TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

Thesis No: 075/MSCCD/012

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

by

Mandip Bhandari

A THESIS

SUBMITTED TO THE DEPARTMENT OF APPLIED SCIENCE AND CHEMICAL ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREEOF MASTER OF SCIENCE IN

CLIMATE CHANGE AND DEVELOPMENT PROGRAMME

DEPARTMENT OF APPLIED SCIENCE AND CHEMICAL ENGINEERING

LALITPUR, NEPAL

Sep, 2021

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING,

PULCHOWK CAMPUS

DEPARTMENT OF APPLIED SCIENCE AND CHEMICAL ENGINEERING

The undersigned certify that we have read, approved and recommended to the Institute of Engineering for acceptance, a thesis entitled **" Embodied-Carbon Emission from Building In Overall Life Cycle - A case study of Kathmandu"** submitted by **Mandip Bhandari (075/MSCCD/012)** in partial fulfillment of the requirement for the degree of M.Sc. in Climate Change and Development Programme.

Supervisor:

……………………..

Prof. Dr. Kamal Bahadur Thapa

Department of Civil Engineering

IOE, Pulchowk Campus, Nepal

Program Coordinator:

……………………..

Prof. Dr. Khem Narayan Poudyal

Program Coordinator

Climate change and Development

Department of Applied Sciences and

Chemical Engineering

IOE, Pulchowk Campus

Committee Chairperson:

……………………..

Prof. Dr. Ram Kumar Sharma

Head of Department

Department of Applied Sciences and

Chemical Engineering

IOE, Pulchowk Campus

External Examiner:

……………………..

Prof. Dr. Gokarna Bahadur Motra

Department of Civil Engineering

IOE, Pulchowk Campus, Nepal

Date: Sept, 2021

COPYRIGHT

ACKNOWLEDGEMENT

I would like to express my gratitude to thesis supervisor Professor Dr. Kamal Bahadur Thapa for this continuous guidance and motivation during the research period of thesis. My sincere gratitude goes towards the Department of Applied Science and Chemical Engineering, Institute of Engineering for providing the opportunity to carry out thesis work as a partial fulfillment of Master of Science in Climate Change and Development. I am also grateful to Prof. Dr. Khem Narayan Poudyal, Program Coordinator of "Climate Change and Development" for his guidance, encouragement and continuous support throughout the project.

I want to thank all my friends of 2075 Batch, MSc. In Climate Change and Development, Institute of Engineering, Pulchowk Campus, for their valuable suggestions and motivation during the thesis preparation.

I would like to acknowledge the help from Mr. Hari Bhattari project manager of Synergy Builders, Mr. Subash Bhattari project manager of Bright Future Construction Pvt.Ltd., Mr. Basanta Pun director of Mahakaya Construction Pvt. Ltd and Mr. Shambhu Lal Shrestha director of Pashupatinath Construction Pvt. Ltd for helping me to collect the data from the study area. Lastly, I would like to extend my appreciation to all my family for their constant support to bring this research together.

Mandip Bhandari

PUL075MSCCD012

ABSTRACT

Most of the studies haven often focused on the mitigating measures of operation carbon with little focus on the embodied carbon emission. To achieve the embodied carbon emission from the buildings of Kathmandu district, a process-based approach was adopted to estimate the embodied carbon from the building sector of Kathmandu district in overall life cycle.

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 have 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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AAC	Autoclave Aerated Concrete Blocks
BoQ	Bill of Quantity
DC	Demolition Carbon
EC	Embodied Carbon
EE	Embodied Energy
GGGI	Global Green Growth Institute
GHG	Green House Gas
GJ	Giga Joule
HVAC	Heating Ventilation and Air Conditioning
IEC	Initial Embodied Carbon
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
MJ	Mega Joule
ODS	Ozone-depleting substances
RCC	Reinforced Cement Concrete
REC	Recurring Embodied Carbon
UN	United Nation
UNEP	United Nation Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

Chapter 1: INTRODUCTION

1.1.Background of the study

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. (Cabeza, et al., 2013).By 2020, the building sector is estimated to account for more than 31% of worldwide CO_2 emissions, rising to 52% by 2050. (Mitigation, 2011). About 20–30% of the global carbon footprint is the product from the building sectors having extensive worldwide environmental impact (Company, 2009). Building construction utilizes 24 percent of the raw materials mined from the lithosphere globally (Zabalza, I.B, Valero, & Aranda , 2011)and produces substantial amounts of pollution as a result of the energy needed during the quarrying, processing, and transportation of construction materials for building purposes (Morel et al 2001).

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. Building construction uses 40% of the world's stone, sand, and gravel, 25% of its timber, and 16% of its water, according to the Globe Watch Institute (Arena AP, de Rosa C, 2003). 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 (UNEP, 2009). The construction of new buildings requires huge amount of raw materials, which have an associated embodied energy for manufacturing, transport, construction and demolition wastes disposal. According to Ding (2014), Lehne and Preston (2018), Mokhlesian and Holmen (2012), and Ramesh et al. (2010), the construction of new structures generates roughly 40-50 percent of greenhouse gas emissions.

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 (Säynäjoki et al., 2012).

1.2.Need for research

Building sector accounts major consumption of energy which leads to the carbon emission and that carbon emission is measured through embodied carbon. In the past, embodied carbon emissions were disregarded, but according to the Intergovernmental Panel on Climate Change, achieving a significant decrease in all carbon emissions is vital to keeping global temperature rise to 1.5°C. (IPCC). It is even more critical to combat the climate disaster, as new building construction is predicted to quadruple by 2060, resulting in a rise in carbon emissions. In context of Nepal, after devastating Gorkha Earthquake in 2015, many houses were devastated, many were damaged and few remained intact. After that many houses are under reconstruction and many of them are completed. This study tries to understand and find out the total embodied carbon and embodied energy from the buildings.

1.3.Problem Statement

The construction sector emitted a record 10 gigatonnes (Gt) of worldwide energy-related carbon dioxide (CO_2) in 2019, according to the United Nations Environment Programme on December 16, 2020. After the devastating earthquake on 2015, the reconstruction of building were taken into action without the proper planning and are converting to concrete building. With the increase in number of building construction the potential of greenhouse gases emission also increases, yet the study of carbon emission from building construction materials remains unexplored.

The fact that carbon dioxide emissions, including those from the use of electricity in buildings, increased at a rate of 2.5 percent per year for commercial buildings and 1.7 percent per year for residential buildings between 1971 and 2004, resulting in gigatonnes (Gt) of carbon dioxide emissions in 2019 is particularly frightening(Levine et al, 2007).

Pre-construction, construction, operation, and recycling after demolition are the four phases of a building's life cycle. According to various estimations, the operative phase of a building consumes roughly 80% of the energy, with the remainder going to other phases such as air quality and HVAC. The complex interaction phenomena between construction materials, embodied energy, and global warming are created by the entire process throughout the building life cycle. Materials such as steel and aluminium used in building, are created by a production process of raw materials mining, raw material process, melting, manufacture to final products and transportation to construction site. Each and every steps consumes energy, which is also expressed in terms of carbon emission. The combination of all carbon emissions from all building materials, products and construction are known as the building's embodied carbon. Embodied carbon accounts for about 20% of the carbon emissions from the building sector. Energy demand in buildings could increase by 50% by 2060 due to rapid population growth as well as rapid growth in purchasing power in emerging economics and developing countries. Embodied carbon accounts for 11% of global greenhouse gas emissions and 28% of emissions from the building sector (Smart, 2019). On the other hand, the building sector offers largest cost-effective GHG mitigation potential, with net cost saving and economic gains which is possible through the implementation of existing technologies, policies and building design because carbon management is very much important.

In Nepal, per capita total CO_2 emission is only 0.1 metric tonnes which is quite negligible and consumption of ozone-depleting substances (ODS) is only 0.88 ODS tonnes. Reduction in CO_2, ODS and greenhouse gases from agricultural, transportation, industrial and commercial sectors is the proposed target for 2030. If we do not achieve a 45-45% reduction in total global emission by 2030, we will fail the chance to meet the 1.5-2 °C warming threshold and climate change will become irreversible. The key to solving climate change and meeting the Paris Climate Agreement targets is to eliminate the embodied carbon of building structures (CLF, 2020).

1.4.Research objective

The general objective of the study is to estimate the amount of carbon emission from building construction to cope against impact of climate change.

The specific objectives of the study are as follows:

- To assess factor affecting the carbon emission during for manufacturing, transport, construction and end-of-life disposal of building construction materials.
- To identify the contribution of emitted carbon from building construction material to climate change.

1.5.Research Questions

This study attempts to address the following research questions:

- How much carbon emits from building in its overall lifecycle?
- What is the percentage share of different building materials being used in terms of embodied carbon and embodied energy?
- What would be the mitigating /adapting measures to control carbon emission from building construction?

The Research is guided by following breakdown of the study into several areas. To answer the above questions, the following assessment has been done.

- Building Type and Constructions material trends in the Kathmandu District.
- Analysis of embodied carbon and embodied energy contents in the construction materials.
- Study of alternative construction materials like Hollow concrete blocks, AAC blocks etc.
- Comparative analysis between the conventional material and alternative materials.
- Suggest the amount of carbon emission reduced through alternative materials.

1.6. Scope of the Study.

The study estimates the total embodied carbon and embodied energy from different construction products and elements produced during the overall life cycle of the building. Different residential building, commercial building and office buildings constructed using modern materials, were used in the study. The buildings studied in this research are constructed within the Kathmandu District.

1.7. Limitation of Study.

The limitations of the study can be summarized by the following categories;

- When building material specifications have not been defined, data availability is limited during the early stages of design.
- Data quality varies across many various sources and trades, making it difficult to assess for the whole study.
- The environmental impact of the construction could not be accurately represented by assumptions in material manufacturing and demolition.

1.8.Area of Study.

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 km^2.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.

Figure 1 Map of Nepal (source: Survey Department, Government of Nepal,2020)

Chapter 2: LITERATURE REVIEW

This chapter provides a review of technical expressions related to climate change and embodied carbon, alternative construction materials and different tools to find the embodied energy and carbon emission from the overall life span of the building. Among four phases of building life span, each and every phases requires certain amount of the energy for their operation. The research begins with the study of available literatures and references having different ideas of building system, methods for calculation of EE and EC and eCO_2.

2.1.Embodied Carbon and Embodied Energy

Any environmental issues and the study of climate change starts with energy and carbon emission. Building construction requires the large volume of the construction materials and huge amount of the energy for the construction. Energy is always related to the gaseous emission in different forms. Different terminologies related to this study have been studied and brief definitions are mentioned below;

2.1.1. Embodied Carbon

Embodied carbon is the carbon trail of a construction material of the building or infrastructure project before it becomes operational. Embodied carbon is the sum impacts of all the greenhouse gas emission attributed to the materials throughout their life cycle which includes the mining, manufacturing, construction, maintenance and disposal. CO_2 emission associated with overall construction material and building processes throughout the whole service lifecycle of the building is the embodied carbon.

2.1.2. Carbon dioxide-equivalence (CO_2e)

The relative role of various greenhouse gases in the enhancement of the natural greenhouse effect, either in equivalent units of concentration of carbon dioxide or in units of emission of carbon dioxide. Carbon dioxide-equivalent (CO_2e) is a principal unit of measurement to cumulative or make comparisons across greenhouse gases (Maunder, 1992). CO_2e states the tons of a greenhouse gas in the equivalent effect of tons of CO_2 on climate change (Ramseur, 2010).

2.1.3. Embodied Energy Coefficient

Embodied energy coefficient is also known as the embodied energy factor or embodied energy intensity which indicates the total energy required (in Mega Joule, MJ) to manufacture the unit weight (1 kg) of building material. The embodied energy and embodied carbon coefficient of several typical building construction materials are presented in the table below, according to the 'Inventory of Carbon and Energy (ICE)' in the United Kingdom.

Table 1Embodied coefficient of Different Materials

Materials		**Embodied energy coefficient**	**Embodied carbon coefficient**	**Embodied carbon coefficient**
		MJ/kg	kg CO e/kg	kgCO2/kg
Aluminium	General	155	9.16	8.24
	Virgin	218	12.79	11.46
	Recycled	29	1.81	1.69
Aggregate		0.083	0.0052	0.0048
Bricks	General	3	0.24	0.23
Cement	PPC (15-20%Flyash)	5.28 to 4.5	0.89 to .076	0.75
		4.89	**0.825**	**0.75**
	OPC	5.5	0.95	0.93
Concrete	1:2:4 M15	0.7	0.1	0.093
Glass	Primary	15	0.91	0.86
	Toughened	23.5	1.35	1.27
Iron		25	2.03	1.91
	GI Sheet	22.6	1.54	1.45
Stone	General	1.26	0.079	0.073
	Granite	11	0.7	0.64
	Lime stone	1.5	0.09	0.087
	Marble	2	0.13	0.116
	Marble Tile	3.33	0.21	0.192
	Sandstone	1	0.06	0.058
Paints	General water base	70	2.91	2.41
Timber		10	0.41	0.46
Tin		258	14.7	13.7
(Hammond & Jones,2011)				

2.1.4. Life Cycle Energy

The overall energy consumed by the building over its entire service life is known as life cycle energy. In case of building construction, life cycle energy is divided into two component- operational and embodied energy.

a. Operational Energy

Operational Energy is the energy used during the operation phase of the building for space and water heating, space cooling, lightning, running the equipment and appliances, etc. Energy involved from contracting to demolition but it does not include maintenance or renovations is operational energy.

b. Embodied Energy

Building construction requires variety of construction materials, which consumes the energy throughout its life cycle stages of manufacturing/mining, transporting, maintenance and demolition of building such an energy is known as embodied energy. Embodied energy is measured in MJ or GJ. Based on the stage of uses embodied energy is categorized into three type which are listed below;

i. Initial Embodied Energy

It is the energy consumed in the extraction/mining, processing and manufacturing, transporting and assembling the building materials to construct the building. Mainly two types of the energy are used namely non-renewable and renewable energy. Non-renewable energy is the indirect energy used for the extraction, processing and manufacturing of the raw materials whereas renewable energy are the direct energy used for the transportation of raw materials to the site.

ii. Recurring Embodied Energy

It is the energy consumed during the maintenance and renovation of the building during its entire service life cycle.

iii. Demolition Embodied Energy

It is the energy consumed in the demolition and disposal of the building waste materials with the help of machinery, equipment and the manpower.

2.1.5. Building Life Cycle

The entire life cycle of the building consists of six life cycle stages namely, raw material extraction/mining stage, manufacturing and processing stage, transporting stage, construction stage, operation and maintenance stage, demolition stage.

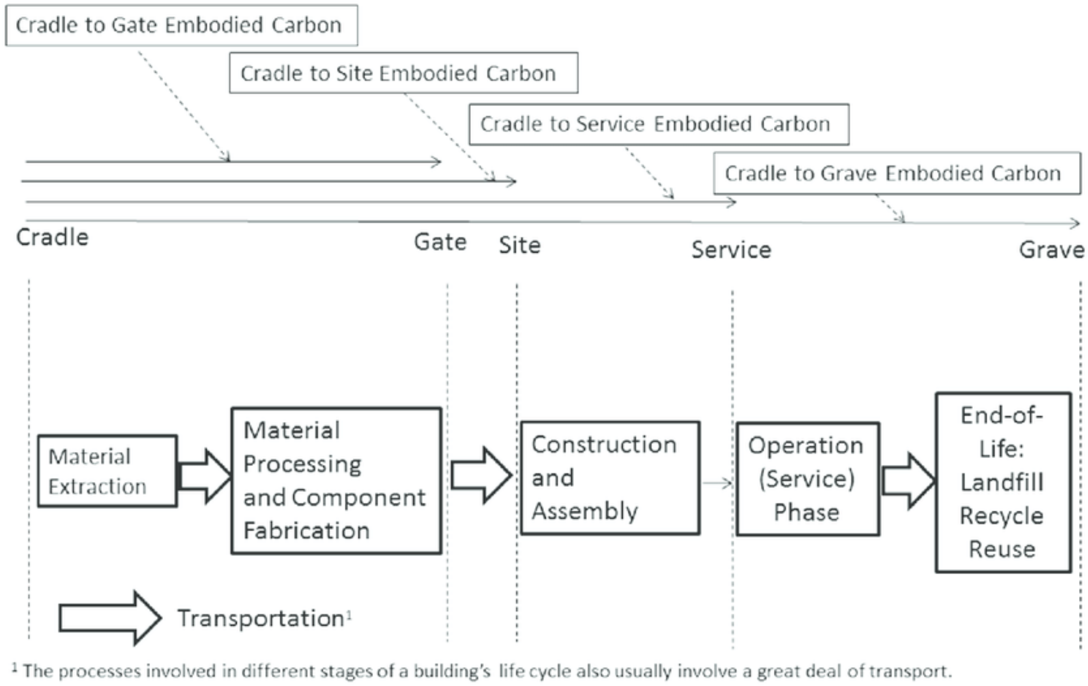


Figure 2 Different phases of building life cycle (adopted from Ali Akbarnezhad and Jianzhuang Xiao, 2017)

a. Raw Material Extraction

It is the first and foremost stage involve in the building construction phase. Different types of raw materials like iron ore, limestone, granite, marble, timber, petroleum, which are naturally embedded in the nature. The raw materials are processed using different techniques to change in useful forms which can be used as the building construction materials. Steels, cement, aluminium are the processed form of the raw materials becoming the common construction materials. The continuous extraction of these resources leads to the depletion of natural resources which also involves the large quantity of energy and water as well as evolves the emission and pollutants. Extraction of raw material relay on the fossil fuels for the mining of ores, resulting the contribution of greenhouse gases emission.

b. Manufacturing and Processing

The process of converting the natural resources into the basic construction material is known as the manufacturing phase according to Crawford, 2011. The conversion of the natural resources to the basic construction material is the most complex method utilizing the huge amount of energy mainly fossil fuel-based energy. Among total building life cycle energy consumption, embodied energy accounts for 15-60% of total consumption.

In South Africa alone, an average of 39.7 Mt of raw materials are consumed per year emitting 4.92 x 10^9kg CO2 to produce cement and aggregate for concrete production (Muigai et. Al, 2013). Construction materials and products account for almost half of all materials mined from the earth's crust (koroneos et. al, 2007). Sawing of the timber into appropriate shape and size, turning basic steel in roll form into corrugated roof sheeting products are some of the examples of raw material manufacturing and processing stage.

c. Building Construction

The process of assembling, gathering and fitting parts or materials together to form something or to build a structure. Construction is the stage of structure development which follows design. It is one of the longest and complex phase which require large quantity of construction materials. Large amount of energy are consumed by the transportation and the different operation on-site and off-site activities. About 69% of total construction energy is shared by the transportation only. Electricity is form of energy to power electrical tools, machinery operation on on-site construction. Fossil fuel is another form of energy used by the different types of the vehicles used for the transportation of raw materials to the construction site. Large consumption of water for the concrete curing, dust suppression and for cleaning purposes takes place in the construction phase.

d. Operation and maintenance

Operation and use

The operation stage of buildings is the longest having the life span of over 50 years. HVAC, power lighting systems, electricity and telecommunication networks are the basic needs for the operation of the building. Operation of these needs require large amount of thee energy which is supplied by the fossil-fuel-based sources. Crude oil, gas, hydro, nuclear, petroleum products are some primary source of energy used for the operation of building. Construction, operation and deconstruction stages of the building uses approximately 15% of world's fresh water resources; 40 % of the world's energy producing 23-40% of the world's greenhouse gas emissions (DEAT, 2009).

Maintenance and repair

Generally, maintenance and repair works are carried out several times during the overall service life of the building. Regular maintenance and repair helps to increase the life span of the building. During the maintenance and repair of the different component of building large amount of waste materials are produced and large amount of energy are required for the installation of new components having crucial impact on the environment.

e. Demolition

It is the final stage of building life cycle. The process of dismantling the structure, separating the components for the purpose of removing the whole from the existing is known as the demolition. Building have the finite lives so, it is necessary to demolish the building for the safety purpose. Large quantities of the solid waste were produced during the demolition of the building which the matter of concern for the proper disposal without hampering the environment. Releasing of the GHG emission through the burning of fossil fuel used for demolition machinery, transportation of waste to landfill site causes the environmental impacts. Disposed materials may decompose and percolate into the ground degrade the surrounding environment. When timber decompose they may release CO_2 (carbon dioxide) and CH4 (methane) into the soil and the atmosphere.

f. Recycling and reuse

Windows and doors are the raw material which can be reused directly after the demolition. The reuse of the materials helps to decrease some of the impacts of using new materials having potential impacts. Re-processing of the materials needs fuel for transportation, energy and other resources to make up the new products having potential environmental impacts involved in the re-processing.

2.2. Sources of GHG Emissions

Searched By searching using terms ‘‘GHG or greenhouse gas or CO_2 or carbon dioxide’’ within title and ‘‘building or construction’’ within title, found 67 papers at Science Direct – Online Journals by Elsevier Science (1996þ) and 73 articles at Science Citation Index Expanded (1970). However, only 20 papers were found that dealt with calculating GHG or CO_2 emissions from buildings. The construction stage of buildings was the subject of 13 research. The production of building materials, transportation for building materials, transportation for construction equipment, energy consumption of construction equipment, transportation for workers, and disposal of construction waste are the main sources of GHG emissions in building construction, according to these 13 studies.

2.3. Review of GHG Emissions Calculation Method

Process-based and economic input–output analysis are the most common methodologies for calculating environmental consequences (GHG emissions are also considered).

Process-based method is a simple models in which different activities associated with a product or a service is analyze using process flow diagrams (Guggemos AA, Horvath A, 2005). All materials and energy utilized in the process for each activity are identified throughout the process. As a result, environmental impacts and emissions can be calculated by accounting for material production and energy usage. (Gustavsson and Sathre, 2006) looked at the energy consumption of wood and concrete construction materials and calculated CO2 emissions from various sources of energy; Energy consumption was determined by applying embodied energy intensities for manufacturing, transporting, and installing various types of building components (Chen et al., 2001); (Gonza lez and Navarro,2006)and (Dimoudi and Tompa,2008)calculated CO2 emissions related to building material manufacturing using CO2 emission factors for various building materials.

The economic input–output analysis-based method evaluates both the direct and indirect environmental impacts of a product or service along the supply chain. The input-output approach has been adopted by researchers in the United States and Japan, owing to the fact that the Input/Output Table of the United States and Japan comprises over 400 sectors, which is detailed enough to examine the environmental consequences of the construction industry. Using this technique, (Suzuki et al., 1995), (Suzuki and Oka, 1998) and (Seo and Hwang, 2001) calculated CO2 emissions from residential buildings; computed GHG emissions from power plant construction and operation, residential building construction and operation, and water treatment system construction and operation, respectively.

2.3.1. Review of embodied carbon emission

The total lifecycle energy consumption of a building is made up of embodied energy and operating energy (Dixit et al., 2010). Embodied energy is the energy used throughout the entire process, from the extraction of raw materials to the processing, transportation, completion, and maintenance of building components, as well as the demolition of the structure once it has served its purpose. Operating energy accounts for 80% to 90% of energy consumption, followed by embodied energy accounting for 10% to 20%. However the construction and operating stage are the main source of energy consumption so, many earlier researchers concentrated on energy conservation (Ramesh et al., 2010).

The construction sector not only responsible for a direct effect on carbon emissions, but also responsible for indirect driving effect on the carbon emissions of the whole industrial system. The direct effect of the construction sector refers to the carbon emissions focused by its on-site actions. The indirect effect, which is the carbon emissions embodied in the products delivered to the building sector by other sectors, accounts for more than 90% of the construction sector's total CO_2 emissions (Chuai et al., 2015). Input-output models are extensively used to calculate the economic system's direct and indirect economic impacts by accounting for the interconnectedness of inputs and outputs across entire industrial sectors in detail. This reflects the indirect effects on the environment caused by upstream industry, and is appropriate for pollutant calculations (Palm et al., 2019). The MRIO model has been frequently used to investigate human-caused environmental issues such as water footprint (Ewing et al., 2012), CO_2 emissions, and so on (Wang et al., 2018), and embodied energy consumption (Liu et al., 2019) even can distinguish between the relationships that exist between distinct sectors as well as the relationships that exist between different areas

(Guo et al., 2012). According to (Hui Yan et al., 2009), embodied GHG emissions of building materials account for 82–87 percent of overall GHG emissions, transportation of construction materials accounts for 6–8%, and energy consumption of construction equipment accounts for 6–9%. Because concrete and reinforced steel account for 94–95 percent of all embodied GHG emissions in construction materials, employing recycled building materials, especially reinforced steel and aluminum, would dramatically reduce GHG emissions.

