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Impact Of Concrete, Steel And Timber On The Environment: A Review *

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ABSTRACT: The elements of the built environment are all products of construction. Construction uses materials obtained from natural sources or processed from raw materials obtained from natural sources. Concrete, steel and timber are used predominantly in construction. In addition to satisfying construction needs, these materials also bring about serious environmental problems. The purpose of this paper is to review the impact of the use of these three basic construction materials on the environment. It was pointed out that the negative impact could be reduced by the recycling and reuse of the materials which will reduce the consumption of new materials. The use of naturally occurring materials where available in place of these materials was also suggested as an additional means of reducing the impacts from construction materials. These were strongly recommended. It was revealed that timber is the most environmentally friendly construction material. Steel was shown to be capable of being reused and recycled many times and therefore should be preferred above concrete for structural purposes. Informed and intelligent material selection was given to be an important key as well. Proper understanding of the material environmental performance can be achieved with the use of Life Cycle Assessment. This provides a means through which the environmental impact of the materials right from processing through the use in construction, unto the demolition/deconstruction of the facility will be determined, and was strongly advocated.

Keywords : Environmental impact, concrete, steel, timber, embodied energy, life cycle assessment.

1 INTRODUCTION

THE built environment consists of elements that provide space and accommodation for man and his activities like education, recreation, manufacturing, vending of goods and services, governance/public service, healthcare delivery, and of course worship, among others. In addition to these structures, there is the infrastructure which includes roads and associated structures (bridges, culverts, drains etc), power plants and transmission facilities, telecommunications and similar installations. All these structures and infrastructure are products of the construction industry. The construction industry directly contributes to the creation and maintenance of the built environment and its activities are also directly related to the creation and maintenance of the built environment[1].Construction entails the assembly of finished construction products or processing of construction materials into components that make up the structure and then coupling them together to produce the desired structure. The materials used for construction are obtained from natural sources or processed from raw materials obtained from natural sources.The human population is increasing rapidly[2]. Due to the increase in human population, the need for people to use more of the structures and infrastructure will increase. This will lead to increase in the volume of construction as well. The construction materials, in addition to meeting construction needs, also bring about environmental challenges. The main one being the contribution to the green house gas and ozone depleting emissions selected from the "basket of emissions" against which reduction targets were agreed at the Kyoto conference on climate change. They are carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF_6)[3]. In addition to these are also the particulate materials (PMs). The usage of large quantities of construction materials results in the depletion of natural resources. The basic construction materials require high amounts of embodied energy with consequent high amount of green house gases (GHG) emissions and its attendant consequences. Also, the use of construction materials generate high amount of solid wastes running into billions of tones annually. These wastes are generated at various stages of a construction project [4]. During the erection or construction stage of a structure, wastes are generated and when the structure has served its purpose it may be demolished or remodelled to suit new purposes. For this reason construction wastes are comprehensively referred to as construction and demolition (C & D) wastes. The C&D wastes present disposal problems as land fill sites are becoming scarce and also some hazardous materials my leach into the underlying soil layers.The purpose of this paper is to review the negative impacts of three chosen structural materials, commonly used in construction, on the environment. This is with the view to making recommendations that will help minimize these impacts on the environment. The three materials are concrete, steel and timber. These three materials are used as structural materials either alone or in combination with one another to construct composite structures.

2 CONCEPT OF ENVIRONMENTAL IMPACTS OF CONSTRUCTION MATERIALS

The built (or human) environment consumes large quantities of resources, in its creation (construction) and operation (use). Construction materials are most times obtained from natural resources (directly or indirectly) which are limited. This leads to depletion of the natural resources. Also, in the processing of these materials for use, there are emissions and wastes released into the environment which results in damage to some aspects of the environment which needs to be protected and conserved [5]. Increase in population with changing tastes and lifestyles will lead to increased level of construction to meet the resulting needs. The level of consumption of construction materials has therefore increased along with the production. This uncontrollable consumption tendency will result in environmental degradation on a global scale and ultimate extinction of human lives [6]. After the constructed facilities come to the end their expected lifespan, the usual practice is to demolish them. Demolition generates wastes, the disposal of which most times results in environmental degradation. For instance, during wet weather, there is the potential for the chemical constituents in these materials to leach into the soil and the possibility of being transported to adjacent surface and under-

