Borneo Journal of Sciences & Technology, 3(2): 33-38
DOI: http://doi.org/10.3570/bjost.2021.3.2-06
e-ISSN: 2672-7439

Submitted: 29th June 2021 Accepted: 04th July 2021 Published: 31st July 2021

Embodied Energy and Carbon from Building Demolished Debris Associated with Urban Road Construction in Gombe City, Nigeria

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Abstract: The expanding manner in which humans are exploiting environmental resources has brought about numerous problems. The energy embodied during the production of materials for construction are responsible to the emission of greenhouse gasses that are directly responsible for climate change, acid rain and other associated impacts such as land degradation, depletion of natural resources, change in land use among others. Determining the embodied energy and carbon emissions emanating from building Demolition Debris associated with road construction in Gombe, Nigeria with a view to advising the authorities on its environmental ramifications is the thrust of this study and it was conducted in Gombe State in North-Eastern Nigeria. Both qualitative and quantitative research design method were employed to obtain data from 23.37Km network of 13 roads. Results revealed that huge amount of energy and carbon were generated with a total of 228,065,635.86MJ embodied energy in the materials was generated with 7.11%, 83.09% and 9.80% from concrete, sandcrete and Mud/Clay respectively. Also, for carbon emission a total of 19,226,703.50MJ was estimated to be emitted with 9.50%, 84.48% and 6.02% from concrete, sandcrete and Mud/Clay respectively. These numbers as high as they are, speak volume where effective management of resources and efficient use of energy is sought. As such, energy intensive material production and construction have heavy costs, both financially and environmentally. It is recommended that relevant stakeholders should device means of using energy efficiently in materials production and construction using appropriate technology.

Keywords: Embodied energy, Carbon Emission, Demolished Debris, Road Construction

INTRODUCTION

The expanding manner in which humans are exploiting environmental resources has brought about numerous problems. The energy embodied during the production of materials for construction are responsible for the emission of greenhouse gasses that are directly responsible to climate change, acid rain and other associated impacts such as land degradation, depletion of natural resources, change in land use among others. Construction industry and its activities are responsible for a substantial amount of global resource use and waste emissions [1]; [2]. Consequently, it was realized that every activity involved in extraction, processing and delivery of construction materials result in energy consumption, pollution and waste; making the industry often referred to as 40% industry due to its responsibility for roughly consuming of 40% of all global resources and 40% of all waste production including greenhouse gas emission [3]; [2]. Disposal of demolition waste resources in landfill spaces result in further consumption of energy, pollution, environmental degradation, and ecosystem change and biodiversity loss especially when new materials are manufactured in their place [4]. Infrastructural development such as roads within the urban built environment has seen the demolition of thousands of buildings in Nigeria [5]. In addition, it has led to the released of huge amount of energy i.e., embodied energy and carbon dioxide in to the environment with its corresponding adverse effect. Some studies seem to have been carried out in the context of embodied energy and carbon emission worldwide [6]; [7]; [8]. However, most of the studies are not related to mass scale road construction demolition led debris like [6] in their studies calculated the embodied energy and carbon footprint of a 1-bedroom 1-storey building in Nigeria. Acquaye [8], did his study of embodied energy and CO_{2eq} intensity analysis of buildings and construction processes in Ireland. As such, the aim of this study is to determine embodied energy and carbon emissions emanating from building demolished debris associated

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with urban road construction in Gombe city, Nigeria with a view to advising the authorities on its environmental ramifications.