Chapter 3: RESEARCH METHODOLOGY

The methodology is approach that examines the procedures used in the field study in a methodical, theoretical manner. It includes ideas like an example, a theoretical model, segments, and quantitative and qualitative methodologies.

This research is an exploratory research. The embodied carbon emission is calculation is done using the data from different buildings. The embodied carbon emission from the buildings having brick wall is obtained for the overall life span of buildings, which is then replaced by the AAC block works and hollow concrete blocks, and the amount of the embodied carbon emission is compared.

3.1. Research Design

Each and every research begins with the research topic selection and setting of end destination. It basically responds to the design of the research in many alternative ways to reach the end goal. The success of any research depends upon the research framework and data calculation. In this research, data computation was a major challenge and extraction of detail data was done through engineering analysis norms and survey. Various literatures were referred and field works was performed. The research design is briefly mentioned in the chart below,

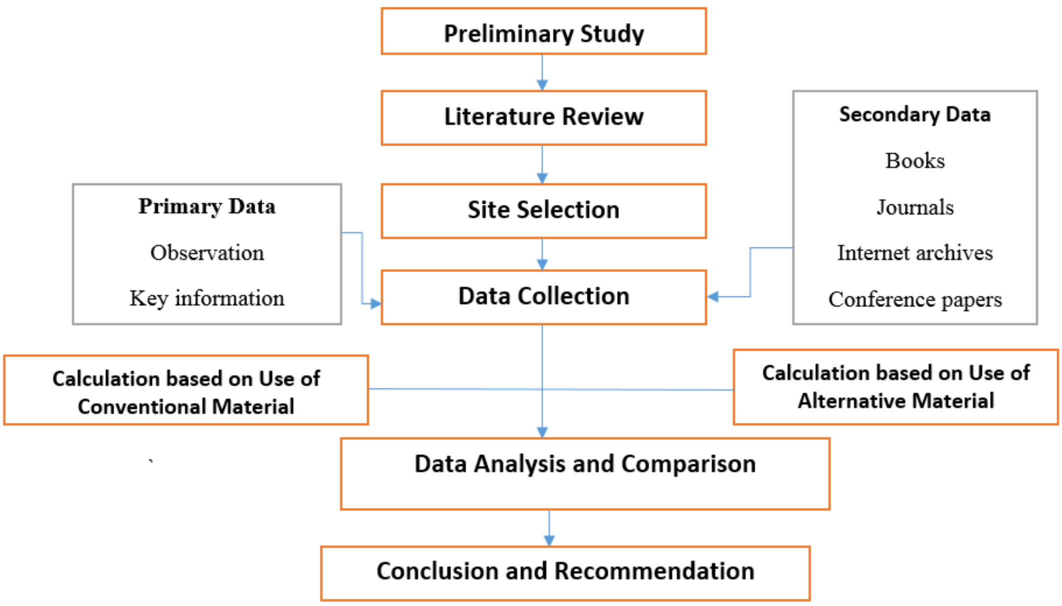


Figure 3 Flow chart of Research Design

3.2.Site Visit and Collection of data

A total of thirty one different building sites with varying story and plinth area were selected for the study. The plinth area varies from 850 sq. ft to over 7000 sq. ft and single to multi story. The building drawings were collected from the respective contractors. All the selected buildings included burnt clay bricks used in the design. For the purpose of the study, the same buildings were used for the estimation of the quantity of AAC blocks and hollow concrete blocks.

3.2.1. Data Collection

Primary data was collected from the field visit of the construction site and interview between the contractors and secondary data was collected from various online sources, offices and organization. Both ways of data collection method are taken into action in this research.

a. Primary Data Collection

The primary data for the study is collected from the contractors and owners of the buildings that were selected. At the first step, questionnaire was prepared to assess necessary information. Set of questionnaire used in this method have been attached in the annex 1.

- Primary data like household information, construction data, photographs, drawings, BoQs, building information like construction materials used were collected.
- Materials estimation is done by researcher himself.

b. Secondary Data Collection

The secondary data were collected from various sources like national and international journals, publications, articles and books. The embodied carbon coefficients and embodied energy coefficients were taken from the database of the Inventory of Carbon and Energy (ICE), UK, 2008.Following data were collected for the secondary sources,

- Embodied energy and embodied carbon coefficient
- EE and eCO_2 estimation tools

3.2.2. Data Compilation and Analysis

After collection of the primary and secondary data, they were analyzed entering in computer-aided software (MS-Excel). Calculation of embodied energy (EE) and embodied carbon (EC) and embodied carbon dioxide equivalent (ECO_2e) was estimate. For this purpose detail estimation of materials was needed.

3.2.2.1. Building Materials Estimation

After gathering all the information regarding the building, material estimation of the building was done with the help of material estimator and civil engineers. To carried out this process different municipal drawings, BoQ of each buildings were thoroughly analyzed which took nearly 2 weeks to complete detail material estimation of 31 buildings.

3.2.2.2. Allocation of coefficient of Embodied Energy and Embodied Carbon

From the ICE database, coefficient of different building construction materials have been extracted and used for further calculation. There are 11 different building construction materials used in the building that were selected for the study. Materials like sanitary fixtures and electrical fixtures etc. are not used due to the complexity of data.

Table 2 Table Embodied Energy and Embodied Carbon of different materials

SN	Building Material	Embodied Energy(EE)	Embodied Carbon (EC)	Embodied CO_2e
		MJ/Kg	CO_2/Kg	CO_2e
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
4	Sand	0.081	0.0048	0.0051
5	Aggregates	0.083	0.0048	0.0051
6	Rebar	25	1.91	2.03
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

3.2.3. A method for estimating embodied carbon dioxide based on process analysis

In this study, the carbon emission from building construction material was calculated based on process data Process-based assessment is a bottom-up approach that represents carbon emissions for specific building construction processes (Zhang and Wang, 2016). Embodied carbon dioxide is the entire amount of carbon dioxide released by building materials during manufacturing, transportation, construction, maintenance, and demolition. There are three types of embodied carbon dioxide in buildings: initial embodied carbon (IEC), recurring embodied carbon (REC), and demolition carbon (DC) (Li et al., 2014). The IEC is emitted during the construction of a building, whereas the REC is emitted over the life cycle of a building. And DC is the carbon emitted from buildings demolition and disposal. Fig. 1 illustrates the scope of annual embodied carbon dioxide estimation in the building sector in this study.

Figure 4 Research scope of embodied carbon dioxide in the building sector

The yearly embodied carbon dioxide emissions (Cemb) in the building industry can be computed using Eq. 1-5, as shown previously.$C_{emb} = C_{new} + C_{maintenance} + C_{demolition}$ (1)

$C_{new} = C_{em} + C_{ep} + C_{et} + C_{ec}$ (2)

$C_{maintenance} = C_{er}$ (3)

$C_{demolition} = C_{ed} + C_{ew}$ (4)

Therefore, the total annual ECDBS can be illustrated as followings:

$C_{emb} = C_{em} + C_{ep} + C_{et} + C_{ec} + C_{er} + C_{ed} + C_{ew}$ (5)

Where:

building

Cnew stands for the embodied carbon dioxide of new structures.

Cmaintenance stands for the embodied carbon dioxide of building maintenance

Cdemolition stands for the embodied carbon dioxide from buildings demolition

Cem stands for the carbon emissions from the production of building materials.

Cep stands for carbon emissions from chemical reactions in the process of material production.

Cet stands for the carbon emissions from transporting construction materials from production facilities to construction sites

Cec stands for the carbon emissions from energy usage on construction sites

Cer stands for the carbon emissions from the replacement of building components

Ced stands for the carbon emissions from building demolition

Cew stands for the construction and demolition waste disposal carbon emissions.

Several assumptions (Table 3) were made for embodied carbon estimation in this study. Because of some data unavailability, some data were derived from the analysis results of existing cases in literature.

Table 3 . Assumptions of embodied carbon estimation in different stages

Emission Sources	Assumptions and Limitations	References	Country of study
Cem	Classification of two main structure and three main function of buildings were proposed	Jing et al. (2019)	China
Cep	65% of the clinker cement average ratio was adopted in the construction sector.	Wei et al. (2016),	
	Clinker carbon emission factor of Nepal's cement is 498.5 kg per ton in construction sector.	IPCC(1996)	Nepal
Cec	The carbon emissions on construction sites of new construction and demolition of buildings were merged together to calculate total emission.	Zhu et al. (2019)	China
Cet	The main construction materials were considered in the transportation process.		
	The average transport distance of main building materials is set according to the contractor log sheet.		
Cer	The carbon emissions of building component replacement are annually estimated to account for	(Dixit, 461 2019)	USA

	1.55% of the initial embodied carbon of buildings.		
Cew	the amount of building waste is assumed to be 85% of the total weight of the building materials in this study.	Li et al., (2014);	China
	Steel and aluminum are recyclable, and the recycle rate of steel and aluminum in the final disposal were assumed to be 60% and 20%, respectively.	Zhang and Wang (2015);	China
	Average distance of transportation of building materials to landfill was assumed to be 25 km and recycling site was assumed to be 10km.		

3.2.3.1 Embodied Carbon dioxide emitted during the manufacture of building materials

Construction materials provide the most embodied carbon, and the most carbon-intensive activities are mostly mining, processing, and producing construction resources(Pomponi and Moncaster, 2018). 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 building height, building function, building structure, 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 (Cabeza 284 et al., 2013b).

Based on the carbon emission factors of construction materials, the embodied carbon emissions of construction materials of each building were calculated, as shown Eq. 6:

$$C_i = \sum_{j=1}^{6} Mj * fj \qquad (6)$$

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

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

fj stands for the carbon emission factor unit weight of jth construction material

The carbon emission factors of the main building materials were collected and are listed in Table 4.

Table 4 Carbon Emission Factors of Building Materials

Materials		**Embodied energy coefficient**	**Embodied carbon coefficient**	**Embodied carbon coefficient**
		MJ/kg	kg CO e/kg	kgCO2/kg
Aluminium	General	155	9.16	8.24
	Virgin	218	12.79	11.46
	Recycled	29	1.81	1.69
Aggregate		0.083	0.0052	0.0048
Bricks	General	3	0.24	0.23
Cement	PPC (15-20%Flyash)	5.28 to 4.5	0.89 to .076	0.75
		4.89	**0.825**	**0.75**
	OPC	5.5	0.95	0.93
Concrete	1:2:4 M15	0.7	0.1	0.093
Glass	Primary	15	0.91	0.86
	Toughened	23.5	1.35	1.27
Iron		25	2.03	1.91
	GI Sheet	22.6	1.54	1.45
Stone	General	1.26	0.079	0.073
	Granite	11	0.7	0.64
	Lime stone	1.5	0.09	0.087
	Marble	2	0.13	0.116
	Marble Tile	3.33	0.21	0.192
	Sandstone	1	0.06	0.058
Paints	General water base	70	2.91	2.41
Timber		10	0.41	0.46
Tin		258	14.7	13.7
(Hsmmond & Jones,2011)				

By multiplying the associated emission factor and the total weight of construction materials used on construction sites, the embodied carbon and embodied energy from building construction materials was calculated. For the estimation of EE and EC, ten different conventional construction materials were used.

Table 5 ECe of different Construction Materials

Building	Embodied carbon kg CO e (ton)										Cmm=ton Coe
	Cement	Aggregate	Rebar	Brick	Tile	Sal wood	Aluminium	Paints	Glass	Granite	
R1	98.95	1.04	36.99	57.95	5.19	3.03	0.00	1.32	0.63	3.93	209.03
R2	93.80	1.02	34.43	83.70	3.34	1.56	7.05	1.02	0.86	2.52	229.29
R3	45.80	0.52	20.40	28.58	1.45	3.26	4.20	0.60	0.51	0.29	105.59
R4	46.67	0.53	19.95	28.61	1.26	3.15	2.47	0.37	0.30	0.62	103.94
R5	45.71	0.52	23.36	32.40	1.76	0.59	3.73	0.53	0.46	0.11	109.18
R6	45.13	0.52	23.36	32.40	1.76	0.92	3.73	0.53	0.46	0.11	108.92
R7	69.70	0.87	65.08	34.35	1.95	0.73	6.60	1.95	0.81	2.87	184.90
R8	77.77	0.91	32.43	56.71	2.78	17.25	0.00	0.83	2.10	2.83	193.60
R9	76.00	0.96	33.46	15.43	1.60	0.56	9.88	0.46	1.03	1.98	141.37
R10	91.71	1.17	43.03	72.12	0.74	4.01	9.88	0.80	0.78	3.10	227.35
R11	33.86	0.37	15.12	33.82	0.28	0.00	3.13	0.26	0.22	0.00	87.07
R12	100.61	1.17	42.24	55.94	3.10	0.98	6.33	1.14	0.78	2.65	214.93
C1	453.57	3.96	201.11	79.54	11.20	2.02	54.43	2.86	6.66	8.87	824.22
C2	390.28	3.42	297.74	51.31	4.06	0.93	25.55	1.59	3.13	7.69	785.71
C3	419.75	3.77	350.93	82.58	4.11	1.43	5.16	1.89	0.63	11.34	881.60
C4	3913.92	33.56	2464.92	620.69	57.57	21.12	81.94	30.91	10.02	188.11	7422.76
C5	4058.70	36.01	854.80	475.09	51.37	21.12	81.94	16.11	10.02	188.11	5793.27
C6	128.20	0.58	69.47	157.77	4.48	0.00	17.62	0.72	0.49	1.54	380.88
C7	507.40	6.43	536.50	272.24	13.19	0.00	60.48	3.30	0.33	1.54	1401.40
C8	455.17	5.10	319.23	61.62	6.18	3.06	26.79	1.35	5.98	7.71	892.19

Building	**Embodied carbon kg CO e (ton)**										**Cmm=ton Coe**
	Cement	**Aggregate**	**Rebar**	**Brick**	**Tile**	**Sal wood**	**Aluminium**	**Paints**	**Glass**	**Granite**	
O1	378.30	4.67	164.59	204.82	13.29	0.00	57.33	3.31	2.25	14.33	842.89
O2	1665.44	14.01	578.72	303.53	29.83	5.10	33.78	8.30	4.13	24.86	2667.71
O3	755.78	6.34	296.39	276.01	24.08	4.99	26.99	4.61	3.30	23.81	1422.30
O4	718.68	5.96	337.01	188.72	14.24	2.29	36.30	5.65	4.44	19.71	1333.00
O5	447.05	6.18	322.74	34.99	8.66	0.00	66.43	2.79	6.58	5.42	900.84
O6	1255.99	10.42	550.33	387.23	4.77	5.59	0.00	4.48	5.98	4.92	2229.71
O7	256.46	2.66	164.64	191.11	9.58	1.12	19.98	1.69	2.66	6.70	656.59
O8	757.55	6.11	470.60	282.73	4.14	8.33	0.22	2.61	1.19	5.68	1539.16
O9	105.82	0.86	31.56	157.00	0.00	0.00	12.32	0.90	0.85	0.00	309.31
O10	861.74	10.94	648.34	236.32	1.15	4.52	22.46	9.65	2.26	1.57	1798.95
O11	1277.77	13.06	997.58	203.12	19.53	2.26	63.24	5.51	2.94	37.26	2622.27
Total	**19633.30**	**183.66**	**10047.06**	**4798.43**	**306.63**	**119.92**	**749.95**	**118.05**	**82.77**	**580.17**	**36619.92**
no	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**
mean	**633.33**	**5.92**	**324.10**	**154.79**	**9.89**	**3.87**	**24.19**	**3.81**	**2.67**	**18.72**	**1181.29**

Table 6 EC of different Construction Materials

Building	Embodied carbon kg CO2										Cem=ton CO2
	Cement	Aggregate	Rebar	Brick	Tile	Sal wood	Aluminium	Paints	Glass	Granite	
R1	94.40	0.96	34.80	55.54	4.74	3.40	0.00	1.09	0.60	3.60	199.13
R2	89.51	0.94	32.39	80.21	3.05	1.75	6.34	0.84	0.81	2.31	218.15
R3	43.79	0.48	19.19	27.38	1.32	3.65	3.78	0.49	0.49	0.26	100.84
R4	44.60	0.49	18.77	27.42	1.16	3.53	2.22	0.31	0.29	0.57	99.35
R5	43.64	0.48	21.98	31.05	1.61	0.66	3.35	0.44	0.43	0.10	103.75
R6	43.11	0.48	21.98	31.05	1.61	1.03	3.35	0.44	0.43	0.10	103.59
R7	66.85	0.80	61.23	32.91	1.78	0.82	5.94	1.62	0.76	2.62	175.34
R8	74.25	0.84	30.51	54.35	2.54	19.36	0.00	0.69	1.98	2.59	187.10
R9	73.15	0.88	31.49	14.78	1.47	0.63	8.89	0.38	0.98	1.81	134.46
R10	88.35	1.08	40.49	69.11	0.68	4.50	8.89	0.66	0.73	2.84	217.33
R11	32.29	0.34	14.23	32.41	0.26	0.00	2.81	0.22	0.21	0.00	82.76
R12	96.11	1.08	39.74	53.61	2.83	1.10	5.70	0.94	0.73	2.42	204.27
C1	438.50	3.66	189.22	76.23	10.24	2.26	48.96	2.37	6.29	8.11	785.84
C2	378.49	3.16	280.14	49.17	3.71	1.04	22.99	1.32	2.95	7.03	750.00
C3	406.62	3.48	330.18	79.14	3.75	1.60	4.64	1.57	0.60	10.37	841.97
C4	3791.21	30.98	2319.21	594.82	52.63	23.70	73.71	25.60	9.47	171.98	7093.32
C5	3933.84	33.24	804.27	455.29	46.97	23.70	73.71	13.34	9.47	171.98	5565.81
C6	119.40	0.54	65.36	151.20	4.10	0.00	15.85	0.60	0.46	1.41	358.92
C7	476.49	5.94	504.78	260.90	12.06	0.00	54.40	2.73	0.31	1.41	1319.02
C8	439.86	4.71	300.36	59.05	5.65	3.44	24.10	1.12	5.65	7.05	850.98

Building	**Embodied carbon kg CO2**										**Cmm=ton CO2**
	Cement	**Aggregate**	**Rebar**	**Brick**	**Tile**	**Sal wood**	**Aluminium**	**Paints**	**Glass**	**Granite**	
O1	363.84	4.31	154.87	196.29	12.15	0.00	51.57	2.74	2.12	13.10	800.98
O2	1609.72	12.94	544.51	290.88	27.27	5.72	30.39	6.87	3.91	22.73	2554.94
O3	729.50	5.85	278.87	264.51	22.02	5.60	24.27	3.82	3.12	21.77	1359.33
O4	693.92	5.50	317.09	180.86	13.02	2.57	32.66	4.68	4.20	18.02	1272.51
O5	433.61	5.70	303.66	33.53	7.92	0.00	59.76	2.31	6.21	4.96	857.68
O6	1212.85	9.62	517.80	371.09	4.36	6.27	0.00	3.71	5.65	4.50	2135.85
O7	246.61	2.45	154.91	183.15	8.76	1.25	17.98	1.40	2.51	6.13	625.14
O8	732.01	5.64	442.78	270.95	3.79	9.34	0.20	2.16	1.12	5.19	1473.19
O9	100.61	0.80	29.69	150.46	0.00	0.00	11.08	0.75	0.80	0.00	294.18
O10	832.88	10.10	610.02	226.48	1.05	5.07	20.20	7.99	2.13	1.44	1717.36
O11	1238.67	12.05	938.61	194.65	17.86	2.54	56.89	4.57	2.78	34.07	2502.68
Total	**18968.68**	**169.53**	**9453.14**	**4598.49**	**280.35**	**134.54**	**674.62**	**97.77**	**78.22**	**530.44**	**34985.79**
no	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**
mean	**611.89**	**5.47**	**304.94**	**148.34**	**9.04**	**4.34**	**21.76**	**3.15**	**2.52**	**17.11**	**1128.57**

Table 7 EE of different Construction Materials

Building Notation	EE (MJ)										Total EE
	Cement	**Aggregate**	**Rebar**	**Brick**	**Tile**	**Sal wood**	**Aluminium**	**Paints**	**Glass**	**Granite**	
R1	577725.8	16603.9	455486.0	724432.3	82242.3	73876.0	0.0	31692.4	10410.8	61827.3	**2034296.7**
R2	547615.3	16201.8	424002.5	1046189.4	52907.8	38050.5	119220.9	24523.0	14208.8	39659.5	**2322579.3**
R3	267210.4	8303.3	251199.5	357191.7	22945.0	79422.2	71022.8	14325.7	8464.5	4518.5	**1084603.5**
R4	272366.1	8502.4	245724.8	357600.9	20041.6	76769.0	41817.0	8872.8	4983.8	9800.4	**1046478.5**
R5	266856.9	8343.4	287717.0	405061.9	27913.8	14450.4	63055.9	12671.1	7515.0	1727.2	**1095312.7**
R6	263395.1	8343.4	287717.0	405061.9	27913.8	22414.0	63055.9	12671.1	7515.0	1727.2	**1099814.4**
R7	406228.0	13910.8	801469.5	429319.4	30879.4	17881.4	111688.2	46944.6	13311.0	45027.3	**1916659.5**
R8	453946.9	14513.2	399364.3	708915.7	44020.5	420785.8	0.0	19933.1	34562.3	44450.0	**2140491.7**
R9	442436.5	15248.6	412125.0	192843.6	25447.6	13698.0	167209.0	11095.9	17021.4	31129.1	**1328254.7**
R10	533771.2	18745.3	529953.0	901438.1	11757.9	97836.8	167209.0	19290.0	12804.8	48729.9	**2341535.8**
R11	197759.0	5827.2	186250.0	422693.7	4507.0	0.0	52899.0	6361.0	3705.8	0.0	**880002.6**
R12	587180.6	18709.1	520141.8	699282.2	49113.5	23810.3	107195.0	27428.4	12775.5	41649.2	**2087285.4**
C1	2636835.5	63225.4	2476744.0	994302.1	177601.0	49185.8	921012.0	68791.0	109766.3	139342.8	**7636805.8**
C2	2266599.3	54605.2	3666720.5	641350.6	64363.3	22625.3	432423.5	38353.7	51536.3	120877.6	**7359455.3**
C3	2438625.5	60244.6	4321746.3	1032309.4	65118.2	34854.1	87296.5	45582.9	10404.0	178238.9	**8274420.3**
C4	22739088.3	535688.5	30356177.3	7758571.6	912861.8	515219.4	1386473.8	743586.4	165240.0	2955938.6	**68068845.5**
C5	23575504.2	574731.8	10527120.7	5938588.2	814563.5	515219.4	1386473.8	387494.7	165240.0	2955939.9	**46840876.0**
C6	754266.0	9327.5	855538.5	1972145.5	71043.4	0.0	298231.6	17368.2	8066.3	24186.0	**4010173.0**
C7	2977462.8	102638.8	6607091.0	3403044.9	209146.2	0.0	1023355.1	79362.8	5404.5	24186.0	**14431692.1**
C8	2646485.5	81442.1	3931462.5	770199.8	97999.6	74683.0	453360.3	32424.6	98550.0	121101.9	**8307709.3**

Building Notation	EE (MJ)										Total EE
	Cement	Aggregate	Rebar	Brick	Tile	Sal wood	Aluminium	Paints	Glass	Granite	
O1	2202995.4	74587.6	2027029.5	2560306.8	210727.4	0.0	970021.9	79545.9	37035.0	225174.8	**8387424.2**
O2	9682808.0	223679.2	7127075.8	3794096.4	473015.8	124411.4	571618.4	199630.3	68125.5	390659.9	**22655120.5**
O3	4395983.9	101126.4	3650147.2	3450133.8	381876.8	121801.6	456626.4	110916.1	54420.8	374112.8	**13097145.7**
O4	4179742.5	95123.9	4150383.5	2359043.6	225755.7	55834.4	614322.7	135810.2	73215.0	309699.4	**12198930.9**
O5	2596108.5	98625.6	3974650.0	437347.5	137336.6	0.0	1124142.7	67225.0	108380.6	85228.2	**8629044.6**
O6	7304491.2	166380.9	6777425.0	4840335.4	75611.4	136384.0	0.0	107792.2	98550.0	77296.0	**19584266.0**
O7	1493529.7	42385.1	2027598.0	2388910.0	151871.3	27262.6	338141.1	40642.8	43845.7	105295.0	**6659481.4**
O8	4404718.2	97585.0	5795521.8	3534151.5	65686.7	203138.0	3756.9	62862.8	19572.8	89210.1	**14276203.7**
O9	618564.3	13759.3	388629.0	1962486.9	0.0	0.0	208424.2	21703.0	13972.5	0.0	**3227539.3**
O10	5010141.6	174676.7	7984500.0	2954036.6	18253.3	110144.5	380015.4	232146.1	37208.3	24720.4	**16925842.9**
O11	7421692.9	208383.9	12285500.0	2538975.3	309733.9	55120.0	1070061.7	132605.3	48496.5	585517.4	**24656087.0**
Total	**114162135.0**	**2931469.8**	**123732210.6**	**59980366.5**	**4862256.1**	**2924877.6**	**12690130.2**	**2839652.7**	**1364308.2**	**9116971.6**	**334604378.3**
no	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**
mean	**3682649.5**	**94563.5**	**3991361.6**	**1934850.5**	**156847.0**	**94350.9**	**409359.0**	**91601.7**	**44009.9**	**294095.9**	**10793689.6**

The total embodied carbon was found to be 1128.56 Mt and the embodied energy to be 10793689.5 MJ, as shown in table 1. It appears that having a large quantity on a weighted average contributes nothing to carbon emissions.

