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Embodied Energy Analysis of Multistorey Building in Kathmandu Valley

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Abstract

The escalating urbanization in developing nations, driven by industrialization and globalization, has led to an unprecedented demand for housing and infrastructure to cater to the expanding population and its associated activities. The production and transportation of various construction materials contribute significantly to the substantial energy consumption in these regions. This paper focus on various concerns concerning embodied energy and embodied carbon emissions in buildings, specifically in the Nepali context. Energy consumption and emission in the manufacturing, transportation, and construction/ erection of basic building materials and different types of construction materials have been examined. The energy and emission in various forms of masonry have been compared. A process-based LCA method has been used for the estimation of embodied energy and carbon emission. The study is limited to multistorey RCC frame structure building with single case study and only civil construction materials has been taken for energy and GHG emission analysis. The overall result shows 6.701GJ/m2 embodied energy consumption, 0.673Tons/m2 of CO2 equivalent emission, and 9.72GJ/m2 total operational energy over 60 years of service life respectively can be estimated for the high-rise apartment building in Kathmandu Valley. Embodied energy and embodied carbon can be reduced significantly after the substitution of Clay Brick and Fly ash brick with AAC Block, virgin steel with 43.2% recycled steel, Ordinary Portland Cement by Portland Pozzolana Cement, and Aluminium by U-PVC section can reduce embodied energy up to 27% and embodied carbon up to 57% respectively.

Keywords

Embodied Energy, Embodied Carbon, Energy Conservation

1. Introduction

Over the recent decades, an escalating worldwide apprehension has centered around the emission of greenhouse gases, the occurrence of global warming, and the overarching challenge of climate change. This increased awareness is prompted by the substantial energy consumption and pollution emissions arising from swift global economic growth and urbanization [1, 2]. As of 2020, the construction sector contributed to more than 31% of the total global CO2 emissions, with forecasts suggesting a projected rise to 52% by the year 2050 [2, 3]. Roughly 20–30% of the world's carbon emissions originate from the construction sector, causing noteworthy and extensive environmental repercussions globally [2, 4].

The construction of buildings contributes to 24% of the raw materials extracted globally from the lithosphere [5]. Additionally, the construction sector generates substantial pollution due to the energy-intensive processes involved in mining, processing, and transporting materials for construction or renovation purposes [6]. Without significant improvements in building energy efficiency, it is anticipated that the current boom in urbanization will result in a doubling of GHG emissions linked with the building and construction industry over the next 20 years [7]. Building construction comprises 24 percent of the raw materials extracted from the lithosphere globally [6] and produces extensive amounts of pollution as a result of the energy needed during the mining, processing, and transportation of material for construction or renovation purposes [4].

According to Praseeda et al. 2015, Buildings utilize roughly half of the total energy produced globally and hence contribute significantly to CO2 emissions. The Life cycle energy (LCE) of a building is made up of Embodied Energy (EE) and Operational Energy (OE). The LCE of a structure is mostly determined by its design, prevalent environmental conditions, and tenant behavior. Thus, investigations into building LCE are critical for identifying optimal emission-reduction techniques. While OE indicates the energy used to operate, EE includes the original capital energy used in its creation (material and load associated with material usage in buildings). The assessment of EE and OE in buildings is critical for finding appropriate design and operational methods for reducing the life cycle energy of the building [8].A significant amount of energy is expended in the manufacturing and transportation of various building materials. Energy conservation is crucial in the context of controlling greenhouse gas emissions into the atmosphere and lowering material costs. The materials and methods used in building construction should be chosen to meet the user's perceived needs as well as the society's development needs while minimizing environmental effects. Environmental consciousness has developed in the building and construction industry in recent years [9]. Building material manufacturing operations emit greenhouse gases such as CO2 into the atmosphere. There is a considerable deal of worry and emphasis on lowering greenhouse gas emissions into the atmosphere to control negative environmental effects.

According to Bardan S. 2011 [10], There is a need for more research in the field of energy efficiency in the building sector, particularly from the perspective of developing countries. There is also a need for many more evaluation studies from these regions, particularly from a quantitative perspective. Even the World Business Council for Sustainable Development (WBCSD) has embraced the goal of all buildings consuming zero net energy by the year 2050.

Climate change and global warming are widely acknowledged as key challenges in sustainable development, with the building sector contributing significantly to global greenhouse gas emissions. Until recently, it was widely assumed that a building's embodied energy content was insignificant in comparison to its operating energy over its lifetime. A recent study in Australia and elsewhere, however, has revealed that the embodied energy of house construction processes is comparable to 10-15 years of operating energy. As a result, minimizing embodied energy in the construction process has gained prominence as a means of lowering carbon dioxide emissions and global warming [11] .

2. Methodology

The research has been carried out using the quantitative method based on realism. The research is exploratory research where embodied energy and embodied carbon emission have been calculated using the data from the residential apartment building.

2.1 Study Area

The focus of this study is the Kathmandu District within the Bagmati Province, Nepal. The study area encompasses one of the largest cities, boasting a population of approximately 3.1 million people (CBS, 2021). Kathmandu Valley, nestled in the heart of Nepal, is a captivating region renowned for its cultural vibrancy, historical significance, and diverse landscape. The valley comprises three major cities—Kathmandu, Bhaktapur, and Lalitpur (Patan)—and is the country's political, cultural, and economic nucleus. The population of Kathmandu Valley reflects a tapestry of ethnicities, languages, and traditions, creating a dynamic and multicultural atmosphere. The region's climate is characterized by distinct seasons, with warm summers, cool winters, and a monsoon season bringing heavy rains. The study area encompasses a total area of 49.45 square kilometers, with Kathmandu situated at an elevation of around 1400 meters above sea level. Kathmandu is bordered by the Bhaktapur district to the east, Lalitpur and Makawanpur to the south, Dhading and Nuwakot to the west, and Sindhupalchowk district to the north [2]. The case study building is located in the core urban area of Maharajgunj Kathmandu opposite to President's Office Sital Niwas. The apartment building's name is a "Premier Apartment" which is a nine-story including GF with a double basement.Apartment building case study has been selected for the research work due to large buildup area and high number of storey (Ten storey including basement), apartment building is selected due to the significant utilization of resources in the construction of the apartment building is attributed to factors such as its size, scale, structural and finishing materials, infrastructure system, and construction techniques. Different data has been collected by field visit and literature review. The primary data are materials estimation and inventory analysis, equipment and vehicle log sheet collection, electricity consumption over one year period secondary data such as embodied energy coefficient, embodied carbon coefficient, material density, vehicle carrying capacity and fuel consumption per unit distance (Km) has been estimated by using different literature findings.