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ground water bodies. Nelson et al (2001) [7] are of the opinion that this might result into adverse environmental effects on the ecological health of streams, ponds, wetlands and ground water systems. In addition to all these, dump sites where construction solid wastes are deposited usually become unsuitable and therefore unavailable for agricultural purposes. A very high percentage of Nigerians are farmers, mainly at subsistence level, which availability of agricultural land very important. For this reason the basic strategy for C&D waste management should be aimed at conserving natural resources, reducing the quantity of wastes released for final disposal, and reducing the environmental harm caused by waste. The depletion of the natural resources from which construction materials are obtained, the emissions released into the environment, the leaching of harmful chemicals from the construction solid wastes into bodies of water and the rendering of agricultural land unfit for that purpose among others all constitute the negative impact of construction materials on the environment. Deliberate should therefore be made by the practitioners in the construction industry in Nigeria to take care of this issues even right from the design stage as any regulations put in place to combat this problem at a later time are most times observed in the breach by people concerned.

3 TRENDS IN CONSTRUCTION MATERIALS CONSUMPTION

To properly access the impacts of the selected construction materials on the environment, it is important to look at the trends in the consumption of these materials over the years.

3.1 Concrete

Concrete is the most versatile among construction materials[8]. It has good performance characteristics in very many respects: strength, durability, fire resistance abrasion etc. The world consumes an estimated 11 billion metric tonnes of concrete annually [9]. The most important constituent of concrete is the binding agent, cement being the most common. Roberts (2011) [10] reported that based on Global Cement Report for 2011 released by International Cement Review, the global cement consumption growth increased from 2,830 million tonnes in 2008 to 2,998 million tonnes in 2009 and up to 3,294 million tonnes in 2010. This shows an increase of 5.9% and 9.9% between 2008 and 2009 and between 2009 and 2010.respectively. By 2012, it is projected that worldwide cement consumption will reach 3,859 tones. This increase in cement consumption is an indication that the amount of concrete consumption is also increasing. In Nigeria more cement factories are being built or ailing ones are being put back on production tracks.

3.2 Steel

The global economic crisis has pushed down the demand for steel which has consequently led to a decline in steel trade and prices. Steel production capacity on the global scale has continued to rise [11]. World total steel consumption increased from 705 million metric tonnes in 1999 to 1121 million metric tonnes in 2009, representing an increase of 59% [12]. The construction sector is one of the highest consumers of steel in the world, accounting for about 42% of world steel production [13]. The share of steel consumed in the construction industry is higher in developing economies than in developed ones. For example, 55% of finished steel consumed in China and 50% in India is used in the construction sector. It follows therefore that in a developing country like Nigeria where there is a lot of room for additional roads, railways, seaports, airports, industrial plants and such other facilities, the demand for and consumption of steel will continue to rise.

3.3 Timber

World production of timber in 1993 was 3400x106 m3. About 55% of this quantity according was used as fuel wood [14]. The balance of 45%, about 1520x106m3 was used for industrial and construction purposes. The bulk of this is used in construction, either for structural purposes as in roof trusses or floor joists (accounting for 43% of total consumption in this area), or non structural purposes as in doors, windows, frames, skirting boards and external cladding (accounting for 9% of total consumption). Food and Agricultural Organization (FAO) of the United Nations [15] puts, logs and sawn-wood for construction as the largest use of industrial wood accounting for about 56%. Between 1961 and 1998, production and consumption increased by almost 50% [16]. Most of this production and consumption occurred in high income countries. The production level in Africa as at 1998 stood at 4% of the world production. But with the increased level of activities of conservationists and more stringent environmental laws in most developed countries, most of the companies that engage in timber production are moving to Africa and other developing countries. It is clear from the above facts that the consumption of the basic construction materials is on the increase. Where there have been slight declines before, it was attributable to the global economic down turn. The recovery of the world economy has again increased the demand for these materials with its attendant consequences.

4 EMBODIED ENERGIES AND CONSTRUCTION MATERIAL ENVIRONMENTAL IMPACTS

There are many definitions of embodied energy. The simplest and most concise one is given in [17] where it is defined as the amount of energy required to extract, process, transport, and install a given building element. Holtzhausen (2007) [18] divided embodied energy into two classes: initial embodied energy and recurring embodied energy and both are non-renewable. The initial embodied energy is the energy consumed in the process from the acquisition of raw materials to the construction of the structure. This one is influenced by the source and type of construction as well as the type of structure. On the other hand, recurring embodied energy is consumed to maintain, repair, restore, refurbish or replace materials, components or system during the lifespan of the structure. Recurring embodied energy is influenced by the durability and maintenance of the building materials, system and components installed in the structure as well as the lifespan of the structure. The environmental impacts of building materials include resource depletion, production of green house gases (GHG), maintenance of biodiversity and environmental degradation. These are all embodied in the measurement of embodied energy. Embodied energy is measured in mega joules (MJ) or gigajoules (GJ) per unit weight (kilogram or tonne) or area (square metre). Values of embodied energy of some selected construction materials are shown in Table 1.