LITERATURE REVIEW

When a building is demolished energy is used to deconstruct it, and remove, process and dispose of the waste. Carbon "CO_2" may also be released through associated chemical processes. According to Bashir, Iro & Babanyara [2], buildings are constructed with a variety of materials that consume energy throughout their stages of manufacture, use and demolition. In addition, these stages consist of raw materials extraction, transport, manufacture, assembly, as well as disassembly and demolition. In addition, [2] proposed that embodied energy comprises the energy consumed during the extraction and processing of raw materials and components, and the energy used in various processes during the construction and demolition of the building. Embodied energy is just one of the environmental impacts associated with a building product's life cycle; the embodied energy of a typical building product is derived from the energy associated with other steps in its lifecycle from extraction of materials through processing and manufacture, to transportation and construction, and in some cases its eventual disposal and reuse/recycle [2]. Also, [9] opined that, the biggest sector influencing climate change is cement and steel. Cement production is the biggest contributor of greenhouse gas emissions. Ononiwu and Nwanya [6], on their opine that the construction, renovation and deconstruction of a typical building on the average are responsible for emissions ranging from 1000 $kgCO_{2e}/m^2$ to 1500 $kgCO_{2e}/m^2$. Furthermore, construction alone is responsible for as much as 500 $kgCO_{2e}$/m. To this end it has been realized that, where a building is demolished, all the non-renewable energy used to create the building were lost and many more is needed to rebuild.

Basically, most studies reviewed has shown that both embodied energy and embodied carbon are very tasking to calculate as it involves tracking down all the Recording and evaluation of primary data for the estimation of the quantities of debris in Gombe city was based on the appropriate scheme for the management of demolition debris. Quantities of demolished debris were first extracted from the acquired primary data and composition of materials were calculated in volume using Microsoft excel. processes that culminated into the production of the structure up to its demolition stage. Willmott Dixon in 2010 has developed a scale or constant as the case may be for estimating embodied energy and carbon for a typical masonry walls as presented in Table 1.

According to Bashir *et al.,* [2] demolition debris can be regarded as an act or process of wrecking or tearing down of buildings and other structures through which rubbles or ruins of broken-down structure is generated. In addition, typical demolished materials generated includes: concrete rubble, blocks rubble, stone, wood, scrap metals, insulations, broken glass and other building materials. In Gombe state, it has been reported that in the last decade or so thousands of buildings were earmarked and partially or fully demolished for the provision of road network.

Table 1: Masonry walls – expressed in volume

Material	**Embodied Energy (MJ/kg)**	**Embodied Carbon ($Kg/CO_2/kg$)**
Bricks (common)	5100	374
Concrete blocks (medium weight)	1349	152
Aerated block	2625	225
Formed earth	657	34

Source: [11]

MATERIALS AND METHODS

In this study, data used for the evaluation of the embodied energy and embodied carbon from building demolished debris associated with road construction are: The Inventory of carbon and energy, which is an open access database for embodied energy and carbon dioxide emissions associated with materials used in the construction industry developed by Geoffrey Hammond and Craig Jones in 2008 and later revised in 2011 [6]. In addition, it is a spreadsheet format database which shows the embodied energy coefficients as well as the embodied carbon coefficient to calculate the value of the embodied energy and carbon of construction materials.

The study was conducted in Gombe, the capital of Gombe State, Nigeria. Both qualitative and quantitative research design method were employed to obtain data. A simple random sampling technique was employed to select 13 no. roads sub-divided in to Lot 1 (8.33 km) and Lot 2 (15.04 km). Handheld (GPS) was used in establishing coordinates; photographs were taken from different locations showing demolition activities taking place and composition of different materials debris.

The calculations were carried out using a mathematical model developed by [10] which was based on the following equation:

$$\frac{L(m) \times W(m) \times H(m) \times 0.33}{27} = \text{Vol } (m^3)$$

"Where L = length of the structure; W = width of the structure; H = height of the structure; and 0.33 represents the constant to account for the air space in the building"

To calculate the energy embodied of the different materials in Gombe city requires modification to suit the study: Densities of the typical walling materials (Concrete, Sandcrete and Clay) in Gombe city were calculated and volume of the energy embodied determined using the empirically derived formulae from the adapted table; Density = Mass/Volume i.e. "(M^3) = k(D).M^3(m)" from the equation, the volume of energy embodied in the representative material is then determined from the volume of the debris generated along each road considered for the study. Another tool of measurement considered was the engineering design of the Gombe township road obtained from the relevant authorities and materials estimation techniques applied Microsoft excel as an instrument used in determining the quantity of materials require for respective roads. Gombe city Typical Road Cross Section specified: Width 10m; Base (stone base) 125mm; and Sub-base (Laterite sub base) 150mm.

