BUILDING CONSTRUCTION AND ITS CARBON FOOTPRINT

(A Tip Off)

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SUMMARY

The paper attempts to have a critical insight into the construction activity regarding construction materials, the generated waste, their embodied energy and CO2 emission as an ongoing and future concern of the human habitat. Infrastructure development and handling processes including: design, construction, service time care, deconstruction and salvaging at life end could be managed by establishing embodied energy and CO2 emission factors fit for individual local conditions until such a time that the world can have a unifying descriptor. The establishment of the anticipated factor can help the whole industry stakeholders to consider knowledge based environmental proactive and sustainable development by selecting low energy construction material type, its service life state and the whole life cycle handling; right from the design stage. The study conducted on selected five building construction sites has revealed that, the materials waste alone has inflated the embodied energy and the CO2 emission by 37 and 17%; respectively.

The whole effort in here is to ignite awareness and sensitize policy makers and the society at large; how the construction activity and the materials used are impacting the environment and suggest the methods to be adopted to join the international endeavor in order to curb the unmonitored infrastructure development, materials use and abuse leading to a non-sustainable development both in terms of economy and eco-friendliness for the aspired for social welfare and wellbeing.

Key Words: Materials, Embodied energy, Construction, CO2 emissions, Factors, Life cycle

1. INTRODUCTION

Construction is a process through which service rendering infrastructures are developed. To pick the fruits of the actual construction work there are chains of engagements. All along the lengthy process various activities and actors are involved. These activities and the supposed actors use materials and generate some process leftovers/trashes. The leftovers are generally disposables in the form of all the states of matter (solid, liquid and gas).

The focus of this paper is construction materials, their waste plus the intrinsic embodied energy and the resulting carbon-dioxide (CO2) emissions. Moreover, further boundaries are imposed on the lengthy process of construction materials use to erect structures. Generally, under normal circumstances; the life cycle of construction materials is phased as: Cradle-to-Gate, Cradle-to-Site and Cradle-to-Grave. In here, a Cradle-to-Site is dealt with; only.

To fully understand the situation and arrive at a conclusion a research is conducted on active construction sites. The study tries to identify which materials are used extensively and are sources of construction waste; simultaneously. Referring to the work of Venkatarama and Jagadish (2003), "conservation of energy becomes important in the context of limiting greenhouse gases emission in

to the atmosphere and reducing costs of materials "[1]. Considering this as one of the pillars for sustainable development a report to the UN by Brundtland (1987), defines it as: "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2].

2. LITERATURE REVIEW

This section of the paper attempts to assess and summarize few but relevant research out comes to grasp and fall in line with the world knowledge level in the understanding of construction materials and the generated waste in reference to their embodied energy, the CO2 emission and the ensuing burden on the environment. The construction industry first started thinking about embodied carbon around 20 years ago in the UK; one of the leaders in the field [3].

To that effect, here is a provoking quote from one of the reviewed literatures, "Our use of materials is very large and is increasing with population and economic growth; accompanied by Energy and water use. Our use of materials now challenges the capacity of the Earth-air, water and land to withstand the many resulting environmental problems. This situation fundamentally affects many other aspects of our future, such as; the economy, energy and climate. We need to fulfill our human needs and prosper while using less material, reducing toxics and recovering more. Business as usual can't continue "[4].

Besides the benefits of the actual construction, its activities can be a major source of environmental damage through the depletion of the natural resource base, degradation of the fragile eco-zones, chemical pollution, and the use of building materials harmful to human health. The design, construction, and maintenance of buildings have a negative impact on the environment and natural resources [5].

The idea of sustainability involves enhancing the quality of life, thus allowing people to live in a healthy environment with improved social, economic and environmental conditions [6].

Construction activities affect the environment throughout the life cycle of development. These impacts occur from initial work on site through the construction period, operational period and to the final demolition when a building comes to an end of its life. Even though the construction period is shorter in relation to the other stages of a building's life, it has diverse significant effects on the environment. For that matter, there is a progressively growing concern about the impact of construction activities on human and environmental health. Even though construction project development potentially contributes to the economic and social development; and enhancing both standard of living and the quality of life, it is also associated with deterioration of the environment [7].

