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Embodied - Carbon Emission from Building in Overall Life Cycle - A case study of Kathmandu

Mandip Bhandari [a], Kamal Bd. Thapa [b]

[a] *Department of Applied Sciences and Chemical Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] bhandarimandip22@gmail.com, [b] kamal.thapa@ioe.edu.np

Abstract
The majority of research have concentrated on operation carbon mitigation techniques, with little attention paid to embedded carbon emissions. A process-based approach was used to estimate the embedded carbon from the building sector of Kathmandu district in the total life cycle in order to obtain the embodied carbon emission from the buildings of Kathmandu district. The overall result of the study shows the total embodied carbon emission from the building sector in the overall life cycle was 1444.86 Mt. While using the alternative materials AAC block, hollow cement concrete block and AAC block with aluminium openings in the same building reduces the total emission by 4.7%, 3.37% and 1.93% respectively. The research has focused on the construction phase including only the civil raw materials rather than the sanitary and electrical fixtures. So, detail analysis considering the electrical and sanitary fixtures and other phases like operation and maintenance and demolition should be considered in future study.

Keywords
embodied carbon, carbon emission, process decomposition

1. Introduction

In recent decade the common concern of the world is emission of greenhouse gases, global warming and climate change. Due to strong economic growth and urbanization, it accounts for a large part of world energy consumption and pollution emissions [1]. By 2020, the building sector is estimated to account for more than 31% of worldwide CO2 emissions, rising to 52% by 2050 [2]. About 20–30% of the global carbon footprint is the product from the building sectors having extensive worldwide environmental impact [3].Building construction utilizes 24 percent of the raw materials mined from the lithosphere globally [4] and produces substantial amounts of pollution as a result of the energy needed during the mining, processing, and transportation of resources for construction purposes [5].

Construction industry is one of the greatest consumers of resources and raw materials in present era. The construction of buildings has a very important impact on different environmental aspects. According to figures released by the Globe Watch Institute, building construction consumes 40% of the stone, sand, and gravel, 25% of the timber, and 16% of the water in the world each year [6]. Building materials take a lot of energy to manufacture and transport, and they release a lot of greenhouse gases (GHG) during the planning and construction phase of a building. Buildings are major contributors to climate change which shares more than one third of global GHG emissions [7]. The construction of new buildings requires huge amount of raw materials, which have an associated embodied energy for manufacturing, transport, construction and end-of-life disposal. It is estimated that the construction of new buildings emits about 40-50% of greenhouse gas emissions (GHG) [8]. In the beginning of a building life cycle, construction phase GHG emissions lasts within a very short timeframe which makes them more harmful considering the short and midterm climate change mitigation targets in comparison to the use phase emissions [9].

This research will show the total amount of embodied carbon emitted by buildings. This finding will help to know the share of embodied carbon from the building sector that will contribute in climate change. Other similar research calculated the average amount of embodied carbon based on the building's area rather than estimating the construction materials in detail. However, this study is based on the detailed estimation of major construction materials that produce embodied carbon.

2. Methodology

2.1 Study Area

Study area is Kathmandu District in Bagmati Province, Nepal. Study area is one of the largest city with a population of around 1 million. Study area covers the area of 49.45 km2.kathmandu stands at an elevation of approximately 1400m above sea level. Kathmandu is surrounded by Bhaktapur district in east, Lalitpur and Makawanpur in south, Dhadhing and Nuwakot on west and Sindhupalchowk district in north. The research area is mixed residential and commercial urban area with low rise to high rise commercial buildings.

2.2 Methods

Based on process data, the embodied carbon emissions from the building sector were computed in this study. BoQ of 31 different buildings were collected from the four different contractors and detailed estimation of quantity of the construction materials was done. The average quantity of construction materials used in the buildings is shown in table 1.

