Comparative Study on Carbon Footprint between Steel and Concrete Industrial Structures in Kenya

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Abstract-
In this paper, the embodied carbon for a steel and concrete warehouse is studied. To achieve this, two structures are first designed optimally for gravity and lateral loads. Thereafter, the cost-benefit analysis and Carbon print analysis is carried out on the structures. In addition, the overall time taken for construction of the structures is taken into consideration. The comparison will be used to determine the most economical, environmentally friendly and most time efficient building material.

Index Terms- Carbon Analysis, Cost-benefit Analysis, Environmental Sustainability, Sustainable Construction, Sustainable Development.

I. Introduction

Sustainable development has been defined as one that meets the needs of the present generations without compromising future generations from meeting their needs(Brundtland, 1987). Human activities, of which construction is part, produce greenhouse gas (GHG) emissions that have a negative impact on the environment leading to climate change. Sustainability in construction has been focused on the use of locally available and environmentally friendly materials and/or waste as replacement in cement manufacture (Muigai, 2014). In addition, there needs to be focus on design as part of enhancing sustainability. This will ensure that every material is optimally paired to the required needs.

A structure that is sustainable is one designed to cater for specific needs, and that minimizes environmental impacts and costs through:
1) Construction technologies and production processes that are efficient.
2) Material that gives optimum properties for durability and minimal environmental impact.
3) Structural layout and volume that is optimized and appropriate.
4) Design for destruction and recycling.

Carbon footprint is described as the measure of the carbon dioxide (CO_2) and other GHG emissions accumulated over the life span of a product(Goodier, 2010). Carbon footprint analysis is carried out in construction studies as an important metric for sustainability. Measurement of carbon footprint has been of interest to many researchers in the past. The unit of measurement of global warming potential (GWP) is carbon dioxide equivalent (CO_2-e) which represents mathematical relation of average warming potential of a GHG compared to CO_2. The consideration of GHGs and energy is usually phased i.e., during construction, occupation, and deconstruction. Through this life cycle analysis of emissions, their impact on GWP may be determined.

There exists latency of emissions in the process of design, manufacture, and transportation of construction materials over and above the quantifiable and more evident forms of energy consumption(Muigai, 2014). These indirect contributions to GHG emissions are termed "embodied carbon." The choice of materials and the technology applied impacts on the embodied carbon emissions in a project. With clearer understanding on the level of GHG emissions, designers can make data-driven decisions on preference and selection of materials to use in a particular scenario.

It is widely known that the level of emissions varies for different materials, processes, or products. For every ton of cement produced, an estimated ton of CO_2 is emitted(Weidmann & Minx, 2008). On the other hand, it is estimated that production of one ton of steel releases 1.85 tons of CO_2 (Weidmann & Minx, 2008). Such comparisons are not only insightful but are also useful yardsticks for assessing how green a particular building is. However, important conclusions can be drawn from a comparative study of a whole building project comparing, for example a steel and reinforced concrete building.

This study seeks to compare quantities of embodied carbon in steel and concrete construction, being most common materials for construction in Kenya, and their impacts on sustainability.

2) LITERATURE REVIEW

Embodied carbon analysis on different types of buildings has been extensively studied in the past. Muigai (2014), carried out a case study using a life cycle assessment framework. From this study, embodied carbon of a house constructed using offsite panelised timber frame was found to be approximately 35 tCO_2. This was about 32% lesser when compared to a home constructed using traditional masonry construction, at 52 tCO_2. The recent past has seen steel gaining significant momentum as a construction material on merit of its flexibility, reduced construction time, and being lightweight as compared to reinforced concrete. Dabhade, et.al (2009), reports that a steel framework is 60% lighter than a RC frame hence demand less expensive foundation. Conversely, concrete, with proper care, is water resistant hence its strength not compromised by corrosion as it is with steel. The choice on either material is usually dependent on design criteria and performance, but rarely on their contribution to CO_2 and GHG emissions (CEN, 2002). Sustainable development calls for mitigations on environmental degradation which, consequently, demands carbon footprint analyses that give the amount of (kg CO_2-eq) equivalent carbon dioxide emissions that is caused directly or indirect by an activity or is accumulated by stages of a product (Weidmann & Minx, 2008), necessary for structural engineers to make informed decisions on selection of materials. Muigai (2014), establishes carbon footprint as the embodied energy of a product, and, at such, can be used in Life Cycle Analysis of a product. The embodied energy measures gross energy requirement of a material, structure and/or structural component (Ashley & Lemay, 2008). According to (Muigai, 2014), a sustainable structure is a "structure designed to cater to specific needs and minimizes environmental impacts and costs through (i) construction technologies and production that is efficient, (ii) material that gives optimum properties for durability and minimal environmental impact (iii) structural layout and volume that is optimized and appropriate and, (iv) designed for destruction and recycling."

Principle of Design

The Limit State Design criteria offers the best outcome in designing for all loads that will act on a structure's lifetime(Gupta, 2008). In the method, design loads are obtained from applying partial factors of safety to nominal working loads. The design strength are derived from dividing characteristic strength of materials by a set of partial factors of safety. Therefore, the member are designed to carry limit state design loads, while the materials are stressed to limiting design strengths (Pandit & Gupta, 1981). The partial factors of safety are necessary to cater for variations which occur in loading and material strengths.