Building is constructed in the land of 1621.10 m2 opposite to the President Office Sital Niwas. The developer of apartment building is CE Real-estate and Construction Company is CE Construction. Apartment building comprises fifty-one apartment units, the size of apartment unit ranges from 79 m2 to 130m2. Foundation type is Mat Foundation of thickness 1m, for basement protection shear wall is constructed upto two storey of height 7.31m total, typical floor height of building is 3.05m. Grade of RCC used for structure are M40 for Columns and M25 for Beam and Slab. The major construction materials include Reinforcement, Cement, Aggregate, Sand, Admixture, earth brick and fly ash brick. Construction materials extracted and transported from the range of 20Km-250Km. During the construction phase various equipment's and machine-like bar bending machine, rebar cutter, electric motors, electric lift, 20KVA diesel generator, double bag concrete mixture, concrete pumps, excavators, backhoe etc. are used.

2.2 Method

For calculating the embodied energy of the building, numbers studied have selected bottom-up techniques a process-based approach. This methodology primarily depends on the embodied energy intensity of construction materials as well as detailed drawings, specifications, or data from actual buildings. This technique requires the adequacy of estimating the total embodied energy content of a building design or construction project depending on the availability of certain information.

When the data on building quantities, final drawings, and environmental impact databases for construction products are accessible, along with knowledge of the buildings' locations with material suppliers and waste management operations, the estimation process becomes more reliable(yourhomess). To calculate the total embodied energy content, it is essential to have information about the quantity and type of building materials used. Equally important are the values of embodied energy intensity factors, which play a significant role in the computation. These factors help to convert the quantity of each building material into its corresponding energy content. Table 1 shows the number of major construction materials used during the construction of the building. All material's quantity is expressed in Kg by multiplying with their density for easy calculation.

Figure 1 shows the mass distribution of building materials used during construction where coarse aggregate and fine aggregate dominate other materials in above figure the predominant materials are coarse sand and coarse aggregate comprising 37% and 30% share respectively after that remaining share

are occupied by bricks, cement, reinforcement accordingly by decreasing percentage.

Table 1: Quantity of Major Construction Materials

S.N	Description	Unit	Quantity	Density(IFC, 2017)	Quantity (Kg)
1	OPC Cement	Bag	26459.0	1440Kg/m^3	1322950
2	PPC Cement	Bag	9073.0	1440Kg/m^3	453650
3	Aggregate	m^3	2932.4	1600Kg/m^3	4691840
4	Sand	m^3	3212.2	1840Kg/m^3	5910448
5	Local Clay Brick	m^3	457.7	1760Kg/m^3	805552
6	Cement Block	m^3	851.0	2200Kg/m^3	1872200
7	Rebar	Kg	638243.7	7850Kg/m^3	638243.73
8	Aluminum	m	10656.0	2Kg/m	21312
9	Plywood	m^2	18515.6	600Kg/m^3	133312.464
10	Tile	m^2	3393.3	18Kg/m^2	61079.4

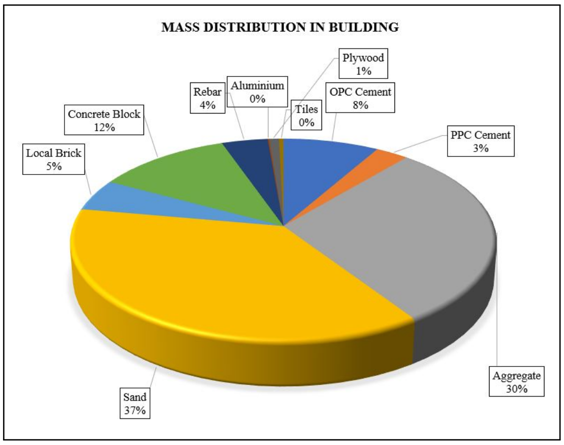

Figure 1: Mass distribution of Materials

2.2.1 Embodied Energy

Embodied energy (EE) is a comprehensive measure encompassing the total primary energy expended in the construction, maintenance, and eventual demolition of a building. This calculation considers all the energy involved in producing a material or product, incorporating activities like mining, manufacturing, and transportation. It encompasses the energy used in the extraction of raw materials, various manufacturing stages, and the delivery of the final product to the facility, constituting what is often termed "cradle-to-gate" – the largest portion of the life cycle energy use. Following production, the products are transported to the construction site for installation, and the associated embodied energy is referred to as "cradle-to-site." Throughout a building's operational years, maintenance activities and the replacement of aging elements or outdated systems contribute to recurring embodied energy. This recurring energy accounts for processes and new materials/systems added over time to maintain or enhance the building's performance. The analysis extends to the end of a building's lifespan, including the energy used in its demolition, recycling of some materials, and the disposal of others. This comprehensive evaluation from raw material extraction to end-of-life is commonly known as "cradle-to-grave." In essence, embodied energy provides a holistic understanding of a building's energy footprint, covering its entire life cycle and reflecting the energy inputs at each phase of its existence [12].

The initial EE is the energy used by all the processes for manufacturing the materials that are directly used in building construction or for the production of equipment or other system components used in electromechanical installations. It starts with the extraction of the raw materials, followed by all the necessary manufacturing stages for producing the final product that is delivered at the gate of the facility. This represents the largest percentage of the life cycle energy use and is commonly referred to as cradle-to-gate. From the factory, the products are then transported to the construction site for use and installation in the building. In this case, the calculated embodied energy is commonly referred to as cradle-to-site. Over the years of a building's operation, it will be necessary to perform several maintenance works and replace some aged building elements or obsolete systems, to keep or improve its performance [13].

According to Chau et al 2015, frequently, the initial three energy components (Extraction +Manufacture +Onsite +Operation +Demolition +Recycling +Disposal........1) presented in Equation (1) are combined and referred to as embodied energy when evaluating energy effects [14]. Embodied energy refers to the energy expended during the manufacturing phase of a material. In the context of constructing a building, it encompasses the energy content of all utilized materials, including technical installations. Moreover, it covers the energy expended during the processes of erection, construction, and renovation.

The purpose of conducting an embodied energy analysis in building construction is significant: it aims to quantify the energy inherent in building materials, both initially and over time. This analysis also allows for comparing the total embodied energy content among different building materials, components, elements, and designs. Embodied energy comprises two main components: Initial embodied energy and recurring embodied energy. Initial embodied energy involves the energy required for extracting, manufacturing, and transporting materials used in the building's initial construction. On the other hand, recurring embodied energy in buildings encapsulates the total energy associated with material usage. This includes activities such as maintenance, repair, restoration, refurbishment, or replacement throughout the building's service life [14].