3.2.3.2. Process carbon emission from the chemical reaction

Carbon dioxide emissions resulting from chemical reactions in industrial manufacture processes are termed as the process carbon emission (Chau et al., 2015). In this study, cement production is considered as the main source of the carbon emissions of chemical reactions. As a result of calcination reaction, limestone decomposed into calcium oxide which evolves the carbon dioxide during the process of cement production. The carbon dioxide emissions from the calcination reaction in the cement manufacturing can be estimated using Eq. 7, established by Pommer and Pade (2006):

$$C_{ep} = \beta * M_{cement} * f_{clinker} \qquad (7)$$

Where:

Cep stands for carbon emissions of chemical reactions in the industrial production process

β stands for the carbon dioxide per kilogram of clinker produced

Mcement stands for the quantity of cement used for building construction

fclinker 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 (IPCC, 1996).The adopted average clinker ratio in the Nepal's cement industry is 65%.

Table 8 EC from chemical reaction

Building Type	Mcement (ton)	β=498.5 kg CO2/t	fclinker=65%	Cep=β*Mcement*fclinker(kg CO2)	Cep(ton CO2)	EF(MJ/kg)	EF(MJ)
R1	109.78	498.50	0.65	35572.59	35.57	1.75	192121.06
R2	104.02	498.50	0.65	33706.36	33.71	1.75	182041.93
R3	50.59	498.50	0.65	16393.01	16.39	1.75	88535.65
R4	51.62	498.50	0.65	16726.84	16.73	1.75	90338.61
R5	50.66	498.50	0.65	16416.44	16.42	1.75	88662.18
R6	49.96	498.50	0.65	16187.04	16.19	1.75	87423.28
R7	76.51	498.50	0.65	24792.74	24.79	1.75	133901.08
R8	86.15	498.50	0.65	27914.92	27.91	1.75	150763.38
R9	82.84	498.50	0.65	26840.70	26.84	1.75	144961.73
R10	99.80	498.50	0.65	32337.03	32.34	1.75	174646.43
R11	37.62	498.50	0.65	12189.63	12.19	1.75	65833.99
R12	111.34	498.50	0.65	36078.23	36.08	1.75	194851.97
C1	490.06	498.50	0.65	158791.14	158.79	1.75	857602.03
C2	418.99	498.50	0.65	135764.64	135.76	1.75	733240.10
C3	451.65	498.50	0.65	146345.67	146.35	1.75	790386.31
C4	4211.96	498.50	0.65	1364781.65	1364.78	1.75	7370937.07
C5	4362.31	498.50	0.65	1413498.13	1413.50	1.75	7634045.93
C6	148.88	498.50	0.65	48241.94	48.24	1.75	260545.91
C7	580.27	498.50	0.65	188023.12	188.02	1.75	1015478.61
C8	492.20	498.50	0.65	159486.44	159.49	1.75	861357.19
O1	413.06	498.50	0.65	133841.22	133.84	1.75	722852.03
O2	1800.27	498.50	0.65	583333.74	583.33	1.75	3150479.29
O3	819.21	498.50	0.65	265444.21	265.44	1.75	1433615.82
O4	778.48	498.50	0.65	252245.97	252.25	1.75	1362334.54
O5	479.76	498.50	0.65	155454.65	155.45	1.75	839582.24
O6	1360.23	498.50	0.65	440750.02	440.75	1.75	2380410.55
O7	280.12	498.50	0.65	90764.92	90.76	1.75	490204.81
O8	819.31	498.50	0.65	265475.84	265.48	1.75	1433786.66
O9	118.22	498.50	0.65	38306.70	38.31	1.75	206887.52
O10	931.55	498.50	0.65	301846.89	301.85	1.75	1630220.06
O11	1372.88	498.50	0.65	444847.54	444.85	1.75	2402540.53
			Total	**6882399.95**	**6882.40**		**37170588.44**
			N	**31.00**	**31.00**		**31.00**
			Avg	**222012.90**	**222.01**		**1199051.24**

As illustrated in table 8, 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.

3.2.3.3. Embodied carbon dioxide from building construction and demolition activities

As for the carbon emissions from building construction and demolition, the main sources are the machines and the equipment on sites (for example, trucks, loaders, cranes, etc.), offices and living at the construction site (lighting, cooking, heating, cooling, etc.) (Zhu et al., 2019). 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:

$$\text{Cec}= \sum_{k=1}^{8} \text{Ek} * fek \qquad (8)$$

Where:

Cec 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)

The energy consumption of buildings and carbon factors are shown in Table 8

Table 9 Energy consumptions and emission factor for building construction and demolition

Energy	**Unit**	**Carbon Factor (Ton/Ton, MWh, or M3)**	**source**	**Energy factor**
Liquefied petroleum gas	ton	3.085	Smith et al, 2000;	1.51
Kerosene	ton	2.985	Smith et al, 2000;	1.205
Diesel oil	ton	3.18		38.6mj/l

Electricity	MWh	0.6808		3.6mj/kwh
firewood	ton	1.46242	aStockwell et al., 2016	0.5Mj/kg

Construction sites used a variety of construction equipment and vehicles, all of which required energy to operate, resulting in carbon emissions. The energy required for the seated activities is calculated in this way (lighting, cooking, heating and cooling). The common energy utilized in building work that cause carbon emissions are electricity, diesel, firewood, petrol, and so on.

Table 10 Cec in different Buildings

Building Type	**EE**	**Cec(ton CO2)**
R1	9490.13	1.99
R2	13500.32	2.73
R3	14010.06	2.76
R4	17326.99	3.47
R5	16001.10	3.13
R6	13651.22	2.78
R7	14454.59	5.42
R8	24155.73	7.80
R9	15389.08	3.18
R10	24603.54	9.07
R11	26996.63	9.63
R12	17287.74	3.28
C1	95515.17	14.80
C2	100435.07	17.59
C3	84590.17	17.86
C4	139895.27	25.74
C5	206687.31	33.82
C6	86940.78	19.57
C7	78842.31	14.45
C8	100344.12	33.79
O1	77498.27	16.09
O2	65980.00	19.85
O3	89613.14	21.89
O4	48630.50	12.15
O5	70582.46	13.69
O6	80725.40	17.41
O7	69721.09	13.34
O8	44849.51	9.02
O9	42789.04	8.84

O10	49449.18	11.21
O11	43715.68	9.29
Total	**1783671.60**	**385.65**
N	**31.00**	**31.00**
Avg	**57537.79**	**12.44**

3.2.3.4. Embodied carbon dioxide from material transportation

Various construction materials must be transported from their manufacturing facilities to the construction site, which necessitates 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 materials 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;

$$C_{et} = \sum_{i=1}^{6} \mathrm{Mi} * Di * Ti \quad (9)$$

Where:

Cet 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

According to expert interviews and literature, the type of diesel-based vehicle for aggregate, sand, and steel is a heavy goods vehicle, but the type of diesel-based vehicle for wood, bricks, aluminum, and glass is a medium goods vehicle. The transportation of various construction materials from their manufacturing sites to the construction site necessitates a significant amount of energy. The transportation method and distance, as well as the weight on the vehicle, vehicle type, and vehicle energy consumption, can all be used to determine the carbon dioxide emissions from material transportation. Construction supplies are transported from the manufacturing site to the construction site using diesel-powered medium or heavy-goods transport vehicles. Table 12, shows the total amount of EE and EC emitted during material transport to the building site.

Table 11 Carbon emission factor for different vehicles

Type of Vehicle	Gross Vehicle Weight(ton)	Carbon Emission Factor(kgCO2/t-km)
Medium goods vehicle	8-10 ton	0.25
Heavy goods vehicle	10-18 ton	0.18
	18-30 ton	0.16

Data source: HKEMSD (2013), Gan et al. (2017b), Zhang and Wang (2017), Wang et al. (2016).

Table 12 Cet in different Buildings

Building Type	**EE due to transport**	**Cet(ton CO2)**
R1	350.400	0.832
R2	392.400	0.971
R3	392.400	0.461
R4	392.400	0.450
R5	392.400	0.472
R6	392.400	0.462
R7	442.800	0.380
R8	183.600	0.215
R9	153.600	0.075
R10	146.400	0.307
R11	147.600	0.110
R12	160.800	0.232
C1	1059.120	1.859
C2	1058.400	1.490
C3	1049.520	1.660
C4	1268.640	14.815
C5	1034.880	14.612
C6	1032.240	0.562
C7	1022.640	2.841
C8	1233.600	2.132
O1	1070.400	1.927
O2	1077.600	6.377

O3	1382.400	3.716
O4	405.600	2.834
O5	325.200	1.145
O6	321.600	2.263
O7	216.000	0.550
O8	252.000	1.250
O9	115.200	0.229
O10	1082.400	4.113
O11	1070.400	5.833
Total	**19625.040**	**75.177**
N	**31.000**	**31.000**
Avg	**633.066**	**2.425**

3.2.3.5. Embodied carbon dioxide from building maintenance

Throughout the service life of a building, many components are repaired, maintained, and replaced, resulting in recurring embodied carbon, which is often overlooked due to data inaccessibility and its minimal contribution to life-cycle carbon emissions (Zhang and Wang, 2017). However, other researchers (Wang et al., 2016) 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}) is generally related to the building service life which is difficult to obtain the annual statistical data. 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 0.3-2.8 percent of the buildings' initial embodied carbon (Dixit, 2019). In this study the annual recurring embodied carbon was taken as 1.55 percentage of initial embodied carbon from the building. For the embodied energy, 5 percent of initial embodied energy of the building was taken into action.

Table 13 Maintenance frequency for some building components

Building Components	Lifetime (year)	Maintenance times
Main structure	50	0
Thermal insulation layer	50	0
Water supply and ventilation pipe	50	0
Decoration board	30	1
Ceramic tile	30	1
Roofing	25	1
Plastic–steel window	30	1
Drain pipe	30	1
Painting	10	4

Data sources: Zhang and Wang (2017), Wang (2011).

Throughout the life of a building, it will need to be repaired and replaced on a regular basis. Due to a lack of data and its modest contribution to life cycle carbon emissions, the carbon emissions from various types of maintenance are frequently overlooked.. The carbon emissions from building component maintenance are calculated as a percentage of the total embodied carbon in buildings, which ranges from 0.3 to 2.8 percent of total emissions. As a result, the recurrent embodied carbon in this study was considered to equal around 1.55 percent of the structures' initial embodied carbon, resulting in a total of 21.16Mt.

Table 14 EC & EE from building maintenance

Building Type	**Cmm=ton CO2**	**Cep(ton CO2)**	**Cec(ton CO2)**	**Cet(ton CO2)**	**Cinitial**	**Cer(ton CO2)=1.55%of Cinitial**	**EEinitial**	**EE demolition+5%of initialEE**
R1	199.13	35.57	1.99	0.83	237.52	3.68	2236258.29	11181.29
R2	218.15	33.71	2.73	0.97	255.56	3.96	2518513.96	12592.57
R3	100.84	16.39	2.76	0.46	120.46	1.87	1187541.66	5937.71
R4	99.35	16.73	3.47	0.45	120.00	1.86	1154536.50	5772.68
R5	103.75	16.42	3.13	0.47	123.76	1.92	1200368.37	6001.84
R6	103.59	16.19	2.78	0.46	123.02	1.91	1201281.33	6006.41
R7	175.34	24.79	5.42	0.38	205.93	3.19	2065457.98	10327.29
R8	187.10	27.91	7.80	0.22	223.03	3.46	2315594.42	11577.97
R9	134.46	26.84	3.18	0.08	164.56	2.55	1488759.10	7443.80
R10	217.33	32.34	9.07	0.31	259.05	4.02	2540932.20	12704.66
R11	82.76	12.19	9.63	0.11	104.70	1.62	972980.77	4864.90
R12	204.27	36.08	3.28	0.23	243.86	3.78	2299585.93	11497.93
C1	785.84	158.79	14.80	1.86	961.29	14.90	8590982.07	42954.91
C2	750.00	135.76	17.59	1.49	904.85	14.03	8194188.85	40970.94
C3	841.97	146.35	17.86	1.66	1007.83	15.62	9150446.30	45752.23
C4	7093.32	1364.78	25.74	14.81	8498.66	131.73	75580946.46	377904.73
C5	5565.81	1413.50	33.82	14.61	7027.74	108.93	54682644.12	273413.22
C6	358.92	48.24	19.57	0.56	427.30	6.62	4358691.93	21793.46
C7	1319.02	188.02	14.45	2.84	1524.34	23.63	15527035.64	77635.18
C8	850.98	159.49	33.79	2.13	1046.39	16.22	9270644.19	46353.22
O1	800.98	133.84	16.09	1.93	952.84	14.77	9188844.94	45944.22
O2	2554.94	583.33	19.85	6.38	3164.50	49.05	25872657.35	129363.29
O3	1359.33	265.44	21.89	3.72	1650.39	25.58	14621757.02	73108.79
O4	1272.51	252.25	12.15	2.83	1539.74	23.87	13610301.50	68051.51
O5	857.68	155.45	13.69	1.15	1027.96	15.93	9539534.55	47697.67
O6	2135.85	440.75	17.41	2.26	2596.27	40.24	22045723.58	110228.62
O7	625.14	90.76	13.34	0.55	729.80	11.31	7219623.32	36098.12
O8	1473.19	265.48	9.02	1.25	1748.95	27.11	15755091.90	78775.46
O9	294.18	38.31	8.84	0.23	341.55	5.29	3477331.02	17386.66
O10	1717.36	301.85	11.21	4.11	2034.53	31.54	18606594.52	93032.97
O11	2502.68	444.85	9.29	5.83	2962.65	45.92	27103413.58	135517.07
Total	**34985.79**	**6882.40**	**385.65**	**75.18**	**42329.01**	**656.10**	**373578263.34**	**1867891.32**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**1128.57**	**222.01**	**12.44**	**2.43**	**1365.45**	**21.16**	**12050911.72**	**60254.56**

3.2.3.6. Embodied carbon dioxide from construction and demolition waste disposal

Building waste can account for 80–90 percent of the weight of building materials during the construction phase, according to (Jie et al., 2011; Zhang and Wang, 2015).

Assuming that the materials were transported via vehicle based, the carbon dioxide emissions generated in the waste disposal process can be calculated as in Eq. 10:

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

Where:

Cew stands for the embodied carbon of waste disposal

Qw stands for the quantity of waste transported to landfills

Qrw stands for the quantity of recyclable materials to landfills

Qr stands for the quantity of recyclable materials to recycling sites

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

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

EFt stands for the emission factor due to waste transportation

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

EFr stands for the emission factor of recyclable materials

The weight of waste materials is estimated to be 85 percent of the total weight of building materials in this study. Other wastes are disposed in disposal sites and landfills, and aluminium and steel reinforcing are considered recycled resources. The distance traveled to transfer recyclable material for the recycling process was 10 kilometers, while the distance to the disposal location was 25 kilometers. Construction and demolition waste disposal is predicted to have produced 59.211 Mt carbon.

Table 15 Percentage changes of the carbon dioxide emissions from the recycled construction Type of Materials Percentage Changes in Carbon

Type of Materials	Percentage Changes in Carbon Emissions over the Virgin Materials
Recycled steel	-40%
Recycled aluminum	-80%

Data source: Chau et al. (2012), Purnell (2012).

Table 16 Cew in different Buildings

Building Type	Wt of material	Qw	Qr	Qrw	Eft	Efr	ε	Cew(kg CO2)	Cew(ton CO2)
R1	1106869.5	940839.11	18219.44			1.91	-0.8	19118.663	19.119
			0	1088650.1	0.25	1.69	-0.4		
R2	1141230.7	970046.10	16960.1			1.91	-0.8		
			769.167	1123501.44	0.25	1.69	-0.4	18822.073	18.822
R3	522067.3	443757.21	10047.98			1.91	-0.8		
			458.2116	511561.11	0.25	1.69	-0.4	10956.079	10.956
R4	515721.59	438363.35	9828.99			1.91	-0.8		
			269.787	505622.81	0.25	1.69	-0.4	10519.04	10.519
R5	536865.18	456335.41	11508.68			1.91	-0.8		
			406.812	524949.693	0.25	1.69	-0.4	12334.905	12.335
R6	530035.85	450530.47	11508.68			1.91	-0.8		
			406.812	518120.355	0.25	1.69	-0.4	12326.131	12.326
R7	762671.53	648270.80	32058.78			1.91	-0.8		
			720.5688	729892.185	0.25	1.69	-0.4	32945.405	32.945
R8	965648.12	820800.90	15974.57			1.91	-0.8		
			0	949673.546	0.25	1.69	-0.4	16756.778	16.757
R9	684920.38	582182.32	16485			1.91	-0.8		
			1078.768	667356.61	0.25	1.69	-0.4	18129.581	18.130
R10	1091590.1	927851.61	21198.12			1.91	-0.8		
			1078.768	1069313.24	0.25	1.69	-0.4	23229.918	23.230
R11	438838.06	373012.35	7450			1.91	-0.8		
			341.2836	431046.773	0.25	1.69	-0.4	8191.568	8.192
R12	1103863	938283.58	20805.67			1.91	-0.8		
			691.5804	1082365.78	1.25	1.69	-0.4	243286.34	243.286

Building Type	Wt of material	Qw	Qr	Qrw	Eft	Efr	ε	Cew(kg CO2)	Cew(ton CO2)
C1	3246388.2	2759429.95	99069.76	3141376.4	0.18	1.91	-0.8	31505.684	31.506
			5942.013			1.69	-0.4		
C2	2619826.6	2226852.64	146668.8	2470367.98	0.18	1.91	-0.8	42653.583	42.654
			2789.829			1.69	-0.4		
C3	3021706.3	2568450.32	172869.9	2848273.21	0.18	1.91	-0.8	49014.004	49.014
			563.2032			1.69	-0.4		
C4	26126827	22207802.60	1214247	24903634.5	0.18	1.91	-0.8	349425.53	349.426
			8944.992			1.69	-0.4		
C5	25813049	21941091.63	421084.8	25383019.2	0.18	1.91	-0.8	133753.75	133.754
			8944.992			1.69	-0.4		
C6	1298350.9	1103598.24	34221.54	1262205.26	0.18	1.91	-0.8	10930.681	10.931
			1924.075			1.69	-0.4		
C7	5673644	4822597.41	264283.6	5402758.08	0.18	1.91	-0.8	78129.698	78.130
			6602.291			1.69	-0.4		
C8	3665814.8	3115942.54	157258.5	3505631.35	0.18	1.91	-0.8	46213.033	46.213
			2924.905			1.69	-0.4		

Building Type	Wt of material	Qw	Qr	Qrw	Eft	Efr	ε	Cew(kg CO2)	Cew(ton CO2)
O1	3864393.8	3284734.75	81081.18			1.91	-0.8		
			6258.206	3777054.44	0.18	1.69	-0.4	27127.618	27.128
O2	11511350	9784647.12	285083			1.91	-0.8		
			3687.86	11222578.7	0.18	1.69	-0.4	85947.068	85.947
O3	6032573.1	5127687.13	146005.9			1.91	-0.8		
			2945.977	5883621.23	0.18	1.69	-0.4	44572.748	44.573
O4	5429333.1	4614933.09	166015.3			1.91	-0.8		
			3963.372	5259354.34	0.18	1.69	-0.4	50105.641	50.106
O5	3783805.7	3216234.86	158986			1.91	-0.8		
			7252.533	3617567.18	0.18	1.69	-0.4	48689.906	48.690
O6	9569344.7	8133942.99	271097			1.91	-0.8		
			0	9298247.69	0.18	1.69	-0.4	79341.588	79.342
O7	2826343.2	2402391.70	81103.92			1.91	-0.8		
			2181.556	2743057.7	0.18	1.69	-0.4	24691.498	24.691
O8	5965849.6	5070972.15	231820.9			1.91	-0.8		
			24.2382	5734004.49	0.18	1.69	-0.4	66539.164	66.539
O9	1498932.7	1274092.78	15545.16			1.91	-0.8		
			1344.672	1482042.86	0.18	1.69	-0.4	5716.5973	5.717
O10	7599333.8	6459433.77	319380			1.91	-0.8		
			2451.712	7277502.14	0.18	1.69	-0.4	92385.171	92.385
O11	9410874.2	7999243.08	491420			1.91	-0.8		
			6903.624	8912550.59	0.18	1.69	-0.4	142195	142.195
Total								**1835554.4**	**1835.554**
N								**31**	**31**
Avg								**59211.433**	**59.211**

3.2.4. 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.

Table 17 EE and eCO2 coefficients of different alternative materials

Alternative Materials for wall					
Material 1:Autoclave Aerated Concrete Blocks					
Literature	EE:MJ/kg	eCO2/kg	Co2/kg	Source	Remarks
Source 1 :	0.72	0.05		(Shukla,2014)	Ref: 3.0EE, 0.24 eCO2 and 0.076CO2
Source 2 :	3.5	0.24-0.375	0.076-0.102	(Jones & hammond, 2008)	
Material 2:Concrete Blocks					
Source 1 :	0.59	0.063	0.059	(ICE,2011)	same
Material 3: Stabilized Soil Blocks (8% Cement)					
Source 1 :	0.83	0.084	0.082		same
Alternative Materials for Openings (window)					
Material 1:Timber					
Source 1 :	8.5	0.125		(Jones,2008)	Ref: 10 EE, 0.46 eCO2 and 0.45 CO2
Source 2 :	10	0.46	0.45	(ICE,2011)	

Chapter 4: CASE STUDY

The study was carried on residential, commercial and office buildings of the Kathmandu district. The research area is located in the Bagmati province. The research area is a mixed residential and commercial urban area with low rises houses and commercial buildings. Study area covers the area of 49.45 km^2.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 total population of the district is 1,740,977 in 2011.

4.1. Building and Vicinity

The study area comprises majority of residential buildings followed by commercial and institutional buildings. There were considerable of schools, colleges, shopping malls. The rate of lands transaction was increasing day by day for the building purpose.

