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Applicability of LCA Tools for Building Materials Produced From Construction and Demolition Waste: Case of Tanzania

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It is estimated that about 10 million tonnes of construction and demolition (C&D) waste is generated annually in Tanzania. This waste is expected to increase even more because of population increases, urbanization, industrialization and commercialization which results in more utilization of natural resources as well. The stock of material resources (raw materials) decrease worldwide and any excessive material extraction puts pressure on natural resources, including ecosystems which depend on this resource for survival. This justifies the research to find a proper technology for recovery (reusing, recycling and upcycling) of C&D wastes which would alleviate the excessive extraction and utilization of natural resources. The research aims at solutions to use the C&D waste to produce building materials (for example concrete blocks) which is a commonly used building material in Tanzania. To ensure the sustainability of such building materials, the environmental, social and economic parameters have to be assessed by using a Life Cycle Assessment (LCA) tool. Life cycle assessment is a technique for assessing the environmental impacts associated with a product over its life cycle. Currently, most of Life Cycle Assessment tools applied are developed in developed countries such as SimaPro (Netherlands), INVEST (United Kingdom), BEES (United States) *etc.* Their direct applicability is limited due to the fact that they are developed in countries with different environmental conditions as well as economic status. Therefore, this research paper discusses the identification of an appropriate Life Cycle Assessment tool which can be applied in research to determine the extent to which building products resulting from construction and demolition waste are sustainable in ecological sense.

Keywords: Sustainability, Innovation, LCA tool, building materials, recovery, C&D wastes, Tanzania

1.0 Introduction

Shelter is one of the basic needs of man. Since beginning of time man has exploited natural resources to provide shelter. The total amount of locally available materials used to produce building materials in Tanzania is only 47% (NCC, 1992). Almost all locally available building materials are derived from natural resources (Lowton, 1997). The rest is imported. Importation of building materials was even encouraged by the Tanzanian Government, given the fact that there were deficit of materials like cement (Guardian paper of 29th December 2007). Even though building materials are limited in many countries like Tanzania, the demand for these materials increases day to day.

Increased building construction activities on other hand increase the waste generation from construction and demolition activities. According to Ding (2005), construction industry worldwide, is responsible for high levels of pollution resulting from the energy consumed during the extraction, processing and transportation of raw materials (see Appendix A).The construction industry has a significant irreversible impact on the environment across a broad spectrum of its activities during the off-site, on-site and operational activities, which alter ecological integrity (Uher 1999). It is a wasteful sector and is responsible for 12-16% of fresh water consumption; 25% of wood harvested; 30-40% of energy consumption; 40-47% of virgin material extracted; 20-30% of greenhouse gas emission; 35-44% of the total waste stream of which 15-30% ends up in landfills; and up to 15% of purchased materials at job site end up as waste (NCC, 1992, McDonald, 1996, Ekanayake and Ofori, 2000; Muller, 2000; and Macozoma, 2002; Lichtenburg, 2006). It is estimated that for every 1 kg of cement produced, 1 kg of CO_2 emission is released (Mora, 2007). According to McDonald, 1996; Manyele, 2004; Lichtenburg, 2006, the amount of C&D wastes ranges from 35-44% to those wastes put into landfill. For the case of Tanzania, it is estimated that the amount of wastes generated from construction and demolition activities is 10 million tonnes per year (as 40% to the waste disposed). The generation of C&D waste arises every year in both developing and developed countries. For example, in The Netherlands (developed country), C&D waste increased from 11 million tonnes in 1999 (EU commission, 2000) and it is estimated to be 22 million tonnes in 2006 (Lichtenberg, 2006). It doubled for only 17 years. This predicts that for 20, 30, 50 years to come, the generation of C&D wastes will be doubling and tripling.

Still, the demand and consumption of natural resources continue to increase. In Tanzania, for example, the demand for aggregates was 60 million in 1997 (Woodbridge, 1997). This was equivalent to 2 tonnes of aggregates required per capita annually. In Tanzania where population estimated to be 43.7 million (in 2009) and 109.5 million (in 2050) according to World Population Data Sheet (2009), it gives the amount of aggregates required to satisfy the demand is 87.4 million tonnes and 219.0 million tonnes respectively. This indicates that the natural resources demand increases as the population increase, and urbanization, agriculture and commercialization expand in Tanzania like other countries in the world. This means that building materials competition and conflict are expected to increase more in future. Mufuruki *et al* (2007) predetermined that the current expansion of the construction industry in Tanzania with resource depletion will result in conflicts among users. The increased building materials use, depletion of its source (origin), and at the same time increases in the generation of the C&D wastes (residues) will result in building material deficit. This gives a bad signal for the future. Therefore, a proper technology is needed to support and alleviate the building materials problem and enable the reuse of C&D wastes into construction industry in a sustainable manner.

