Innovations

Examining Carbon Emissions in Building Materials: A Case Study of Government Buildings in Pokhara Metropolitan City

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Abstract: *Numerous studies placed particular emphasis on reducing carbon emissions from operations, often ignoring the importance of embodied carbon emissions. To evaluate the embodied carbon emissions associated with government buildings in Pokhara Metropolitan City, a systematic process-based approach was used to estimate the total embodied carbon over the lifetime of these structures. The research findings reveal that the cumulative embodied carbon emissions stemming from these buildings contributed a total of1281.56 metric tons (Mt) and 12504540.5 MJ of embodied energy. Furthermore, the study explored the potential for reducing these emissions by adopting alternative construction materials. In particular, the inclusion of AAC (Autoclaved Aerated Concrete) blocks, hollow cement concrete blocks, and stabilized soil blocks (8% cement)in the same building demonstrated reductions in total emissions by 5.56%, 4.38%, and 5.16%, respectively. It is crucial to acknowledge that this study primarily focuses on the construction stage of the building and exclusively considers civil construction materials. It did not encompass elements such as sanitary and electrical fixtures or other stages in the building's lifecycle, including operation and maintenance and eventual demolition. Consequently, it is recommended that future research endeavors undertake a more comprehensive analysis, encompassing electrical and sanitary fixtures, as well as all phases of a building's lifecycle, to gain a more holistic understanding of embodied carbon emissions in government buildings.*

Keywords*: embodied carbon, alternative materials, sustainable development*

1. Introduction

Nestled within the magnificent Himalayan range, Nepal stands as a tribute to the beauty of nature with its beautiful surroundings and rich heritage in culture(Bernbaum, 2022). Sustainable development calls for concerted efforts toward building an inclusive, sustainable, and resilient future for people and the planet. The significance of sustainable urban development cannot be stressed as this country advances. The environmental impact of building materials becomes a crucial point of focus in this endeavor(Suman, 2021). The embedded carbon emissions linked to these materials are an important but frequently disregarded aspect of a building's environmental impact(Fenner et al., 2018). In order to understand the complexities of government buildings' carbon emissions and pave the road for greener, more environmentally conscious urban areas. (Franco et al., 2021)This study looks deeply into this crucial issue, concentrating on government buildings within Pokhara Metropolitan City. Owing to robust economic growth and urbanization, these factors contribute considerably to the substantial share of global energy usage and the discharge of pollutants into the environment(Cabeza et al., 2013). In 2020, it was projected that the construction industry contributed to over 31% of worldwide carbon dioxide (CO2) emissions, and this figure is expected to increase to 52% by the year 2050.(*Renewable Energy Sources and Climate*

Change Mitigation — IPCC, n.d.). Building sectors have a substantial global environmental impact, accounting for 20 to 30 percent of the planet’s carbon footprint(*Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve | McKinsey*, n.d.). The construction of buildings consumes 24 percent of the raw materials extracted from the Earth's lithosphere on a worldwide scale(Zabalza Bribián et al., 2011), leading to substantial pollution levels stemming from the energy requirements involved in mining, processing, and transporting resources for construction applications (Morel et al., 2001). In the contemporary era, the construction industry is a big consumer of resources and raw materials. The construction of structures exertssignificant influence over various environmental aspects. As per the Globe Watch Institute's report, the construction industry utilizes 40% of the global supply of stone, sand, and gravel each year, along with 25% of its timber, and 16% of its freshwater resources.(Arena & de Rosa, 2003). During the planning and construction phases, building materials require a significant amount of energy and result in the release of substantial greenhouse gases (GHGs). With over one-third of global GHG emissions coming from buildings, they stand out as significant climate change contributors(Programme, 2009). Constructing new buildings necessitates vast quantities of raw materials, each carrying embodied energy derived from their manufacturing, transportation, construction, and eventual disposal. An estimated 40-50% of greenhouse gas emissions are attributed to the building of new structures(Ding, 2008). Accounting the immediate and mid-term climate change mitigation targets, construction-phase GHG emissions are more detrimental than usage-phase emissions at the beginning of a building’s life cycle(Säynäjoki et al., 2012).