Table 1: Average Weight of Construction Materials used

Materials	Quantity (kg)
OPC Cement	544520.9258
PPC Cement	140651.2112
Aggregate	1139319.777
Rebar	159654.4653
Brick	644950.1777
Tile	47101.19238
Sal wood	9435.088946
Aluminium	2543.240306
Paints	1308.59571
Glass	2933.996079
Granite	26735.98718
Sand	2066491.464

Table 2 shows the different EE and EC emission factors which are incorporated in the study.

2.2.1 An embodied carbon dioxide estimation method based on process analysis

In this study, the carbon emission from building construction material was calculated based on process data. The bottom-up technique of process-based evaluation depicts carbon emissions for specific building construction processes [10].

Table 2: Emission factors of construction materials

SN	Building Material	Embodied Energy(EE)	Emboided Carbon (EC)	Embodied CO2e
		MJ/Kg	CO2/Kg	CO2e
1	Stone	1.26	0.073	0.079
2	Bricks	3	0.23	0.24
3	Cement			
i	OPC	5.5	0.93	0.95
ii	PPC	4.89	0.75	0.825
7	Marble	2	0.116	0.13
8	Tiles	6.5	0.45	0.48
9	Timber	10	0.46	0.41
10	Glass	15	0.86	0.91
11	Aluminium	155	8.24	9.16
11	Granite	11	0.64	0.7
12	Paints	70	2.41	2.91

(Adopted from Hammond & Jones, 2011)

Carbon dioxide emitted by building materials throughout production, transportation, construction, maintenance, and demolition is referred to as embodied carbon dioxide. Initial embedded carbon (IEC), recurring embodied carbon (REC), and demolition carbon (DC) are the three types of embodied carbon dioxide found in buildings [11]. The IEC is emitted during the construction of a building, over the course of a building's life cycle, REC is emitted. And DC refers to the carbon released during the demolition and disposal of buildings. Eq. 1-5 can be used to determine the yearly embodied carbon dioxide emissions (Cemb) in the building industry, as described above.

$$C_{emb} = C_{new} + C_{maintenance} + C_{demolition} \tag{1}$$

$$C_{new} = C_{em} + C_{ep} + C_{et} + C_{ec} \tag{2}$$

$$C_{maintenance} = C_{er} \tag{3}$$

$$C_{demolition} = C_{ed} + C_{ew} \tag{4}$$

As a result, the annual ECDBS total can be represented as follows:

$$C_{emb} = C_{em} + C_{ep} + C_{et} + C_{ec} + C_{er} + C_{ed} + C_{ew} \tag{5}$$

Where:

C_{emb} stands for the total annual carbon emission from building

C_{new} stands for the embodied carbon dioxide of new structures.

$C_{maintenance}$ stands for the embodied carbon dioxide of building maintenance

$C_{demolition}$ stands for the embodied carbon dioxide from buildings demolition

C_{em} stands for the carbon emissions from the production of building materials.

C_{ep} stands for carbon emissions from chemical reactions in the process of material production.

C_{et} stands for the carbon emissions from transporting construction materials from production facilities to construction sites

C_{ec} stands for the carbon emissions from energy usage on construction sites

C_{er} stands for the carbon emissions from the replacement of building components

C_{ed} stands for the carbon emissions from building demolition

C_{ew} stands for the construction and demolition waste disposal carbon emissions.

2.2.2 Embodied carbon dioxide from building construction material manufacturing

Building construction materials has the greatest contribution for embodied carbon. The mining of construction materials, as well as the processing and production of construction resources, are the most carbon-intensive processes [12]. Process-based method and a statistical method are adopted in this study for determining the construction material manufacturing. Some of the statistical indicators employed in this study were height, function, structure of building, and consumption of the primary construction materials. Steel, cement, wood, brick, glass, aluminum, paints, and other construction materials were employed in the study because they required more energy and released more carbon than other materials [1].

The embodied carbon emissions of construction materials for each structure were computed using carbon emission factors for construction materials, as stated in Eq. 6:

$$C_i = \sum_{j=1}^{6} M_j * f_j \tag{6}$$

Where:

C_i stands for the carbon emissions of ith building structure type (i = 1, 2, 3, 4, ...)