To achieve sustainable innovative building construction in Tanzania and other countries, an opportunity could be found in the so-called "*Slimbouwen"* strategy and the use of concrete blocks produced from C&D wastes. Concrete blocks are the dominantly used building material in developing countries like Tanzania. The technology should be able to recycle and upcycle the C&D waste to produce building materials that should comply local and international standards to safeguard inhabitants. Concrete block production from construction and demolition waste as a technology that will be applied to produce building materials from recycled and upcycled C&D waste in order to reduce threats to natural resource and environment as whole. According to Lichtenberg (2006), Slimbouwen is a building strategy which focuses on process efficiency, flexibility and reduction of material utilization and wastes production, emissions, energy and the environmental impact at large (this is beyond of the scope of this paper). The authors therefore aim to discuss on identification of an appropriate Life Cycle Assessment tool which can be applied in research to determine to which extent building products produced from construction and demolition waste are sustainable in the ecological sense.

2.0 Production of Concrete Blocks from Construction and Demolition waste

A concrete block is primarily used as a building material in the construction of structural walls. It is used extensively in building and civil engineering construction for works both below and above ground. In use, concrete blocks are stacked one at a time and held together with fresh concrete mortar to form the desired length and height of the wall. Why concrete block? Concrete blocks were chosen due to the fact that: in building and civil engineering applications concrete blocks estimated to be 70% of all materials used; building wide range of products and finishes; low movement; durability; excellent thermal properties; excellent acoustic properties; outstanding energy efficiency and green guide rating. Others include concrete blocks high acceptable in urban areas for all types of buildings. They are also very popular as a long lasting, low maintenance, materials for institutional and industrial buildings. Also, in concrete block technology utilizes wastes and local resources, has cost effective compared to other traditional walling systems; its structural performance can be engineered; it can be decentralized in local production and offers business opportunities.

The main goal is to develop a technique which can reuse, recycle and upcycle construction and demolition waste by producing concrete blocks which will qualify being used as building materials for different buildings construction in Tanzania and other countries of the world. Laboratory trials will be employed to determine the material product which can satisfy building material requirements. This is important because nowadays most of the recycling techniques are downcycling; this revealed by Ministry of Housing and Spatial Planning and the Environment (MHSPE, 2001) which stated that the environmental standards of recycled (secondary) materials are laid down in the building materials. The author (MHSPE, 2001) continued to explain that the recycled building materials are mostly used for construction of road foundations and small extent as a substitute for gravel in concrete. MacDonough and Braungart (2002) also**,** described that mostly recycling refers to down-cycling because it reduces the quality of materials. This indicates that, available recycling techniques in both developing and developed countries are down-cycling the recyclable C&D waste. Poon, *et al* (2002), tried to develop a technique for recycling C&D waste to produce building materials, but ended up producing concrete bricks and paving blocks using C&D waste which was used for pavement purposes. Even though, the compression and transverse strengths were achieved. The authors concluded that the replacement of coarse and fine natural aggregates by recycled aggregates at the levels of 25% and 50% had little effects on compressive strength of bricks and block, but higher levels of replacement reduced the compressive strength. Authors (Poon et al, 2002) also recognized that by using recycled aggregates as the replacement of natural aggregates at the level of up to 100%, concrete paving blocks with a 28-day compressive strength of not less than 49 MPa produced without incorporation of fly ash. Paving blocks for footway uses with a lower compressive strength of 30 MPa and masonry bricks were produced with incorporation of fly ash. Because such analysis do not usually include the of the product it is not possible to use them for construction. It is therefore necessary that the any building materials produced should be analyzed in terms of quality parameters including physical, mechanical and chemical composition. In order that the technique can be applied in producing building materials, the generated product should meet both local and International Building Material Standards. Analysis of the building material quality is part of the ongoing research but beyond scope of this paper.

2.1 Concrete Blocks Design

The shapes and sizes of most common concrete blocks have been standardized to ensure uniform building construction. The most common block size in the United States is referred to as an 8-by-8-by-16 block, with the nominal measurements of 8 in (20.3 cm) high by 8 in (20.3 cm) deep by 16 in (40.6 cm) wide. This nominal measurement includes room for a bed of mortar of 1 cm, and the block itself actually measures 7.63 in (19.4 cm) high by 7.63 in (19.4 cm) deep by 15.63 in (38.8 cm) wide (Koski, 1992). In Tanzania, the most common concrete blocks (locally known as chipping blocks) dimensions are 45/46 cm length x 15 cm width x 23cm height, normally applied mix ratio of 1.5:12:9 of cement sand and gravel respectively and gives the compressive strength of 700 to 800 N/cm^2. When manufacturers design a new block, they must consider not only the desired shape, but also the manufacturing process required to make that shape. Shapes that require complex molds or additional steps in the molding process may slow production and result in increased costs. In some cases, these increased costs may offset the benefits of the new design and make the block too expensive.

2.2 Raw Materials

There are four basic structural materials that are employed in building construction such that wood, concrete, masonry, and steel (Nweman, 1968). These materials will be focused in generating the new building materials product such as concrete blocks. The concrete commonly used to make concrete blocks is a mixture of powdered Portland cement, water, sand, gravel and admixtures. In general, the concrete mixture used for blocks has a higher percentage of sand and a lower percentage of gravel and water than the concrete mixtures used for general construction purposes. This produces a very dry, stiff mixture that holds its shape when it is removed from the block mold. A typical concrete block weighs between 17.2-19.5 kg (Koski, 1992) which is equivalent to 4.5 bricks, thus construction is faster than with other masonry units. Water also will be used as material required generating concrete blocks. When Portland cement is mixed with water a chemical reaction takes place which makes the cement harden. In this research paper, materials required for generating concrete blocks are those recycled from C&D waste. The laboratory trials will start with generating blocks from crushed concretes. If the recycled concrete will not comply with standards, steel fibers and/or timbers will be added in order to get the concrete block product which meet not only physical quality but also mechanical and chemical composition as specified with local and international standards. The aggregate from the source will be used for comparison purpose.