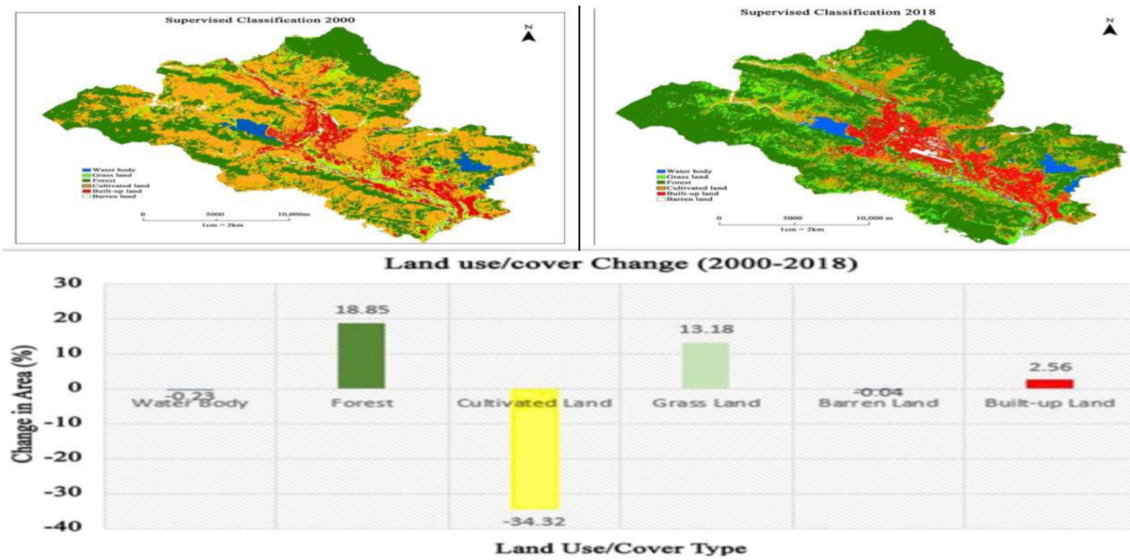
The purpose of this study is to assess thetotal carbon emissions associated with government buildings. This includes calculating the carbon emissions that are embedded or "embodied" in the materials, construction, and maintenance of these buildings. The goal is to provide an in-depth analysis of the environmental impact of government-owned structures. This research will provide insights into the extent to which the building sector’s embodied carbon impacts climate change. Unlike previous analogous research thatestimated average embodied carbon values based on building area, this analysis relies on a meticulous assessment of primary construction materials responsible for generating embodied carbon.

2. METHODOLOGY

2.1 STUDY AREA

The research location is within Pokhara Metropolitan City, situated in the Kaski district of the Gandaki Province in Nepal. This city is among the largest in the region, housing approximately 500,000 residents. The study encompasses a land area of 464.20 square kilometers, and Pokhara is situated at an altitude of roughly 1400 meters above sea level.Pokhara Metropolitan City is surrounded by Madi RM and Rupa RM in the east, Syangja and Tanahun district in the south, Parbat and Annapurna RM inthe west, and Machapuchre RM in the north. The reason for the selection of the site is the increasing built-up urban areas which increased from 5.1% of the area in 2000 to about 26.06 % in 2018 (Raut et al., 2020) which is depicted in the figure alongside. This indicates that the built-up area is bound to increase further thus increasing the carbon emission.

Figure 1Land use land cover map of Pokhara Valley (2000-2018)



2.2 METHODS

For the study, calculations of the embodied carbon emissions in the government building sector are based on process data. We collected Bills of Quantities (BoQ) from 25 different buildings. These buildings were sourced from various governmental bodies within the metropolitan area. We conducted a comprehensive analysis to estimate the quantities of construction materials used in these buildings. The data provided in Table 1 displays the typical amounts of construction materials used in the buildings.

Table 1: Typical Mass of Construction Material Employed

Materials	Materials (kg)
Ordinary Portland Cement (OPC)	519230.82
Portland Pozzolana Cement (PPC)	135090.06
Aggregate	1073878.98
Reinforcement	141556.86
Brick	556819.67
Tile	50944.14
Sal wood	9571.32
Aluminium	2758.64
Paints	1281.07
Glass	2940.43
Granite	29945.21
Sand	1935478.17

The proportion of building materials used in the study area can be depicted in pictorial form as in Figure 2.