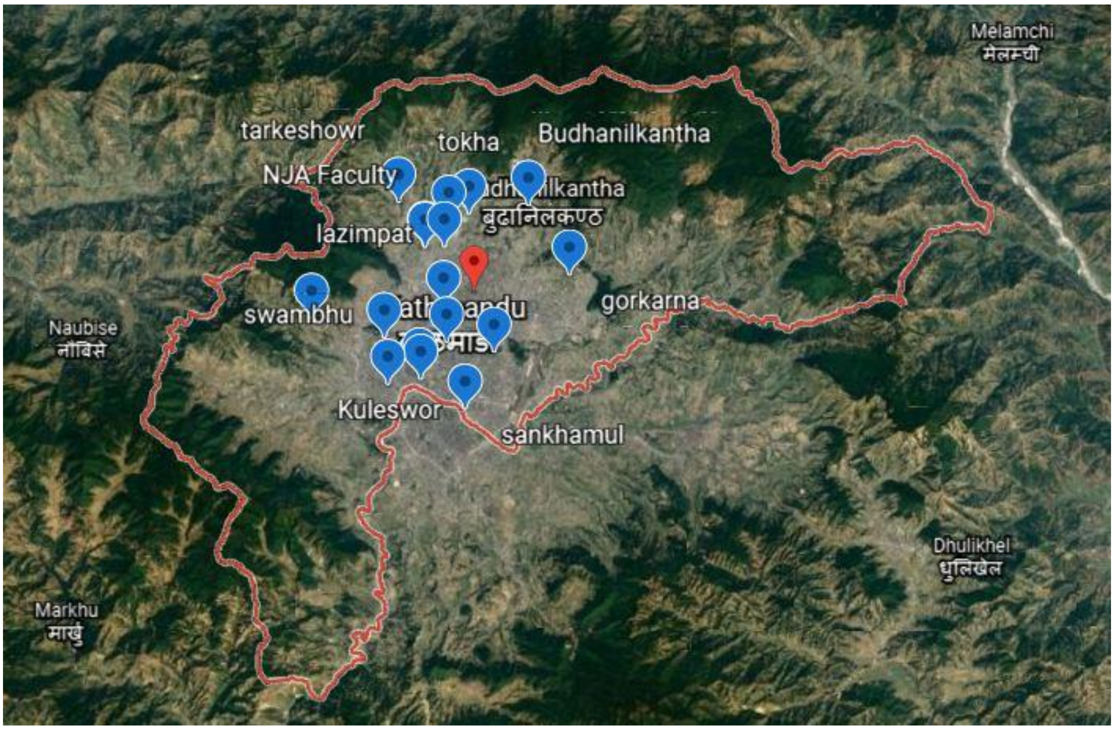


Figure 5 Google image of Kathmandu (july 2021)

4.2. Background of the Study Area

The reason for the selection of the site is the increasing built-up urban areas which increased from 5.1% of area in 1989 to about 26.06 % in 2016 as shown in the figure below (GGGI, 2016). This indicates that the built-up area is bound to increase further thus increasing the carbon emission.

Table 18 Summary of land use land cover change in the period of 1989–2016 (areas are presented

LULC Class	1989		1999		2009		2016	
	Area	%	Area	%	Area	%	Area	%
Built-up area	2153.79	5.1	4712.88	11.15	10,216.20	24.16	11,020.62	26.06
Agriculture	34,057.40	81	31,069.20	73.48	27,007.37	63.87	23,387.06	55.3
Forest	4138.56	9.8	4172.76	9.89	3627.99	8.58	6227.37	14.73
BG	1854.54	4.4	2252.7	5.34	1355.13	3.21	1576.73	3.73
River	80	0.2	76.8	0.18	74.5	0.18	73	0.17
Total	42,284.30	100	42,284.30	100	42,284.30	100	42,284.30	100

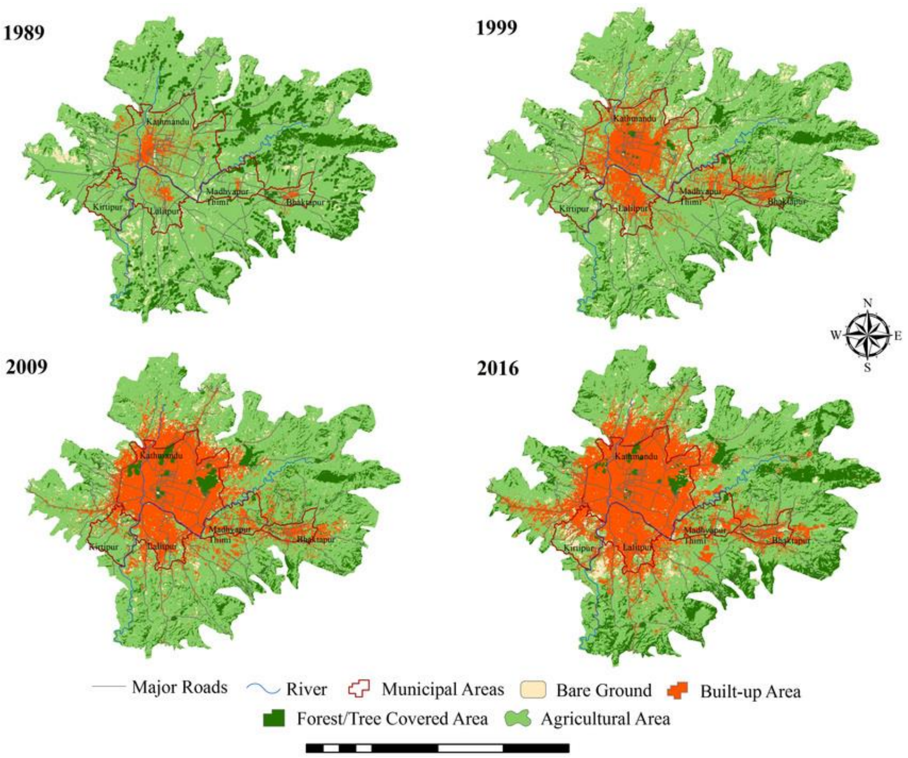


Figure 6 Land use land cover maps of Kathmandu Valley (Asif Ishtiaque et. al., 2017)

The 2011 national census (CBS 2012) reported the following for Kathmandu district:

- Out of 435544 households in Kathmandu, about 39 % lived in their own buildings while about 59% lived in rented houses.
- Of the 435544 households in Kathmandu 18.5% lived in the building with mud bonded bricks/stone, 38% lived in building with cement bonded bricks/stone, 40% lived in building with reinforced concrete (RCC) foundation, 0.5% lived in building with wooden pillar.
- 77% households are having RCC roof and 16% houses with galvanized iron roofing.
- Many houses made with mud bonded bricks/stones, reinforced concrete (RCC) foundation buildings were damaged due to 2015 earthquake in the rural part of the Kathmandu district.

4.3. Building Materials used and Construction Technology

4.3.1. Building Materials

Brick is the most common building construction material having high EE and EC evolving potential. Brick is followed by sand and aggregate for RCC and timbers for the openings of building. Majority of the bricks used for the construction purpose in Kathmandu are originated in Bhaktapur district and few houses used bricks from Terai. The percentage share of 5 major construction materials brick, aggregate, cement, rebar and timber is 13.5%, 23.8%, 14.3%, 3.33% and 0.2% respectively in RCC construction.

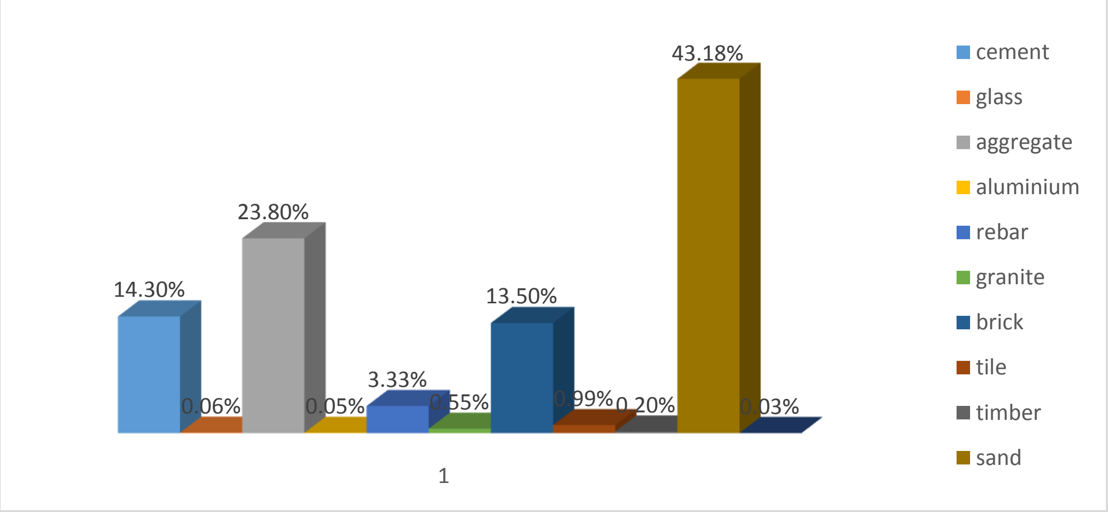


Figure 7 shares of construction material

Most of the houses in the study area used timber as primary opening material which is 12.9% of the selected buildings whereas 87.1% of the buildings used aluminium in their opening. Detail of the construction material used in the buildings have been showed in preceding chapter.

Chapter 5: DATA ANALYSIS, RESULTS AND DISCUSSION

This chapter deals with overall findings and analysis in response to research questions. Data collected from the field are thoroughly studied, entered in excel and examined for errors.

5.1.Materials used and EE, EC and CO2 e Estimation

In this, data collected from the site are first stored in MS-excel based worksheet. The quantity included in the BOQ of distinct buildings is used to do detailed material estimation, which is followed by mass analysis and then the Embodied Energy, Embodied Carbon, and Embodied Carbon dioxide equivalent analysis. Embodied Energy, Embodied Carbon and Embodied Carbon dioxide equivalent of each construction materials is found out. After that, Embodied Energy, Embodied Carbon and Embodied Carbon dioxide equivalent due to chemical reaction from cement production is found out. Then, the Embodied Energy, Embodied Carbon and Embodied Carbon dioxide equivalent due to transportation of construction materials to the site is found out. Followed by the calculation of embodied energy, embodied carbon and embodied carbon dioxide equivalent due to waste production and labor activities (site activities) is done. Lastly, embodied energy, embodied carbon and embodied carbon dioxide equivalent due to building maintenance and building demolition is calculated. The total embodied energy, embodied carbon and/or carbon dioxide equivalent is obtained by adding the embodied energy, embodied carbon and/or embodied carbon dioxide equivalent due to mass, chemical reaction, material transportation, waste and labor activities (site activities), building maintenance and building demolition activities. The findings are then analysed and the result are discussed.

Step 1: Material Analysis

All surveyed buildings were grouped and given a code as R, R2, R3 …Rn for residential building, C1, C2, C3 …Cn for the commercial building and O1, O2, O3 …On for the office buildings. The building construction materials that were used in the construction, such as foundation, wall, openings, flooring, ceiling and roofing were identified. In this study, sanitary and electrical works have been intentionally discarded due to the complexity of the work. The key construction material used in foundation was aggregate, sand, OPC cement, rebars.

All the selected buildings had a bricks wall. The material constituted of bricks and mortar of PPC cement as well as plasterwork was done with PPC cement. All the concreting works were of OPC cement. All the ceilings have plaster work and all floors have PPC cement punning. Openings such as doors and windows had either wooden frame and glass shutter or aluminium and glass.

Step 2: Mass Analysis

The weight of all the construction materials was calculated in kg. The calculation of weight of construction material was done by using the BoQ of the buildings as well as the buildings drawings collected from different contractors. The mass analysis of the building shows that aggregate, brick, cement and sand were the extensively used material. Reinforcement, tile and granite were also the major constituents of building materials. Detail mass analysis of the construction materials have been attached in annex 8.

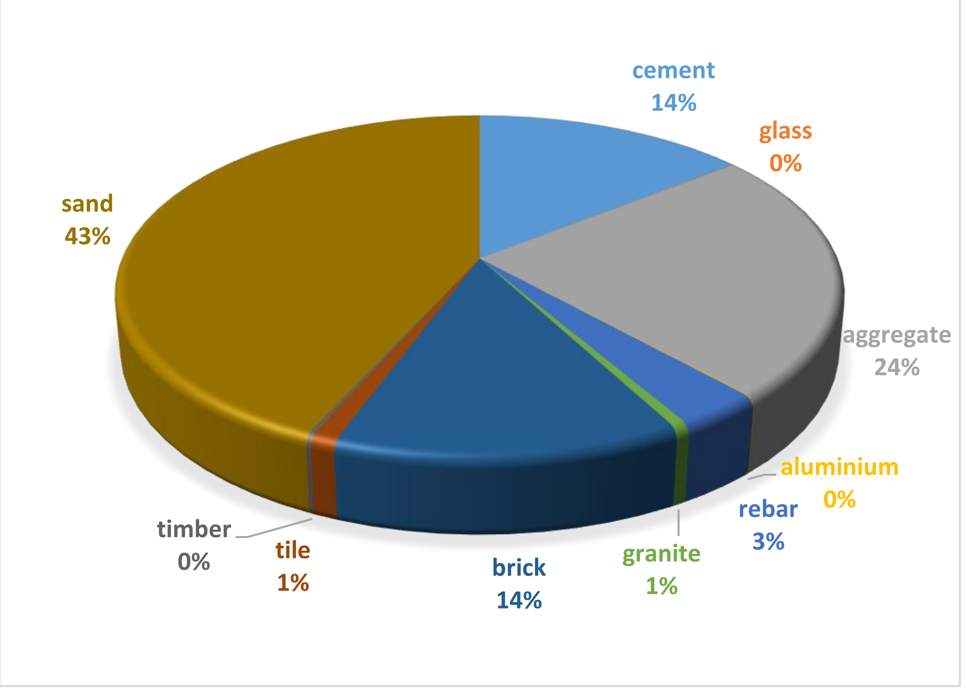


Figure 8 Building Materials proportion according to weight

Step 3: EE, EC and ECO_2e Analysis

After multiplying the mass of the construction material obtained in the previous stage by the respective coefficients, the mass was changed into EE, EC, and ECO2e. 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 ECO_2e (expressed in $kgCO_2e$) was obtained by multiplying the mass with the EC coefficient (expressed in $kgCO_2e$ /kg of material). The figures were taken from the Inventory of Carbon and Energy V3.0 because there was no appropriate database in Nepal for embodied energy, embodied carbon, and embodied carbon dioxide equivalent Co-efficient.

5.2.EE, EC and CO_2 e Calculation

Estimation of EE, EC and CO_2 e of 31 building were calculated by using the values obtained from material estimation. The detail estimation is attached in annex 6. It was found that cement accounts for highest proportion of EC and CO_2 e contribution which is 611.89 tonCO_2 and 633.33 ton CO_2 e. Glass and paints accounts for the lowest proportion of EC and CO_2 e contribution which is 2.52 tonCO_2 and 2.67 ton CO_2 e and 3.15 tonCO_2 and 3.81 ton CO_2 e respectively.

Table 19 Construction material wise total EE and EC

Building Material	**Avg Embodied carbon**	**Avg Embodied carbon**	**Avg Embodied Energy**
	ton CO e	**tonCO_2**	**MJ**
Cement	633.33	611.89	3682649.515
Aggregate	5.92	5.47	94563.54149
Reinforcement	324.10	304.94	3991361.632
Brick	154.79	148.34	1934850.533
Tile	9.89	9.04	156846.9706
Sal Wood	3.87	4.34	94350.88946
Aluminium	24.19	21.76	409359.0395
Paints	3.81	3.15	91601.69973
Glass	2.67	2.52	44009.94118
Granite	18.72	17.11	294095.859

From the detail analysis, it was found that, cement contribute highest share of EC in term of weight (54.21%). Followed by reinforcement which is 27% of total emission. After that, brick contribute third highest share of EC in term of weight (13.1%).Though other construction materials contributes the negligible share which is less than 1%.

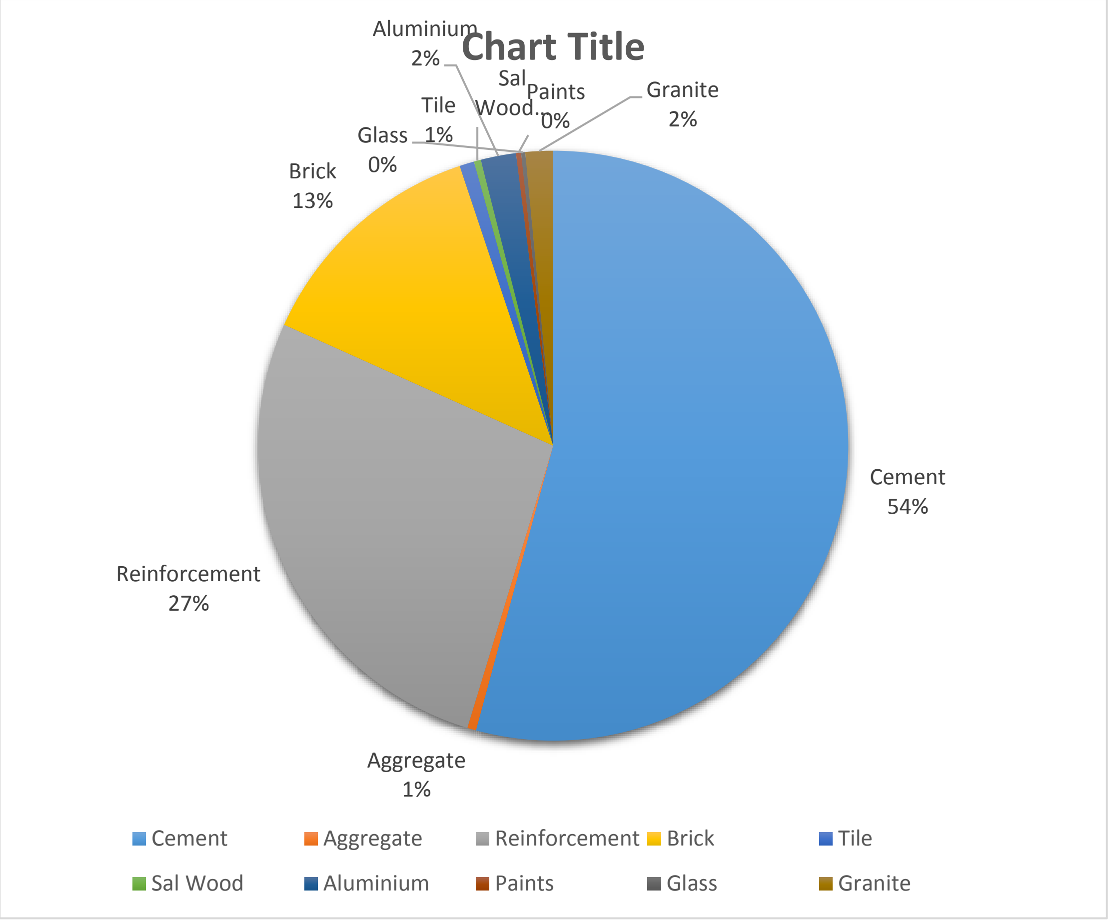


Figure 9 EC contribution of construction material by weight

If we consider EE of the construction materials reinforcement comes at the first rank and cement comes at the second place contributing 36.9% and 34.12% respectively. 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.

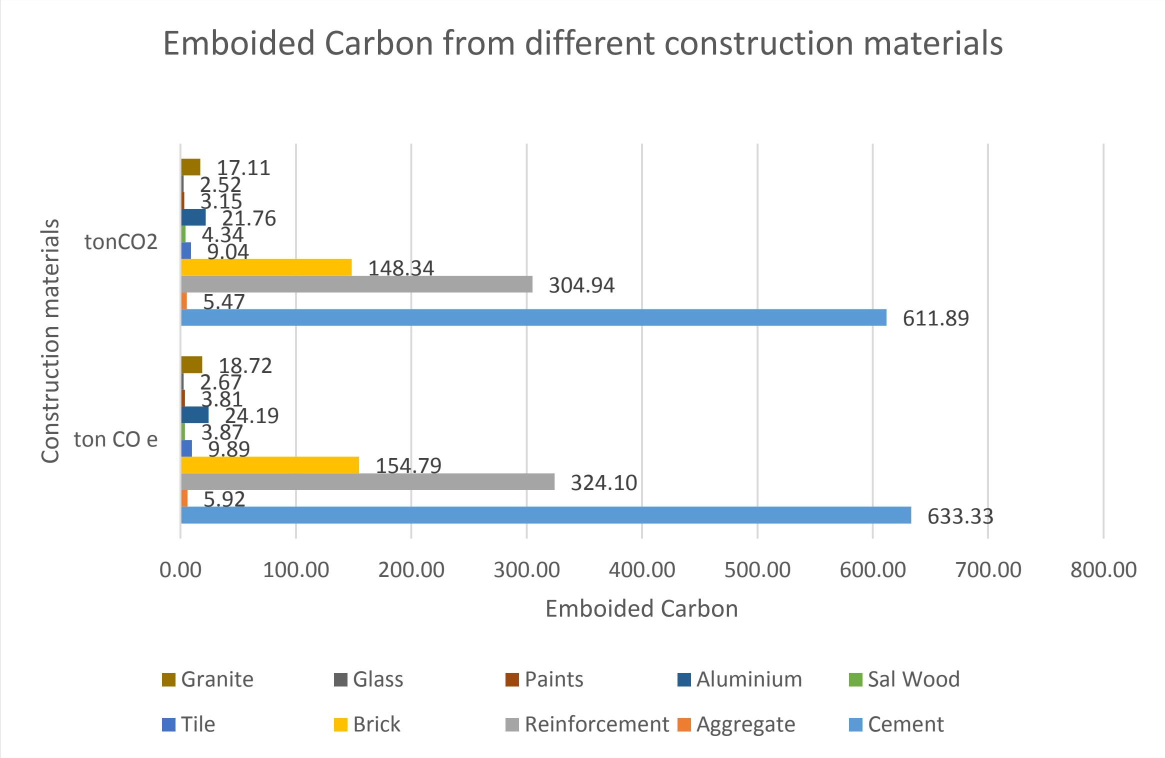


Figure 10 Material wise share of EC and carbon equivalent emission

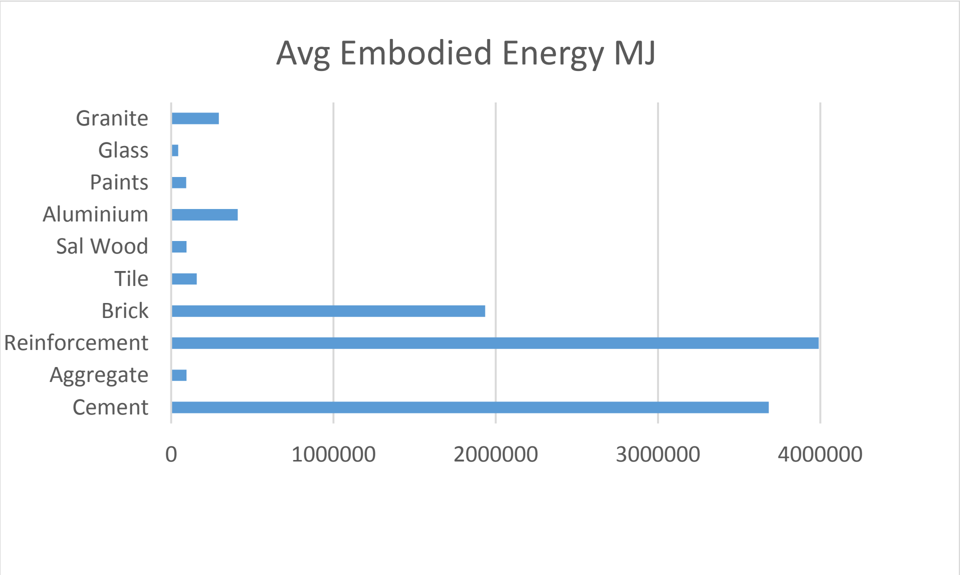


Figure 11 Material wise share of EE

5.3. Alternative Material Analysis

Different types of alternative construction material are available in the market. Among them, some of the construction materials were selected like AAC blocks in place of the bricks and same as hollow concrete blocks in place of the bricks. At first, total 31 buildings brick work was replaced by the AAC block and further analysis was carried out. After that, Bricks works was replaced by hollow concrete blocks and same process was repeated.