2. 3 Production Process

In order to improve the building materials sector in developing countries, Tanzania inclusive, we have to address the needs of the majority of the population. Majority of them in developing countries need building materials that are required for walling, roof-cladding and binders. There are two types of concrete block technologies in production process: Large and small scale technologies. This paper will focuses on discussing small scale building material techniques because large scale technologies require good quality, large deposits raw materials to function and also is energy intensive. Small scale technologies however, can operate on small scale deposits which are often discarded as raw materials of no economic value and also the technology is related to energy, labour and capital (Ramachandran, 1989). For producing concrete blocks from C&D wastes (residues), the small scale technology is recommended because the waste generation is scattered and also reduces transport costs. Table 1 below indicates that the small scale technology is viable in developing countries because the production cost is low. For the case of Egypt and Ghana countries (developed showed that the production costs for the small scales £E 22.79 and Cedis 73.91 were smaller than those of large scales £E 25.74 and Cedis 116.5 respectively.

Table 1. Cost of production of concrete blocks at different scales of production

	Egypt (Cost per ton production, £E)				**Ghana (Cost per 150 mm block, Cedis)**			
	Large		Small		Large		Small	
	£E	Percentage	£E	Percentage	Cedis	Percentage	Cedis	Percentage
Raw Material	12.92	50.2	15.76	69.2	49.6	42.6	43.0	58.2
Energy and fuel power	0.52	2.0	0.22	1.0	2.7	2.3	0.09	0.1
Direct labour	1.6	6.2	3.47	15.2	1.0	0.9	5.0	6.8
Other Costs (Depreciation, administration, etc.)	10.70	41.6	3.34	14.6	63.20	54.2	25.82	34.9
Total production Cost	25.74		22.74		116.5		73.91	

Source: Ramachandran, (1989) UN-Habitat

In a small scale technology, concrete blocks are usually produced using a semi-mechanized stationary type machine. The other production systems are - manual moulds that require hand tamping. The machine also compacts and consolidates the mix so that the blocks are uniform in size and attain desired physical properties.

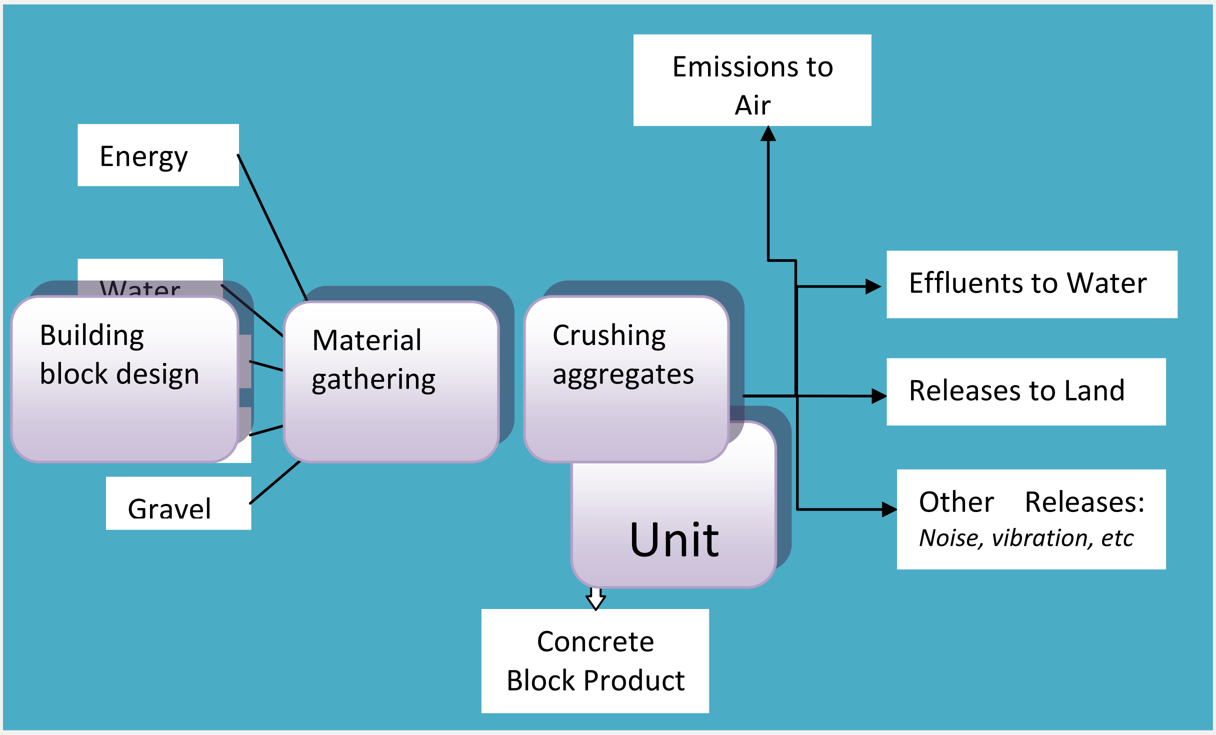
The production of concrete blocks consists of four basic processes: mixing, molding, and curing. The following steps are commonly used to manufacture concrete blocks.