2.2.2 Embodied Carbon

Embodied carbon is the carbon footprint of the construction material of the building or infrastructure project before its operational phase. It is the total impact of the sum of all greenhouse gas emissions during the overall life cycle of materials including mining, processing, production, transportation, construction/ erection, maintenance, and disposal [15]. Construction materials provide a tremendous amount of carbon and the most carbon-emitting activities are mining, processing, and producing construction materials [16].

According to Kang et al. 2015 [17], buildings contribute significantly to the greenhouse effect by emitting huge amounts of carbon dioxide during their entire cycle. Buildings' life cycle carbon has two components: operational carbon (OC) and embodied carbon (EC). Because significant work has already been devoted to lowering OC, recent research has indicated that EC is becoming increasingly important (1,19). It is critical in this situation to estimate and reduce EC. According to the Akbarnezhad & Xiao 2016 [18] different embodied carbon reduction strategies are (i) low carbon materials (ii) material maximization (iii) Material reuse and recycling (iv) Local Sourcing of Materials and Components (v) Construction Optimization Strategies.

2.2.3 Embodied energy and carbon emission calculation using process method

During materials production, raw materials go through different processes in which all process takes energy either in the form of electricity or fossil fuels. During this process of manufacturing both energy is consumed and carbon emitted. The embodied energy coefficient is also known as the embodied energy factor or embodied energy intensity which indicates the total energy required to manufacture the unit weight of building material [2]. This factor covers energy used and emission from materials quarry to packaging inside the factory/plant.

Table 2 shows the embodied energy emission factor and carbon emission factor of materials during production adopted from Indian and New Zealand Construction Materials Database [19, 20].

Table 2: EE and EC Coefficient

S. N	Type of Material	EE Coefficient (MJ/ Kg)	EC Emission (CO_2 eq)	Density (Kg/m^3)	Database Source
1	OPC Cement	6.4	0.91	1440	(IFC, 2017)
2	PPC Cement	4.6	0.64	1440	(IFC, 2017)
3	Coarse Aggregate	0.11	0.009	1600	(IFC, 2017; Subedi R Bhattarai N, 2023)
4	Fine Aggregate	0.11	0.009	1840	(IFC, 2017; Subedi R Bhattarai N, 2023)
5	Local Brick	4.4	0.39	1760	(IFC, 2017)
6	Dense Concrete Block	1.3	0.16	2200	(IFC, 2017)
7	AAC Block	3.5	0.089	500	(IFC, 2017)
8	CSEB Block(OPC)	0.70	0.096	2000	(IFC, 2017)
9	CSEB Block(PPC)	0.11	0.010	2000	(IFC, 2017)
10	Virgin Reinforcement	30	2.6	7850	(IFC, 2017)
11	42.3% Recycled Steel	24.4	0.482	7850	(Hammond & Jones, 2008)
12	Aluminium	280	26	2Kg/m	(IFC, 2017)
13	U-PVC section	61	3.9	2.8Kg/m	(IFC, 2017)
14	Ceramic Tile	7.8	0.67	18Kg/m^2	(IFC, 2017)
15	Formwork	18	0.35	600	(IFC, 2017)

Based on process data, the embodied carbon emissions from the building sector were computed in this study. Material inventory of the building was collected from the contractor and a detailed estimation of the quantity of the construction materials was done. The energy required by building materials throughout their production, transportation, and construction is referred to as embodied energy, and Carbon dioxide emitted by building materials throughout production, transportation, and construction is referred to as embodied carbon dioxide.

Total Embodied Energy (EE) =
EE from material (Production + Transportation + Construction)

Total Embodied Carbon (EC) =
EC from material (Production + Transportation + Construction)

2.2.4 EE and EC emissions during the material production phase

This is the phase where materials are quarried/mined, transported to the factory for processing, material processing, and packaging, and made ready for product dispatch. This is the most energy-consuming and pollution (CO2, Greenhouse Gas) emitting process. Aluminium and related products are highly energy-consuming materials but due to the low quantity of usage, these provide less impact than Cement and Steel which are used in huge quantities in buildings. Moreover, Clay bricks are another highly energy-intensive material because of their manufacturing process in kilns. Production energy can be lowered by adopting recycled aluminum and steel as far as possible [21] and usage of sustainable building materials like cement soil stabilized blocks, hollow concrete blocks using fly ash, etc. Production energy and emission can be calculated by multiplying materials quantity with their respective energy intensity and emission factor. This phase is also called cradle to the gate because materials undergo their origin to the manufacturing factory. This is the most energy-consuming phase where 95-98% of energy can be used of total embodied energy [10].

Sattary and Thorpe 2011 suggest there can be substantially energy saving opportunity by using recycled or recyclable construction materials while special attention to be made if there is any environmental risk of using recycle materials [11] for example; certain sustainable materials may pose environmental risks, such as the potential leaching of contaminants from the residual Portland cement binder in recycled concrete aggregate used in road construction [22, 23]. To reduce the embodied energy of building materials, the preference is given to options that are lightweight, renewable, durable, and sourced locally whenever feasible. This approach involves extensive use of locally grown plantation timber, along with recycled bricks, reclaimed timber for decorative elements, and locally sourced window frames [24].

$$\text{EE of Production} = \sum \text{Material quantity} \times \text{EEC} \qquad ([18])$$

2.2.5 EE and EC emissions during the material transportation phase

This is the second phase of embodied energy calculation where manufactured materials were transported to the construction site using different transportation systems. Since the major construction activities are performed in urban areas of the country as materials manufacturing plants are located far away from urban regions [10, 9] materials need to travel great haulage distance.

According to Reddy, 2001 [9] In the Indian setting, materials travel between 10 to 100 kilometers in metropolitan areas.

Cement and steel go even larger distances, up to 500 kilometers. Rail transport is used for long-distance delivery of cement and steel. Fancy building materials such as marble, paints, and so on are sometimes brought from long distances (more than 1500 km) in India. Natural sand and crushed stone aggregate use around 1.75 MJ/m3 per km of transportation distance. Similarly, bricks require around 2.0 MJ/m3 per kilometer of transit. Assuming that steel and cement are also transported by truck, a total of 1 MJ/tonne/km of diesel energy is expended during transportation. Natural sand requires no thermal energy to produce, but it requires around 175 MJ of diesel energy/m3 to carry it across a 100-kilometer distance. Crushed aggregate consumes around 20 MJ/m3 during manufacture and 400-800% more during transportation across distances of 50-100 km. Hence transportation energy can be lowered by using high-capacity (Volume) vehicles like containers or trains or collecting necessary materials from nearby vicinity. The transportation phase is less energy-consuming than the production phase by covering only around 2-3% share.