5.3.1. Analysis from alternate materials

Total 31 buildings were selected and firstly brickwork was replaced by AAC block and secondly replaced by hollow concrete block then detail analysis was done. The detail calculation of the buildings is presented in the tables below;

Table 20 Total EC after replacing brick work by AAC blocks

Building Type	Cmm=kg CO2	Cep(ton CO2)	Cec(ton CO2)	Cet(ton CO2)	Cer(ton CO2)	Cew(ton CO2)	Cemb
R1	180.09	35.57	1.99	0.75	3.39	19.08	**240.86**
R2	197.39	33.71	2.73	0.94	3.64	18.78	**257.18**
R3	92.79	16.39	2.76	0.45	1.74	10.94	**125.08**
R4	89.40	16.73	3.47	0.43	1.71	10.50	**122.24**
R5	94.55	16.42	3.13	0.45	1.78	12.32	**128.63**
R6	94.38	16.19	2.78	0.45	1.76	12.31	**127.87**
R7	161.56	24.79	5.42	0.35	2.98	32.92	**228.01**
R8	169.73	27.91	7.80	0.20	3.19	16.72	**225.55**
R9	123.22	26.84	3.18	0.05	2.38	18.11	**173.79**
R10	204.41	32.34	9.07	0.28	3.81	23.20	**273.12**
R11	70.05	12.19	9.63	0.08	1.43	8.17	**101.54**
R12	186.78	36.08	3.28	0.20	3.51	243.10	**472.94**
C1	748.51	158.79	14.80	1.83	14.32	31.47	**969.72**
C2	716.46	135.76	17.59	1.46	13.50	42.62	**927.40**
C3	799.61	146.35	17.86	1.62	14.96	48.97	**1029.38**
C4	6750.95	1364.78	25.74	14.60	126.42	349.11	**8631.59**
C5	5332.68	1413.50	33.82	14.43	105.31	133.54	**7033.28**
C6	341.33	48.24	19.57	0.55	6.35	10.91	**426.96**
C7	1285.25	188.02	14.45	2.77	23.10	78.03	**1591.62**
C8	806.09	159.49	33.79	2.11	15.52	46.17	**1063.17**
O1	745.82	133.84	16.09	1.86	13.91	27.08	**938.60**
O2	2364.60	583.33	19.85	6.16	46.10	85.77	**3105.80**
O3	1265.65	265.44	21.89	3.51	24.13	44.49	**1625.11**
O4	1203.74	252.25	12.15	2.77	22.80	50.04	**1543.75**

O5	834.84	155.45	13.69	1.13	15.58	48.67	**1069.35**
O6	1864.61	440.75	17.41	1.93	36.03	79.09	**2439.82**
O7	567.35	90.76	13.34	0.49	10.42	24.64	**707.00**
O8	1307.84	265.48	9.02	1.10	24.54	66.39	**1674.36**
O9	255.70	38.31	8.84	0.20	4.70	5.68	**313.42**
O10	1621.10	301.85	11.21	4.05	30.04	92.30	**2060.54**
O11	2409.82	444.85	9.29	5.77	44.48	142.11	**3056.32**
Total	**28855.38**	**6135.71**	**365.15**	**63.12**	**549.00**	**1833.21**	**42684.02**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**930.82**	**197.93**	**11.78**	**2.04**	**17.71**	**59.14**	**1376.90**

Table 21 Total EE after brickwork replaced by AAC Block

Building Type	EE due to Cmm	EE due to Cep	EE due to Cec	EE due to Cet	EE due to Cer	EE due to Cew	Total EE
R1	1944742.07	192121.055	9490.128	374.4	10733.64	107873.06	**2265334.4**
R2	2224909.3	182041.93	13500.32	416.4	12104.34	121648.61	**2554620.9**
R3	1046752.17	88535.65	14010.06	416.4	5748.571	57773.143	**1213236**
R4	999675.738	90338.605	17326.99	416.4	5538.789	55664.826	**1168961.3**
R5	1052037.47	88662.175	16001.1	416.4	5785.586	58145.136	**1221047.9**
R6	1056539.2	87423.28	13651.22	416.4	5790.15	58191.013	**1222011.3**
R7	1851824.84	133901.075	14454.59	466.8	10003.24	100532.53	**2111183.1**
R8	2058794.18	150763.375	24155.73	207.6	11169.6	112254.52	**2357345**
R9	1275396.28	144961.734	15389.08	177.6	7179.624	72155.216	**1515259.5**
R10	2280752.05	174646.43	24603.54	170.4	12400.86	124628.66	**2617201.9**
R11	820205.672	65833.985	26996.63	171.6	4566.039	45888.696	**963662.62**
R12	2005016.96	194851.965	17287.74	184.8	11086.71	111421.41	**2339849.6**
C1	7461244.41	857602.025	95515.17	1083.12	42077.22	422876.1	**8880398**
C2	7201701.56	733240.095	100435.1	1082.4	40182.3	403832.07	**8480473.5**
C3	8075192.49	790386.31	84590.17	1073.52	44756.21	449799.94	**9445798.6**
C4	66458527.2	7370937.07	139895.3	1292.64	369853.3	3717025.3	**78057531**
C5	45744391.7	7634045.93	206687.3	1058.88	267930.9	2692705.7	**56546821**
C6	3927443.99	260545.906	86940.78	1056.24	21379.93	214868.34	**4512235.2**
C7	13933891	1015478.61	78842.31	1046.64	75146.29	755220.24	**15859625**
C8	8096597.62	861357.193	100344.1	1257.6	45297.78	455242.72	**9560097**
O1	8127942.81	722852.025	77498.27	1094.4	44646.94	448701.72	**9422736.2**
O2	21759880	3150479.29	65980	1101.6	124887.2	1255116.4	**26357444**
O3	12656488.7	1433615.82	89613.14	1406.4	70905.62	712601.49	**14964631**
O4	11875505.1	1362334.54	48630.5	429.6	66434.5	667666.71	**14021001**
O5	8521627.5	839582.239	70582.46	349.2	47160.71	473965.11	**9953267.2**
O6	18308506.7	2380410.55	80725.4	345.6	103849.9	1043691.9	**21917530**
O7	6387681.77	490204.812	69721.09	240	34739.24	349129.35	**7331716.3**
O8	13498459.5	1433786.66	44849.51	276	74886.86	752612.93	**15804871**
O9	3046560.86	206887.52	42789.04	139.2	16481.88	165642.93	**3478501.4**
O10	16473080.8	1630220.06	49449.18	1106.4	90769.28	912231.29	**19156857**
O11	24219351.8	2402540.53	43715.68	1094.4	133333.5	1340001.8	**28140038**
Total	**324390721**	**37170588.4**	**1783672**	**20369.04**	**1816827**	**18259109**	**383441286**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**10464216.8**	**1199051.24**	**57537.79**	**657.0658**	**58607.31**	**589003.51**	**12369074**

Table 22 Total EC after replacing brickwork by hollow cement block

Building Type	**Cmm=kg CO2**	**Cep(ton CO2)**	**Cec(ton CO2)**	**Cet(ton CO2)**	**Cer(ton CO2)**	**Cew(ton CO2)**	**Cemb**
R1	185.74	35.57	1.99	0.78	3.47	19.23	**246.79**
R2	203.55	33.71	2.73	0.97	3.73	18.95	**263.64**
R3	95.18	16.39	2.76	0.46	1.78	11.00	**127.58**
R4	92.35	16.73	3.47	0.45	1.75	10.58	**125.33**
R5	97.28	16.42	3.13	0.45	1.82	12.39	**131.48**
R6	97.12	16.19	2.78	0.46	1.81	12.38	**130.73**
R7	165.65	24.79	5.42	0.37	3.04	33.03	**232.30**
R8	174.89	27.91	7.80	0.23	3.27	16.86	**230.96**
R9	126.56	26.84	3.18	0.07	2.43	18.20	**177.28**
R10	208.25	32.34	9.07	0.30	3.87	23.31	**277.14**
R11	73.82	12.19	9.63	0.10	1.48	8.27	**105.50**
R12	191.97	36.08	3.28	0.23	3.59	243.83	**478.97**
C1	759.59	158.79	14.80	1.87	14.49	31.61	**981.16**
C2	726.42	135.76	17.59	1.50	13.66	42.75	**937.68**
C3	812.18	146.35	17.86	1.68	15.16	49.13	**1042.36**
C4	6852.59	1364.78	25.74	15.02	128.00	350.37	**8736.51**
C5	5401.89	1413.50	33.82	14.72	106.39	134.40	**7104.72**
C6	346.55	48.24	19.57	0.57	6.43	10.98	**432.35**
C7	1249.00	188.02	14.45	2.90	22.54	78.42	**1555.33**
C8	819.42	159.49	33.79	2.16	15.73	46.34	**1076.93**
O1	762.19	133.84	16.09	1.93	14.17	27.28	**955.51**
O2	2421.10	583.33	19.85	6.39	46.98	86.47	**3164.13**
O3	1293.46	265.44	21.89	3.51	24.56	44.83	**1653.70**
O4	1224.16	252.25	12.15	2.86	23.12	50.30	**1564.82**
O5	841.62	155.45	13.69	1.15	15.68	48.75	**1076.35**
O6	1945.13	440.75	17.41	2.27	37.29	80.09	**2522.94**
O7	584.51	90.76	13.34	0.56	10.68	24.85	**724.71**
O8	1356.93	265.48	9.02	1.30	25.31	67.00	**1725.03**
O9	267.12	38.31	8.84	0.25	4.88	5.82	**325.22**
O10	1649.67	301.85	11.21	4.17	30.49	92.65	**2090.04**
O11	2437.39	444.85	9.29	5.89	44.91	142.45	**3084.78**
Total	**29376.23**	**6135.71**	**365.15**	**65.53**	**557.11**	**1842.53**	**43281.97**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**947.62**	**197.93**	**11.78**	**2.11**	**17.97**	**59.44**	**1396.19**

Table 23 Total EE after replacing brickwork by hollow cement block

Building Type	**EE due to Cmm**	**EE due to Cep**	**EE due to Cec**	**EE due to Cet**	**EE due to Cer**	**EE due to Cew**	**Total EE**
R1	1824181.67	192121.055	9490.128	374.4	10130.84	101814.9	**2138113**
R2	2093423.8	182041.93	13500.32	416.4	11446.91	115041.47	**2415870.8**
R3	995795.817	88535.65	14010.06	416.4	5493.79	55212.586	**1159464.3**
R4	936668.838	90338.605	17326.99	416.4	5223.754	52498.729	**1102473.3**
R5	993779.419	88662.175	16001.1	416.4	5494.295	55217.669	**1159571.1**
R6	998281.153	87423.28	13651.22	416.4	5498.86	55263.545	**1160534.5**
R7	1764542.99	133901.075	14454.59	466.8	9566.827	96146.614	**2019078.9**
R8	1948811.18	150763.375	24155.73	207.6	10619.69	106727.88	**2241285.4**
R9	1204237.16	144961.734	15389.08	177.6	6823.828	68579.47	**1440168.9**
R10	2198923.6	174646.43	24603.54	170.4	11991.72	120516.78	**2530852.5**
R11	739705.802	65833.985	26996.63	171.6	4163.54	41843.578	**878715.13**
R12	1894265.36	194851.965	17287.74	184.8	10532.95	105856.14	**2222979**
C1	7224899.91	857602.025	95515.17	1083.12	40895.5	410999.79	**8630995.5**
C2	6989330.06	733240.095	100435.1	1082.4	39120.44	393160.4	**8256368.5**
C3	7806987.69	790386.31	84590.17	1073.52	43415.19	436322.64	**9162775.5**
C4	64290681.8	7370937.07	139895.3	1292.64	359014	3608091	**75769912**
C5	44268280.8	7634045.93	206687.3	1058.88	260550.4	2618531.2	**54989154**
C6	3816072.38	260545.906	86940.78	1056.24	20823.08	209271.92	**4394710.3**
C7	13263740.3	1015478.61	78842.31	1046.64	71795.54	721545.17	**15152449**
C8	7812394.5	861357.193	100344.1	1257.6	43876.77	440961.51	**9260191.7**
O1	7778623.26	722852.025	77498.27	1094.4	42900.34	431148.41	**9054116.7**
O2	20554687.7	3150479.29	65980	1101.6	118861.2	1194555.5	**25085665**
O3	12063266.8	1433615.82	89613.14	1406.4	67939.51	682792.08	**14338634**
O4	11440102.4	1362334.54	48630.5	429.6	64257.49	645787.73	**13561542**
O5	8377020.19	839582.239	70582.46	349.2	46437.67	466698.59	**9800670.4**
O6	16591051.7	2380410.55	80725.4	345.6	95262.67	957389.79	**20105186**
O7	6021779.18	490204.812	69721.09	240	32909.73	330742.74	**6945597.5**
O8	12451443.3	1433786.66	44849.51	276	69651.78	700000.36	**14700008**
O9	2802923.81	206887.52	42789.04	139.2	15263.7	153400.16	**3221403.4**
O10	15863562.7	1630220.06	49449.18	1106.4	87721.69	881603	**18513663**
O11	23631409.4	2402540.53	43715.68	1094.4	130393.8	1310457.7	**27519611**
Total	**310640875**	**37170588.4**	**1783672**	**20369.04**	**1748078**	**17568179**	**368931760**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**10020673.4**	**1199051.24**	**57537.79**	**657.0658**	**56389.6**	**566715.45**	**11901025**

Table 24 Total EC after replacing brick work by stabilized soil blocks

Building Type	Cmm=kg CO2	Cep(ton CO2)	Cec(ton CO2)	Cet(ton CO2)	Cer(ton CO2)	Cew(ton CO2)	Cemb
R1	193.14	35.57	1.99	0.79	3.59	19.28	**254.36**
R2	211.62	33.71	2.73	0.98	3.86	19.00	**271.90**
R3	98.31	16.39	2.76	0.47	1.83	11.02	**130.78**
R4	96.22	16.73	3.47	0.46	1.81	10.60	**129.29**
R5	100.86	16.42	3.13	0.45	1.87	12.41	**135.13**
R6	100.69	16.19	2.78	0.47	1.86	12.40	**134.39**
R7	171.00	24.79	5.42	0.38	3.12	33.06	**237.78**
R8	181.64	27.91	7.80	0.23	3.37	16.90	**237.86**
R9	130.93	26.84	3.18	0.08	2.50	18.22	**181.75**
R10	213.27	32.34	9.07	0.31	3.95	23.34	**282.27**
R11	78.76	12.19	9.63	0.11	1.56	8.30	**110.55**
R12	198.77	36.08	3.28	0.24	3.69	244.04	**486.10**
C1	774.10	158.79	14.80	1.89	14.72	31.65	**995.94**
C2	739.45	135.76	17.59	1.51	13.86	42.78	**950.96**
C3	828.64	146.35	17.86	1.69	15.42	49.18	**1059.13**
C4	6985.62	1364.78	25.74	15.15	130.06	350.75	**8872.10**
C5	5492.47	1413.50	33.82	14.80	107.80	134.65	**7197.04**
C6	353.39	48.24	19.57	0.58	6.54	11.00	**439.32**
C7	1288.31	188.02	14.45	2.94	23.15	78.54	**1595.41**
C8	836.86	159.49	33.79	2.18	16.00	46.39	**1094.70**
O1	783.63	133.84	16.09	1.95	14.50	27.34	**977.35**
O2	2495.06	583.33	19.85	6.46	48.12	86.68	**3239.51**
O3	1329.86	265.44	21.89	3.51	25.12	44.93	**1690.77**
O4	1250.87	252.25	12.15	2.88	23.53	50.37	**1592.06**
O5	850.49	155.45	13.69	1.16	15.82	48.78	**1085.40**
O6	2050.52	440.75	17.41	2.37	38.92	80.39	**2630.35**
O7	606.96	90.76	13.34	0.59	11.03	24.91	**747.60**
O8	1421.18	265.48	9.02	1.36	26.30	67.18	**1790.52**
O9	282.07	38.31	8.84	0.27	5.11	5.87	**340.45**
O10	1687.08	301.85	11.21	4.21	31.07	92.76	**2128.17**
O11	2473.47	444.85	9.29	5.92	45.47	142.55	**3121.55**
Total	**30144.68**	**6135.71**	**365.15**	**66.24**	**569.03**	**1845.27**	**44140.48**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**972.41**	**197.93**	**11.78**	**2.14**	**18.36**	**59.52**	**1423.89**

Table 25 Total EE after replacing brick work by stabilized soil blocks

Building Type	EE due to Cmm	EE due to Cep	EE due to Cec	EE due to Cet	EE due to Cer	EE due to Cew	Total EE
R1	1900486.52	192121.055	9490.128	374.4	10512.36	105649.22	**2218633.7**
R2	2176643.34	182041.93	13500.32	416.4	11863.01	119223.25	**2503688.3**
R3	1028047.01	88535.65	14010.06	416.4	5655.046	56833.208	**1193497.4**
R4	976547.041	90338.605	17326.99	416.4	5423.145	54502.609	**1144554.8**
R5	1030651.99	88662.175	16001.1	416.4	5678.658	57070.516	**1198480.8**
R6	1035153.72	87423.28	13651.22	416.4	5683.223	57116.392	**1199444.2**
R7	1819785.24	133901.075	14454.59	466.8	9843.039	98922.537	**2077373.3**
R8	2018421.4	150763.375	24155.73	207.6	10967.74	110225.79	**2314741.6**
R9	1249275.05	144961.734	15389.08	177.6	7049.017	70842.624	**1487695.1**
R10	2250714.3	174646.43	24603.54	170.4	12250.67	123119.27	**2585504.6**
R11	790655.622	65833.985	26996.63	171.6	4418.289	44403.806	**932479.93**
	1964362.05	194851.965	17287.74	184.8	10883.43	109378.5	**2296948.5**
C1	7374486.6	857602.025	95515.17	1083.12	41643.43	418516.52	**8788846.9**
C2	7123743.82	733240.095	100435.1	1082.4	39792.51	399914.69	**8398208.6**
C3	7976739.35	790386.31	84590.17	1073.52	44263.95	444852.66	**9341906**
C4	65662750.3	7370937.07	139895.3	1292.64	365874.4	3677037.5	**77217787**
C5	45202538	7634045.93	206687.3	1058.88	265221.7	2665477.6	**55975029**
C6	3886561.48	260545.906	86940.78	1056.24	21175.52	212814	**4469093.9**
C7	13687890.8	1015478.61	78842.31	1046.64	73916.29	742858.73	**15600033**
C8	7992271.78	861357.193	100344.1	1257.6	44776.15	450000.34	**9450007.2**
O1	7999713.91	722852.025	77498.27	1094.4	44005.79	442258.22	**9287422.6**
O2	21317475.6	3150479.29	65980	1101.6	122675.2	1232885.6	**25890597**
O3	12438727.6	1433615.82	89613.14	1406.4	69816.82	701658.99	**14734839**
O4	11715676.6	1362334.54	48630.5	429.6	65635.36	659635.33	**13852342**
O5	8468544.76	839582.239	70582.46	349.2	46895.29	471297.7	**9897251.7**
O6	17678059.9	2380410.55	80725.4	345.6	100697.7	1012012	**21252251**
O7	6253365.53	490204.812	69721.09	240	34067.66	342379.95	**7189979**
O8	13114118.7	1433786.66	44849.51	276	72965.15	733299.8	**15399296**
O9	2957126.09	206887.52	42789.04	139.2	16034.71	161148.83	**3384125.4**
O10	16249337.7	1630220.06	49449.18	1106.4	89650.57	900988.2	**18920752**
O11	24003528.7	2402540.53	43715.68	1094.4	132254.4	1329156.7	**27912290**
Total	**319343401**	**37170588.4**	**1783672**	**20369.04**	**1791590**	**18005481**	**378115101**
N	**31**	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**10301400**	**1199051.24**	**57537.79**	**657.0658**	**57793.23**	**580821.97**	**12197261**

Table 26 Comparison with alternative materials in wall and opening

Total EE	12716724.59	As Built	Total EE	12716724.59	As Built
Total EC	1444.86		Total EC	1444.86	
New EE	12369073.75	Using AAC	New EE	11901024.52	Using concrete block
New EC	1376.90		New EC	1396.19	
Reduced EE	347650.84	2.73%	Reduced EE	815700.07	6.85%
Reduced EC	67.96	4.70%	Reduced EC	48.67	3.37%

Total EE	12716724.59	As Built	Total EE	12716724.59	As Built
Total EC	1444.86		Total EC	1444.86	
New EE	13157044.06	Using aac block and aluminium	New EE	12197261.32	Using stabilized soil blocks
New EC	1417.01		New EC	1423.89	
Reduced EE	-440319.46	-3.35%	Reduced EE	519463.27	1.45%
Reduced EC	27.85	1.93%	Reduced EC	20.97	4.08%

5.3.2. Interpretation of the Findings; Using Alternative Materials

From the 3 different cases, some interesting results have derived. In this section, the result has been presented and conclusion has been made on the basis of the findings. Case 1 is the case in which the brickworks in wall is replaced by the AAC block in all 31 buildings. Case 2 is the case in which the brickworks in wall is replaced by the hollow cement concrete block in all 31 buildings. Similarly, case 3 is the case in which the brickworks in wall is replaced by the AAC block and the openings was replaced by aluminium in all 31 buildings. The result found due to alternative materials replacement has been elaborated below;

Case 1 ; In this case**,** AAC blocks was used as alternative material in the wall replacing traditional bricks to check EE and EC performance. The result summarized in the chart below shows that EE is reduced by 2.73% and EC is decreased by 4.7% when brick is replaced by AAC block.

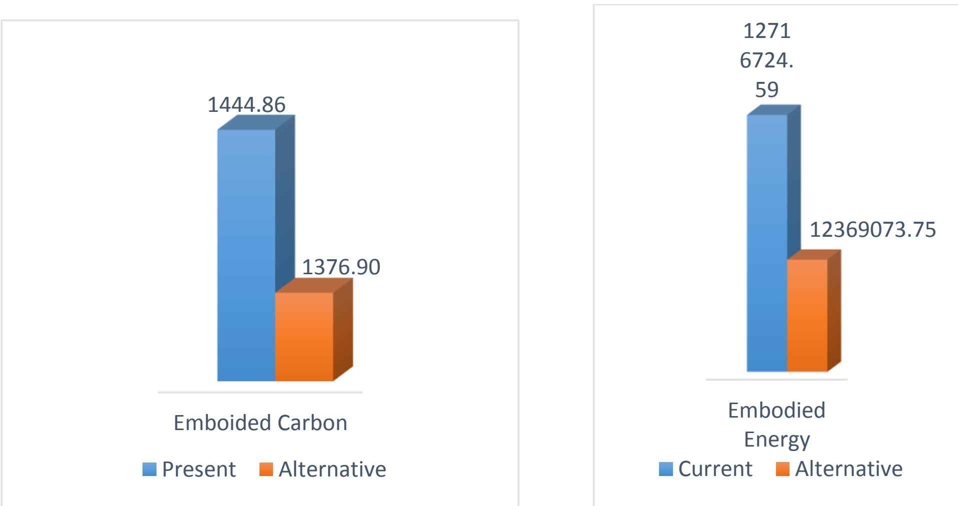


Figure 12Comparision of current building materials and AAC alternative materials

Case 2 ; In this case**,** hollow cement concrete blocks was used as alternative material in the wall replacing traditional bricks to check EE and EC performance. The result summarized in the chart below shows that EE is reduced by 6.85% and EC is decreased by 3.37% when brick is replaced by Cement concrete block.