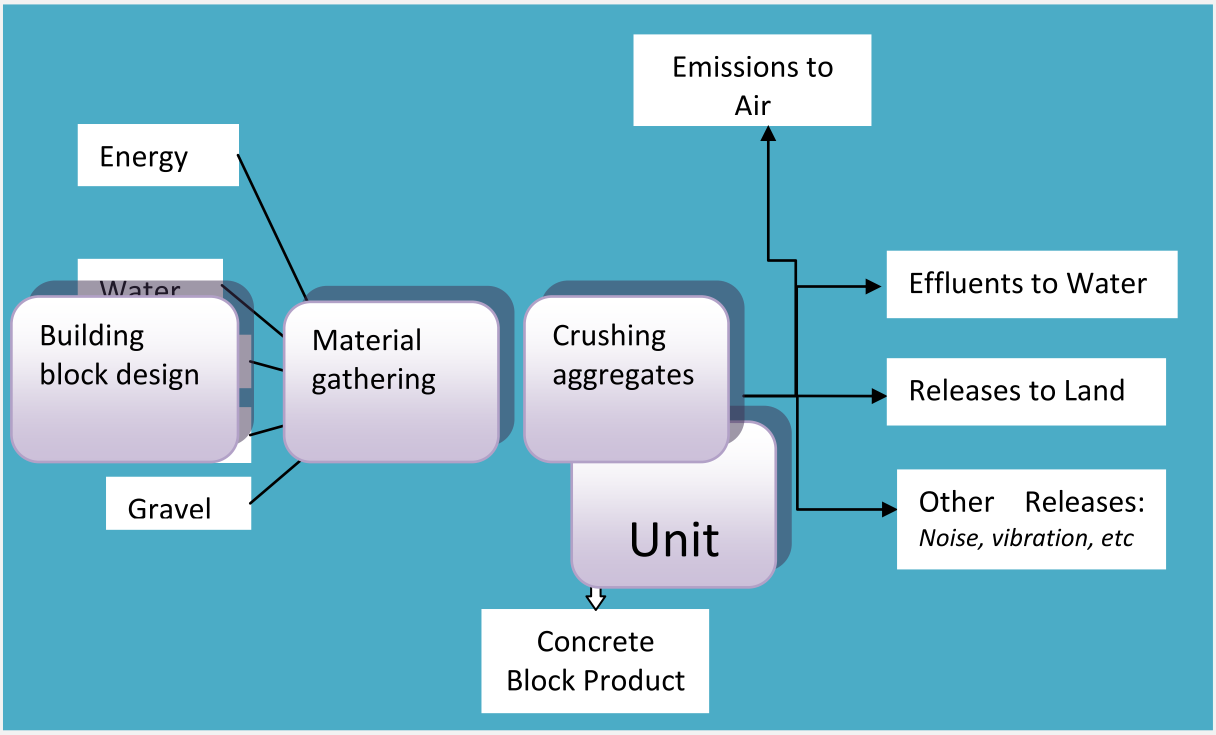
2.3.1 Mixing: For labour-based technology, the crew hauls the sand and gravel from storage site. The portland cement is stored outside in large vertical silos and/or sealed bags to protect it from moisture. As the production run starts, amount of sand and gravel are estimated with respect to number of cement bags by using equipments like wheelbarrows. The dry materials are then mixed and blended. The mixing starts with cement and sand and then gravel is added. This makes the mixing process easier and effective. After the dry materials are blended, water is added. Admixture chemicals and coloring pigments may also be added at this time.

2.3.2 Molding: Once the load of concrete is thoroughly mixed, material is fed into an open top mold from the top side. The conventional mold consists of stationary sides, to define the sidewalls of the block, and an open bottom. A removable pallet is used temporarily to close the open bottom of the mold and serve as a base during the block forming operation (see Figure 1&2 below). During manufacturing process, the material introduced through the open top, when the molds are full, the concrete is compacted by the weight of the upper mold head coming down on the mold cavities. A compression head is then pressed downwards under high pressure onto the material through the open top of the mould to compact the material therein. The head forces material into the mold so as to conform to the shape of the mold. The mold may also be vibrated during compaction to promote uniform compaction.

Figure 1: moulding concrete block machine (*Source: Development Alternatives (2009*)**.**

3.3 Curing: After moulding, the concrete block will be cured. After 28 days, tests will be carried out to check quality. If the recycled concrete blocks quality will not meet available standards, the steel fibers and/or wood have to be mixed into concrete mixture in order to get the concrete block products which, comply not only with physical quality but also mechanical and chemical composition of the local and international standards, that and can be applied to building construction industry. By achieving this, recycled C&D wastes will be no longer problem to the environment; rather, it will be valuable resource in the society.