Different construction materials are transported from their production sites to the construction site which requires a 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 of the vehicle, vehicle type, and vehicle energy consumption. Diesel-based medium or heavy-goods-carrying vehicles are used to transport the construction materials from the production site to the construction site [2].

$$\text{EE of Transportation} = \sum \text{MQ} \times \text{TD} \times \alpha \qquad ([18])$$

where, α is the Factor for unit distance and quantity

2.2.6 EE and EC emissions during the building erection phase

This is the third phase of embodied energy calculation where the materials delivered to the site go through their point of use of service stage. Different types of equipment are used in this phase. According to the LCA guideline energy use by manpower is not considered because of easy calculation so only equipment's are considered with their respective power rating. According to Bardan 2015, Two approaches were studied for this assessment: top-down and bottom-up. Both of these strategies are primarily concerned with the electrical energy utilized during construction activities on the site. The top-down method took into account the electrical load estimated by the developers and requested from the electricity supply agency. When the first meter proved insufficient to power the construction site, the second was installed. The bottom-up approach considers the site's energy bills, which were evaluated to determine the real power use over the whole construction time [10].

$$\text{EE of Construction} = \sum \text{EEC} \times \text{EF} \qquad ([18])$$

where, EEC is the energy consumption and EF is Emission Factor.

2.2.7 EE and EC emissions during the building maintenance and demolition phase

Maintenance is the recurring embodied energy phase where defects are identified and rectified to their original stage. According to BS3811, building maintenance is classified as either scheduled or unplanned [25]. Planned maintenance is performed for specific intervals of time while unplanned maintenance shall need to be performed at any time as necessary. Different materials have different life cycles for their maintenance some components need to repair while some need to replacement. Demolition is the final stage where building service life has been over and it is unsafe for use. According to Bandari 2023, these stages were typically neglected due to data inaccessibility and its minor contribution to life-cycle assessment [2]. According to Ramesh et al. 2010, Energy savings from recycling or reusing demolished building materials are not factored into building life cycle energy estimates. This is partly because there is no universal agreement on how to attribute the saved energy to the demolished building [26].

3. Earlier Studies

Several studies have been conducted on the life cycle energy of buildings. While a few research focus on features of embedded energy in buildings, the vast majority of studies focus on operational energy [21, 11, 27], its properties, and conservation methods. Demolition and disposal energy are rarely studied since they account for less than 1% of Life Cycle Energy [10, 26, 28]. Energy and CO2 emissions of building construction in Nepal have been examined by Subedi et al. 2023 [15] and Bhandari & Thapa 2023 [2]. Bhandari & Thapa 2021. [2] provide new insight on energy usage and CO2 emissions associated with housing construction in Nepal. The majority of research has focused on carbon mitigation measures for operations, with little attention paid to embedded carbon emissions. To calculate the embodied carbon emission from Kathmandu district buildings, a process-based technique was utilized to estimate the embedded carbon from the building sector in the complete life cycle. The total embodied carbon emission from the building industry in the full life cycle was 1444.86 Mt, according to the study's findings. Using AAC blocks, hollow cement concrete blocks, and AAC blocks with aluminum apertures in the same building reduces overall emissions by 4.7%, 3.37%, and 1.93%, respectively.

Subedi et al 2023 [15], performed a full life cycle energy analysis of a 648.12 m2 three-story structure with an estimated life span of 60 years. The primary energy intensity of the structure was 2.9 x 104 GJ over its life cycle. The manufacturing of building materials, transportation to the site, and building construction account for 12.11% of total life cycle primary energy consumption. The remaining 87.89% was the building's operational energy.

Reddy & Jagadish 2001 [9] perform the Embodied energy of common and alternative building materials and technologies in the Indian context. The broad conclusions that emerged from the research are (i) The least energy-intensive alternative material for walling is the soil-cement block, which uses only one-fourth of the energy of burned clay brick. It has been demonstrated that the use of energy-efficient/alternative building materials can reduce the total embodied energy of load-bearing masonry buildings by 50%.

Bardan S. 2011 [10] has attempted to estimate the embodied energy of a multistorey residential apartment building located in the Kolkata core of India. The author performs embodied energy analysis during material manufacturing, transportation of materials from factory to site, and construction/erection phase of the building using a process-based approach. The conclusions revealed that a total of 9.56GJ/m2 embodied energy was consumed by building with a 98% share by materials production and a 2% share in the materials transportation and construction stage.

Ramesh et al. 2010 [26] recommended performing a comprehensive examination of the building life cycle energy evaluations obtained from 73 instances in 13 different countries. The study covers both residential and commercial structures. The operating (80–90%) and embedded (10–20%) phases of energy usage are substantial contributors to the life cycle energy demand of a structure, according to the results. Conventional residential buildings' life cycle energy (primary) requirements range from 150 to 400 kWh/m2 per year, whereas office buildings' life cycle energy (primary) requirements range from 250 to 550 kWh/m2 per year. Ramesh et al. 2014 [7] perform Life Cycle Energy of Low Rise Residential Buildings in Indian Context. In the context of India, the study proposes LCE for twenty (20) low-rise residential buildings. The LCE of the buildings under study ranges from 160 to 380 kWh/m2 per year (Primary). An equation is proposed to easily calculate the LCE of a new building based on the LCE data of analyzed buildings.

More information on Japan's energy use and CO2 emissions as a result of housing development is provided by a study by Suzuki et al. [29] Comparing the total energy needed and CO2 emissions per square meter of various construction types. Steel and reinforced concrete (RC) multi-storeyed family homes require 8–10 GJ/m2 of energy to construct, compared to 3 GJ/m2 for wooden single-family homes. They conclude that, in terms of energy needs and CO2 emissions, wooden houses outperform other methods of building.

4. Data Analysis

4.1 EE and EC emissions during the material production phase

The embedded carbon and energy from building construction materials were calculated by multiplying the applicable emission factor by the total weight of construction materials used on construction sites. Ten different common construction materials were taken into consideration for the estimation of EE and EC. A high share of EE and EC has been contributed by Reinforcement around 50% of the whole material. Cement and Brick followed by reinforcement. Total EE during material production is 6.19 GJ/m2 and EC is 0.6 Ton of CO2 eq/sqm respectively. Figure 2 and 3 shows the embodied energy and carbon share of construction materials used in building.

Table 3: EE and EC emission during material production

Description of Items	EE(GJ)	EC(Ton Co2 eq)
OPC Cement	8466.88	1203.88
PPC Cement	2086.79	290.33
Aggregate	516.01	42.22
Sand	650.14	53.19
Clay Brick	3544.42	314.16
Cement Brick	2433.86	299.55
Reinforcement	19147.31	1659.43
Aluminium	5967.36	544.11
Formworks	2399.62	46.65
Tile	476.41	40.92
Total	45688.89	4504.44
Average per Sqm	6.84	0.67

From Table 3 average EE and EC are found to be 6.84 GJ/m2 and 0.67 Ton of CO2 equivalent respectively.