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TABLE 1
EMBODIED ENERGY OF SELECTED CONSTRUCTION MATERIAL

Material	*Embodied Energy*	
	MJ/kg	MJ/m^3
Concrete (30 pascals)	1.30	3180
Concrete (precast)	2.00	2780
Steel (recycled)	8.90	37210
Steel	32.00	251200
Softwood timber (air dried, rough sawn)	0.30	165
Hardwood timber (air dried, rough sawn)	0.50	388

Source: Alcorn, 2003[19].

5 ENVIRONMENTAL IMPACTS OF THE SELECTED MATERIALS

The energy consumed in the construction materials production is highly correlated to carbon dioxide (CO_2) emissions [18]. An average of 0.098 tonnes of CO_2 per GJ of embodied energy is produced. This implies that the higher the amount of embodied energy the higher the amount of CO_2 emissions.

5.1 Concrete

Concrete is made using cement and aggregates mixed with water. Cement is one of the biggest contributors of green house gases [18]. The process involved in cement production entails grinding of the cement ingredients and heating to very high temperatures to form clinkers. The clinkers are ground with small amount of gypsum into cement powder. The high energy consumed in the manufacturing process of cement is due mainly to the high temperatures required to produce clinkers (up to 1870°C). With respect to cement, increasing the levels of mineral additions into cement up to 10% can help reduce the level of carbon dioxide emissions [20]. A reduction of between 375,000 and 750,000 tonnes of carbon dioxide emissions can be achieved every year through this means, and this without any adverse effects on the performance of the resulting concrete. Another means is the recycling of the cement kiln dust. Waste-derived fuels can be made use of in the heating process. The quarrying and mining of the aggregates does not add as much emission to the environment compared to cement.

5.2 Steel

Steel is heavy. It is therefore high in embodied energy, when it has to be transported over long distances. It however has a wide range of structural qualities that make it the material of choice in certain situations. It can be recycled completely and when used in construction it can be designed for easy deconstruction and re-use of the structural sections. The process involved in the manufacturer of steel requires a lot of energy and the procedures are many. Molten iron is produced in the blast furnace where iron ore, coke sinter and flux are heated up to 900°C and the blast furnace is used continuously for 10 years. Steel is produced by oxidising the carbon and other unwanted elements in the iron inside the furnaces to purify the iron. This process is done at very high temperatures and uses a large amount of energy as a result.Catalli and Williams (2001) [21] stated that the most effective way of reducing the environmental impact of steel in construction is to design for disassembly. The existing structural steel members can also be re-used. The cost of transportation and resulting carbon dioxide emission can be reduced by sourcing steel from local sources.

5.3 Timber

Obtaining timber as raw material for construction has less harmful impact on the environment than the mining of raw materials such as iron ore, coal and limestone for use in steel and concrete [22]. Environmental impacts associated with harvesting timber include unwanted changes to ecosystems. Timber as a construction material is light and easy to handle in a general sense, with its higher strength to weight ratios. It therefore requires less energy to transport and position than heavier materials like concrete and timber. Depletion of the forests also reduces the green leaves that help in processing the CO_2 in the atmosphere into usable oxygen. The reduction in the forest cover means less green leaves with the accompanying consequences.The ability of timber to be reused depends on the particular species and how well the timber has been maintained. It also depends on the resources required for disassembly and remanufacturing. Timber building components that can be reused include doors, window frames, and skirting boards.