Emissions to Air
Energy
Water
Building block design
Material gathering
Crushing aggregates
Effluents to Water
Releases to Land
Gravel
Unit
Other Releases: *Noise, vibration, etc*
Concrete Block Product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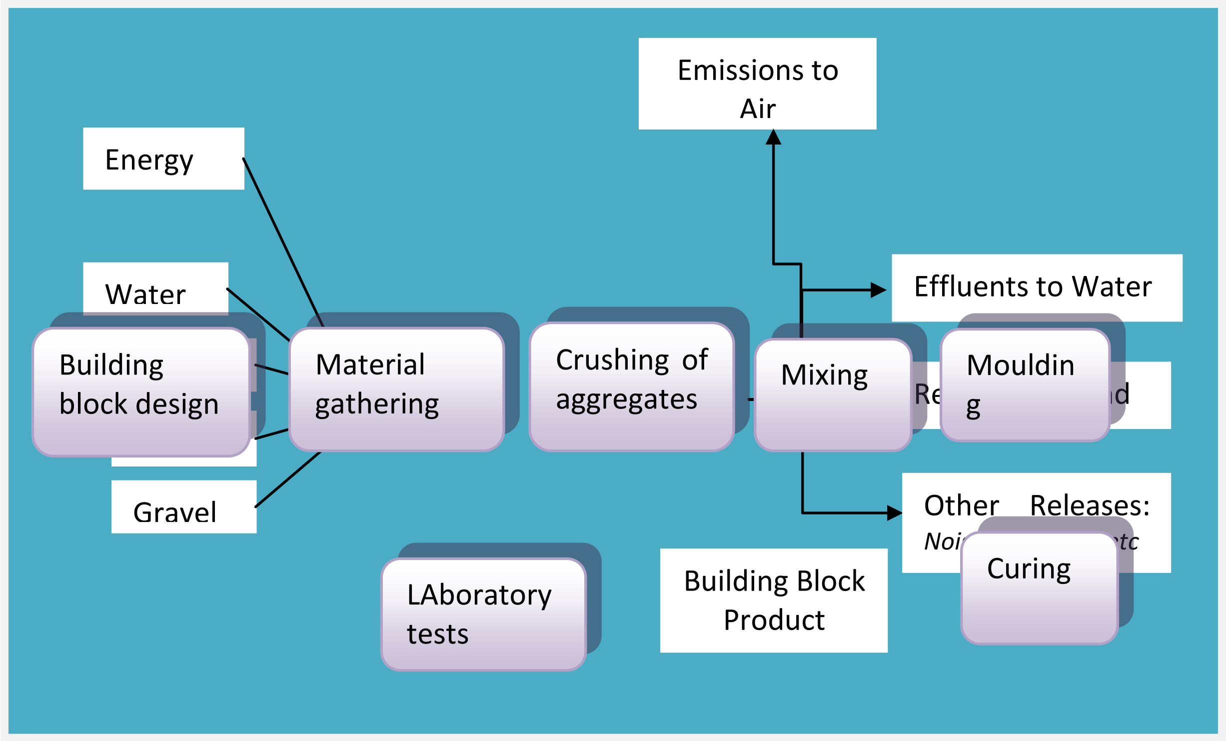

Figure 2: Concrete Block generation process

2.4 Quality Control

The manufacture of concrete blocks requires constant monitoring to produce blocks that have the required properties. The requirements for structural concrete of a building depend upon the concrete durability, water tightness, and resistance to deterioration; the economics of the construction; and the strength of the concrete that will be needed to resist the dead and live loads (Newman, 1968). Both concrete blocks produced from natural resource and those recycled from C&D waste should comply with the local and international standards. The specimens should be measured in the laboratory regularly. But also the production processes should be supervised well to ensure the required mixed ratio(s), mixing and molding done well. In the curing kiln, the temperatures, pressures, and cycle times are all controlled to ensure that the blocks are cured properly in order to achieve their required strength.

3.0 Building Material Production Assessment Tools

Most of the environmental building assessment tools cover the building level and based on some form of life-cycle assessment database (Seo *et al.*, 2006). Tools are basically in two categories: assessment and rating tools. Assessment tools provide quantitative performance indicators for the design alternatives whilst rating tools determine the performance level of a building in stars (Ding, 2008). Rating tools include BREEAM in the UK, and LEED in the United States (Edwards and Bennett 2003) while assessment tools include SimaPro and Eco-Quantum (Netherlands), EcoEffect (Sweden), ENVEST (U.K), BEES (U.S.A) ATHENA (Canada) and BeCost (Finland). Since, in this paper deals with building material and not the entire building, the assessment tools are used for determining the sustainability of the building material production from construction and demolition waste. The Life-Cycle Assessment (LCA) and sustainable index tools have been discussed. The appropriate method applicable for determination of sustainability of concrete block product will be recommended.