M_j stands for the consumption of jth construction materials (j = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

f_j stands for the carbon emission factor unit weight of j^{th} construction material

2.2.3 Process carbon emission from the chemical reaction

Process carbon emissions are carbon dioxide emissions caused by chemical reactions in industrial manufacturing processes [13]. Cement manufacture is identified as the primary source of carbon emissions from chemical reactions in this study. As a result of calcination reaction, limestone decomposed into calcium oxide which evolves the carbon dioxide during the process of cement production. Eq. 7, proposed by [14], can be used to determine the carbon dioxide emissions from the calcination reaction in cement manufacture.

$$C_{ep} = \beta * M_{cement} * f_{clinker} \tag{7}$$

Where:

C_{ep} stands for carbon emissions of chemical reactions in the industrial production process

β stands for the carbon dioxide per kilogram of clinker produced

M_{cement} stands for the quantity of cement used for building construction

$f_{clinker}$ stands for the proportion of clinker contained in the cement

In this study, clinker carbon emission factor of Nepal's cement is 498.5 kg per ton in construction sector. The adopted average clinker ratio in the Nepal's cement industry is 65%.

2.2.4 Embodied carbon dioxide from building construction and demolition

Machines and equipment on construction sites (for example, trucks, loaders, cranes, etc.), offices, and living on the construction site (lighting, cooking, heating, cooling, etc.) are the main sources of carbon emissions from building construction and demolition [15]. Because data from construction companies for both construction and demolition of buildings was merged, the embodied carbon in this study from both construction and demolition was estimated. On construction sites, eight different types of energy are used. The embodied carbon can be calculated according to Eq. 8:

$$C_{ec} = \sum_{k=1}^{8} Ek * fek \tag{8}$$

Where:

C_{ec} stands for the carbon emissions of energy consumption on construction sites

Ek stands for the ith energy consumption;

fek stands for the carbon emission factor of kth energy k stands for the energy type consumed on construction sites (k =1, 2,. . . ,8)

2.2.5 Embodied carbon dioxide from material transportation

Various construction materials must be transported from their manufacturing facilities to the construction site, which consumes a significant amount of energy. This carbon dioxide emission from material transportation may be calculated using the transportation method and distance, as well as the weight on the vehicle, vehicle type, and vehicle energy consumption. Construction supplies are transported from the manufacturing site to the construction site using diesel-powered medium or heavy-goods transport vehicles. In this study, embodied carbon dioxide is estimated by using Eq. 9;

$$C_{et} = \sum_{i=1}^{6} Mi * Di * Ti \tag{9}$$

Where:

C_{et} stands for the total carbon emissions from transportation of construction materials

Mi stands for the consumption of the ith main construction materials (i = 1, 2, 3, 4, 5, 6)

Di stands for the average distance of the ith construction materials

Ti stands for carbon emission factor of unit weight and unit transportation distance with some transportation mode of the ith construction material

2.2.6 Embodied carbon dioxide from building maintenance

Many components of a structure are fixed, maintained, and replaced throughout the course of its service life, resulting in recurring embodied carbon, which is typically neglected due to data inaccessibility and its minor contribution to life-cycle carbon emissions [16]. However, other researchers [17] claim that recurring embodied carbon emissions, which account for around one-third of a building's initial embodied emissions, could be significant. .The carbon emissions of building mechanisms maintenance (C_{er}) are often tied to the building service life which makes annual statistical data difficult to come by. Therefore, some proportion of initial embodied carbon from the buildings was taken as the embodied carbon dioxide from building maintenance. The annual repeating embodied carbon in certain studies was around 0.32.8 percent of the buildings' initial embodied carbon [18]. The annual recurrent embodied carbon in this study was calculated at 1.55 percent of the building's initial embodied carbon. In the case of embodied energy, 5% of the building's initial embodied energy was used.