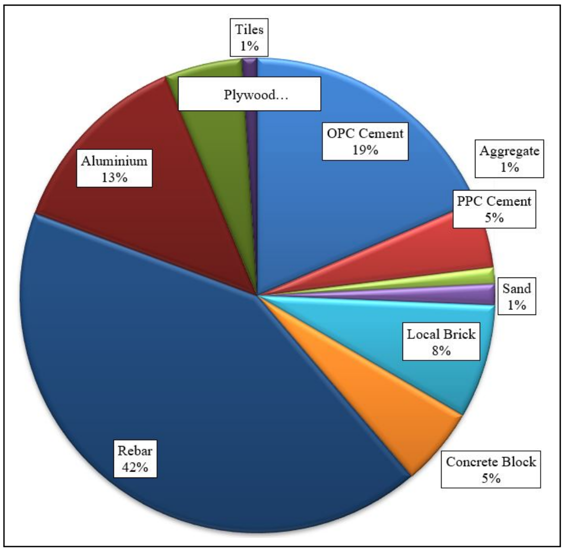

Figure 2: EE share of different materials during production

In the illustration (Figure 2), the distribution of embodied energy among various construction materials is depicted. The breakdown of embodied energy for different materials is as follows: Rebar constitutes 42%, OPC Cement accounts for 19%, PPC Cement contributes 5%, Aluminium represents 13%, the combined consumption of Brick and Block is 13%, and Tile and Plywood together contribute up to 2% of the total embodied energy. Despite the substantial mass of aggregate and sand, their low energy consumption potential results in a combined contribution of only 2% to the embodied energy.

In the illustration (Figure 3), the distribution of embodied carbon among various construction materials is depicted. Despite the substantial mass of aggregate and sand, their low emission potential due to their natural state, results in a combined contribution of only 2% to the embodied carbon. Materials such as rebar, cement, and aluminium are produced using advanced technology and involve high-energy processes, categorizing them as energy-intensive materials with a significant emission potential.

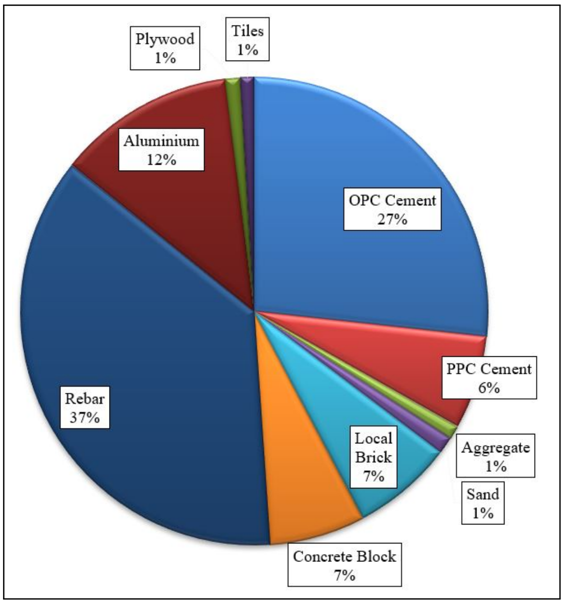

Figure 3: EC share of different materials during production

4.2 EE and EC emissions during the material transportation phase

Different construction materials are brought from different places, so the transportation distance varies from within a 4-5km radius to 275 km.OPC Cement has been transported from Shivam Cement factory located in Hetauda and PPC cement from Bhairahawa Accordingly different materials with their source of production and their distance from the construction site have been calculated be below table. For Transportation purpose mini tripper (3m3), Haiba Tripper (7.5m3), and 12-Wheeler Truck (22 Ton Capacity) has been used for transporting brick, Aggregate, Rebar plus Cement respectively. Fuel consumption varies from distance traveled, types of road conditions, and Vehicle type. Assume 1-ltr/ Km fuel consumption for long haulage distance traveled (Cement, Rebar), 1.75Km/ltr for medium haulage distance traveled (Sand, Aggregate), and 2-Km/ltr for short transportation distance (Brick, aluminium). The calorific value of fuel(diesel) is used as EE for transportation and carbon emission from burning diesel fuel. From the calculation, it has been found that 0.21 GJ/Sqm EE and 0.039 Ton Co2 eq/sqm EC were emitted from transportation respectively.

Table 4: EE and EC emission during material transportation

Description of Items	EE(GJ)	EC(Ton Co2 eq)
OPC Cement	312.22	46.983
PPC Cement	124.75	19.118
Aggregate	384.88	52.953
Sand	421.6	57.963
Clay Brick	16.48	1.194
Cement Brick	17.02	1.217
Reinforcement	147.43	21.889
Aluminium	1.54	0.126
Formworks	5.4	0.442
Tile	10.04	0.822
Total	1441.36	202.717
Average per Sqm	0.21	0.039

The product of materials quantity, travel distance and their respective per Km factor of embodied energy coefficient and embodied carbon emission gives the total embodied energy in MJ and embodied carbon in Kg-CO2 -eq. From calculation it has been found that 0.21 GJ/m2 EE and 0.039 Ton CO2 eq/sqm EC emitted from transportation respectively. The highest share for transportation is attributed to coarse aggregate and fine aggregate, primarily because of their substantial mass contribution. Following them in a decreasing order, cement, reinforcement, and bricks sequentially contribute to the transportation share.

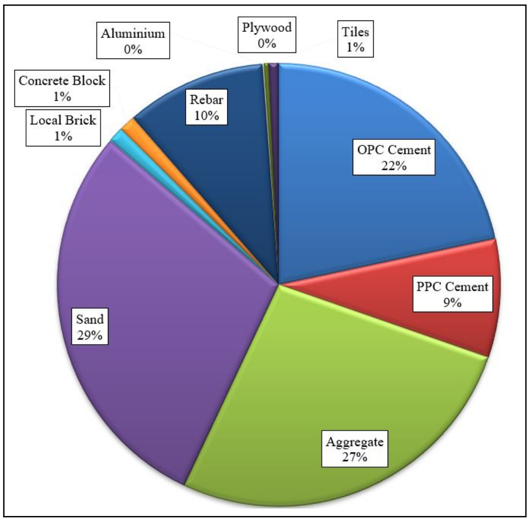

Figure 4: EE share of materials during transportation

The breakdown of embodied energy for different materials during transportation is as follows: Rebar constitutes 10%, OPC Cement accounts for 22%, PPC Cement contributes 9%, Aluminium represents nearly zero, the combined consumption of Brick and Block is 2%, and Tile and Plywood together contribute up to 1% of the total embodied energy. Due the substantial mass of aggregate and sand, combined contribution of whopping amount of 56% to the embodied energy. Bricks and blocks entail lower energy consumption in transportation since the materials are sourced from the nearby vicinity of the construction site.