RESULTS AND DISCUSSION

Table 2 present the results in lot 1. Findings revealed that a total of 70353.38 m^3 volume of material were generated during demolition. With 99,920,548.47 MJ of embodied energy in the materials generated and a corresponding 8,444,541.72 MJ embodied carbon emission were obtained from the building demolished debris associated with road construction. The energy embodied in the materials was 13.03% concrete; 73.08% sandcrete and 13.39% from Mud/Clay while the corresponding embodied carbon emission obtained were 17.38% concrete, 74.12% sandcrete and 8.50% mud/clay respectively.

Table 2: Embodied Energy and Carbon in building demolished debris estimated in Lot 1

Road	Concrete			Sandcrete			Mud/Clay		
	Volume (m^3)	Energy Embodied (MJ)	Carbon Emission (MJ)	Volume (m^3)	Energy Embodied (MJ)	Carbon Emission (MJ)	Volume (m^3)	Energy Embodied (MJ)	Carbon Emission (MJ)
Road 1: Gen. Hosp-T/Dku	1,901.17	2,564,683.05	288,978.37	346.21	908,788.13	77,896.13	305.49	200,704.96	10,386.56
Road 2: T/Dku-Gsu	-	-	-	35.07	92,058.75	7,890.75	-	-	-
Road 3: Bello S/ Kudi	2,867.26	3,867,938.06	435,824.01	9,592.40	25,180,042.13	2,158,289.33	931.37	611,912.13	31,666.69
Road 4: Cent.Pri. Sch. - K/Doya	11.35	15,308.59	1,724.91	4,027.13	10,571,216.25	906,104.25	1.8	1,182.60	61.2
Road 5: O.P.Off-Bello S/Kudi	4,652.11	6,275,695.04	707,120.57	9,104.57	23,899,503.60	2,048,528.88	13,756.68	9,038,139.94	467,727.18
Road 6: Emir's P. T-Idi	221.5	298,807.01	33,668.40	4,713.68	12,373,411.31	1,060,578.11	6,120.48	4,021,156.94	208,096.40
Road 7: Y/Bogo	984.24	1,327,739.76	149,604.48	6,197.70	16,268,952.00	1,394,481.60	4,583.16	3,011,136.12	155,827.44
Total	**10637.64**	**13,022,431.74**	**1,467,316.25**	**34016.8**	**73,025,020.16**	**6,259,287.44**	**25698.98**	**13,873,096.57**	**717,938.03**

Source: Authors field work (2019)

Table 3 is the result of embodied energy and carbon emission of building demolished debris associated with road construction in lot 2. Findings revealed that a total volume of 59640.19 m^3 of materials was generated during demolition. With 128,145,087.39 MJ of embodied energy in the materials generated and a corresponding 10,782,161.78 MJ embodied carbon emission were obtained from the building demolished debris associated with road construction. Percentages of energy embodied in the generated materials are: 2.50% Concrete; 90.89% Sandcrete and 6.61% Mud/Clay while the corresponding embodied Carbon emission obtained were 3.61% Concrete; 92.59% Sandcrete and 4.07% Mud/Clay respectively.

Table 3: Embodied Energy and Carbon in building demolished debris estimated in Lot 2