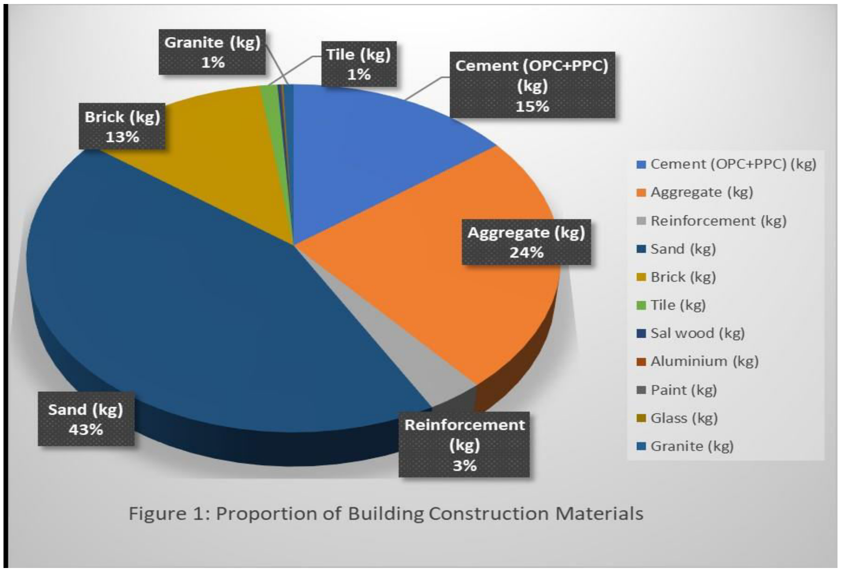


Figure 2 Building Materials proportion according to weight

The mass analysis of the building shows that aggregate, brick, cement, and sand were the extensively used materials. Reinforcement, tile, and granite were also the major constituents of buildingmaterials.

Table 2 displays the various emission factors for EE (Energy Efficiency) and EC (Emission Control) considered in the research.

2.2.1 A METHOD FOR ESTIMATING CARBON DIOXIDE EMISSIONS THAT ARE INTEGRATED WITHIN A PROCESS ANALYSIS

This study employed a process-based approach to calculate carbon emissions from building construction materials.

Building Material	Embodied Energy (MJ/Kg)	Embodied Carbon (CO2/Kg)	Embodied Carbon (CO2e/kg)
Stone	1.25	0.072	0.078
Bricks	3	0.23	0.24
Cement			
OPC	5.5	0.93	0.95
PPC	4.89	0.75	0.825
Marble	2	0.116	0.13
Tiles	6.5	0.45	0.48
Timber	10	0.46	0.41
Glass	15	0.86	0.91

Aluminium	155	8.24	9.16
Granite	11	0.64	0.7
Paints	70	2.41	2.91

Table 2 Factors related to the emissions produced by construction materials

Adoptedfrom(Hammond & Jones, 2008)

In various construction methods, the bottom-up process-oriented approach illustrates carbon emissions as explained by Z. Zhang and Wang in 2016. Carbon dioxide is released from construction materials at different stages, including manufacturing, transportation, construction, upkeep, and ultimately demolition, contributing to the creation of embodied carbon dioxide.In buildings, there are three types of embodied carbon dioxide namely, initial embedded carbon (IEC), recurring carbon (REC), and demolition carbon (DC)(Li et al., 2014). IEC arises during the building construction phase, REC accumulates throughout the life of the building, and DC relates to carbon emissions emitted during dismantling and disposal of structures. The givenequations ranging from 1 to 5 can be used to find out the annual embodied carbon dioxide emissions (CO2emb) in a construction sector, which was outlined previously.

CO2emb = CO2new +CO2maintenance +CO2demolition (1)

CO2new = CO2em +CO2ep +CO2et +CO2ec (2)

CO2maintenance = Cer (3)

CO2demolition = Ced +Cew (4)

Consequently, the total for the annual ECDBS can be expressed in the following manner.

CO2emb = CO2em +CO2ep +CO2et +CO2ec +CO2er +CO2ed +CO2ew (5)

Where:

CO2emb represents the overall yearly carbon emission from building

CO2new represents the overall yearly carbon dioxide of new structures.

Cmaintenance represents the overall yearly carbon dioxide of building maintenance

CO2demolition represents the overall yearly carbon dioxide from building demolition

CO2em represents the overall carbon emissions due tothe production of building materials.

CO2ep represents the overall carbon emissions due to chemical reactions during material production.

CO2et represents the overall carbon emissions from the transportation of construction materials from production facilities to construction sites.

CO2ec represents the emissions of carbon dioxide resulting from the utilization of energy at construction sites.

CO2er represents the carbon emissions from the changein building components

CO_2ed represents the carbon emissions from the demolition of building components.

CO_2ew represents the emissions of carbon dioxide associated with the disposal of construction and demolition waste.