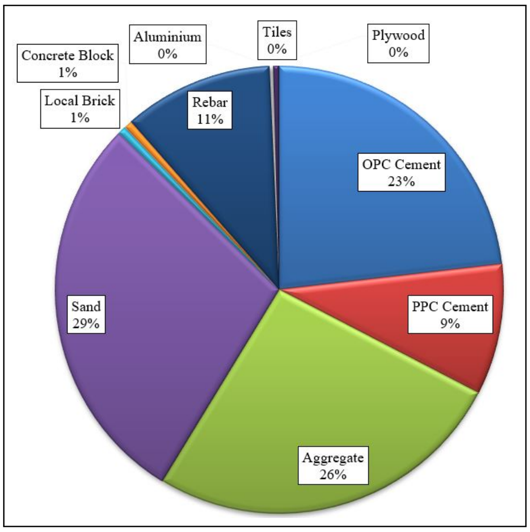

Figure 5: EC share of materials during transportation

In the illustration above (Figure 5), the distribution of embodied carbon among various construction materials during transportation from manufacturing location to construction site is depicted. The breakdown of embodied carbon for different materials during transportation is as follows: Rebar constitutes 11%, OPC Cement accounts for 23%, PPC Cement contributes 9%, Aluminium represents nearly zero, the combined emission of Brick and Block is 2%, and Tile and Plywood together contribute up to 1% of the total embodied carbon. Due the substantial mass of aggregate and sand, combined contribution of whopping amount of 55% to the embodied energy. In the above figures (4 and 5), the highest share for transportation is attributed to coarse aggregate and fine aggregate, primarily because of their substantial mass contribution. Following them in a decreasing order, cement, reinforcement, and bricks sequentially contribute to the transportation share.

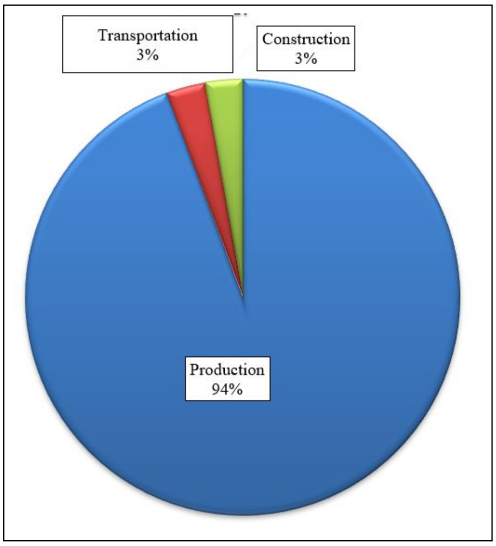

Figure 6: EE in Different Stages of Building

4.3 EE and EC emissions during the building construction phase

Due to the difficulty in obtaining correct data or log sheets of equipment operating hours and usage duration per day, it has been assigned based on the Project Manager's, Engineers', and Operators' best guess. Some equipment is electrically operated and some diesel-based equipment is. Certain equipment (mixer, vibrator, concrete pump, rebar fabrication machine) are operated during the structure part only, some machines are running during the finishing stage and some are running throughout the project duration. It's been very complicated to split equipment used per construction material hence overall usage during the construction period has been made in analysis. From the calculation, it has been found that 0.201GJ/Sqm EE and 0.0139 Ton CO2 eq/ Sqm EC are used for the erection of the building respectively.

Table 5: EE and EC emission during building construction phase

Description of Items	EE(GJ)	EC(Ton Co2 eq)
Construction Phase	1378.7	92.97
Average per Sqm	0.201	0.0139

4.4 Total Embodied Energy and Embodied Carbon

Total embodied energy and carbon emissions have been calculated from the calculations above by adding EE or EC for the production, transportation, and construction stages.

Table 6: EE and EC emission during building construction phase

Description	EE(GJ/m2)	EC(T.CO2eq/m2)
Production	6.84	0.670
Transportation	0.210	0.030
Construction	0.201	0.0139
Total	7.251	0.714

Total embodied energy and embodied carbon has been calculated by adding different phases of building life cycle namely (1) Material Production (2) Material Transportation (3) Construction/ Erection. Total embodied energy has been found to 7.251GJ/m2 and embodied carbon is 0.714 Ton/m2 -CO2 equivalent. Different phases of building shares different amount of EE and EC, the production phase of material alone consume 94% embodied energy while transportation and construction phase together consume 6%. Bardan 2011, concludes that 98% of embodied energy is consumed by material production phase while transportation and construction phase share 2% embodied energy [10].

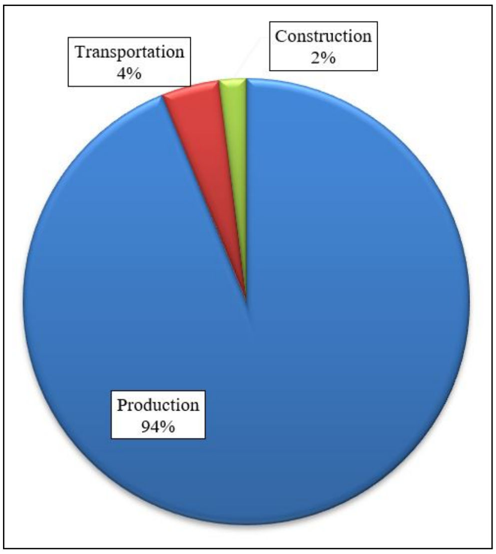

Figure 7: EE in Different Stages of Building

In the illustration above (Figure 7), the distribution of embodied energy among various stages of building construction is depicted. The breakdown of embodied energy for different process is as follows: Production phase constitutes 94%, transportation phase consumes 4% and construction phase consumes 2%. With the comparison of production phase transportation and construction phase are very low due to high energy were already expended during material manufacturing process. Similar result can be seen on the carbon emission also.

Major quantities such as RCC (M20, M25, M40), brick works, plaster and flooring works are segregated from BOQ and embodied energy and carbons are calculated as per previous method. Mix ratio for different grade of concrete are obtained from concrete mix design, due to less quantity and difficulties in obtaining embodied energy database, calculation of admixtures is neglected. OPC cements are used for all RCC works, IPS flooring works and PPC cements are used in all non-structure parts like brickwork, plaster etc.