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3) MATERIALS & METHODS

3.1 BUILDING DESCRIPTION AND DESIGN CRITERIA

The case study is a design involving two separate designs of the same structure in structural steel and Reinforced concrete. It is a straightforward model structure that is easy to formulate a comparison. It is a 60m by 20m, 7.73m high double volume portal frame industrial shed. The structure is large enough to allow complexities of large span design considerations.
The parameters to be used as date for analysis and drawing conclusions include:

1) Sizes of foundation bases (from the weight of the structure)
2) Shear Resistance capacity
3) Construction Cost
4) Construction Period
5) Carbon footprint.

The design criterion was compiled from the Kenyan Standards, British Standards, Eurocode and Other International Standards and Codes of Practice. The referenced codes were used in a complementary manner and where requirements of Two or more codes or standards were found to conflict, the more stringent of them is adopted.

A 50-year design life was envisaged for the structure.
The structures are designed using Staad Pro. The procedure entails:

1) Modelling-Input of geometry, material properties, support conditions, section properties and assigning them to the structure. Determination and assigning of loading and load combinations
2) Analysis- Analysis for gravity loads, wind loads and seismic loads
3) Post-Processing- Checking the displacements and forces (shear and moments) and adjusting geometry and/or properties in case of excessive/abnormal figures
4) Design- Definition of load envelopes and design briefs and checking all members for adequacy. Foundations are designed from loads extracted from the structural analysis
5) Drawings- Production of Construction drawings

This is done for both steel and concrete structures and with the assumption that all conditions including but not limited to climatic, seismic and geotechnical are similar

Once the designs were complete, bills of quantities were drawn out.

The bills of quantities are used to determine the cost effects for the two designs and the carbon footprint.

3.2 CARBON FOOTPRINT ANALYSIS

The quantities used in the bills of quantities were converted to Mass in Kgs. The conversion rates and references are inferred from the Inventory of Carbon and Energy (ICE) Summary.

4) RESULTS AND DISCUSSION

Table 1: Steel member sizes

Member No.	Size (mm)
R1=4	300-600x200x6x12
R2	600-300x200x6x12
R3	300x180x6x8
R5	600-300x200x6x12

Table 2: Concrete member sizes

Member No.	Size (mm)
R1=R2	600-300x200x6x12
R3	300x180x6x8

R4	400 x 400

The bills of quantities yielded the following results

Table 3: Cost analysis for the Steel Structure

Item		Cost (Kshs)
1.	Substructure	5,841,970.00
2.	Walling	7,567,270.00
3.	Roof Construction and Finishes	2,050,000.00
4.	Finishes	3,707,900.00
5.	Windows	386,660.00
6.	Doors	544,520.00
7.	Builders work in connection with mechanical installations	500,000.00
8.	Builders work in connection with electrical installations	500,000.00
	Sub-Total	21,098,320.00
9.	Preliminaries	1,500,000.00
10.	Provisional Sums	4,305,000.00
	Total Sum	26,903,320.00

Table 4: Cost analysis for the Concrete Structure

Item		Cost (Kshs)
1.	Substructure	5,551,990.00
2.	RC Superstructure	943,600.00
3.	Walling	1,330,400.00
4.	Roof Construction and Finishes	2,050,000.00

5.	Finishes	3,930,700.00
6.	Windows	386,660.00
7.	Doors	544,520.00
8.	Builders work in connection with mechanical installations	500,000.00
9.	Builders work in connection with electrical installations	500,000.00
	Sub-Total	15,737,870.00
10.	Preliminaries	1,500,000.00
11.	Provisional Sums	4,305,000.00
	Total Sum	21,542,870.00

Table 5: Steel Structure EC (KgCo2e/kg)

	Item	**Steel Structure EC (KgCo2e/kg)**
1.	Substructure	69330.67
2.	Walling	52894.19
3.	Roof Construction and Finishes	3522.43
4.	Finishes	36585.48
5.	Windows	3410.12
6.	Doors	1450.68
	Total Sum	**167193.57**

Table 6: Concrete Structure EC (KgCo2e/kg))

Item	Concrete Structure EC (KgCo2e/kg))
1. Substructure	63854.71
2. RC Superstructure	5296.88
3. Walling	19617.28
4. Roof Construction and Finishes	2124.50
5. Finishes	56075.13
6. Windows	760.67
7. Doors	1450.68
Total Sum	**149179.85**

The analysis for Equivalent Carbon (EC) was conducted and results are as follows:

1) Embedded Carbon in the Concrete structure - 149,179.84 kilograms of CO2e

2) Embedded Carbon in the Steel Structure – 167,193.56 kilograms of CO2e

5) CONCLUSION

The study objectives were met in the sense that there was a clear significant difference in the carbon emission for the two materials with steel have significantly higher figures. The Equivalent Carbon (EC) analysis was performed, and the results are tentative due to the subjectivity of the database and the fact that the embodied carbon for some items was extremely difficult to quantify due to a lack of previous information/data on the subject. However, assuming that these conditions are the same for both structures, it is safe to say that the results are accurate representations of the expected results. Steel structures contain more carbon than concrete structures. This is due to the material's manufacturing.

The boundaries within the ICE database used in the carbon footprint analysis are cradle-to-gate. However, even with these boundaries, there are many possible variations that affect the absolute boundaries of study. One of the main problems of utilizing secondary data resources is variable boundaries since this issue can be responsible for large difference in results.

The ICE database has its ideal boundaries, which it aspires to conform to in a consistent manner. However with the problem of secondary data resources, there may be instances where modifications of these boundaries was not possible.

Any item not covered by the ICE database was converted by use of available past research and/or material.

APPENDIX

1) Concrete and Steel Design calculations
2) Structural drawings
3) Bills of quantities excel documents
4) Carbon footprints excel analysis document

5) Inventory of Carbon and Energy (ICE) Summary tables

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