According to Inventory of Carbon and Energy (ICE), University of Bath 2008, "The embodied energy (carbon) of a building material can be taken as the total primary energy consumed (carbon released) over its life cycle. This would normally include (at least) extraction, manufacturing and transportation. Ideally, the boundaries would be set from the extraction of raw materials (including fuels) until the end of the products' life time (including energy from manufacturing, transport, energy to manufacture capital equipment, heating and lighting of factory, maintenance, disposal, etc.) known as Cradle-to- Gate. It has become a common practice to specify the embodied energy as Cradle-to-Gate, which include all energy (in primary form), until the product leaves the factory gate. The final boundary condition is 'Cradle-to-Site'; which includes all the energy consumed until the product has reached the point of use" [8]. The complete life cycle of a building is simulated by the following trend line according to an MDPI document [9].

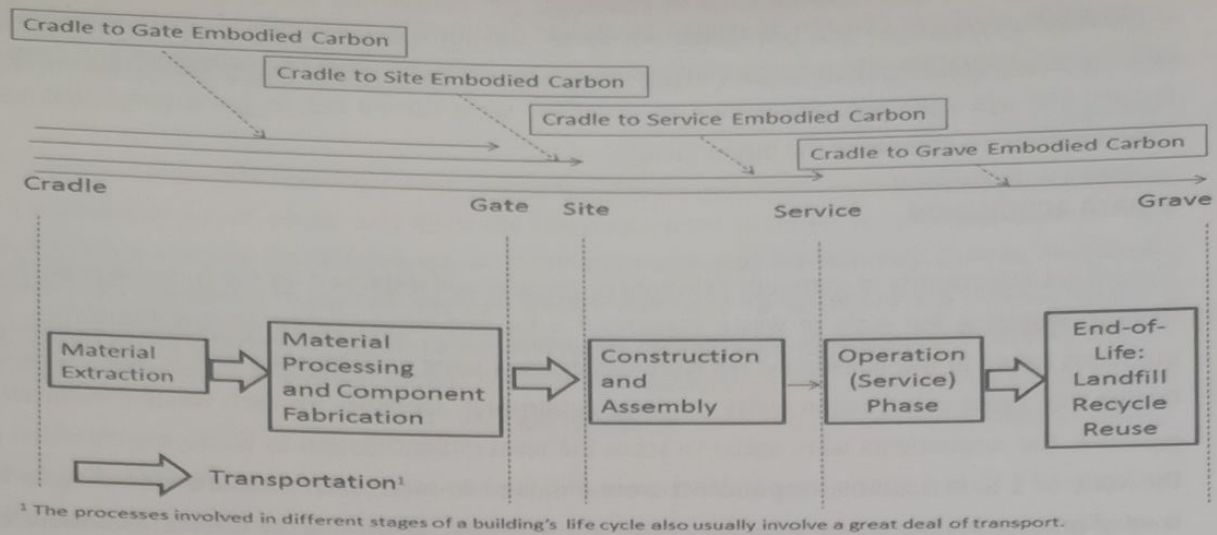


Fig. 1: Different phases of a building's life cycle [9]

Though the literature resources on the subject of materials' embodied energy and carbon emission are many, the bottom line of the difference between them is the variability to individual local conditions. It all differs from production, storage, transportation and delivery to import and locally produced building materials characterization. As the list of variability increases depending on refinements of embodied energy details, nations of the world are conducting un-abating research with a due consideration to the global sustainable healthy environment. The effort aims at formulating a unifying method of embodied energy and the emanating CO2 emission quantification factor at every level of the products life phase; globally. At last it is worth to mention why should there be such a big concern on this issue? According to the International Environmental Agency (IEA),"Quantification of Embodied Energy and Green House Gas (EEG) emissions could help policy makers to identify the key industries affecting building construction in their country in line with their own country's intended contribution to the Paris Agreement" [10].

3. RESEARCH OBJECTIVES

It is a daily routine phenomenon to come across building construction sites with a messy and haphazard bustling interaction. This always triggers a doubt of the normalcy of the activities taking place within the site. Among the many issues triggering queries is, the magnitude and quantity of construction materials arriving at site, their proper storage, efficient handling and appropriate use take the lead. In this regard, the three main objectives in here are:

a. To assess and understand the real situation of construction materials use on construction sites.

b. To identify the most extensively used and waste generators of construction materials by accounting their volume.

c. To reckon with the effect of construction materials and the waste generated on the economy and the environment by calculating the embodied energy and CO2 emission.