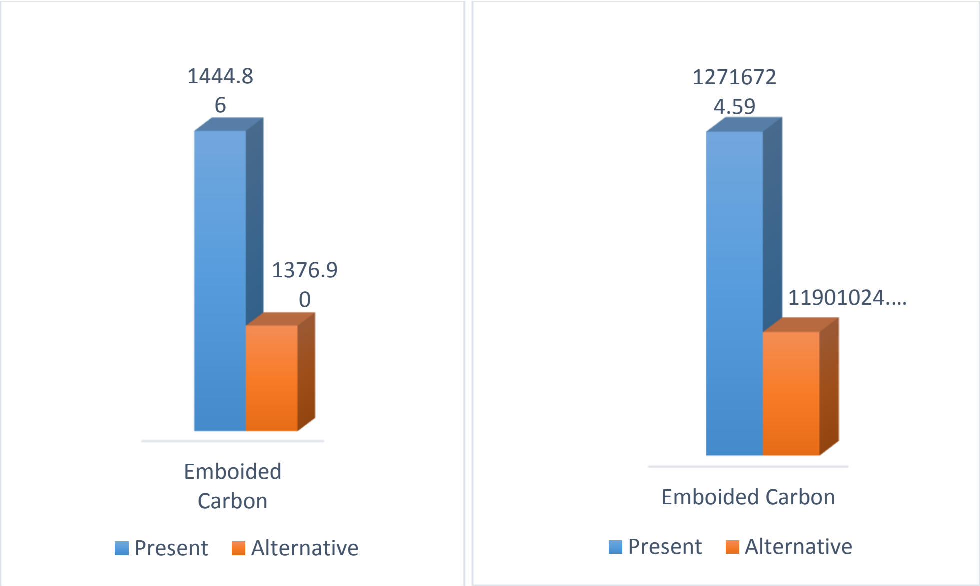


Figure 13 Comparison of current building material with concrete block alternative material

Case 3 ; In this case**,** AAC blocks and aluminium were used as alternative materials in the wall replaced traditional bricks and whereas, aluminium being widely used as opening materials was replaced for timber as openings in the wall to check EE and EC performance. The result summarized in the chart below shows that EE is increased by 3.35% and EC is decreased by 1.93% when brick is replaced by ACC block replaced bricks and aluminium replaced timber.

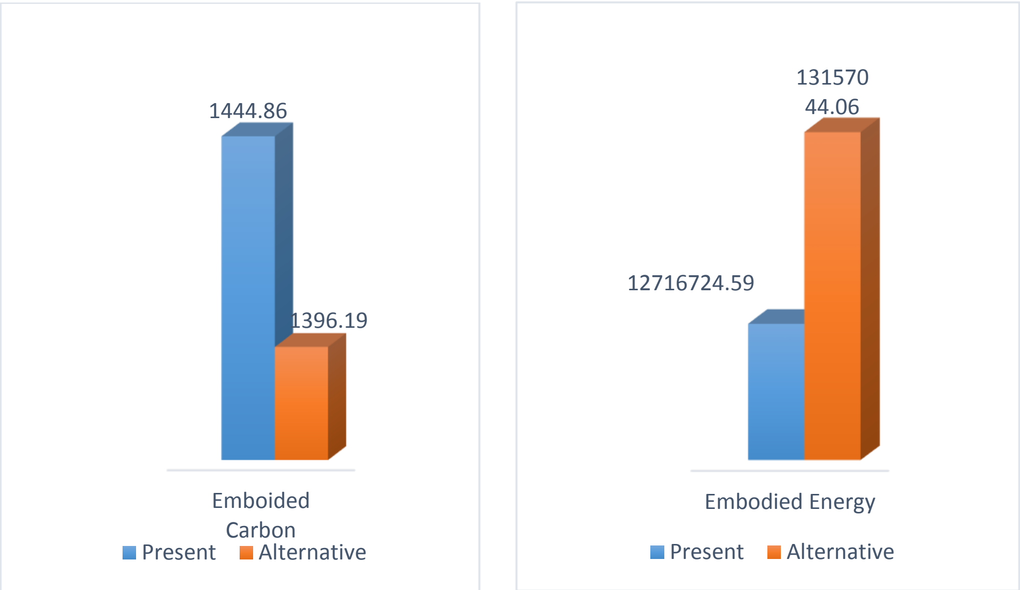
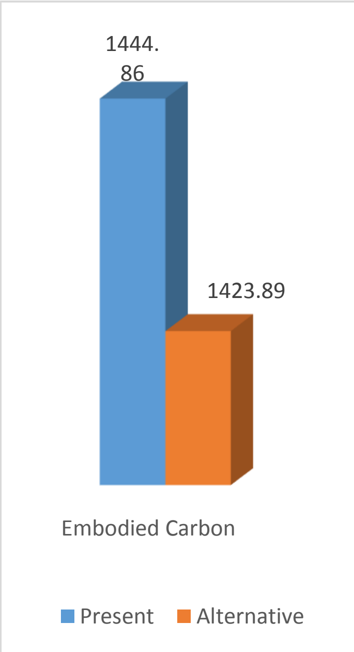


Figure 14 Comparison of current building materials and AAC , Aluminium alternative material

Case 4 ; In this case**,** stabilized soil blocks was used as alternative material in the wall replacing traditional bricks to check EE and EC performance. The result summarized in the chart below shows that EE is reduced by 1.45% and EC is decreased by 4.08% when brick is replaced by stabilized soil block.



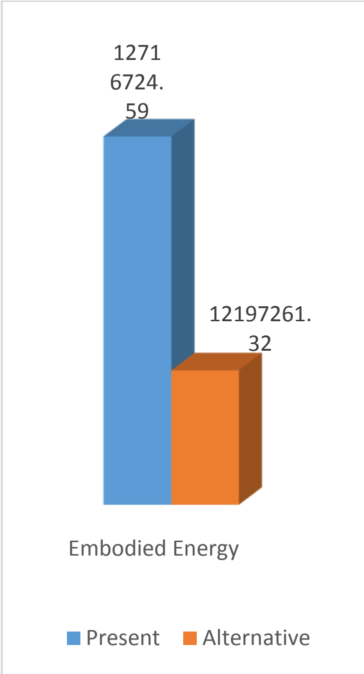


Figure 15 Comparison of current building materials and Stabilized earth block alternative material

5.3.3. Interpretation of EC and EE of different reconstruction model of earthquake resistance houses

Three different design model of the houses namely: brick masonry structure, steel structure and timber structure were taken from the design catalogue for reconstruction of earthquake resistance houses, approved by Nepal Government, Ministry of Urban Development for the estimation of the EE and EC. For the calculation portion all three model are chosen of two storey. The drawing and the quantity estimation was included in the ANNEX portion. The following tables shows the summary of EE and EC from three different models.

Table 27 Comparison of EE and EC of different reconstruction model houses

Building Type	Total EC (ton CO2)	Total EE (MJ)
Steel Structure	307.140	5742322.953
Brick Masonry	19.673	249386.126
Timber Structure	297.505	5726061.473

5.3.4. Summary of the findings

Reinforcement accounts highest share of EE (36.9%) followed by cement (34.12%), brick (17.92%) aluminium (3.79%), Granite (2.75%), tile (1.45%) contribution. In case of EC, cement has highest share of eCO_2 (53.61%) followed by reinforcement (27.44%), brick (13.1%) contribution.

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 is 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.

When a wall materials 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 materials 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.

Similarly, when a wall materials of the building is replaced by stabilized earth block, total carbon emission and total embodied energy of the building is reduced by 4.08 % and 1.45 % 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%.

5.3.5. Discussion and Data Validation

We gained some insight into embodied carbon emissions, embodied energy from various building construction materials, and the impact of alternative construction materials on reducing embodied carbon in the building industry across its whole life cycle as a result of this research. According to our research, the building's total embodied carbon emissions during its entire life cycle are 1444.86 Mt. Buildings produce 1421.70 Mt CO2- 1599.6216 Mt CO2, according to a study published by

Weina Zhu et al. in 2020. This finding is relevant to the research and comes within the scope of Weina Zhu et al.

Buildings produce 2084 tonnes CO2-e, according to a 2014 study by Wahidul K. Biswas. Buildings produce 2992.207 tonnes CO2 according to a study conducted by Lei Luo et al. in 2020. This discovery is directly related to the study and fits within the scope of Wahidul K. Biswas and Lei Luo et al.

According to this study, using alternative building construction materials such as AAC blocks and hollow cement concrete blocks in walls can cut carbon emissions by 4.7 percent and 3.37 percent, respectively, while reducing embodied energy by 2.73 percent and 6.85 percent. According to a 2017 study by Akbarnezhad & Xiao, using wood in building construction alone reduces carbon dioxide emissions by 20 percent, accounting for 1.5 percent of New Zealand's total carbon dioxide emissions.

Chapter 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

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

- The primary construction materials utilized in building construction include cement, sand, aggregate, brick, steel reinforcement, and timber. RCC roof construction accounts for 77 percent of all residences in Kathmandu (CBS 2012).
- Shares of the construction material by weight in building construction; Cement: 14%, Sand: 43%, aggregate 24%, brick: 14%, steel reinforcement: 3%, granite: 1%, tile: 1% and timber, aluminium, glass shares less than 1%.
- The data shows that the building sector in Kathmandu emits 1444.86 tonnes of embodied carbon and 12716724.59 MJ of embodied energy.
- According to the detailed study, there are a variety of alternative building materials that can lower carbon and energy footprints. The study looked at alternate materials such as AAC blocks, stabilized earth block and hollow cement concrete blocks for the wall, as well as aluminum for the apertures. According to the study, 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. Similarly, replacing wall with stabilized earth blocks resulted in a 4.08 percent reduction in carbon and a 1.45 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.

6.2. Recommendation

The study has following recommendation are as follows:

- ➢ Only civil construction materials such as cement, sand, aggregate, wood, steel reinforcement, brick, tiles, granite, glass, paints, aluminum, and other similar materials are considered, while electrical fixtures and sanitary and plumbing fixtures are not. The inclusion of electrical, sanitary, and plumbing components in the analysis broadens 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.

Chapter 7: REFERENCES

Akbarnezhad, A., & Xiao, J . (2017). Estimation and Minimization of Embodied Carbon of buildings: A Review. Buildings/MDPI,2-24.

Ali Akbarnezhad and Jianzhuang Xiao, 2017.Estimation and Minimization of Embodied Carbon of Buildings: A Review. Buildings.

Arena AP, de Rosa C. Life cycle assessment of energy and environmental implications of the implementation of conservation technologies in school buildings in Mendoza–Argentina. Building and Environment 2003;38:359–68.

Arıoğlu Akan, M.Ö., Dhavale, D.G., Sarkis, J., 2017. Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. Journal of Cleaner Production 167, 1195-1207.

Asif Ishtiaque, Milan Shrestha, Netra B. Chhetri, 2017.Rapid Urban Growth in Kathmandu Valley, Nepal: Monitoring Land Use Land Cover Dynamics of a Himalayan City with Landsat Imageries.

Azari, R. 2019. Life Cycle energy Consumption of Buildings; Embodied + operational. Sustainable Construction Technologies.

Cabeza, L.F., Barreneche, C., Miró, L., Morera, J.M., Bartolí, E., Inés Fernández, A., 2013b. Low carbon and low embodied energy materials in buildings: A review. Renewable and Sustainable Energy Reviews 23, 536-542.

Chen TY, Burnett J, Chau CK. Analysis of embodied energy use in the residential building of Hong Kong. Energy 2001;26(4):323–40.

Chau, C.K., Leung, T.M., Ng, W.Y., 2015. A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings. Applied Energy 143, 395-413.

Chuai, X., Huang, X., Lu, Q., Zhang, M., Zhao, R., Lu, J., 2015. Spatiotemporal changes of built-up land expansion and carbon emissions caused by the Chinese construction industry. Environ. Sci. Technol. 49 (21), 13021e13030.

Crawford, R.H. Life Cycle Assessment in the Built Environment, Spon Press, London and New York, 2011

D'Amico, B., Pomponi, F., 2018. Accuracy and reliability: A computational tool to minimise steel mass and carbon emissions at early-stage structural design. Energy and Buildings 168, 236-250.

Department of Environmental Affairs and Tourism (DEAT), 'Green Building in South Africa: Emerging Trends', 2009, pp1-21.

Dimoudi A, Tompa C. Energy and environmental indicators related to construction of office buildings. Resources, Conservation and Recycling 2008;53(1–2): 86–95.

Ding, G., 2004. 'The Development of a Multi-Criteria Approach for the Measurement of Sustainable Performance for Built Projects and Facilities', Doctor of Philosophy Thesis. University of Technology, Sydney.

Ding, G., 2008. Sustainable construction-The role of environmental assessment tools. J. Environ. Manag. 86 (3), 451e464.

Ding, G., 2014. Life Cycle Assessment (LCA) of Sustainable Building Materials: anOverview, pp. 38e62.

Dixit, M.K., Fernandez-Solís, J.L., Lavy, S., Culp, C.H., 2010. Identification of parameters for embodied energy measurement: a literature review. Energy Build. 42 (8), 1238e1247.

Ewing, B.R., Hawkins, T.R., Wiedmann, T.O., Galli, A., Ercin, A.E., Weinzettel, J., SteenOlsen, K., 2012. Integrating ecological and water footprint accounting ina multi-regional inputeoutput framework. Ecol. Indicat. 23,1e8.

Gan, V.J.L., Cheng, J.C.P., Lo, I.M.C., Chan, C.M., 2017b. Developing a CO2-e accounting method for quantification and analysis of embodied carbon in high-rise buildings. Journal of Cleaner Production 141, 825-836.

Gerilla GP, Teknomo K, Hokao K., 2007An environmental assessment of wood and steel reinforced concrete housing construction. Building and Environment;42(7):2778–84.

Guggemos AA, Horvath A., 2005 Decision support tool for environmental analysis of commercial building structures. In: Proceedings of construction research congress: broadening perspectives.

Guo, J.e., Zhang, Z., Meng, L., 2012. China’s provincial CO2emissions embodied in international and interprovincial trade. Energy Pol. 42, 486e497.

Gustavsson L, Sathre R. Variability in energy and carbon dioxide balances of wood and concrete building materials. Building and Environment 2006;41(7): 940–51.

Gonza´lez MJ, Navarro JG., 2006 Assessment of the decrease of CO2 emissions in the construction field through the selection of materials: practical case study of three houses of low environmental impact. Building and Environment;41(7): 902–9.

Hammond, P.G., & Jones, C. (2011). The Inventory of Carbon and Ice. UK: BSRIABG.

HKEMSD, 2013. Transport - Energy Consumption Indicator. Hong Kong Electrical and Mechanical Services Department (HKEMSD), Hong Kong.

Huo, T., Cai, W., Ren, H., Feng, W., Zhu, M., Lang, N., Gao, J., 2019. China's building stock estimation and energy intensity analysis. Journal of Cleaner Production 207, 801-813. Iddon, C.R., Firth, S.K., 2013. Embodied and operational energy for new-build housing: A case study of construction methods in the UK. Energy and Buildings 67, 479-488.

ICE. (2011). The inventory of carbon and Energy (Ice). London : A joint venture of university of Bath and BSRIA

Jia Wen, T., Chin Siong, H., Noor, Z.Z., 2015. Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia. Energy and Buildings 93, 295-302.

Jing Bingbing, L.X., Chen Su, Liu Chen and Xiong Zhenghui, 2019. Structure Type and Function of Building-Based Building Classification and Its Application. Technology for Earthquake Disaster Prevention 14(2), 293-303.

Koroneos, C and Dompros, A. Environmental assessment of brick production in Greece, Journal of Building and Environment, Vol.42, 2007, pp2114–2123.

Levine, M., Urge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Land, S., Levermore, G., Mongameli Mehlwana, A., Mirasgedis, S., Novikova, A., Rlling, J., Yoshino, H., 2007, Residential and commercial buildings, Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, U.K. & New York, NY, U.S.A.

Liu, B., Zhang, L., Liu, C., Wang, D., Sun, J., Luther, M., Xu, Y., 2019. Measuring energy poverty based on energy embodied in exports of vertical specialisation trade in

the construction sector. Energy Build. 196, 157e168.

Li, X., Yang, F., Zhu, Y., Gao, Y., 2014. An assessment framework for analyzing the embodied carbon impacts of residential buildings in China. Energy and Buildings 85, 400-409.

Maunder, S. E. 1992. Dictionary of Global Climate Change. London: UCL Press Limited.

McKinsey and Company, 2009."Pathways to a low-carbon economy. Version 2 of the Global Greenhouse Gas Abatement Cost Curve," .

Mitigation, 2011"IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation," .

Morel. JC, Mesbah A, Oggero M and Walker P,2011. "Building houses with local materials: Means to drastically reduce the environmental impact of construction.," *Building and Environment* , vol. 36(10), pp. 1119-1126.

Muigai, R, Alexandra, M.G and Moyo, P. Cradle-to-gate environmental impacts of the concrete industry in South Africa, Journal of the South African Institution of Civil Engineering, Vol.55, 2013, No.2, pp2-7.

Palm, V., Wood, R., Berglund, M., Dawkins, E., Finnveden, G., Schmidt, S., Steinbach, N., 2019. Environmental pressures from Swedish consumptioneA hybrid multi-regional input-output approach. J. Clean. Prod. 228, 634e644.

Pommer K, Pade C., 2006, Guidelines – uptake of carbon dioxide in the life cycle inventory of concrete. Nordic Innovation Centre.

Pomponi, F., Moncaster, A., 2018. Scrutinising embodied carbon in buildings: The next performance gap made manifest. Renewable and Sustainable Energy Reviews 81, 2431-2442.

Purnell, P., 2012. Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements. Environmental Science & Technology 46(1), 454-461.

Ramesh, T., Prakash, R., Shukla, K., 2010. Life cycle energy analysis of buildings: an overview. Energy Build. 42 (10), 1592e1600.

Ramseur, J.L. 2010. Cap and Trade : The Kyoto Protocol, Greenhouse Gas (GHG) Emissions, Carbon Tax, emission Allowances,Acid rain SO2 Program, Ozone Transport Comission. Carbon Markets and Climate Change. TheCaoitol.Net.

Säynäjoki, A., Heinonen J., Junnila, S., 2012. A Scenario Analysis of the Life Cycle Greenhouse Gas Emissions of a New Residential Area.Environmental Research Letters 7(3).

Seo S, Hwang Y. Estimation of CO2 emissions in life cycle of residential buildings. Journal of Construction Engineering and Management 2001;127(5):414–8.

Shukla, R. (2014). Burnt clay Bricks Versus Autoclaved Aerated Concrete Blocks: A Comparative Analysis. International Journal of Engineering Research & Technology (IJERT),575-580.

Smart Consulting.2019. Carbon Smart Materials Palette. Retrieved August 23,2019, from Materials Palette : https://materialspalette.org/palette/

SuzukiM,OkaT,OkadaK.The estimation of energy consumption and CO_2 emission due to housing construction in Japan. Energy and Buildings 1995;22:165–9.

Suzuki M, Oka T. Estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan. Energy and Buildings 1998;28:33–41.

UNEP,2009. " Summary for Decision Makers. United Nations Environment Programme," *Buildings and Climate Change* , no. www.unep.org/sbci/pdfs/sbci-bccsummary.pdf (Accessed on 4 January 2015).

Wahidul K. Biswas, 2014. Carbon footprint and embodied energy consumption assassment of building construction works in Western Australia. International Journal of Sustainable Built Environment.

Wang, Y., Lai, N., Mao, G., Zuo, J., Crittenden, J., Jin, Y., Moreno-Cruz, J., 2017. Air pollutant emissions from economic sectors in China: a linkage analysis. Ecol. Indicat. 77, 250e260.

Wang, Z., Yang, Y., Wang, B., 2018. Carbon footprints and embodied CO_2transfers among provinces in China. Renew. Sustain. Energy Rev. 82, 1068e1078.

Säynäjoki, A., Heinonen J., Junnila, S., 2012. A Scenario Analysis of the Life Cycle Greenhouse Gas Emissions of a New Residential Area.Environmental Research Letters 7(3).

Seo S, Hwang Y. Estimation of CO_2 emissions in life cycle of residential buildings. Journal of Construction Engineering and Management 2001;127(5):414–8.

SuzukiM,OkaT,OkadaK.The estimation of energy consumption and CO_2 emission due to housing construction in Japan. Energy and Buildings 1995;22:165–9.

Suzuki M, Oka T. Estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan. Energy and Buildings 1998;28:33–41.

Weina Zhu, Wei Feng, Xiaodong Li, Zhihui Zhang, 2020. Analysis of the embodied carbon dioxide in the building sector: A case of China. Journal of Cleaner Production , doi: https://doi.org/10.1016/ j.jclepro.2020.122438.

Wei Junxiao, G.Y., Wang Song, 2016. Identification of factors influencing CO2 emissions estimation from Chinese cement industry and determination of their uncertainty. Acta Scientiae Cirumstantiae 36(11), 4234-4244.

You, F., Hu, D., Zhang, H., Guo, Z., Zhao, Y., Wang, B., Yuan, Y., 2011. Carbon emissions in the life cycle of urban building system in China—A case study of residential buildings. Ecological Complexity 8(2), 201-212.

Zabalza, I.B, Valero, A.C and Aranda A.U. ,2011 "Life cycle assessment of Building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement," *Build. Environ,* vol. 46 (5), pp. 1133-1140, 2011.

Zhang, X., Wang, F., 2017. Analysis of embodied carbon in the building life cycle considering the temporal perspectives of emissions: A case study in China. Energy and Buildings 155, 404-413.

Zhang, Z., Wang, B., 2016. Research on the life-cycle CO2 emission of China's construction sector. Energy and Buildings 112, 244-255.

Zhu, W., Zhang, Z., Li, X., Feng, W., Li, J., 2019. Assessing the effects of technological progress on energy efficiency in the construction industry: A case of China. Journal of Cleaner Production 238, 117908.

ANNEX

8.1. Questionnaire

1. General Information
   a. Name of Client: ____________________
      Address: __________________________
      Contact Number: ___________________

   b. Name of Contractor:_________________
      Contact Number: ___________________

2. What is the type of Building?
   a. Residential Building
   b. Commercial Building
   c. Office Building
3. What are the construction materials used in the construction of building?

a. Cement	f. Tile	k. Paints
b. Reinforcement	g. Granite	l. Gypsum Board
c. Bricks	h. Aluminium	m. AAC Block
d. Sand	i. Glass	n. CGI sheet
e. Aggregate	j. Sal Wood	

4. How far the construction materials were brought from and taken to the site?

a. Cement	_____km	h. Aluminium	_____km
b. Reinforcement	_____km	i. Glass	_____km
c. Bricks	_____km	j. Sal Wood	_____km
d. Sand	_____km	k. Paints	_____km
e. Aggregate	_____km	l. Gypsum Board	_____km
f. Tile	_____km	m. AAC Block	_____km
g. Granite	_____km	n. CGI sheet	_____km

5. What is the estimated duration of operation of loaders?
   _______ hours
6. What is the estimated duration of operation of mixture machine?