Data from the are BOQ are segregated into different part of building is showing on the table-10. Four different major parts has been analyzed namely (1) Structure Part (2) Finishing Works (3) Plaster Works (4) Flooring works, finishing works contains all internal partition works and outer façade works which mainly constructed by brick masonry.

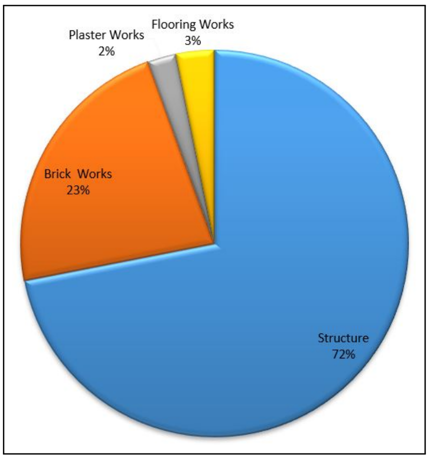

Figure 8: EE share of building component

Figure 8 shows the embodied energy share of different building components. The breakdown of the embodied energy for different building components are as follows; Structure works consume 72%, Brick works/Finishing works consumes 23% and plastering and flooring together have a share of 5%. Structure works consume massive amount of EE due to the use of energy intensive reinforcement and cement.

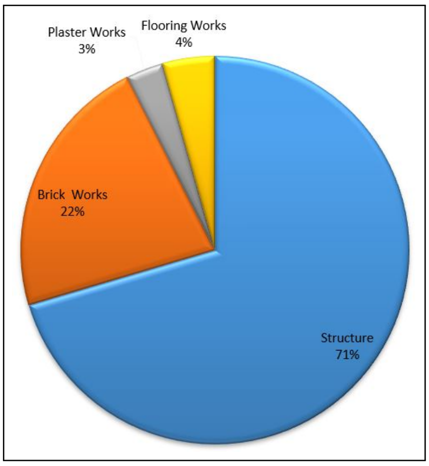

Figure 9: EC share of building component

From Figures 8 and 9 structure part is the most energy-consuming and carbon emission part due to its constituents (cement, steel). Building façade units including brick and plaster together consumes 25%. The breakdown of the embodied carbon for different building components are as follows; Structure works consume 71%, Brick works/Finishing works consumes 22% and plastering and flooring together have a share of 7%.

4.5 Operational Energy

Operational energy is the phase where the building undergoes its service period and operational energy are used such as lighting, heating, cooling and other purpose. In this research operational energy has been calculated by manual calculation in excel by collecting energy consumption data from apartment. Premier Apartment Building consist of 51 apartment units but only 25 apartments are in operational phase. Energy consumption for the period of 1 years is taken from apartment facility manager and calculated for approximately representing average energy consumption of all apartment by simple interpolation technique. Building service life has been assumed 60 years based on the different literature's [15] forecasting energy usage up to 60 years period by considering 8.1% annual energy consumption according to the Nepal electricity authority database. From the electricity consumption data there has been seen large variation some apartment users continuously run air conditioning units, induction stoves for cooking while some occasionally uses air-conditioner and use LPG for cooking hence energy consumption vary from minimum range of 70-100 Kwh to 1000-1500Kwh so for better approximation average electricity consumption values has been taken for calculation.

From the above electricity consumption table average electricity consumption per unit apartment has been calculated to 275Kwh/ apartment with 2 people of average user. By forecasting these values for 60 years it has been found that a total of 9.72GJ/m2 operational energy is used.

4.6 Alternative Material Analysis

Embodied enrgy and embodied carbon can be substantially reduced by substituting energy intensive materials with less energy intensive materials [11]. Different varieties of construction materials are available in markets and some new construction materials are under development stage. Substitution of same nature of materials has been done to base case (existing condition) and identifying if there is any energy and carbon saving potential. Since there is less contribution of energy and carbon from transportation and construction only materials production parts have been analyzed in this research.

4.6.1 Alternative-1: Brick type Substitution

From the previous calculation we can assure that brick are very energy intensive and high GHG emitting construction material hence there is some EE and EC reducing opportunity by replacing high energy and emission causing clay brick by less energy and emission causing alternative materials. The substituted materials are the more energy efficient and environmentally sustainale material than the base case. There is substantial amount of saving can be obtained by materials substitution amoung them CSEB block with PPC cement stablized is less energy consuming materials with less GHG emission potential.

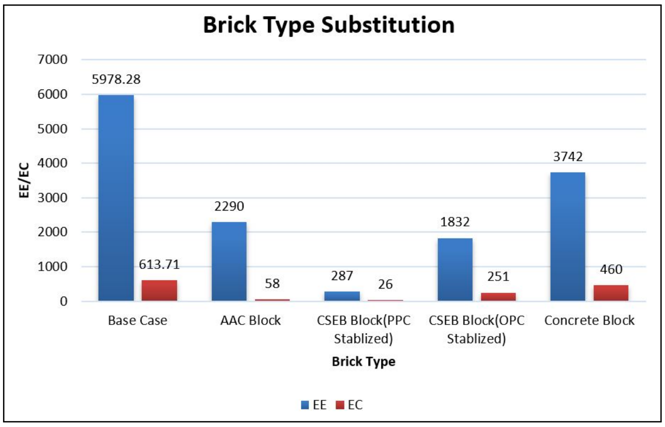

Figure 10: Brick type Substitution

From Figure 10, brick types with their embodied energy consumption and embodied carbon emission are compared. From the figure there is very low density offered by AAC block which is 1/3rd of other conventional materials. Due to its light weight ,low carbon emission and easy construction it is the mostly used materials in current scenario [30] but due to sophisticated technology used in construction its embodied energy is high as compared to other. PPC Stablized CSEB block is the most suitable and sustainable materials as its shows only 5% of the embodied energy consumption as in base case.

4.6.2 Alternative-2: Cement type Substitution

From the previous calculation we can assure that cement is very energy intensive and high GHG emitting construction material hence there is some EE and EC reducing opportunity by replacing high energy and emission causing ordinary Portland cement by less energy and emission causing pozzolana Portland cement [19]. The substituted materials are the more energy efficient and environmental friendly than the base case. There is some reduction of embodied energy and embodied carbon after substituting OPC cement by PPC Cement.