2.2.2 Carbon dioxide emissions resulting from the production of construction building materials

Construction materials play a significant role in contributing to embodied carbon emissions, with the stages of mining, processing, and manufacturing of these resources being the most carbon-intensive(Pomponi & Moncaster, 2018). This research combines both a method that centers on processes and the use of statistical techniques to evaluate the production of construction materials. Significant statistical measures employed in this study included factors like the height of buildings, their intended purpose, their structural characteristics, and the usage of primary construction materials. The investigation primarily concentrated on materials like steel, cement, timber, bricks, glass, aluminum, paints, and various other construction supplies, as these materials demonstrate greater energy demands and carbon emissions when contrasted with alternative options(Chau et al., 2015). The embodied carbon emissions of the building materials for each structure were calculated using the carbon emission factor for the building materials as shown in Eq.6:

$$C_i = \sum_{j=1} M_j * f_j \qquad (6)$$

where:

C_i denotes the carbon emissions associated with the building structure type indexed (i = 1, 2, 3, 4, . . .)

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

f_j *denotes* the carbon emission factor unit weight of construction building material indexed as "j".

2.2.3 Releases of carbon emissions resulting from chemical reactions

Carbon emissions associated with processes pertain to carbon dioxide emissions that arise due to chemical reactions taking place within industrial production processes. (Chau et al., 2015). In this research, it was determined that the primary contributor to carbon emissions resulting from chemical reactions is the production of cement. This is attributed to the calcination process, during which limestone breaks down into calcium oxide, leading to the release of carbon dioxide in the course of cement manufacturing.Equation 7, as proposed by (Pommer & Claus, n.d.)can be embraced toestimate carbon dioxide emissions resulting from the calcination reaction in the production of cement.

$$CO_2ep = \beta * Mcement * fclinker \qquad (7)$$

where:

CO_2ep represents therelease of carbon emissions resulting from chemical reactions occurring during the industrial production process

β representsthe amount of carbon dioxide emitted per kilogram of clinker manufactured

Mcement stands for the quantity of cement used for building construction

fclinker proportion of clinker present in the cement

In this research, we established that the carbon emission factor for cement clinker utilized within Nepal's construction industry stands at 498.5 kilograms per ton. It was found that, on average, cement clinker constitutes 65% of the total composition within the Nepalese cement manufacturing sector.

2.2.4 EMBODIED CARBON DIOXIDE DUE TOTHE TRANSPORTATION OF MATERIAL

Transporting different construction materials from the production facility to the construction site requires a substantial amount of energy. To calculate the carbon dioxide emissions resulting from this transportation, one should consider various factors, including the transportation method, distance, vehicle weight, vehicle category, and the energy used by the vehicle. Typically, construction materials are moved from the manufacturing site to the construction site using medium to large diesel-powered transport vehicles. In this research, we determined the estimated carbon dioxide emissions that are associated with t transportation embracing Equation 9.

$CO2_{et} = \sum Mi*Di*Ti$ (9)

Where:

$CO2_{et}$signifies the total carbon emissions resulting from the transportation of construction materials.

Mirepresents the usage of the construction material corresponding to the ith component.

Di represents the distance covered by the building construction materials indexed i.

Ti represents the carbon emission coefficient of unit weight and unit transportation distance with a certain transportation method of ith construction material.

2.2.5 CARBON DIOXIDE EMISSIONS RESULTING FROM THE MAINTENANCE OF A BUILDING

There are many components of a building that undergo repairs, maintenance and replacement throughout its lifetime, resulting in periodic carbon emissions. These emissions are often overlooked due to a lack of data and their relatively small contribution to total life cycle carbon emissions (Zhang & Wang, 2017). Nonetheless, some scholars propose that occasional carbon emissions from renewable sources, constituting approximately one-third of the initial emissions from a structure, could hold significant significance. (Wang et al., 2017). Calculating the carbon emissions associated with maintaining building mechanics (Cer) can be difficult because they are closely related to the lifespan of the building, making annual statistical data scarce. To address this issue, part of the initial carbon footprint of buildings is considered to be the carbon dioxide footprint due to building maintenance. Previous studies have estimated that the annual recurring carbon consumption is between 0.3% and 2.8% of the initial carbon consumption of buildings(Dixit et al., 2010).

2.3 ASSESSING ALTERNATIVE MATERIALS ANDALLOCATION OF EMBODIED ENERGY AND EMBODIED CARBON

The study explored **DIFFERENT** options for wall and window materials, but due to the intricate calculation process involved, the analysis narrows down to just two particular units for assessing alternative materials. This decision was made because the materials used in wall and windows play a substantial role in determining the embodied energy (EE) and embodied carbon (EC) evaluations.