6 REDUCING THE ENVIRONMENTAL IMPACTS OF CONSTRUCTION MATERIALS

The amount of construction materials can be reduced through two basic steps, namely: recycling and reuse of the materials. The benefits to be achieved in recycling and reuse are twofold: limiting the volumes of waste going to landfill disposal, and reducing the demand for primary materials through their substitution with recycled products [1]. A study [23] carried out has shown that recycling is the most environmentally friendly way to dispose waste generated from construction. This is followed by incineration and landfill. By recycling materials, impacts associated with producing new materials are avoided and this particular benefit outweighs the negative environmental effects caused by the recycling process itself and transporting waste to the recycling plant. Recycling of steel is very common as it is the most recycled materials and easiest to recycle. For every tonne of steel recycled, 1.5 tonnes of CO_2 is saved from being released into the environment, 1.4 tonnes of iron ore is saved, and 13 GJ of primary energy is saved [24]. Most steel products in America, including those used in construction steel are recycled[25]. Steel can also be reused, especially the structural steel. It is difficult to separate the reinforcement steel in concrete and so its reuse and recycling is not very prevalent. Reuse however is the more environmentally friendly option as the energy required for recycling and the CO_2 released in the process of recycling is minimised. During demolition, concrete in structures is usually scattered. So in most cases concrete is recycled and not reused especially with respect to in-situ concrete. The reuse of concrete is not carried out to a very large extent. It finds use as materials for shoreline protection and erosion control [26]. It can also be used a base material for roads, drainage material placed around underground pipes, as a base material for footings and foundations, landscaping material, as hardcore layer in ground floor construction and as coarse aggregates in new concrete. Due to its density and difficulty in reshaping, concrete is difficult to reuse. In demolished buildings, concrete skeleton are sometimes left in place after the infilling panels are removed in situations where an existing building is to be renovated or adapted to new use. The quantity of cement used in construction can be reduced by using pozzolans as partial replacement for cement in concrete. The use of pozzolans in this manner can account for up to 30% savings in cement consumption. The use of pozzolans like pulverised rice husk ash (RHA) and powdered clay bricks can also contribute positively in solid waste management.

7 LIFE CYCLE ASSESSMENT

Physical structures will continue to be constructed, resulting in the continuous usage of construction materials with the consequent environmental impact. The awareness of the importance of environmental protection has increased [27]. The possible impacts associated with products, both manufactured and consumed, has also increased interest in developing methods to better understand and address these impacts. One important means of reducing these impacts is an informed selection of construction materials. Material selection is the prerogative of the designer. There are many techniques available to guide the designer in material selection but most of these techniques are unsuitable for the construction industry. The most common technique used to aid material selection in all industries is the Life Cycle Assessment (LCA). It has emerged as one of the most appropriate tools for assessing product-related environmental impacts in addition to supporting an effective integration of environmental aspects in industry, business and the economy. Life Cycle Assessment models the complex interaction between a product and the environment, from “cradle to grave” [27]. It provides a systematic opportunity to anticipate all along the life cycle of the product from acquisition of raw materials, manufacture of the product, distribution, use and maintenance to the disposal of the product at the end of its useful lifespan [5]. The use of LCA tools eliminates problem of shifting from one lifecycle stage to another, from one type of problem to another and from one location to another [28]. The main driver for LCA is sustainable development. The procedure does not however incorporate the criteria for measuring the social and economic dimensions for now. On the other hand, it covers all aspects of the environment: human health, ecological well being and natural resources, and these, comprehensively. The practice of LCA is guided by the requirements of ISO 14040-2006 [27] which identified four phases in LCA study, namely; the goal and scope definition phase, their inventory analysis phase, the impact assessment phase, and the interpretation phase. The generic or basic steps in life cycle assessment are as shown in figure 1.

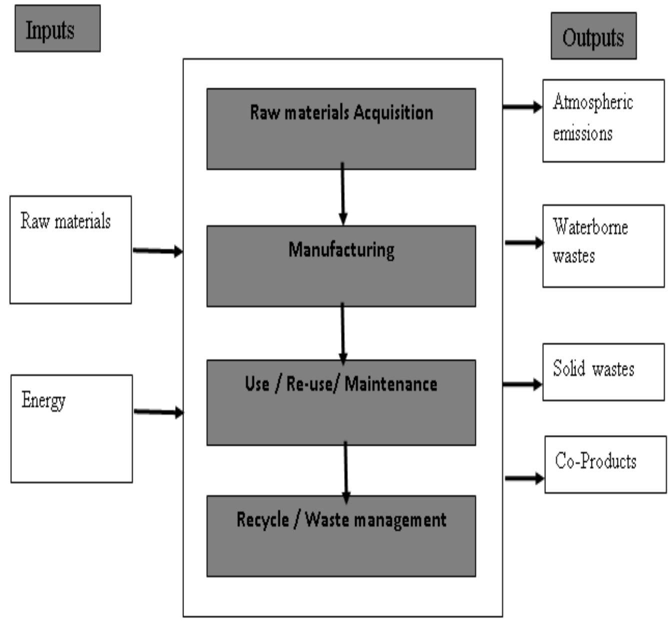

Fig. 1. The generic life cycle stages of an industrial system[29]

7.1 Use of LCA in Material Selection

The main application of LCA in the construction industry is to aid in design decisions, particularly, provide quantitative data to guide in material selection, construction component and building system combinations which will reduce the life cycle impacts of a built facility. The various phases in the life cycle of a built facility are shown figure 2.

