for reuse and recycling of construction and demolition waste. US Army Corps of Engineers: Construction Engineering Research Laboratories. USACERL Technical Report 99/58.

Ekanayake, L. L. and Ofori, G. (2000). Construction material wastes source evaluation. Department of Building, National University of Singapore Proceedings: Strategy for a Sustainable Built Environment, Pretoria.

Golton, B. L. (1997). Illuminating the cumulative impact of small decisions- A study on building demolition, Brandon, P.S., Lombardi, P.L. and Bentivegna, V. (eds). *Evaluation of the Built Environment for Sustainable*, E&FN Spoon, London, UK.

Jackson, N. and Dhir, R. K. (1988). *Civil Engineering Materials*. 4th Edition, ELBS with Macmillan: Hong Kong.

Kartam, N., Al-Mutairi, N., Al-Ghusain, I. and Al-Humoud, J. (2004). Environmental management of construction and demolition waste in Kuwait, *Waste Management*, 24, 1049-1059.

Kizito, M. (2013). Corruption engulfs construction sector in Tanzania, Thomson Reuters Foundation, Online at: http://www.trust.org/item/20130523074657-ep7jl/.

Lichtenberg, J. J. N. (2006). SlimBouwen, a strategy for efficient and sustainable building innovation, *Joint 2006 CIB W065/W055/086 International Symposium Proceedings*, Edizioni scientifiche Italiane, Italy.

Limbachiya, M. C., Marrocchino, E. and Koulouris, A. (2007). Chemical–mineralogical characterisation of coarse recycled concrete aggregate. *Waste Management*, 27, 201–208.

Mueller, A., Sokolova, S. N. and Vereshagin, V. I. (2008). Characteristics of lightweight aggregates from primary and recycled raw materials. *Construction and Building Materials*, 22, 703–712.

McDonald, B. (1996). RECON waste minimization and environmental programme. In: Proceedings of CIB Commission Meetings and Presentations.

Neville, A. M. (1995). *Properties of Concrete*, 4th Edition. Longman Group Limited: England.

Oikonomou, N. D. (2005). Recycled concrete aggregates. *Cement and Concrete Composite*, 27,315–8.

Poon, C. S. (2007). Management of construction and demolition waste. *Waste Management*, 27, 159-160.

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

Sabai, M. M., Cox, M. G. D. M., Mato, R. R., Egmond, E. L. C. Lichtenberg, J.J.N. (2013). Concrete block production from construction and demolition waste in Tanzania, *Resources, Conservation and Recycling, 72,* 163-177.

Sabai, M. M., Marinescu, M.V. A., Mato, R. R., Brouwers, H. J. H., Egmond, E.L.C. and Lichtenberg, J.J.N. (2011a). Investigation on the possibilities for recycling construction and demolition waste in to building materials in Tanzania. *In: Proceedings of EurAsia Waste Management Symposium*, Istanbul, Turkey, November.

Sabai, M. M., Lichtenberg, J. J. N., Egmond, E.L.C., Mato, R.R.A.M. & Ngowi, J. (2011b). Use of recycled aggregates from construction and demolition waste for building construction in Dar es Salaam, Tanzania. *Proceeding of CIB International Conference "Local Wisdom in Global Era"- Enchancing the Locality in Architecture, Housing and Urban Environment.* Yogyakarta, Indonesia. January.

Soutsos, M. N., Jones, N., Millard, S.G., Bungey, J.H., Tickell R.G. and Gradwell, J. (2004). Precast concrete building blocks made with aggregates derived from construction and demolition waste, *In the proceeding of International RILEM Conference on the Use of Recycled Materials in Buildings and Structures*; 8-11 November 2004, Barcelona, Spain available online: http://congress.cimne.upc.es/rilem04/admin/Files/FileStudy/p328.pdf

TZS 283:Tanzania Standard, Concrete bricks and blocks (masonry units) – Specification; 2002(E)

TZS 58 (Part 1): Tanzania Standard, Aggregates - Part 1: Sampling and classification; 1980.

TZS 58 (Part 2): Tanzania Standard, Aggregates - Part 2: Natural aggregates for concrete (Specification); 1980

TZS 58 (Part 3): Tanzania Standard, Aggregates - Part 3: Sampling and test methods; 1980

United Republic of Tanzania (URT, 2004). Environmental Management Act (EMA, 2004). Vice President Office, Dar es Salaam, Tanzania.

United Republic of Tanzania (URT, 2003). Construction industry policy (Tanzania). Dar esSalaam: Ministry of Works, Dar es Salaam, Tanzania.

United Republic of Tanzania (URT, 1998). Dar es Salaam Central Area Redevelopment Plan, Ministry of Land and Human settlements Development-Directorate of Human Settlement, Dar es Salaam, Tanzania.