4. RESEARCH METHODOLOGY

The methods used to further the research were: questionnaire survey plus personal interviews, site visits and observations, desk study of construction documents; as well. The questionnaire survey focused on six distinct groups approached with close ended questions and face to face interviews regarding construction materials and wastage. The groups were identified with focal causes for

construction materials concern as related to: design documents, procurement, materials handling and storage, operation, site management and practices, including other site conditions and external factors. The site visits and observation of situations were carried out to get a direct first hand information and a glimpse of the bigger picture.

5. DATA ACQUISITION

Though getting quantity of materials delivered to projects and disbursed on site is manageable from records, assessing the scale of waste demanded a focused survey based on questionnaires. The questions raised in the questionnaires were constructed using a Likert scale of 1-5, specific to the factors that cause construction waste on construction sites. Likewise, for each waste minimization measure, the respondents were asked to score the level of contribution to waste minimization on the scale of 1-5. In addition, respondents were enquired to score each measure according to the level of practice in their organization on a scale of 1-5. Finally, concerning the effects of construction wastage, the respondents were asked to score the level on a scale of 1-5. The target population were 78 currently active G+3 and above commercial and public projects. Contractors, real estate developers, consultants and owners of the selected projects were the focal respondents.

Sample size calculation for the study to estimate population prevalence was done by using the following Lwanga and Lemeshow (1991) formula, [as cited in 11].

$$n_o = \frac{Z^2 p(1-p)}{e^2} \quad (1)$$

Where: n_o = Sample size, without considering the finite population correction factor

z^2 = Confidence level

P = Population proportion (in proportion of one; if 20%, P= 0.2), and

e^2 = Level of precision or sampling error (in proportion of one; if 5%, e = 0.05

If the population is small (78 in this case) then, the sample size can be reduced slightly. This is because a given sample size provide proportionally more information for a small population than for large population. Then the sample size (n) can be adjusted using the relation:

$$n = \frac{n_o}{1 + \frac{(n_o - 1)}{N}} \quad (2)$$

$$n = \frac{245}{1 + \frac{(245 - 1)}{78}} = 59$$

Where:

n = the adjusted sample size

N = the population size

Going through the above manipulation, the ensured trustworthy slight reduction produced: 42 contractors, 2 real estate developers, 8 consultants and 7 owners as target respondents; which amounted to 59 in total.

Once the questionnaire responses were obtained, checking was done for completeness, consistency, and readability; out of which, only 49 of the responses were accepted as valid data sources. Then, the Statistical Package for Social Sciences (SPSS 16.0) was used for the data analysis. Progressing further, the sequential weighted average model was used to scrutinize the relative levels of significant contribution of the waste causes and waste minimization measures.

$$ASS_i = \frac{\sum_{i=1}^{5} X_j N_{ij}}{N} \quad (3)$$

Where:

ASS_i = the average significant score of the waste minimization measure i,

X_j = the waste minimization score assigned (on a Likert scale of 1-5),

N_{ij} = the number of respondents who assigned the score X_j for the measure i,

N = the total number of respondents.

For the desk study, to learn more about the volume of construction materials consumed and to estimate the subsequent waste generated, eight more or less physically similar in characteristics construction building projects were taken purposively. From the obtained data five top ranking building materials were identified; both in the form of those consumed by the stated projects and as a prime source of generated waste during construction. Focusing on these five construction materials five construction projects were selected amongst the target population to get the actual quantity of materials. The results are summarized in Table 1

Table 1: Construction Materials and Generated Waste from the Five Building Construction Projects [11]

ID. No. (1)	Description (2)	Materials Consumed (Tons) (3)	Materials Wasted (Tons) (4)	Wastage (%) (5)	BaTCoDA Wastage Limits (%) (6)
1	Cement	4184.54	518.46	12.40	5
2	Sand	8781.47	1585.16	18.05	15
3	Coarse Aggregate	12171.77	1561.62	12.83	15
4	HCB	1460.45	189.04	12.94	5
5	Re-bar	1023.41	131.65	12.86	5