2.2.7 Embodied carbon dioxide from construction and demolition waste disposal

According to [19], during the construction phase, building waste can account for 80–90% of the weight of building materials. The carbon dioxide emissions created in the trash disposal process can be computed using Eq. 10:

$$C_{ew} = (Q_w * D_w + Q_{rw} * D_w + Q_r * D_r) * EF_t + \varepsilon * Q_r * EF_r \tag{10}$$

Where:

C_{ew} stands for the embodied carbon of waste disposal

$Q_w$stands for the quantity of waste transported to landfills

Q_{rw} stands for the quantity of recyclable materials to landfills

q_r stands for the quantity of recyclable materials to recycling sites

d_w stands for the distance from the construction site to the landfill

d_r stands for the distance from the construction site to the recycling sites

EF_t stands for the emission factor due to waste transportation

ε stands for the percentage change in carbon dioxide emissions over the virgin materials

EF_r stands for the emission factor of recyclable materials In this study, 85% of total weight of construction material is taken as the weight of waste materials

2.3 Selection alternative materials and allocation EE and EC

Different alternative materials for walls, opening were selected. Due to complexity of calculation, only 2 units were selected for alternative material estimation. It is because; materials for wall and window contribute major proportion of EE and EC.

3. Data Analysis

3.1 Embodied Carbon from Construction materials

For the calculation of the embodied carbon and embodied energy from the building construction materials was estimated by multiplying the corresponding emission factor and the total weight of construction materials used in the construction sites. 10 different common construction materials was taken into action for the estimation of EE and EC. As illustrated in table 3, the total embodied carbon was found 1128.56 Mt and the embodied energy of 10793689.5 MJ. It seems that, having high quantity on the basis of weight aggregate contributes little role in the carbon emission.

Table 3: EE and EC of construction materials

Materials	Cem=ton CO_2e	Cem=ton CO_2	EE (MJ)
Cement	633.33	611.89	3682649.5
Aggregate	5.92	5.47	94563.5
Rebar	324.1	304.94	3991361.6
Brick	154.79	148.34	1934850.5
Tile	9.89	9.04	156847
Sal wood	3.87	4.34	94350.9
Aluminium	24.19	21.76	409359
Paints	3.81	3.15	91601.7
Glass	2.67	2.52	44009.9
Granite	18.72	17.11	294095.9
Total	1181.29	1128.56	10793689.5

3.2 Embodied Carbon from Chemical Reaction

As illustrated in table 4, there exists a strong contribution of calcination reaction during cement production on releasing the carbon dioxide. It was found that 222.01 tonnes of carbon dioxide was evolved during the production of 685.171 tonnes of cement.

Table 4: EC from chemical reaction

Parameter	Values	Units
M_{cement}	685.171	ton
$C_{ep} = \beta * M_{cement} * f_{clinker}$	222012.9	kg CO_2
C_{ep}	222.01	ton CO_2
EE	1199051.24	MJ

3.3 Embodied Carbon from building construction and demolition

Different construction equipment and vehicles was used in the construction sites which requires the energy for the operation resulting in the carbon emission. In this process the energy required for the sit activities (lighting, cooking, heating and cooling).Electricity, diesel, firewood, petrol etc. are the common energies used in the construction work responsible for carbon emission. It was found that 12.44 Mt embodied carbon was emitted from the building construction and demolition.

Table 5: EC & EE from construction and demolition

Parameter	Values	Units
EE	57537.79	MJ
C_{ec}	12.44	ton CO_2

3.4 Embodied Carbon from material transportation

Different construction materials are transported from their production sites to the construction site which required large amount of energy. This carbon dioxide emission from material transportation may be calculated using the transportation method and distance, as well as the weight on the vehicle, vehicle type, and vehicle energy consumption. Diesel based medium or heavy-goods carrying vehicles are used to transport the construction materials from production site to the construction site.The total amount of EE and EC emitted during material transportation to the construction site is shown in table 5.