3. DATA ANALYSIS

3.1 CARBON EMISSIONS RESULTING FROM THE CONSTRUCTION MATERIALS USED IN BUILDING

In order to determine the carbon emissions and energy usage resulting from the utilization of construction materials for a building project, we computed the total emissions and energy by applying the appropriate factor to the combined weight of the construction materials employed at the construction site. We looked at distinct types of construction materials commonly used to estimate Embodied Energy and Embodied Carbon. As shown in Table 3, the total embodied carbon amounted to 1,128.56 metric tons (Mt), while the Embodied energy reached 10,793,689.5 megajoules (MJ). In contrast, it appears that having a larger amount of aggregate by weight does not significantly affect carbon emissions.

Table3: Embodied Energy and Embodied Carbon of Building materials

Building Materials	Cem=ton CO_2e	Cem=ton CO_2	EE (MJ)
Cement	604.72	584.20	3516395.88
Aggregate	5.58	5.15	89131.96
Reinforcement	287.36	270.37	3538921.48
Brick	133.64	128.07	1670458.83
Tile	10.70	9.78	169643.98
Sal wood	3.92	4.40	95713.15
Aluminium	25.27	22.73	427589.20
Paints	3.73	3.09	89674.76
Glass	2.68	2.53	44106.50
Granite	20.96	19.16	329397.30
Total	1094.83	1046.39	9881358.3

3.2 CARBON EMISSIONS RESULTING FROM CHEMICAL REACTION

These results highlight the need for continued efforts to address emissions associated with cement production.

As displayed in Table 4, the calcination response included in cement generation could be a significant source of carbon dioxide emanations. More absolutely, our discoveries show that 212.02 metric tons of carbon dioxide were produced amid the generation of 654.320 metric tons of cement. This underscores the critical natural effect of the calcination handle inside the cement industry, emphasizing the significance of embracing economic hones and innovations to moderate these outflows and decrease the sector's carbon impression. This result highlights the requirement for proceeded endeavors to address emanations related to cement generation.

Table 4 Embodied Carbon resulting from chemical reaction

Parameter	Values	Units
Mcement	654.32	ton
Cep = β * Mcement * fclinker	212016.32	kg CO2
Cep	212.02	ton CO2
EE	1145061.53	MJ

3.3 CARBON EMISSIONS RESULTING FROM TRANSPORTATION OF MATERIALS

Transporting a variety of construction materials from where they are made to the construction sites consumes a significant amount of energy. The carbon dioxide emissions that occur during this transportation can be determined by considering factors such as the mode of transportation, distance traveled, weight of the vehicle, type of vehicle, and its energy consumption. Typically, medium to heavy-duty trucks powered by diesel are employed to move these building materials from production sites to construction locations. The total quantity of EE and EC resulting from the transportation of materials is calculated and presented in Table 5.

Table 5.Embodied Energy & Embodied Carbon due to Material Transportation

Parameter	Values	Units
EE due to transport	624.70	MJ
Cet	3.224	ton CO_2

3.4 CARBON EMISSIONS RESULTING FROM BUILDING MAINTENANCE

Throughout a building's lifecycle, many maintenance and replacement works are performed from time to time. Typically, the carbon emissions resulting from these maintenance processes are not comprehensively considered, mainly due to data limitations and their relatively small contribution to the total carbon emissions over the building life cycle (Zhang & Wang, 2015). This study estimated the carbon emissions associated with the maintenance of building components. This estimate is based on the initial carbon fraction within the building, which typically ranges from 0.3% to 2.8% of initial emissions(Ding, 2008). Therefore, in our analysis, we assumed that the circulating carbon from maintenance activities was approximately 1.5% of the building's initial carbon emissions. As a result, we found that regular CO2 emissions were 19.93 metric tons

Table 6 Embodied Energy & Embodied Carbon due to Maintenance of Building

Parameter	Values	Units
C_{er}= 1.5% of Cinitial	19.93	ton CO_2
EE demolition+5% of initial EE	565164.62	MJ

4. RESULTS AND DISCUSSION

In the former step of the study, the mass of the building construction materials was converted into three main indicators. Embodied Energy (EE), Embodied Carbon (EC), and Embodied Carbon Dioxide Equivalents (ECO2e). This conversion was accomplished by multiplying the mass of the construction material by the appropriate carbon coefficients. Initially, we calculated the EE, measured in megajoules (MJ), by multiplying the building material mass by the Embodied Energycoefficient expressed in Mega Joules per kilogram of material. We then calculated the EC value in kilograms of CO2 (kgCO2) by multiplying the material mass by the EC factor in kgCO2 per kilogram of material. Finally, the ECO2e, expressed in kilograms of CO2 equivalent (kgCO2e), was determined by multiplying the material mass by the ECO2e factor. This is also expressed in kgCO2e per kilogram of material.