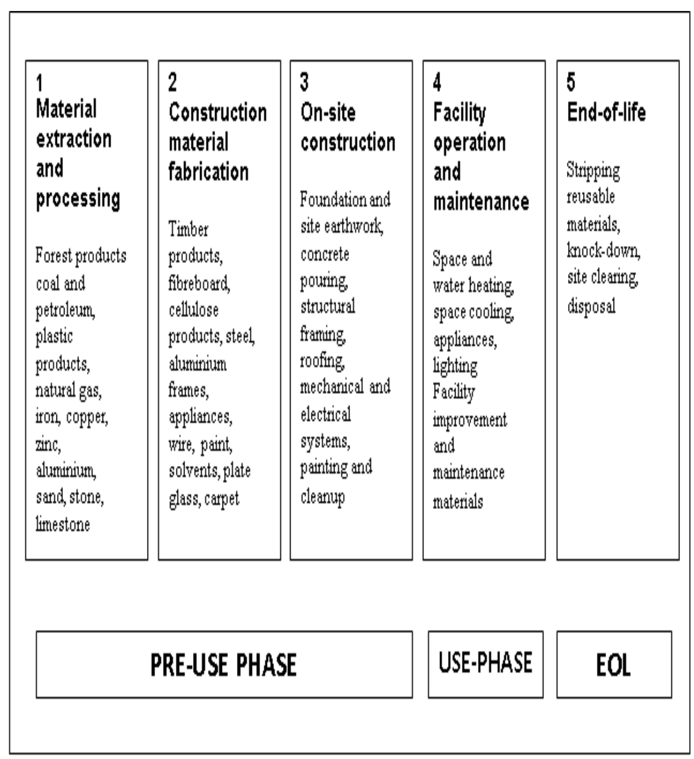

Fig. 2. The generic life cycle stages of a built facility[30]

The pre-use phase of a facility may account for 10-20% of the total life cycle environmental impacts of a built facility [30],

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[31]. This is because it is dominated by environmental impacts due to the extraction and processing of raw materials, construction materials production, transportation in between processes and on-site installation of the materials. Raw materials extraction from the earth contributes to a loss of biodiversity and destroys natural habitats [5]. Large portions of forests are cleared each year, and 20,000 species are lost a year [32]. Fabrication of construction materials from virgin raw materials is an energy intensive process. Energy consumption releases the air pollutants, carbon dioxide and sulphur dioxide which contribute to climate change and acidification respectively. The environmental impacts of the on-site construction life cycle stage consists of transportation of materials to site, use of construction equipment on site, use of energy in materials installation processes and the transportation of construction waste to a landfill [33]. In addition to these, there is the release of toxic emissions of carbon dioxide and particulate matter which characterises the dust commonly generated on construction sites. Construction materials selection process to reduce the negative impact of the materials is a complex process. It requires major shifts in approach to the planning, design, operation and disposal of built facilities [5]. There is most times the tendency to simplify this process by selecting materials on the basis of a single environmental attribute or on the basis of perceived rather than actual environmental benefits. The basis of LCA is that it encapsulates the full life cycle profile of a construction material on the basis of objective data, thereby facilitating well informed decisions which can increase the environmental performance of built facilities, the products of construction activities.

8 CONCLUSION AND RECOMMENDATIONS

The volume of construction has been on the increase to meet the needs of the increasing population. This has also resulted in the increase in consumption of construction materials. The use of these materials has some negative impacts on the environment like harmful emissions, depletion of natural resources and the problems of solid waste disposal. To reduce these harmful impacts, the consumption of these materials should be reduced. The major means is to recycle and reuse the materials and this is highly recommended. Where these are difficult, the alternatives with less negative environmental impacts should be selected. To be able determine the alternative with less environmental impact the use of LCA is imperative. It is recommended that where possible timber should be used for structural purposes in preference to steel and concrete. Timber has been discovered to have less negative environmental impacts than the other two materials. On the basis of environmental accounting, steel is a better alternative compared to concrete because it can be reused and recycled many times. It is strongly recommended that designers should be acquainted with LCA data in respect of the available materials to enable them do material selection that will make their designs to be more environmentally friendly. The use of pozzolans as partial replacement for cement in concrete is highly recommended. Some of these pozzolans when added to cement in concrete have resulted into strength properties and improved durability properties. The use of some pozzolans also helps in reducing the solid waste added to the environment, some of which are C&D wastes.

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