6. COPUTATION OF EMBODIED ENERGY AND CO2 EMISSION

In the 2016 paper of Vanessa Gomes Silva, et.al., it is stated as: "The carbon footprint (or embodied CO2) and embodied energy are indicators that can measure, respectively, the CO2 emission and the energy used during the manufacture of the building materials and components, in transporting these to the site and during the construction process itself" [12]. In line with this, the determination

of both the consumed and wasted construction materials, volume wise, is instrumental to the subsequent computation and quantification of the aimed at embodied energy and CO2 emission. In this regard, among the many sources for the two factors worldwide, due to the in-availability of a unifying document pertinent to a developing country, like, Ethiopia; the Senegalese carbon factor is made use of [13].

The total cradle-to-site, embodied carbon of a building can then be estimated by multiplying the quantities of each material by its estimated cradle-to-site carbon factor [14].

$$EC_B^{c-s} = \sum_j Q_j f_j^{c-s} \quad (4)$$

Where:

EC^{c-s} is the total cradle to site embodied carbon of the building materials (CO2 Kg/ton),

Q_j is the quantity of material j (in tones) as estimated using common quantity takeoff methods,

f_j^{c-s} is cradle-to-site emission factor for material j.

At this point, it has to be noted that, the remaining cradle-to-service embodied carbon are not accounted for; which are:

- Depreciation in embodied carbon of temporary materials.
- Emissions due to transport of materials and equipment to site.
- Emissions due to operation of equipment.
- Depreciation in embodied carbon of equipment

Table 2: Computed Embodied Energy and CO2 Emission of the Five Construction Building Projects

ID. No.	Description	Factors [13]		Consumed Materials		Wasted Materials		Total	
		EE (MJ/Kg)	CO2 Emi. (Kg/Kg)	EE (GJ)	CO2 Emi. (Ton)	EE (GJ)	CO2 Emi. (Ton)	EE (GJ)	CO2 Emi. (Ton)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	Cment	3.32	0.730	13,892.67	3054.71	1,721.29	378.48	15,613.96	3433.19
2	Sand	0.06	0.004	526.89	35.13	95.11	6.34	621.40	41.47
3	Coarse Aggregate	0.16	0.010	1,947.48	121.72	249.86	15.62	2,197.34	137.34
4	HCB	7.96	1.550	11,625.18	2263.70	1,504.76	293.01	13,129.94	2556.71
5	Re-bar	15.97	1.060	16,343.86	1084.81	2,102.45	139.55	18,446.31	1224.36

NB: EE- Embodied Energy CO2 Emi. – Carbon dioxide Emission G. Total: EE=50,009.00GJ, CO2=7393.09Tons

7. ANALYSIS AND DISCUSSIONS

The step-by-step build up of the framework to examine the execution, materials management and generation of waste on construction projects through literary study, surveyed data and detailed material compilation of five typical buildings have produced a tangible result which led to the determination of construction materials embodied energy and CO2 emission quantification. While

compiling the acquired data it was learnt that, the most outstanding construction materials used happened to be cement, sand, coarse aggregate, HCB and reinforcement bar; as it used to happen most of the time in the industry. The factors for both embodied energy and CO2 emission as derived from contemporary works on the subject are selected among the many, based on geographical location, developmental level, data refinement quality level, and dependence on imported and local construction materials. This happened because, there is no a unifying factor reference to date to be considered as a global instrument. As can be easily understood from Table 2, the three top most embodied energy intensive materials are: re-bar, cement and HCB in a descending order and the CO2 emitters are: cement, HCB and re-bar as in the order of their earlier counter parts.