These calculations were used to estimate Embodied Energy, Embodied Carbon, and CO2e values for 25 government buildings based on values determined from material estimates. In particular, our results showed that cement was the material that accounted for the largest proportion of EC and CO2e contributions, i.e. 584.20 tons of CO2 and 604.72 tons of CO2e. Conversely, materials such as glass and paints had the lowest contribution to EC and CO2e, with 2.53 tons of CO2 and 2.68 tons of CO2e, respectively, as shown in Figures 3 and 4.

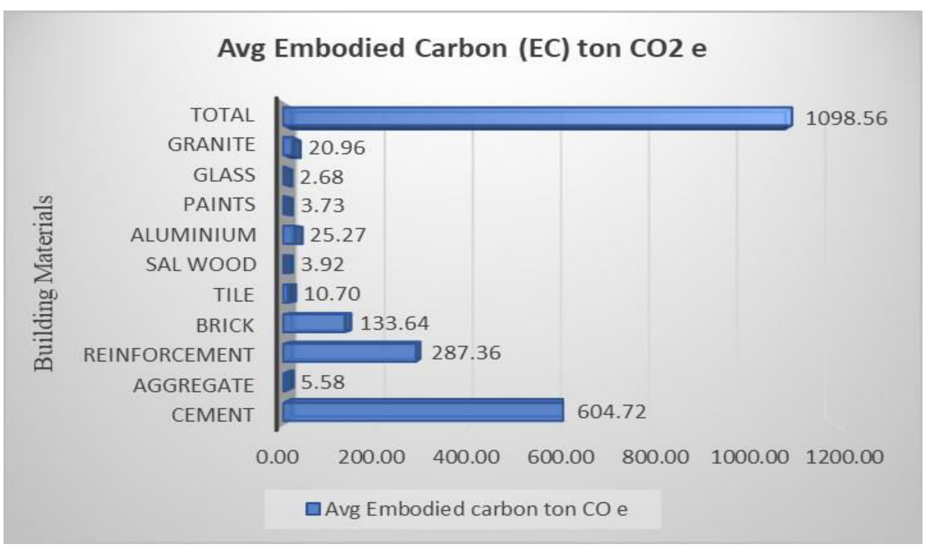


Figure 3 Embodied Carbon from buildings construction materials (ton CO2e)

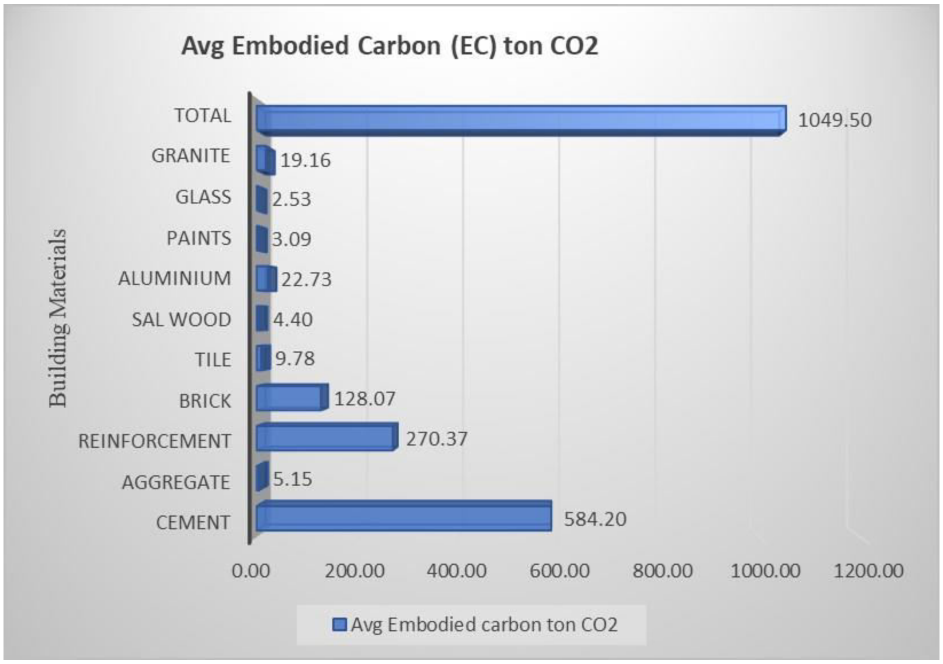


Figure 4 Embodied Carbon from construction materials (ton CO2)

Cement and Reinforcement remain the most carbon-emitting building materialsin the highest order with 584.20 metric tons CO2 and 270.37 metric tons of CO2 respectively.