3.1 Life Cycle Assessment (LCA) tools

Life cycle assessment model (LCA) is the useful model for understanding, assessing, and reducing the environmental consequences of our actions. The notion of life cycle assessment has been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative materials, components and services and is, therefore, a logical basis on which to formulate building environmental assessment tools (Cole, 1998). Life Cycle Assessment (LCA) is a method which assists in identifying opportunities to improve the environmental performance of products/services at various points in their life cycle, informing decision-makers in industry, government etc, the selection of relevant indicators of environmental performance, including measurement techniques, and marketing (ISO 14040:2006). Rather than looking only at a specific part of a life cycle, LCA analyses the whole system of production, from raw material extraction and manufacture through to use and disposal (Werner, 2005). According to ISO 14040:2006, LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. LCA is an iterative technique, so it enables individual phases of an LCA to use results of the other phases. In order to ensure a proper interpretation of the executed LCA results, the transparency is an important guiding principle. LCA considers all attributes or aspects of natural environment, whereby the guiding principles for attribution in ISO 14041 are: the scope and goal dependent choice of life cycle stages and processes, and the relevance of particular flows in relation to the total flows or to total environmental impact (Werner, 2005).

Life cycle assessment study comprised four phases namely: the goal and scope definition, inventory analysis, impact assessment and interpretation (application is out of the framework)(see Figure 3 below). With LCA it is possible to identify the potential environmental burden between life cycle stages or individual processes and avoided.

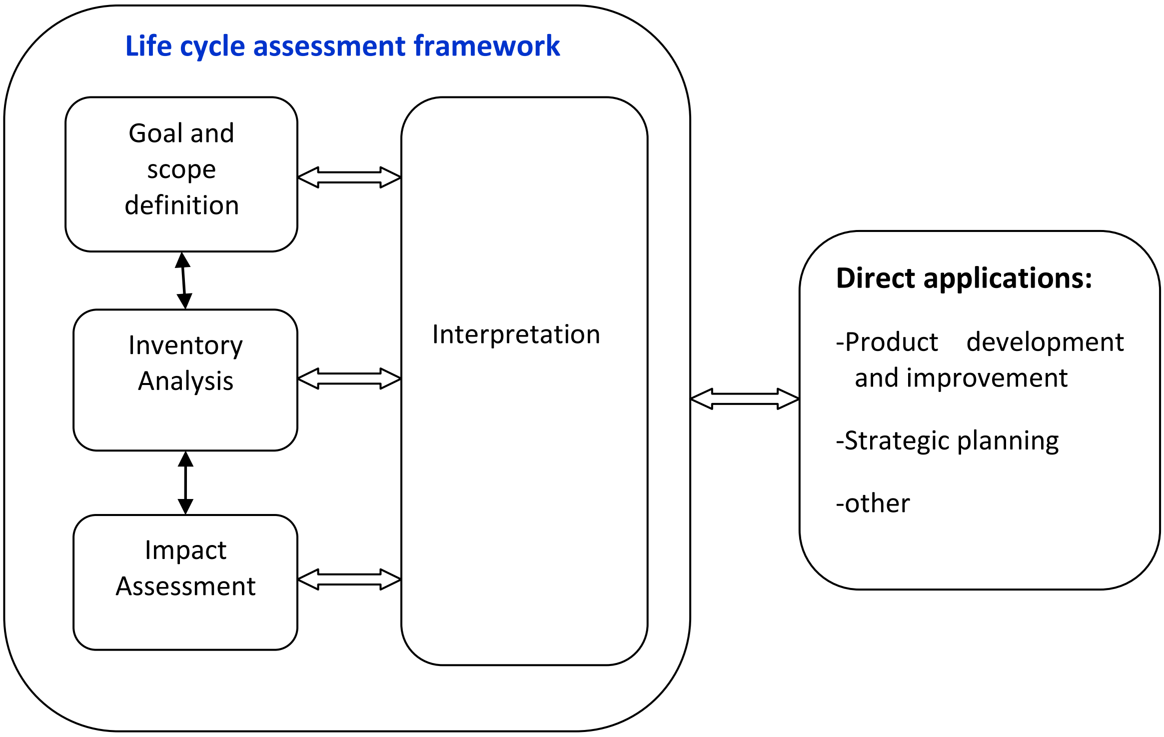

Figure 3: Stages of LCA (ISO 14040:2006)

The life cycle of the building project starts before and during physical construction activities and even at the ends after its usable life time (See Appendix A). The LCA methods are more data intensive, therefore the assessment process can involve enormous expenses of collecting data and keeping it updated, particularly in a period of considerable changes in materials manufacturing process and sometimes these data are not available in many database (Braganca and Mateus, 2007). Pushkar *et al* (2005) concluded that LCA tools can be edited to match with available existing variables and adding new ones according to local conditions. Due to this fact, it qualifies the LCA tools to be applicable anywhere regardless geographical features but the database should be edited and modified to match with the local condition and needs (goal and scope). The assessment tools, either environmental or performance-based are under a constant evolution in order to overcome their various limitations.