Table 6: EE & EC during material transportation

Parameter	Values	Units
EE due to transport	633.066	MJ
C_{et}	2.425	ton CO_2

3.5 Embodied Carbon from building maintenance

Building undergoes several periodic repairing and replacement work throughout their life cycle. The carbon emission from these type of maintenance are usually lack of consideration due to unavailability of data and its low contribution to life cycle carbon emissions [16]. The carbon emissions of building components maintenance are estimated according to some proportion of the initial embodied carbon from buildings which is 0.3-2.8% of initial emission [20]. Therefore, in this study, the recurring embodied carbon was assumed to be approximately 1.55 percent of the buildings' initial embodied carbon and found 21.16Mt.

Table 7: EE & EC from buiding Maintenance

Parameter	Values	Units
C_{er} = 1.55%of Cinitial	21.16	ton CO_2
EE demolition+5%of initialEE	60254.56	MJ

3.6 Embodied Carbon from construction and demolition waste disposal

In this study, 85% of total weight of construction material is taken as the weight of waste materials. Aluminium and steel reinforcement are considered as the recycled materials and other wastes are dumped in the dumping site and landfill site. The distance taken for the transportation of recycling material for recycling process was 10km and the distance of dumping site was considered as 25km.It was estimated that 59.211 Mt carbon was produced from construction and demolition waste disposal.

4. Results and Discussion

The mass of the construction material obtained from the previous step were transformed to EE, EC and ECO2e after multiplying them by corresponding coefficients. EE (expressed in MJ) was obtained by multiplying the mass with the EE coefficient (expressed in MJ/kg of material). EC (expressed in $kgCO_2$) was obtained by multiplying the mass with the EC coefficient (expressed in $kgCO_2$/kg of material) and ECO2e (expressed in $kgCO_2$e) was obtained by multiplying the mass with the EC coefficient (expressed in $kgCO_2$e /kg of material). Estimation of EE, EC and CO2 e of 31 building were calculated by using the values obtained from material estimation. It was found that cement accounts for highest proportion of EC and CO2 e contribution which is 611.89 $tonCO_2$ and 633.33 ton CO2 e. Glass and paints accounts for the lowest proportion of EC and CO2 e contribution which is 2.52 $tonCO_2$ and 2.67 $tonCO_2$ and 3.15 $tonCO_2$ and 3.81 ton CO2 e respectively as illustrated in fig 1.

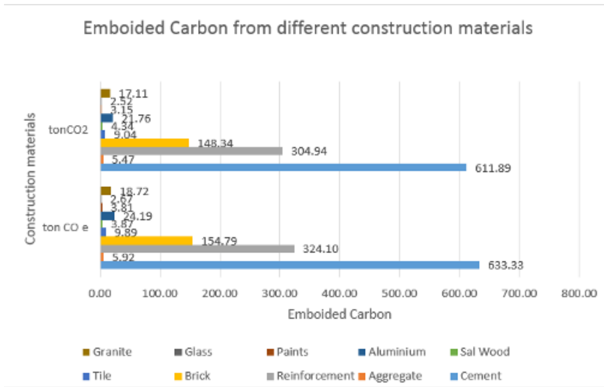

Figure 1: EC from construction materials

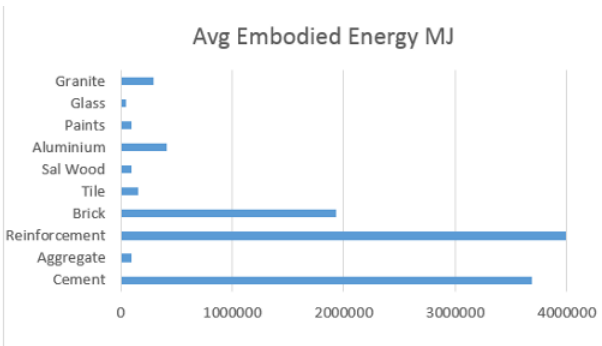

Figure 2: EE of construction materials

As illustrated in fig 2, Aluminium accounts for 3.79% of total EE and 1.92% of total EC emission, the weight of material used in building is 0.05% of the total weight of the building. Thus, the shares of EE and EC emission of aluminium are the highest in building as compared with other construction materials. On the other hand, having high account in weight aggregate has the lowest shares on the EE and EC emission.