Road	**Concrete**			**Sandcrete**			**Mud/Clay**		
	Volume (m^3)	**Energy Embodied (MJ)**	**Carbon Embodied (MJ)**	**Volume (m^3)**	**Energy Embodied (MJ)**	**Carbon Embodied (MJ)**	**Volume (m^3)**	**Energy Embodied (MJ)**	**Carbon Embodied (MJ)**
Road 8: Alheri Juncton-Yalengnguruza Rd	1,099.16	1,482,768.07	167,072.46	9,543.03	25,050,455.06	2,147,181.86	1,961.86	1,288,939.39	66,703.10
Road 9: Madaki To Barunde Bye Pass Rd	1,269.68	1,712,791.58	192,990.60	15,953.83	41,878,793.25	3,589,610.85	5,693.00	3,740,303.63	193,562.14
Road 10: Nasarawo Ring Rd	-	-	-	746.70	1,960,100.10	168,008.58	3,060.00	2,010,420.00	104,040.00
Road 11: Miyetti Junction To Intersect Union Bank Rd	-	-	-	41.28	108,360.00	9,288.00	-	-	-
Road 12: Dogon Dabino Road	-	-	-	4,550.17	11,944,185.75	1,023,787.35	523.80	344,136.60	17,809.20
Road 13: Liberty Junction To General Hospital Road	-	-	-	13,536.05	35,532,141.75	3,045,612.15	1,661.63	1,091,692.22	56,495.49
TOTAL	**2,368.84**	**3,195,559.64**	**360,063.06**	**44,371.06**	**116,474,035.91**	**9,983,488.79**	**12,900.29**	**8,475,491.84**	**438,609.93**

Basically, from this equation Density = Mass/ volume i.e. {(M^3) = 1(D). M^3 (m)} the volume of embodied energy given in was expressed number of joules per unit mass of material (MJ/Kg). The quantity of demolition debris generated was estimated in volume as per FEMA's guide. The density of individual material is sought and modified equation applied, the volume of energy inherent in the volume generated was then calculated. Also, from the 13 road under consideration in the study i.e. roads in lot 1 and 2, huge amount of embodied energy and carbon emission were obtained on account of building demolition associated with road construction in Gombe city- a total of 228,065,635.86MJ of energy embodied in the materials was generated with 7.11% from concrete; 83.09 % from Sandcrete; and 9.80% from Mud/Clay. For the carbon emission from the materials a total of 19226703.50MJ was estimated to be emitted with 9.50% from concrete; 84.48% from sandcrete and 6.02% of carbon was estimated to be emitted from Mud/Clay materials during demolition

associated with the road construction in Gombe city. These numbers as high as they are, speak volume where effective management of resources and efficient use of energy is sought.

According to Pavement Interactive (2012) [12] in a gallon of automotive gasoline there contained an equivalent of 131.76MJ of energy. Therefore the embodied energy of materials i.e. 228,065,635.86MJ total for lot 1 and 2 is equivalent to 1730917.09 gallons of automotive gasoline was used. To put these numbers in context, the energy needed to construct one lane is equivalent to burning 23,000 gallons of conventional gasoline. Assuming a gas mileage of 20 liters per gallon, this means the total energy input to pave one kilometer of a one lane road is equivalent to the gas needed to drive 750,000 cars across the its length. In addition, Muench, *et al.*, (2011) [13] in their green roads manual, estimates that the construction of one kilometer-lane of road uses about same amount of energy as 20-40 average house hold over one-year period.

The highest amount of embodied energy and carbon emission was generated from the walling sandcrete materials. This was in agreement with [6] were they find out that the highest percentage of the embodied energy and carbon is in the wall and frames sections which are predominately composed of cement. Furthermore, the energy embodied in a building is directly proportional to the embodied carbon.

CONCLUSION

Determining the embodied energy and carbon emissions emanating from building demolished debris associated with urban road construction in Gombe city, Nigeria with a view to advise the authorities on its environmental ramifications is the thrust of this study. Huge amount of energy was generated from building demolition debris materials - concrete, sandcrete and mud/clay with a total of 228,065,635.86MJ of energy embodied and 19,226,703.50MJ of carbon was estimated to be emitted.

This goes to say that the quantum and energy efficiency of demolition debris for road construction in Gombe city is not a trivial matter. As such, using demolished debris as alternative to virgin materials for road construction is a welcome development and a veritable tool to energy and resource efficiency. Energy intensive material production and construction have heavy costs, both financially and environmentally. Technologies like mobile crushers and machines are making urban road construction more energy efficient where demolished debris is present in which the approach will reduces the energy foot print on the roads construction and will make natural environment more resilient over a long time period. It is recommended that relevant stakeholders should device means of using energy efficiently in materials production and construction using appropriate technology.

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