3.1.1 Strength of Life Cycle Assessment (LCA)

According to ISO 14040; 2006:

- LCA considers the entire life cycle of product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal.
- A potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.
- LCA addresses the potential environmental impacts of a product and service
- The depth of detail and time frame of an LCA may vary to a large extent, depending on the goal and scope definition
- There is no single method for conducting LCA. Organizations have the flexibility to implement LCA in accordance with the intended application and the requirements of the organization
- LCA may use information gathered by other techniques (i.e. environmental impact analysis, risk assessment etc.) even though they are different technically

3.1.2 Limitations of LCA:

- LCA focuses on environment dimension and does not analyze economic and social dimensions (Werner, 2005; ISO 14040; 2006).
- LCA is used as a tool within the decision support process and does not in itself encompass the whole decision-making procedure (Werner, 2005)
- LCA compresses the time dimension in the modeling phase as well as in the impact assessment phase and does not discount the future (Werner, 2005)
- Weighting in LCA varies from one place to another and this makes the LCA results differ from one place to another
- LCA phases, provides system-wide perspective of environmental and resources issues for one or more product system (ISO 14040; 2006)

3.2 Application of Life Cycle Assessment (LCA)

Life Cycle Assessment method is applied either direct or indirect for product development and improvement, strategic planning, public policy making, marketing and any activity or project which involves environmental aspects and impacts of product systems from material acquisition to final disposal (ISO 14040; 2006). According to ISO 14040; 2006, LCA is also applied in a field of environmental systems and tools including environmental management systems and environmental performance evaluation for example, identification of significant environmental aspects of the products and service of an organization. Others are, environmental labels and declaration (quality assurance), integration of environmental aspects into product design and development (design for environment), inclusion of environmental aspects in product standards. Also includes, environmental communication, quantification, monitoring and reporting of entity and project emissions and removals, and validation, verification and certification of greenhouse gas emissions etc.

These applications are applicable also to concrete blocks as a product produced from recovery of C&D waste. The LCA method is applicable to determine at what extend processes and services affects the environment during production of building materials i.e. concrete blocks. In order to achieve this specific LCA tool is required. The available LCA tools are those generated from developed countries with different economic status and atmospheric condition. For example, in making concrete block, water may be required to be heated before use. Even though, this impact is included in the process most of the developing countries for example Tanzania, are located in the tropical region whereby boiling water is not necessary. This shows that, there is no direct applicability of LCA tools and rather should be validated to suit the local condition. Almost every LCA tool has its own database. This indicates that the data is based on either local or regional condition. These LCA tools available include Eco-Quantum, Eco-Quantum (NL), SimaPro (NL), ENVEST (UK), BEES (USA), EcoEffect (Sweden), ATHENA (Canada), BeCost (Finland), etc. The LCA tools available, are all used to measure/determine the environmental performance scores of the environmental impacts. This makes the LCA methods to be effective tool on reducing the negative environmental impacts which associated with the built environment. But some of the LCA tools like ENVEST, BEES etc. considered economic performance in assessment by incorporating life cycle costing as shown in BEES Computational Algorithms (equations) below.

a) Environmental Performance

BEES environmental performance scores are derived as follows.

$$EnvScore_j = \sum_{k=1}^{p} IAScore_{jk}$$ (Source: Lippiatt, 2007) ……………….……………………(i)

Where:
EnvScorej = environmental performance score for building product alternative j;
p = number of environmental impact categories;
IAScorejk = characterized, normalized and weighted score for alternative j with respect to environmental impact k:

$$IAScore_{jk} = \frac{IA_{jk} \times IVwt_k}{Norm_k} \times 100$$ (Source: Lippiatt, 2007) ……………………….. (ii)

where
IVwtk = impact category importance weight for impact k;
Normk = normalization value for impact k;
IAjk = characterized score for alternative j with respect to impact k:

$$IA_{jk} = \sum_{i=1}^{n} I_{ij} * IAfactor_i$$ (Source: Lippiatt, 2007) …………………………………. (iii)

where
n = number of inventory flows in impact category k;
Iij = inventory flow quantity for alternative j with respect to inventory flow i, from BEES environmental performance data file
IAfactori = impact assessment characterization factor for inventory flow i

b) Economic Performance

BEES measures economic performance by computing the product life-cycle cost as follows:

$$LCC_j = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}$$ (Source: Lippiatt, 2007) ……………………………………………... (iv)

where

LCCj = total life-cycle cost in present value dollars for alternative j;
Ct = sum of all relevant costs, less any positive cash flows, occurring in year t;
N = number of years in the study period;
d = discount rate used to adjust cash flows to present value

c) Overall Performance

The overall performance scores are derived as follows:

$$Scorej = \left[(EnvWt * \frac{EnvScore_j}{\sum_{j}^{n} EnvScore_j}) + (EconWt * \frac{LCC_j}{\sum_{j=1}^{n} LCC_j}) \right] * 100$$ (Source: Lippiatt, 2007) ….. (v)

where
Scorej = overall performance score for alternative j;
EnvWt, EconWt = environmental and economic performance weights, respectively
(EnvWt + EconWt = 1);
n = number of alternatives

Since LCA assesses the life time of the products and services and how these impacts the environment (ISO 14040:2006, Ding 2008), it is single-dimension approach. The single-dimensional approach and the credit award system of the existing environmental building assessment methods are insufficient to evaluate the complex nature of the sustainability in buildings. Just why, BEES (LCA tool) considers multiple environmental and economic impacts over the entire life of the building product (Lippiatt, 2007). Even if nowadays there are LCA tools which are multi-dimensional, but as we observed above, it incorporates only environment and economic impacts but do nothing about social impact. It is clear that environmental building assessment need the multi-dimensional approach which can incorporate all building aspects in which the assessment results will influence the decision making. The tool developed by Langston and Ding (2001) is a multi-dimensional which incorporates environmental, material utilization, social and economic by maximizing the revenue and social benefits and minimizing the material utilization and environmental impacts of the projects. The tool known as *sustainability index* influences decision making process especially for selecting the best among alternatives.