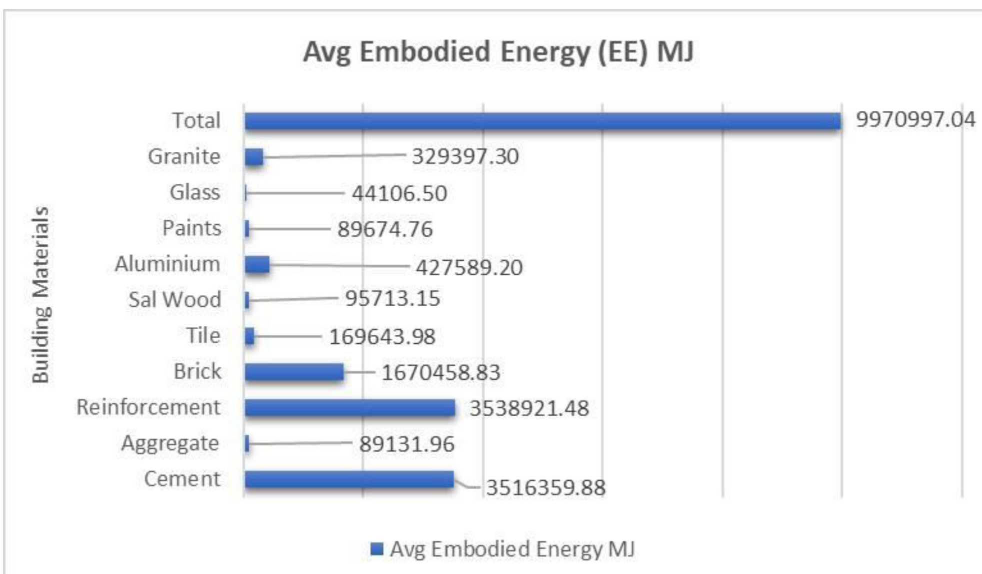


Figure 5 EE from construction materials (ton CO2)

As shown in the data presented in Figure 5, aluminum plays a prominent role in the environmental impact of these buildings. This accounts for approximately 4.29% of the total Embodied energy (EE) emissions and approximately 2.16% of the Embodied carbon (EC) emissions in buildings. Despite aluminum's relatively low mass compared to other building materials (accounting for only 0.06% of a building's total weight), it has high carbon emissions. The fact is that it is emerging as the material that contributes most significantly to the EC emissions highlight the life cycle of a building.

This result highlights the fact that the impact of a material on a building's environmental footprint cannot be determined by its weight alone. Instead, it emphasizes the need to consider the energy and carbon impact of materials used in construction. Materials with a relatively high environmental impact, such as aluminum, can have a disproportionate impact on a building's total EE and EC emissions, even if it is only a fraction of the building's weight. Conversely, heavier materials such as aggregates contribute the least to both EE and EC emissions, highlighting the complex interplay between material mass, embodied energy, and carbon emissions in building sustainability assessments.

Table7 Total Embodied Carbon

CO_2em ton CO_2	**CO_2ep** ton CO_2	**CO_2et** ton CO_2	**CO_2er** ton CO_2	**CO_2emb** ton CO_2
1046.39	212.02	3.224	19.93	1281.564

As shown in Table 7, the total embodied carbon emissions were calculated by summing up the carbon emissions from six different phases, resulting in a total of 1281.564 tonnes of carbon (ton CO_2) emitted over the building's entire life cycle. Likewise, Table 8 presents the total embodied energy, which was determined to be 12504540.35 megajoules (MJ). These figures provide valuable insight into the environmental impact of a building over its lifecycle, considering both CO2 emissions and energy consumption.