Table 8: Total EC

Embodied Carbon	Values	Units
C_{em}	992.443	ton CO_2
C_{ep}	197.926	ton CO_2
C_{ec}	11.779	ton CO_2
C_{et}	2.104	ton CO_2
C_{er}	18.666	ton CO_2
C_{ew}	58.244	ton CO_2
C_{emb}	1444.860	ton CO_2

As illustrated in table 8, total embodied carbon was estimated by the summation of six different phases carbon emissions and found that 1444.86 tonnes of carbon was emitted from the building in its overall life cycle. Similarly, total embodied energy was illustrated in table 9, found to be 12716724.593 MJ.

Table 9: Total EE

Energy	Values	Units
EE due to C_{em}	10793689.621	
EE due to C_{ep}	1199051.240	MJ
EE due to C_{ec}	57537.794	MJ
EE due to C_{et}	633.066	MJ
EE due to C_{er}	60254.559	MJ
EE due to C_{ew}	605558.314	MJ
Total EE	12716724.593	MJ

As illustrated in table 10, when a wall material of the building is replaced by AAC block, total carbon emission and total embodied energy of the building is reduced by 4.7% and 2.73% respectively. Similarly, when a wall material of the building is replaced by hollow cement concrete block, total carbon emission and total embodied energy of the building is reduced by 3.37% and 6.85% respectively. When wall materials of building is replaced by AAC block and opening is replaced by aluminium frames, the embodied carbon of the building is decreased by 1.93% and the embodied energy increased by 3.35%.

Table 10: Comparision of EE & EC with alternative materials

As Built	Total EE	12716724.59	
	Total EC	1444.86	
Using AAC	New EE	12369073.75	
	New EC	1376.9	
	Reduced EE	347650.84	2.73%
	Reduced EC	67.96	4.70%
Using concrete block	New EE	11901024.52	
	New EC	1396.19	
	Reduced EE	815700.07	6.85%
	Reduced EC	48.67	3.37%
Using AAC block and Aluminium	New EE	13157044.06	
	New EC	1417.01	
	Reduced EE	-440319.46	-3.35%
	Reduced EC	27.85	1.93%

5. Conclusion and Recommendation

Various questions about the subject have been systematically answered as a result of this research. We planned to apply a process-based method to determine the different types of building construction materials used in the Kathmandu construction sector, their respective share of embodied energy and embodied carbon, and viable methods for reducing embodied energy and embodied carbon by using different alternative construction materials in building construction. Following conclusion was made based on the study;

- The data shows that the building sector in Kathmandu emits 1444.86 tonnes of embodied carbon and 12716724.59 MJ of embodied energy
- The use of aluminum in openings emits more carbon than the use of wood, hence aluminum cannot be considered an alternative material.
- When a building's wall materials are replaced with AAC blocks, embodied carbon is reduced by 4.7 percent and energy is reduced by 2.73 percent. Similarly, replacing brick wall with hollow cement concrete blocks resulted in a 3.37 percent reduction in carbon and a 6.85 percent reduction in energy.
- When the building's wall materials are replaced with AAC blocks and the openings are replaced

with aluminum frames, the building's embodied carbon is reduced by 1.93 percent while the embodied energy is increased by 3.35 percent.

- Structures that combine timber with other material have less severe environmental impacts than those using metal, brick or concrete. The life-cycle GHG emissions from structures made of a mix of concrete and brick appeared to be higher than those made of simply concrete.

The study has following recommendation are as follows:

- Only civil construction are considered, while electrical fixtures and sanitary and plumbing fixtures are not. The inclusion of electrical, sanitary, and plumbing components in the analysis will broaden the scope of the investigation.
- This study only looked at RCC structures, however it might be expanded to include brick masonry buildings, steel structure buildings, and so on.
- The analysis only takes into consideration the building, maintenance, and demolition phases, but this work might be expanded by including the operational phase.

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