3.3 Sustainability index

Sustainability can be defined as 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). The author (Young, 1997) described sustainability as a three-legged stool, with a leg each representing ecosystem (environment), economy and society. Any leg missing from the sustainability stool will cause instability because society, the economy and the ecosystem are intricately linked together. Young (1997) concluded that any measurement of sustainability must combine the individual and collective actions to sustain the environment as well as improve the economy and satisfy societal needs. This is supported by Elkington (1997) and Roar (2002) who concluded that any sustainable organization or project must be financially secure, minimize the environmental impacts resulting from activities, and conform to societal expectations. This demonstrates that the assessment of a sustainable building has to make explicit the particular cultural/societal expectation in which the development has been designed to maintain (Cooper, 1999; Kohler, 1999). Based on the principle of multiple-dimensional decision model Ding and Langston (2001) developed a multi-dimensional model for the measurement of sustainability that has the advantage of relative simplicity. The model determines a sustainability index, and can be used not only to compare options for a given problem but also to benchmark projects against each other (Ding, 2008).

A model of sustainability index as an evaluation tool combines economic, social and environmental criteria into an indexing algorithms developed in Australia for the purpose of tackling the construction problem by determining the feasibility of the project based on balancing variables of economic, social and environmental criteria to select the best option among alternatives instead of relying single or two variables (Ding, 2005). A sustainability index can provide direction to strategic planning and can make the choice among the alternatives more amenable to rational discussion to society (Krotscheck and Narodoslawsky, 1996). The sustainability index uses monetary and non monetary approaches to rank projects and facilities on their contribution to sustainability (Ding, 2005).

The sustainability index model in Australia demonstrates its applicability, effectiveness and usefulness in building construction industry (Ding, 2005) by considering multi-dimensional variables of environmental, economic, and social criteria to select the best option among alternatives. It has four main criteria which seek to maximize wealth (the objective is to maximize investment return and also profitability is considered part of the sustainability equation) and utility (utility can relate to wider community goals whereby designers, constructors and users all want to maximize utility. Also, minimize resources (these includes all inputs over the full life cycle such that materials and energy in inventory analysis) and environmental impacts (includes loss of habitat encompasses all environmental and heritage issues) (Ding, 2008). Buildings which consume lot of materials have a long life, so any improvement techniques for choosing the best option among alternatives will significantly reduce their future environmental impacts.

$$SI_i = \sum_{j=1}^{J} e_{ji} W_j \quad \text{(i=1, …, I) (Source Ding, 2008)……………………………..….…………….(vi)}$$

$$eji = f\{BCR, EC, EB, EI\} \text{ . (Source Ding, 2008)…………………………..………………….(vii)}$$

Where: SI_i = Sustainability index for an alternatives I;

W_i = weight of criterion j;

e_{ji} = value of alternative I for the criterion j

BCR = benefit-cost ratio

EC = materials input (consumptions)

EB = external benefits

EI = the environmental impact

NB: The higher value score of SI_i implies better.

The criteria included in the sustainability index are based on an absolute assessment approach and are combined into a composite index to rank options for projects at the feasibility stage (Ding, 2008). Ding (2008) revealed that the sustainability index includes the quantification of both objective and subjective measures that gives a full life cycle analysis of buildings. These factors make the sustainable index tool useful for assessing sustainability of the production of building materials from construction and demolition wastes because the whole process has environmental, economic, and social impacts. The production of building materials from recovery construction and demolition waste is a new product to the market and society especially Tanzania, its use must therefore to conform sustainability concept by assessing and achieving all dimensions of sustainability.

4.0 Conclusion and Recommendations

The aggregates demand rose from 60 million in 1997 to 87.4 million in 2009 and 219 million in 2050 respectively. This indicates that the building materials demand increases as the time goes. If the all this amount of resource will be extracted from the source it will result deficit and cause conflict among users. Therefore, reuse, recycling and upcycling of C&D wastes expected to reduce extraction of natural resource to attain demands. Reusing, recycling and upcycling C&D waste by producing building material such as concrete blocks aims to considerably reduce material flows by increasing resource utilization efficiency and extending product life. The generated concrete blocks should meet both local and international Building Material Standards. Also the production process and product must be sustainable. LCA is the one dimensional assessment tool (ISO 14040) but few tools developed tried to be multi-dimensional by incorporating economic aspects as in BEES (USA) and ENVEST (UK). But to the forgoing analysis and discussions reveals that the sustainability index is a more useful method which addresses the economic, social and environmental impacts. It is therefore can be recommended as a more appropriate method for determining the extent to which the building products resulting from construction and demolition waste is sustainable.

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Appendix A: shows the different processes in reusing and recycling C&D waste through cradle to cradle approach