Table 8 Total Embodied Energy

EE due to CO_2em MJ	EE due to CO_2ep MJ	EE due to CO_2et MJ	EE due to CO_2er MJ	Total EE MJ
10793689.5	1145061.53	624.7	565164.62	12504540.35

As illustrated in Table 9, it is clear that material and design choices are important in reducing the environmental impact of buildings. Replacing a building's existing walling with AAC blocks (autoclaved aerated concrete) significantly reduces the total carbon emissions associated with the building's life cycle by 8.08%.In addition, this change increases the total building energy by 4.20%.This shows that AAC (Autoclaved Aerated Concrete) blocks have a positive impact on improving the environmental friendliness of buildings, both in terms of CO2 emissions and energy consumption. The decision to replace the wall material with cement concrete hollow blocks also has environmental benefits. In this case, the building's total carbon emissions are reduced by 5.62% and the total energy is increased by 6.97%.This suggests that the choice of building materials can have a significant impact on the overall environmental footprint of a building. Additionally, a subtler result can be achieved if you consider a combination of changes: replacing the wall material with his AAC block and upgrading the opening with an aluminum frame. This change reduces the embodied carbon of the building by 3.56%, showing a positive impact on the environment, but also increases the embodied energy by 3.56%.These results highlight the importance of thoughtful decision-making when constructing and renovating buildings. By considering not only instantaneous costs but also long-term environmental impacts, builders and designers can make decisions that contribute to a sustainable and energy-efficient built environment.

5. CONCLUSION AND RECOMMENDATION

The study systematically addressed multiple questions related to this topic. Our goal is to adopt a methodical approach to identify the various kinds of construction materials employed in the Pokhara Metropolitan City's construction industry. We will also assess the corresponding levels of embodied energy and carbon footprint associated with these materials. Furthermore, we conducted an evaluation of alternative construction materials to decrease both the embodied energy and carbon emissions in the construction process.

Table 9: Comparison of Embodied Energy and embodied carbon of conventional bricks with Autoclaved Aerated Concrete blocks as an alternative material

Comparison Chart	Using Conventional Bricks	Using AAC Blocks	Reduced Carbon Emission
Embodied Energy (EE)	12504540.35	12129073.75	3.00%
Embodied Carbon (EC)	1281.564	1210.25	5.56%

Table 10: Comparison of Embodied Energy and embodied carbon of conventional bricks with hollow concrete blocks as an alternative material

Comparison Chart	Using Conventional Bricks	Using hollow concrete blocks	Reduced Carbon Emission
Embodied Energy (EE)	12504540.35	11492109.63	8.09%
Embodied Carbon (EC)	1281.564	1225.35	4.38%

Table 11: Comparison of Embodied Energy and embodied carbon of conventional bricks with stabilized soil blocks (8% cement) as an alternative material

Comparison Chart	Using Conventional Bricks	Using stabilized soil blocks (8% cement)	Reduced Carbon Emission
Embodied Energy (EE)	12504540.35	11492109.63	2.22%
Embodied Carbon (EC)	1281.564	1225.35	5.16%

The study on embodied energy and carbon emissions in building materials of government building in Pokhara Metropolitan City reveals significant insights into the environmental impact of the construction industry. It uncovers that the construction sector in Pokhara generates a substantial 1281.564 tons of carbon emissions and consumes 12504540.35 Mega Joules of embodied energy, emphasizing the sector's ecological footprint. Notably, the research highlights the comparative environmental performance of building materials. It finds that aluminum, when used in openings, emits more carbon than wood, indicating that aluminum may not be a favorable alternative material from an environmental standpoint. Furthermore, the study underscores the positive impact of using alternative materials, such as AAC blocks, hollow cement concrete blocks, and stabilized soil blocks (8% cement), which can reduce both carbon emissions and energy consumption in building construction. This research contributes valuable insights for promoting more sustainable practices in the construction industry, aligning with global efforts to reduce environmental impacts.

The research study offers several insightful recommendations for future investigations in the field. Firstly, it suggests expanding the scope of analysis beyond civil construction works to include electrical, sanitary, and plumbing components, providing a more comprehensive understanding of the environmental impact across all construction sectors. Additionally, the study advises extending the focus from Reinforced Concrete Construction (RCC) structures to encompass other building types such as brick and steel structures, allowing for a broader assessment of materials and construction methods. Furthermore, the study encourages future research to incorporate the operations phase in addition to the construction, maintenance, and demolition phases, enabling a more holistic examination of the entire lifecycle of buildings. Lastly, the study highlights the potential benefits of utilizing advanced tools like Building Information Modeling (BIM) to integrate multidisciplinary data and create detailed digital representations, enhancing the precision and depth of environmental assessments in construction practices. These recommendations pave the way for more comprehensive and sustainable research in the construction industry.

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