Though construction itself is a huge magnet of embodied energy and a generator of CO2 emission the waste given off in the process is a cause for their inflation, quantitatively. The computation in here falls short of the whole life cycle of a building. However, the findings show that the embodied energy of the consumed construction materials and the accompanying CO2 emission is a debt burden of the coming generation as it will be released into the environment at the end of the buildings' life cycle. On the other hand, the construction waste part of the embodied energy and CO2 emission are the realities of today. The waste is destined to landfill or recycling. If used for a landfill, it can be an environmental burden to the whole eco-system, as a source of pollution. The situation we are in today tells us that, since there is no a recycling facilitation it surely ends up at a landfill. This coupled with the in excess generation of construction waste as compared to the national BaTCoDA standard set limits [15] calls for a swift action to normalize the unaccounted for cumulative effect on the dearly contested habitat and the fragile environment. Moreover, according to [11], the construction materials' generated waste on the five construction projects incurred an average of 11.15% extra cost; which in actual fact is lose in profit for the contractor. In addition, the materials waste has inflated the embodied energy and CO2 emission by 37% and the CO2 emission by 17%.

Looking at the π-charts of Fig. 2, though the quantities of the materials are different, the percentages as computed on their own total bases are nearly equal with very minimal differences, for both the embodied energy and CO2 emission. Reinforcement bar is with the highest embodied energy, but when it comes to CO2 emission cement takes the lead followed by its derivative HCB; relegating re-bar to a third position.

The accounted for embodied energy and the CO2 emission in here are only for the five picked building projects among those which were successfully covered by the study survey. If this finding is to encompass all the 49 assessed projects the embodied energy is 490049 GJ and the CO2 emission amounts to 72452 tons. It is a huge environmental burden and calls for a wakeup to resolutely act now. The scrutiny was focused on a regional capital of 549,429 inhabitants. In perspective, how about the Capital (Addis Ababa) which is highly preoccupied with redevelopment of the inner most City with a skyscraper zeal using those same materials identified in here as the top three and most excessively used materials for the fundamental reinforced concrete based deconstruction and reconstruction?

7. CONCLUSION AND RECOMMENDATION

7.1. CONCLUSION

Situational assessment and analysis of the construction environment followed by a disclosure of findings to the general public surely helps to instigate social pressure for mitigation and raise the industrial motivation to go for technological improvement by replacing obsolete intensive energy

manufacturing plants with eco-efficient contemporary state-of-the-art production lines. The humble effort in here pin pointed out that, monitoring the health of the construction activity with the trend of time affords a competitive advantage for the social welfare and life style improvement. The burden sharing of the human society is heavily inter-wind with its eco-system. In particular, the non-renewable limited resources should be fairly shared between the current and the future generation with a research based strict value adding; where ever possible. With this as a background, the hitherto attempt of a very much limited diagnosis of the construction envelope highlighted what follows.

a. The construction material use is non-knowledge and non-efficient state-of-the-art technology based. Though construction material waste is particularly dealt with at the construction site level the scenario is prevalent right through raw material extraction and transportation. Need to be addressed very seriously.

b. Implementing lean design and construction frame work is timely to avoid material waste.

c. The top most three extensively used construction materials consumed in the studied construction projects are; re-bar, cement and HCB in a quantitative descending order as embodied energy reservoirs; while, cement, HCB and re-bar are champions as CO_2 emitters in their order of descent. The general picture portrays them as real burdens to the environment; unless otherwise they are handled with a strict sense of knowledge based precaution. The due care has to start from the early design phase.

d. The environmental impact of construction materials misuse and disuse implicate:

- Profit loss and/or delay and even abortion of vital projects.
- Depletion of the non-renewable limited natural resources base.
- Generation of toxic agents today and for the generation to come at landfills and water bodies.

7.2. RECOMMENDATION

During the questionnaire survey and interviews of the study some important issues were highlighted by respondents and noted. Since those matters are considered to be catapults to sustain the effort, they are presented in here as recommendations.

- The basics are to go to standardized design of buildings with prefabrication, including all fittings and furnishings with a good knowledge of building materials characteristics.
- A government legislation to minimize construction waste is needed.
- Lack of local recycling facilities to enable reprocessing of construction waste is raised as a pitfall.
- Lack of contractual incentive packages to allure the contactor to be environment health champion and profit sensitive; i.e., a green contractor.

Above all, it is high time that the country has to embark on a research to develop a national embodied energy and CO_2 emission factors to have data base for both local and imported construction materials as copied or borrowed data are of little or of no relevance to follow and monitor the impact of buildings and infrastructures Life Cycle Assessment (LCA). If done so, the industry as a whole will work under a mandatory selection of appropriate materials from early design stage all along to the end of life of a structure and become a leader in Reduce, Reuse and Recycle (3Rs) of construction materials.