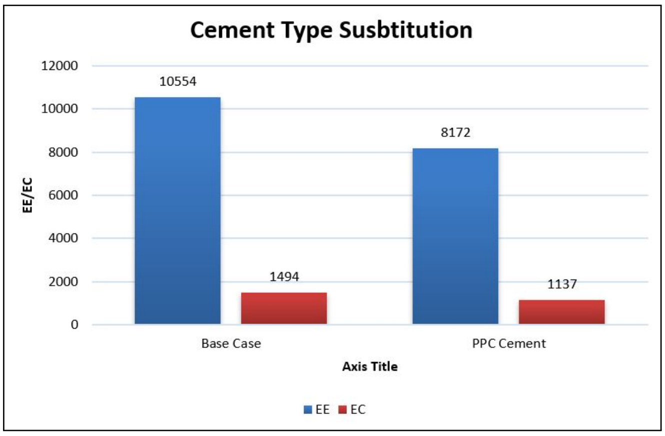

Figure 11: Cement type Substitution

There is reduction of EE (23%) and EC (24%) after changing cement type which is very high amount of energy and emission controlling, but changing OPC into PPC type increases the de-shuttering period of RCC Work

4.6.3 Alternative-3: Rebar type Substitution

Since the rebar is the most energy consuming and emission causing construction materials from the previous figure rebar accounts for 42% of EE and EC from overall construction materials, hence it is very important to reduce the potential effect of rebar. Different literatures suggest that using recycle material is best way to reduce EE and EC in building sector [14, 11].

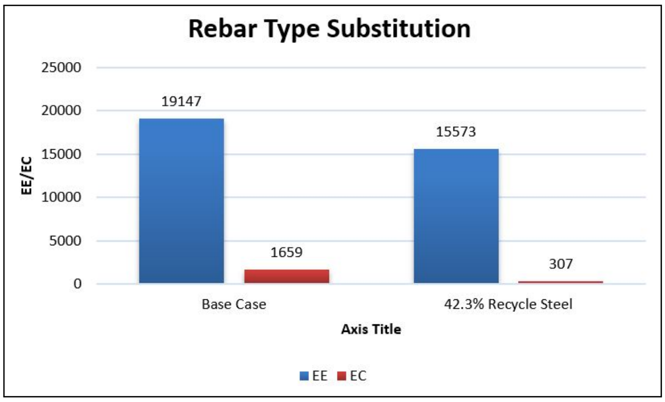

Figure 12: Reinforcement type Substitution

Figure 12 shows the comparative chart of EE and EC by virgin steel and 42.3% recycle steel. From this material substitution around 19% reduction of EE and 81% reduction of embodied carbon. There is no reduction of structural performance by adding recycled contents in Rebar. According to Chau et.al. (2012), Purnell (2012) EC can be reduced up to 40% by using recycled steel [14].

4.6.4 Alternative-4: Aluminum windows Section type Substitution

On the basis of energy intensity and emission potential aluminium lies in the first position among other construction materials like rebar and cement. It can be seen that aluminum consumed around 10 times EE and EC than steel [19]. There is saving energy and emission saving potential by replacing aluminium with U-PVC windows frame [31].

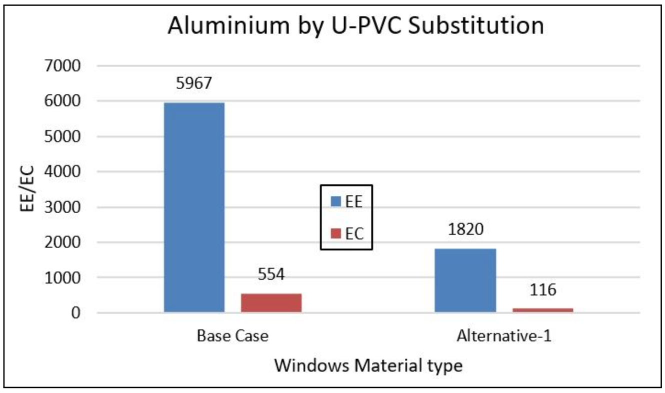

Figure 13: Windows material type Substitution

Figure 13 shows the substitution of aluminium windows section by U-PVC section. From the calculation it is clear that there is great opportunity for saving EE and EC by using U-PVC. Also, there is great amount up to 80% by using recycle aluminium section Chau et.al. (2012), Purnell (2012) [14].

5. Conclusion and Recommendation

As a result of this investigation, various questions about the issue have been systematically answered. We aimed to utilize a process-based approach to analyze the variety of building construction materials employed in the Kathmandu construction sector, their respective proportions of embodied energy and embodied carbon, and potential avenues for reducing both through the integration of alternative construction materials. Conclusions drawn from the research are as follows: [insert the specific conclusions based on your thesis findings:

- Embodied Energy (EE) and Embodied Carbon (EC) of multistorey RCC frame with brick wall as partition materials has been calculated using manual method and found as 7.251 GJ/m2 and 0.714 Ton/m2 of CO2 equivalent per square meter of built-up area respectively.
- Operational Energy (OE) of building has been estimated by taking electricity consumption data from each apartment units. Total OE has been found as 9.72GJ/m2 which is obtained by forecasting current electricity consumption to 60 years of service life period.
- After analyzing major construction materials consumption share of embodied energy and carbon of different building components are Structure Part:72%, Brick Masonry:23%, Plaster:2%, Flooring:3%.
- For the EE and EC major share covered by production phase of materials by taking 92-94%(EE-EC), remaining share covered by Transportation 6% for EE and 3% EC and Construction/Erection takes 2% EE and 3% EC respectively.
- Based on study of different literature review it can be concluded that energy and carbon used in maintenance and demolition are less significant and can be omitted.
- By replacing different materials with their alternatives, we can lower EE upto 27% and EC upto 57%.
- The transportation phase, notably influenced by the mass contribution of coarse and fine aggregates, has underscored the importance of local material sourcing to minimize energy expenditure.
- Traditional clay bricks and compressed stabilized earth blocks (CSEBs) have been compared, revealing insights into their energy efficiency, environmental impact, and suitability for sustainable construction practices.
- As Kathmandu Valley continues to witness urban development, the awareness of embodied energy implications becomes imperative for responsible and eco-friendly construction practices.
- The study contributes valuable information for builders, policymakers, and stakeholders in the construction industry to make informed decisions that align with environmental sustainability goals.
- In this study only major civil construction materials such as rebar, cement, brick, tiles, aluminium, sand, aggregate are considered for calculation while electrical and sanitary items are not. Scope of this study will be broad by taking electrical and sanitary items.
- While the study primarily concentrates on RCC frame structure buildings, there is potential for expansion to incorporate timber frame structures, masonry structure, steel structure buildings, and various types of traditional houses.
- Promoting the utilization of materials sourced locally is in harmony with sustainable construction principles. Initiatives aimed at endorsing and bolstering local suppliers can play a significant role in minimizing embodied energy associated with transportation.

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