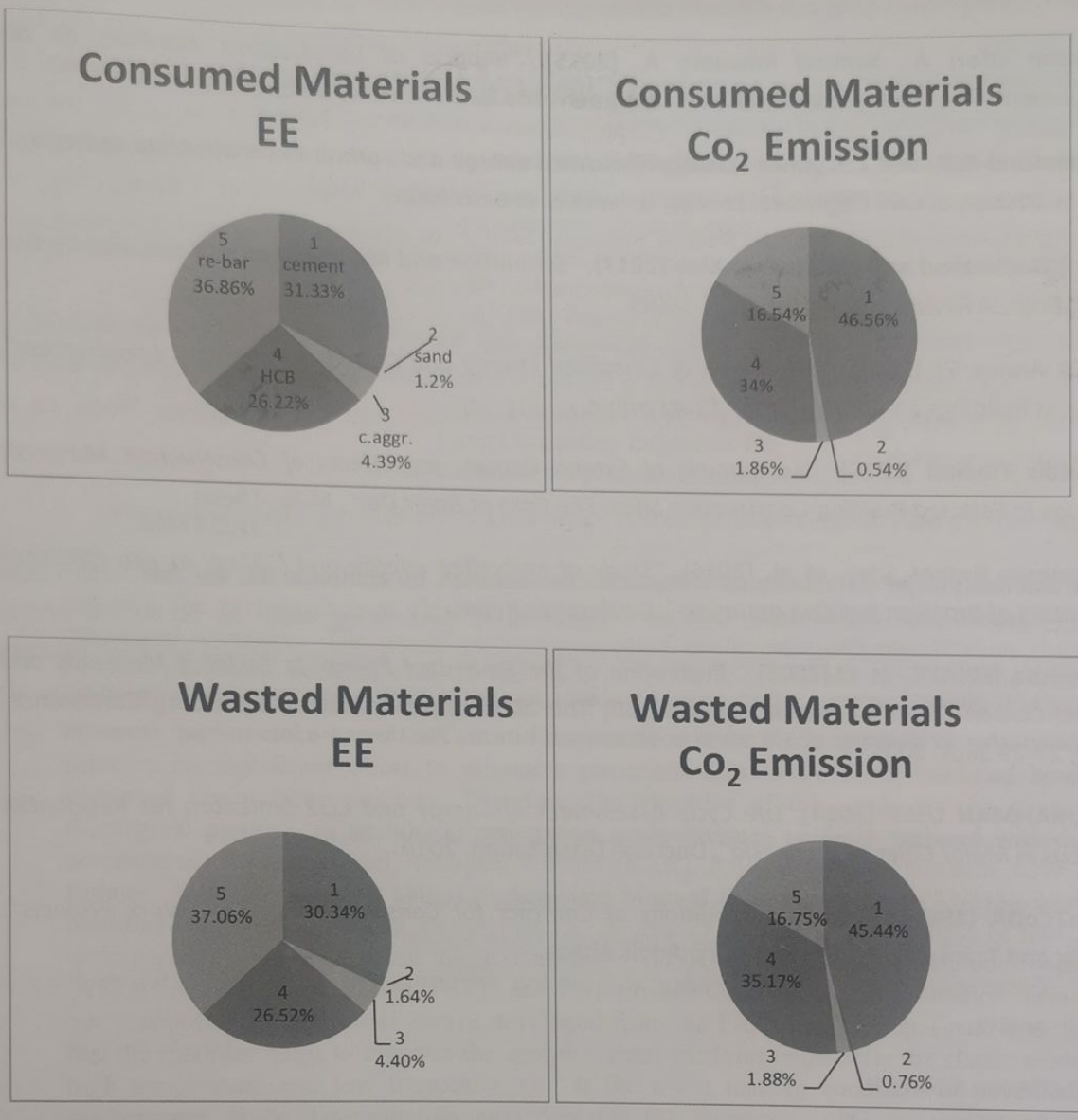


Fig. 2: Embodied energy and CO2 emission of consumed and wasted construction materials

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