_______ hours

7. What is the estimated duration of operation of vibrator machine?

   _______ hours

8. What is the total consumption of electricity in the site?

   _______ kwhr.

9. What is the type of fuel used by the labours for cooking? Also specify the estimated quantity.

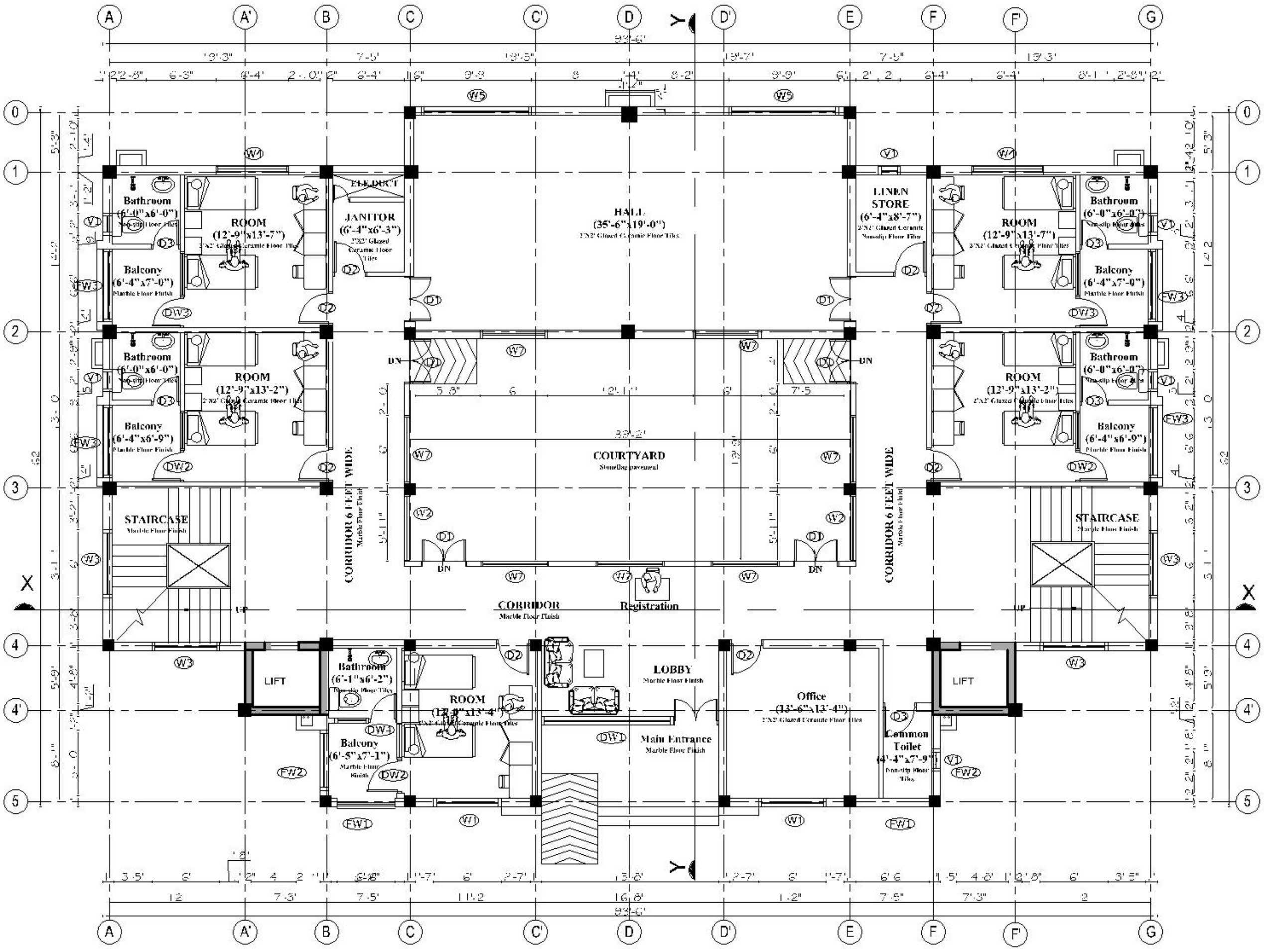
   a. LPG Gas ______ no. of cylinder

   b. Firewood _______ kg

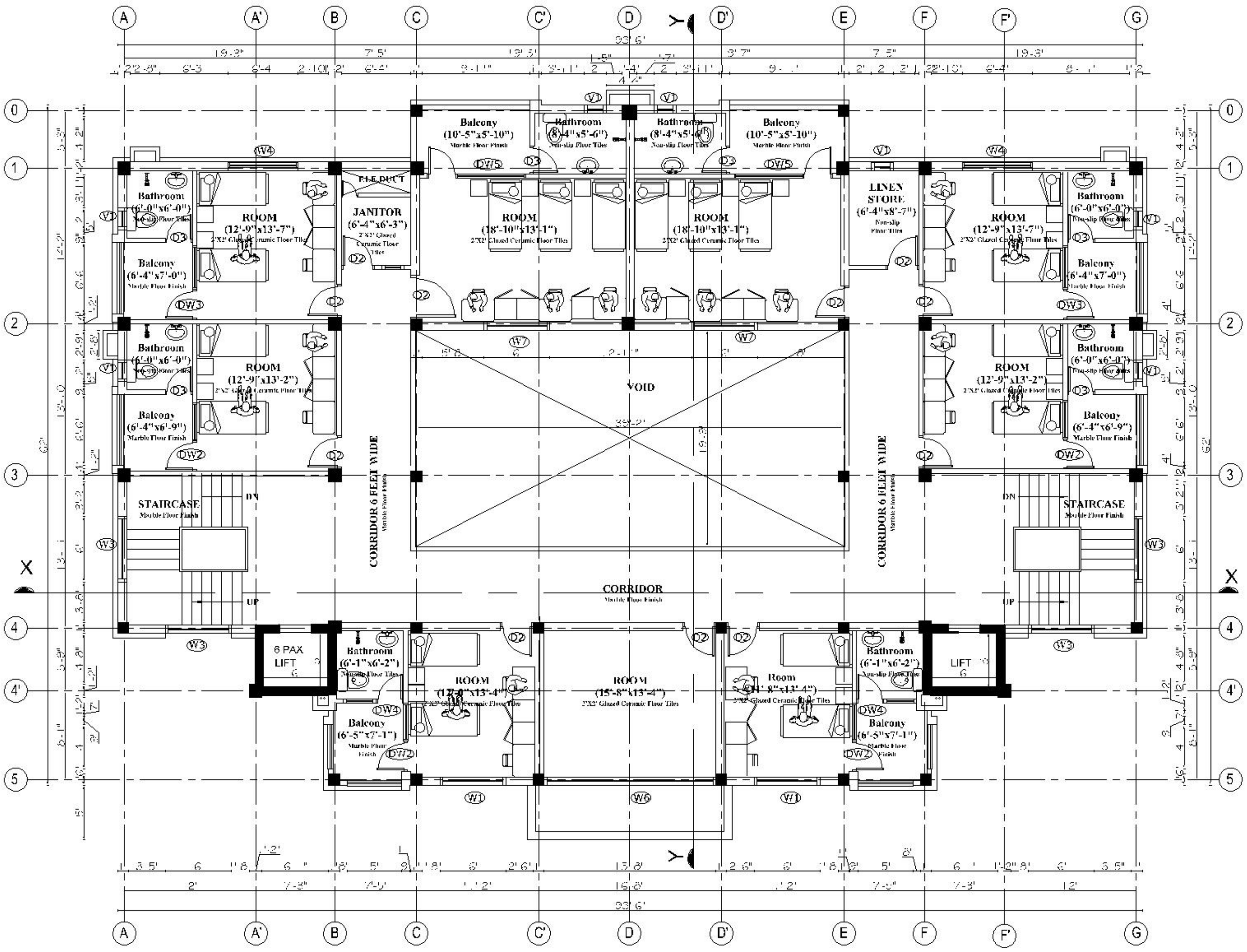
   c. Kerosene ________ liters

8.2.Drawings

8.2.1. Hostel Building, National Judicial Academy, Manamaiju, Kathmandu

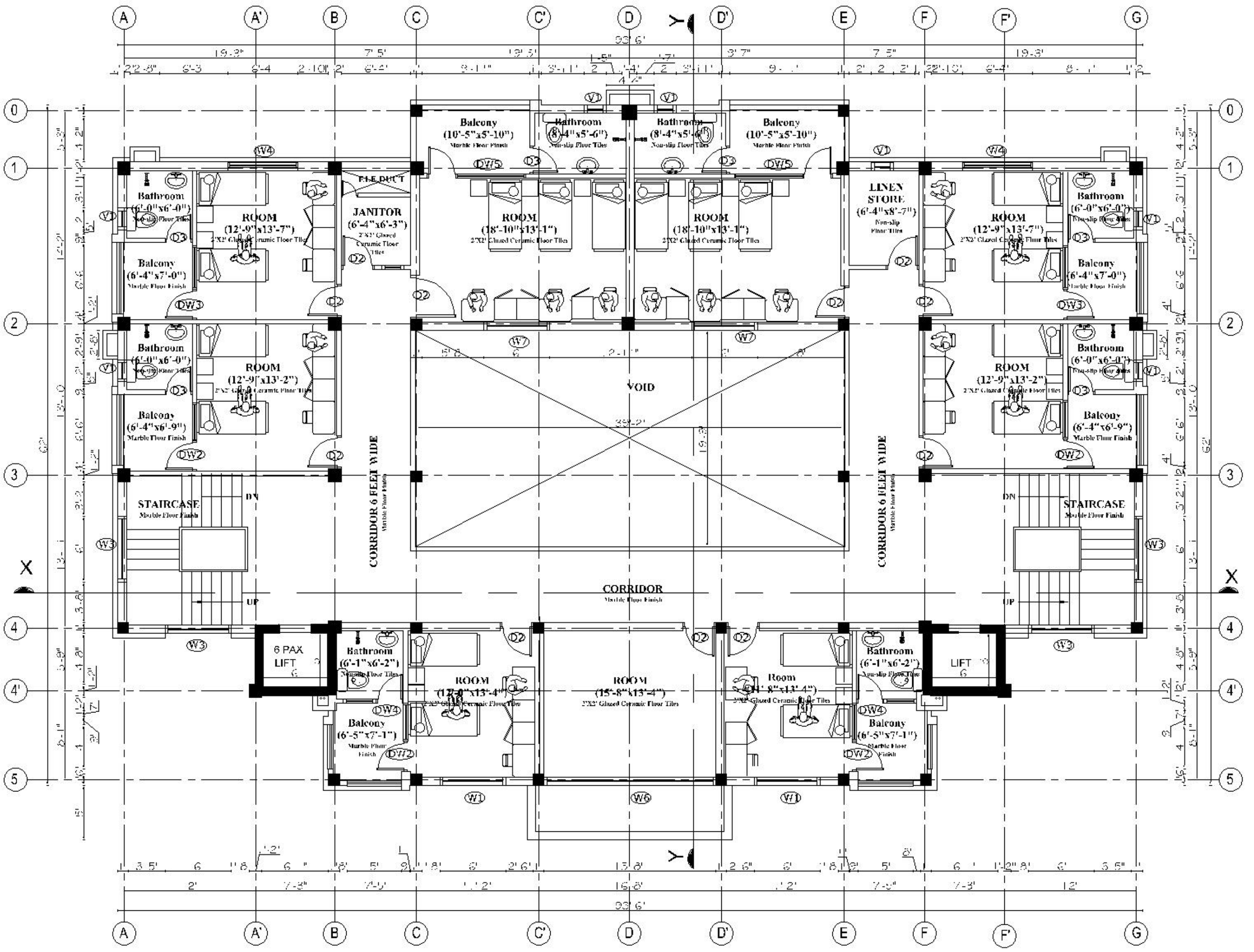


GROUND FLOOR PLAN
(AREA: 4334 Sq. Ft)



FIRST / SECOND / THIRD FLOOR PLAN

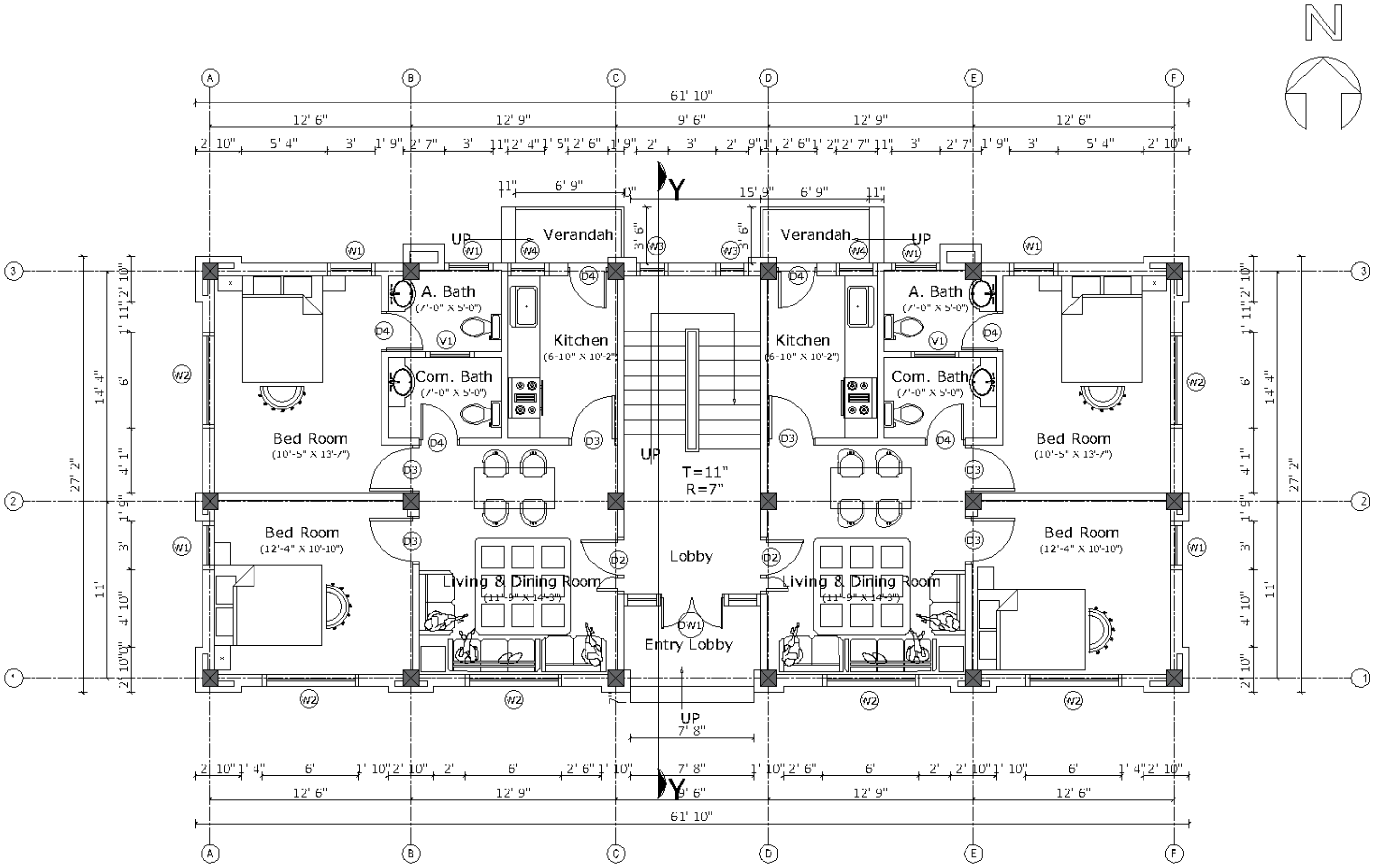
(AREA: 4334 Sq. Ft)



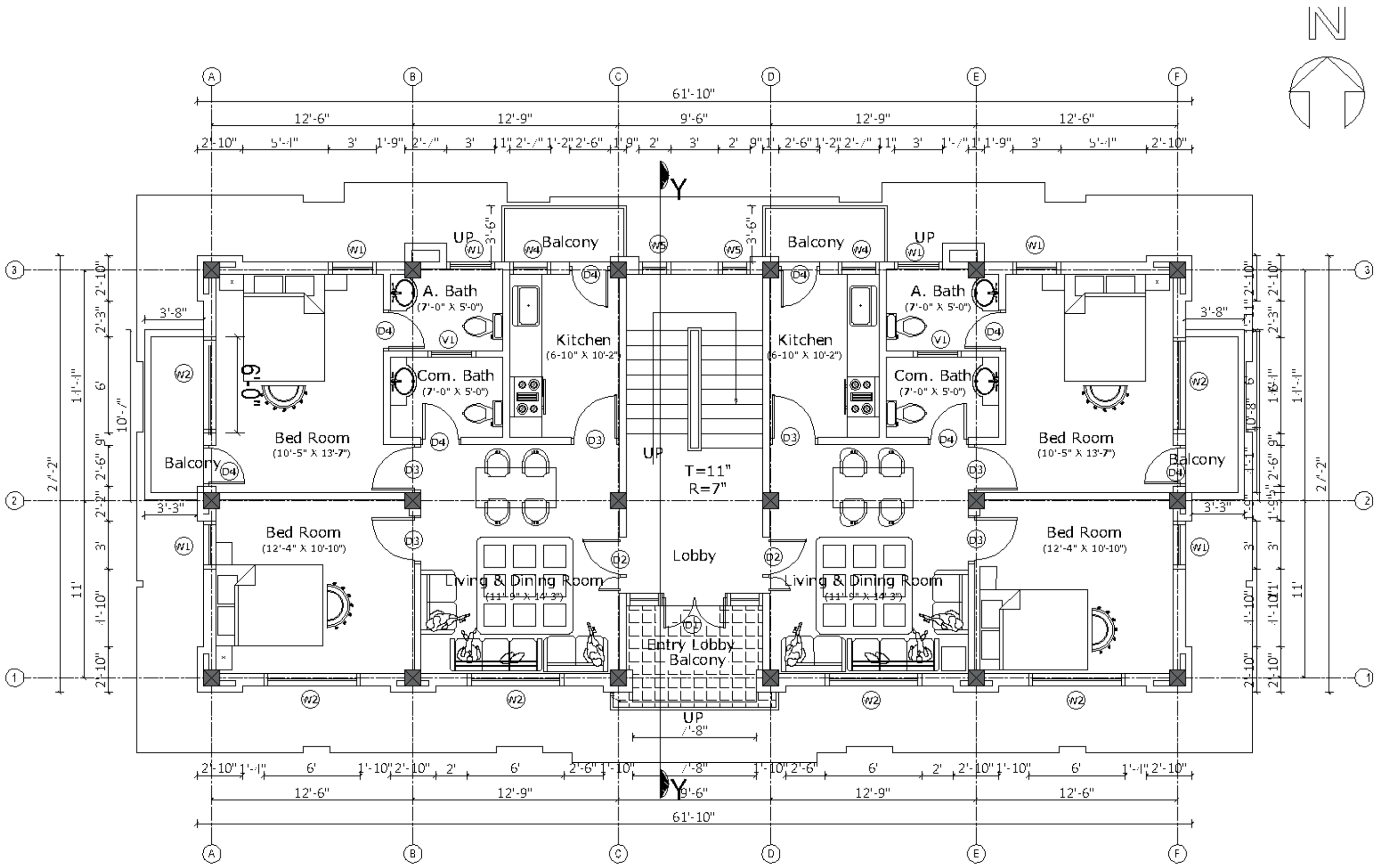
FIRST / SECOND / THIRD FLOOR PLAN

(AREA: 4334 Sq. Ft)

8.2.2. NJA Office Building, Manamaiju, Kathmandu

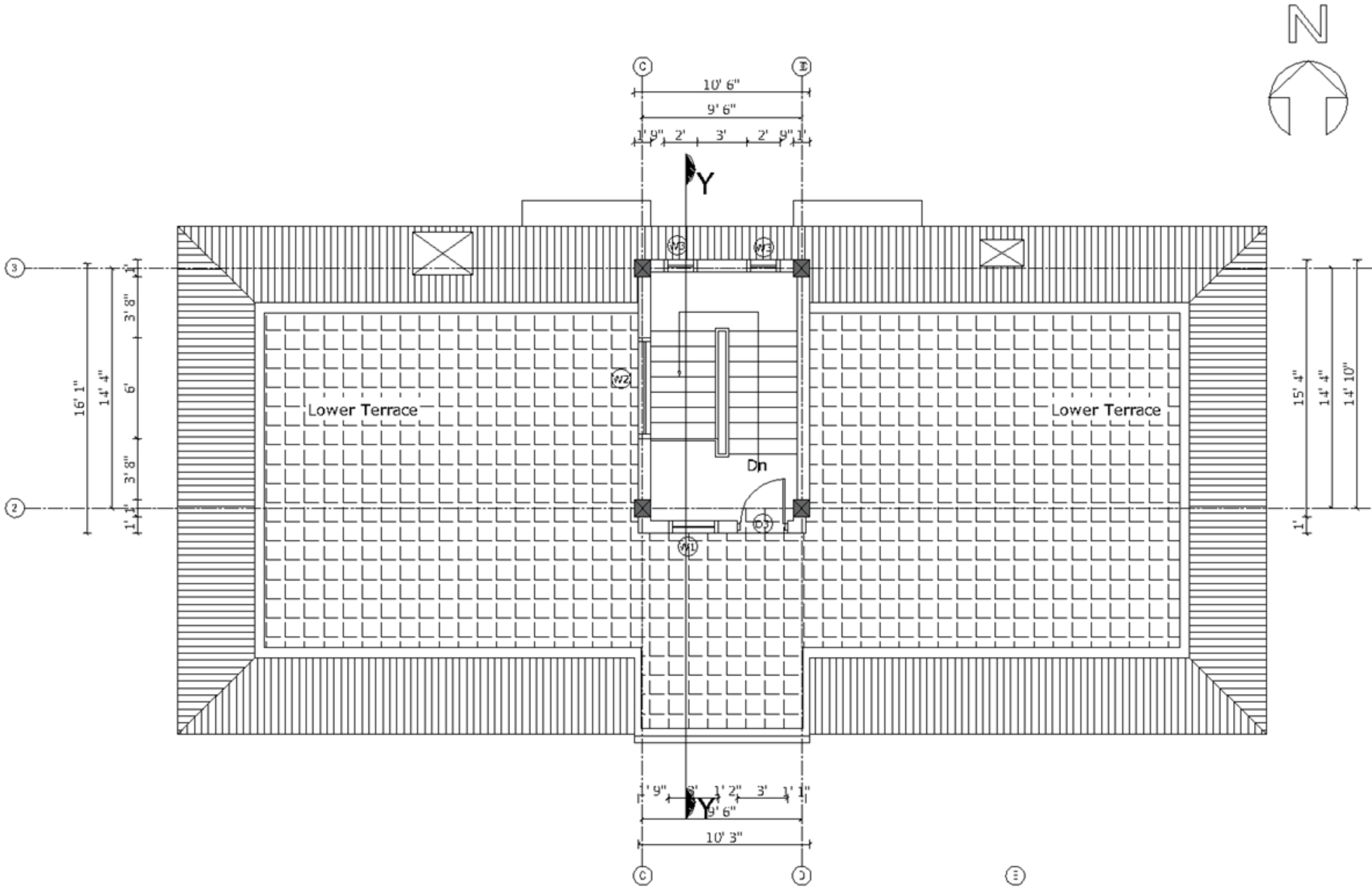


GROUND FLOOR PLAN
Area=1635.29 Sq.ft



FIRST FLOOR PLAN

Area=1642.195 Sq.ft



SECOND FLOOR PLAN
Area=167.66Sq.ft

8.2.3. NJA Faculty Building, Manamaiju, Kathmandu

MODEL I.B.-1.2, INTERLOCKING BRICK MASONRY | TWO STOREY

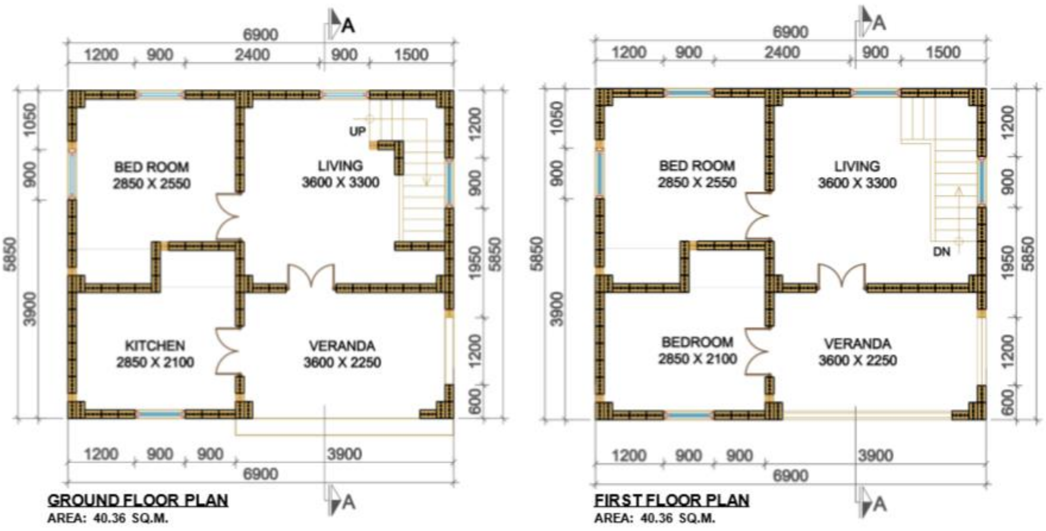
LEVEL	MATERIALS								
	Stone	Interlocking Bricks	Cement	Sand	Aggregate	Reinforcing Bar	CGI sheet	GI Sheet	Wood
	Cu.m	No.	Bags	Cu.m.	Cu.m.	Kg.	Bundle	Sq.m.	Cu.m.
Up to Plinth Level	18.1	-	80.5	10.9	6.1	177.2			-
Super Structure	-	6,447.0	57.5	3.0	6.1	493.9			1.3
Roofing	-	-	-	-	-	-	4.2	8.7	1.5
TOTAL	**18.1**	**6,447.0**	**138**	**13.9**	**12.2**	**671.1**	**4.2**	**8.7**	**2.8**

MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: I.B.-1.2 | SCALE: NONE | I.B.-1.2
DRAWING TITLE: ESTIMATE AND 3D VIEW | DATE: | 1/5

8

MODEL I.B.-1.2, INTERLOCKING BRICK MASONRY | TWO STOREY



MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: I.B.-1.2 | SCALE: NONE | I.B.-1.2
DRAWING TITLE: FLOOR PLANS | DATE: | 2/5

8.2.4. Brick Masonry Model

MODEL S.S.-10.1, STEEL STRUCTURE — TWO STOREY

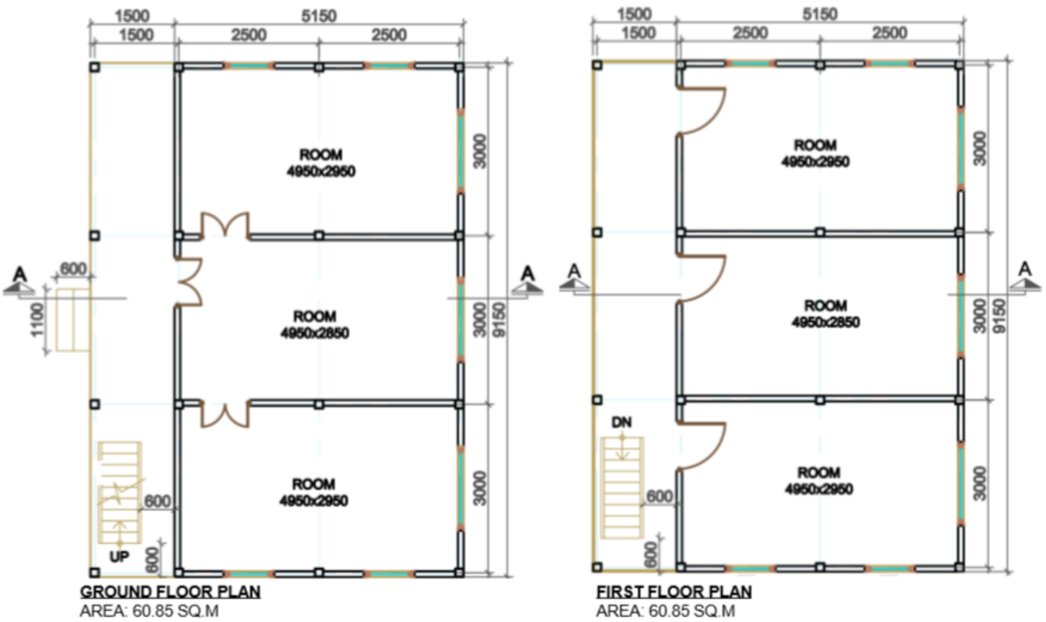
LEVEL	MATERIALS										
	Brick	Cement	Sand	Aggregate	Reinforcing Bar	MS pipe	Steel sections	CGI Sheet	GI Plain sheet	Aluminium Door	Aluminium Window
	No.	Bags	Cu.m.	Cu.m.	Kg.	Kg.	Kg.	Bundle	Sq.m.	Sq.m.	Sq.m.
Up to Plinth Level	3,384.0	130.0	11.0	13.0	974.0	-	-			-	-
Super Structure	-	111.0	5.0	10.0	582.0	-	3,930.1			10.3	22.6
Roofing	-	-	-	-	-	845.4	-	6.3	11.1	-	-
TOTAL	**3,384.0**	**241.0**	**16.0**	**23.0**	**1,556.0**	**845.4**	**3,930.1**	**6.3**	**11.1**	**10.3**	**22.6**

MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: MODEL S.S-10.1 | SCALE: NONE | S.S.-10.1
DRAWING TITLE: ESTIMATION AND 3D-VIEW | DATE: | 1/11

151

MODEL S.S.-10.1, STEEL STRUCTURE — TWO STOREY



MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: MODEL S.S-10.1 | SCALE: NONE | S.S.-10.1
DRAWING TITLE: FLOOR PLANS | DATE: | 2/11

152

8.2.5. Steel Structure Model

MODEL T.S.-11.1, TIMBER STRUCTURE TWO STOREY

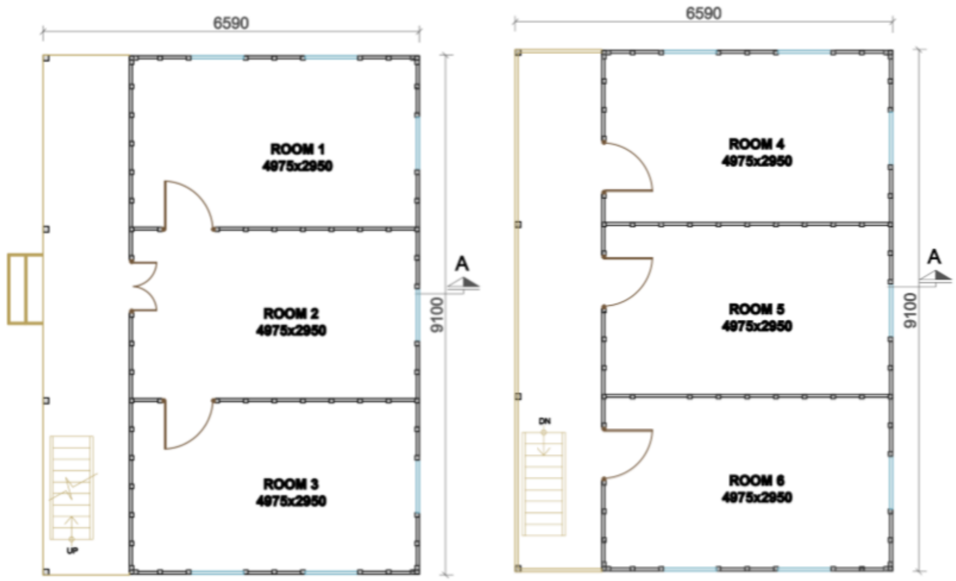
LEVEL	MATERIALS										
	Brick	Cement	Sand	Aggregate	Reinforcing Bar	MS Angle & Plates	Wood	CGI Sheet	GI Plain sheet	Aluminium Door	Aluminium Window
	No.	Bags	Cu.m.	Cu.m.	Kg.	Kg.	Cu.m.	Bundle	Sq.m.	Sq.m.	Sq.m.
Up to Plinth Level	3,652.7	113	16.7	8.7	630.0	-	-			-	-
Super Structure	-	18	1.2	2.2	-	526.3	16.3			10.3	22.6
Roofing	-	-	-	-	-	-	0.2	6.7	11.4	-	-
TOTAL	**3,652.7**	**131**	**17.9**	**10.9**	**630.0**	**526.3**	**16.5**	**6.7**	**11.4**	**10.3**	**22.6**

MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: MODEL T.S-11.1 | SCALE: NONE | T.S.-11.1
DRAWING TITLE: ESTIMATE AND 3D-VIEW | DATE: | 1/8

164

MODEL T.S.-11.1, TIMBER STRUCTURE TWO STOREY



GROUND FLOOR PLAN
AREA: 61.64 SQ.M.

FIRST FLOOR PLAN
AREA: 61.64 SQ.M.

MINISTRY OF URBAN DEVELOPMENT
DEPARTMENT OF URBAN DEVELOPMENT AND BUILDNG CONSTRUCTION

HOUSING TYPE: MODEL T.S-11.1 | SCALE: NONE | T.S.-11.1
DRAWING TITLE: FLOOR PLANS | DATE: | 2/8

165

8.2.6. Timber Structure Model

Table 28 Weight of Materials

Building Type	Cement OPC(kg)	Cement PPC(kg)	Aggregate(kg)	reinforcement(kg)	Brick(kg)	Tile(kg)
R1	67024.00	42759.46	200047.50	18219.44	241477.44	24697.38
R2	63833.00	40190.96	195201.85	16960.10	348729.80	15888.22
R3	32486.00	18105.80	100039.99	10047.98	119063.90	6890.40
R4	32679.00	18943.06	102438.91	9828.99	119200.28	6018.50
R5	31327.00	19337.10	100522.67	11508.68	135020.64	8382.53
R6	31327.00	18629.16	100522.67	11508.68	135020.64	8382.53
R7	52574.00	23940.90	167599.86	32058.78	143106.47	9273.09
R8	53559.00	32591.50	174857.56	15974.57	236305.24	13219.36
R9	61265.57	21569.70	183717.88	16485.00	64281.19	7641.93
R10	75015.00	24782.96	225846.73	21198.12	300479.36	3530.91
R11	22623.00	14996.42	70206.87	7450.00	140897.90	1353.44
R12	70014.00	41329.98	225410.93	20805.67	233094.05	14748.80
C1	394181.00	95877.30	761751.55	99069.76	331434.03	53333.63
C2	356913.00	62081.34	657894.33	146668.82	213783.54	19328.32
C3	377148.00	74501.32	725838.47	172869.85	344103.13	19555.01
C4	3512433.00	699531.04	6454077.74	1214247.09	2586190.52	274132.67
C5	3678358.55	683953.41	6924479.50	421084.83	1979529.39	244613.66
C6	42994.00	105889.38	112379.03	34221.54	657381.85	21334.37
C7	229386.00	350887.49	1236612.64	264283.64	1134348.30	62806.66
C8	392799.00	99405.11	981230.42	157258.50	256733.26	29429.31
O1	300230.00	112828.30	898645.71	81081.18	853435.60	63281.50
O2	1441752.00	358521.88	2694930.21	285083.03	1264698.79	142046.78
O3	639429.00	179780.04	1218390.19	146005.89	1150044.59	114677.73
O4	611460.00	167016.88	1146070.90	166015.34	786347.86	67794.50
O5	409960.36	69800.92	1188260.33	158986.00	145782.50	41242.23
O6	1070400.00	289834.60	2004589.44	271097.00	1613445.12	22706.11
O7	202880.92	77236.12	510664.42	81103.92	796303.34	45607.00
O8	652965.00	166341.66	1175722.61	231820.87	1178050.51	19725.73
O9	66330.30	51891.14	165774.72	15545.16	654162.31	0.00
O10	745641.00	185913.32	2104538.31	319380.00	984678.86	5481.48
O11	**1161161.00**	**211719.30**	**2510649.14**	**491420.00**	**846325.12**	**93013.18**
Total	**16880148.70**	**4360187.5**	**35318913.09**	**4949288.42**	**19993455.1**	**1460136.6**
N	**31**	**31**	**31**	**31**	**31**	**31**
Avg	**544520.92**	**140651.21**	**1139319.77**	**159654.46**	**644950.17**	**47101.19**

Building Type	Sal wood(kg)	Aluminium(kg)	Paint(kg)	Glass(kg)	Granite(kg)	Sand (kg)	Total wt(kg)
R1	7387.60		452.75	694.05	5620.66	498489.26	**1106869.54**
R2	3805.05	769.17	350.33	947.25	3605.41	450949.58	**1141230.71**
R3	7942.22	458.21	204.65	564.30	410.77	225853.08	**522067.30**
R4	7676.90	269.79	126.75	332.25	890.94	217316.22	**515721.59**
R5	1445.04	406.81	181.02	501.00	157.02	228075.67	**536865.18**
R6	2241.40	406.81	181.02	501.00	157.02	221157.91	**530035.85**
R7	1788.14	720.57	670.64	887.40	4093.39	325958.31	**762671.53**
R8	42078.58		284.76	2304.15	4040.91	390432.49	**965648.12**
R9	1369.80	1078.77	158.51	1134.76	2829.92	323387.34	**684920.38**
R10	9783.68	1078.77	275.57	853.65	4429.99	424315.39	**1091590.12**
R11	0.00	341.28	90.87	247.05	0.00	180631.22	**438838.06**
R12	2381.03	691.58	391.83	851.70	3786.29	490357.17	**1103863.03**
C1	4918.58	5942.01	982.73	7317.75	12667.53	1478912.31	**3246388.18**
C2	2262.53	2789.83	547.91	3435.75	10988.88	1143132.38	**2619826.63**
C3	3485.41	563.20	651.18	693.60	16203.54	1286093.54	**3021706.26**
C4	51521.94	8944.99	10622.6	11016.00	268721.69	11035387.2	**26126826.59**
C5	51521.94	8944.99	5535.64	11016.00	268721.81	11535289.2	**25813048.98**
C6	0.00	1924.07	248.12	537.75	2198.73	319242.04	**1298350.87**
C7	0.00	6602.29	1133.75	360.30	2198.73	2385024.22	**5673644.01**
C8	7468.30	2924.91	463.21	6570.00	11009.26	1720523.48	**3665814.76**
O1	0.00	6258.21	1136.37	2469.00	20470.44	1524557.52	**3864393.83**
O2	12441.14	3687.86	2851.86	4541.70	35514.53	5265279.76	**11511349.55**
O3	12180.16	2945.98	1584.52	3628.05	34010.25	2529896.71	**6032573.10**
O4	5583.44	3963.37	1940.15	4881.00	28154.49	2440105.13	**5429333.05**
O5	0.00	7252.53	960.36	7225.37	7748.02	1746587.09	**3783805.72**
O6	13638.40	0.00	1539.89	6570.00	7026.91	4268497.22	**9569344.69**
O7	2726.26	2181.56	580.61	2923.05	9572.28	1094563.72	**2826343.17**
O8	20313.80	24.24	898.04	1304.85	8110.01	2510572.28	**5965849.59**
O9	0.00	1344.67	310.04	931.50	0.00	542642.84	**1498932.69**
O10	11014.45	2451.71	3316.37	2480.55	2247.31	3232190.48	**7599333.85**
O11	**5512.00**	**6903.62**	**1894.36**	**3233.10**	**53228.86**	**4025814.53**	**9410874.21**
Total	**292487.7**	**78840.45**	**40566.4**	**90953.88**	**828815.6**	**64061235.39**	**148358061.2**
N	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**
Avg	**9435.09**	**2543.24**	**1308.60**	**2934.00**	**26735.99**	**2066491.46**	**4785743.91**

Table 29 EC calculation from site activities

Building Type	Vechicle used	No	Duration(hrs)	Energy type	energy cosumption(Ek)	unit	Fek	Cec(ton CO2)	EF	EE(MJ)
R1(6 month construction period)	Loader	1	10	Disel	0.035	ton	3.18	0.11	37195.12	3.18
	Mixture Machine	1	44	Disel	0.038	ton	3.18	0.12	37195.12	3.18
	Vibrator 2.2 hp	1	44	Electricity	0.072	Mwhr	0.68	0.05	3600.00	0.68
	water pump 2 hp	1	360	Electricity	0.537	Mwhr	0.68	0.37	3600.00	0.68
	Gas stove	12		LPG	0.170	ton	3.09	0.53	1510.00	3.09
	Lightining				1.200	Mwhr	0.68	0.82	3600.00	0.68
						Grand Total		**1.99**		
R2(7 month construction period)	Loader	1	15	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Mixture Machine	1	52	Disel	0.045	ton	3.18	0.14	37195.12	3.18
	Vibrator 2.2 hp	1	52	Electricity	0.085	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	720	Electricity	1.074	Mwhr	0.68	0.73	3600.00	0.68
	Gas stove	14		LPG	0.199	ton	3.09	0.61	1510.00	3.09
	Lightining				1.500	Mwhr	0.68	1.02	3600.00	0.68
						Total		**2.73**		
R3(6.5 month construction period)	Loader	1	16	Disel	0.056	ton	3.18	0.18	37195.12	3.18
	Mixture Machine	1	56	Disel	0.049	ton	3.18	0.15	37195.12	3.18
	Vibrator 2.2 hp	1	56	Electricity	0.092	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	682.5	Electricity	1.018	Mwhr	0.68	0.69	3600.00	0.68
	Gas stove	13		LPG	0.185	ton	3.09	0.57	1510.00	3.09
	Lightining				1.625	Mwhr	0.68	1.11	3600.00	0.68
						Total		**2.76**		
R4(8 month construction period)	Loader	1	18	Disel	0.063	ton	3.18	0.20	37195.12	3.18
	Mixture Machine	1	60	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Vibrator 2.2 hp	1	60	Electricity	0.098	Mwhr	0.68	0.07	3600.00	0.68
	water pump 2 hp	1	960	Electricity	1.432	Mwhr	0.68	0.98	3600.00	0.68
	Gas stove	16		LPG	0.227	ton	3.09	0.70	1510.00	3.09
	Lightining				2.000	Mwhr	0.68	1.36	3600.00	0.68
						Total		**3.47**		
R5(7month construction period)	Loader	1	19	Disel	0.066	ton	3.18	0.21	37195.12	3.18
	Mixture Machine	1	60	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Vibrator 2.2 hp	1	60	Electricity	0.098	Mwhr	0.68	0.07	3600.00	0.68

	water pump 2 hp	1	630	Electricity	0.940	Mwhr	0.68	0.64	3600.00	0.68
	Gas stove	14		LPG	0.199	ton	3.09	0.61	1510.00	3.09
	Lightining				2.100	Mwhr	0.68	1.43	3600.00	0.68
						Total		**3.13**		
R6(7.5 month construction period)	Loader	1	15	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Mixture Machine	1	58	Disel	0.050	ton	3.18	0.16	37195.12	3.18
	Vibrator 2.2 hp	1	58	Electricity	0.095	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	450	Electricity	0.671	Mwhr	0.68	0.46	3600.00	0.68
	Gas stove	15		LPG	0.213	ton	3.09	0.66	1510.00	3.09
	Lightining				1.875	Mwhr	0.68	1.28	3600.00	0.68
						Total		**2.78**		
R7(7.5 month construction period)	Loader	1	15	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Mixture Machine	1	58	Disel	0.050	ton	3.18	0.16	37195.12	3.18
	Vibrator 2.2 hp	1	58	Electricity	0.095	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	450	Electricity	0.671	Mwhr	0.68	0.46	3600.00	0.68
	for cooking	1	1	firewood	2.250	ton	1.46	3.29	500.00	1.46
	Lightining				1.875	Mwhr	0.68	1.28	3600.00	0.68
						Total		**5.42**		
R8(7month construction period)	Loader	1	20	Disel	0.070	ton	3.18	0.22	37195.12	3.18
	Mixture Machine	1	62	Disel	0.054	ton	3.18	0.17	37195.12	3.18
	Vibrator 2.2 hp	1	58	Electricity	0.095	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	1050	Electricity	1.567	Mwhr	0.68	1.07	3600.00	0.68
	for cooking	1	1	firewood	3.150	ton	1.46	4.61	1510.00	1.46
	Lightining				2.450	Mwhr	0.68	1.67	3600.00	0.68
						Total		**7.80**		
R9(9 month construction period)	Loader	1	18	Disel	0.063	ton	3.18	0.20	37195.12	3.18
	Mixture Machine	1	60	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Vibrator 2.2 hp	1	60	Electricity	0.098	Mwhr	0.68	0.07	3600.00	0.68
	water pump 2 hp	1	675	Electricity	1.007	Mwhr	0.68	0.69	3600.00	0.68
	Gas stove	18		LPG	0.256	ton	3.09	0.79	1510.00	3.09
	Lightining				1.875	Mwhr	0.68	1.28	3600.00	0.68
						Total		**3.18**		
R10(8.5 month construction period)	Loader	1	21	Disel	0.073	ton	3.18	0.23	37195.12	3.18
	Mixture Machine	1	55	Disel	0.048	ton	3.18	0.15	37195.12	3.18
	Vibrator 2.2 hp	1	54	Electricity	0.089	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	787.5	Electricity	1.175	Mwhr	0.68	0.80	3600.00	0.68

	for cooking	1	1	firewood	3.570	ton	1.46	5.22	500.00	1.46
	Lightining				3.825	Mwhr	0.68	2.60	3600.00	0.68
						Total		**9.07**		
R11(10 month construction period)	Loader	1	15	Disel	0.052	ton	3.18	0.17	37195.12	3.18
	Mixture Machine	1	58	Disel	0.050	ton	3.18	0.16	37195.12	3.18
	Vibrator 2.2 hp	1	58	Electricity	0.095	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	900	Electricity	1.343	Mwhr	0.68	0.91	3600.00	0.68
	for cooking	1	1	firewood	3.600	ton	1.46	5.26	500.00	1.46
	Lightining				4.500	Mwhr	0.68	3.06	3600.00	0.68
						Total		**9.63**		
R12(9 month construction period)	Loader	1	13	Disel	0.045	ton	3.18	0.14	37195.12	3.18
	Mixture Machine	1	50	Disel	0.044	ton	3.18	0.14	37195.12	3.18
	Vibrator 2.2 hp	1	58	Electricity	0.095	Mwhr	0.68	0.06	3600.00	0.68
	water pump 2 hp	1	405	Electricity	0.604	Mwhr	0.68	0.41	3600.00	0.68
	for cooking	18	1	LPG	0.256	ton	1.46	0.37	500.00	1.46
	Lightining				3.150	Mwhr	0.68	2.14	3600.00	0.68
						Total		**3.28**		
C1(18 month construction period)	Loader	2	30	Disel	0.209	ton	3.18	0.66	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	250	Disel	0.218	ton	3.18	0.69	103639.65	3.18
	Vibrator 2.2 hp	1	250	Electricity	0.410	Mwhr	0.68	0.28	3600.00	0.68
	water pump 2 hp	1	1620	Electricity	2.417	Mwhr	0.68	1.65	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				8.100	Mwhr	0.68	5.51	3600.00	0.68
						Total		**14.80**		
C2(20 month construction period)	Loader	2	35	Disel	0.244	ton	3.18	0.77	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	260	Disel	0.226	ton	3.18	0.72	103639.65	3.18
	Vibrator 2.2 hp	1	260	Electricity	0.427	Mwhr	0.68	0.29	3600.00	0.68
	water pump 2 hp	1	2100	Electricity	3.133	Mwhr	0.68	2.13	3600.00	0.68
	for cooking	40		LPG	0.568	ton	3.09	1.75	1510.00	3.09
	Lightining				11.000	Mwhr	0.68	7.49	3600.00	0.68
						Total		**17.59**		

C3(19 month construction period)	Loader	2	32	Disel	0.223	ton	3.18	0.71	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	275	Disel	0.239	ton	3.18	0.76	37195.12	3.18
	Vibrator 2.2 hp	1	275	Electricity	0.451	Mwhr	0.68	0.31	3600.00	0.68
	water pump 2 hp	1	1995	Electricity	2.977	Mwhr	0.68	2.03	3600.00	0.68
	for cooking	38		LPG	0.540	ton	3.09	1.66	1510.00	3.09
	Lightining				11.700	Mwhr	0.68	7.97	3600.00	0.68
						Total		**17.86**		
C4(24 month construction period)	Loader	2	45	Disel	0.313	ton	3.18	1.00	37195.12	3.18
	truck	4	20km	Disel	2.785	ton	3.18	8.86	37195.12	3.18
	Mixture Machine	1	250	Disel	0.218	ton	3.18	0.69	37195.12	3.18
	Vibrator 2.2 hp	1	250	Electricity	0.410	Mwhr	0.68	0.28	3600.00	0.68
	water pump 2 hp	1	2160	Electricity	3.223	Mwhr	0.68	2.19	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				15.600	Mwhr	0.68	10.62	3600.00	0.68
						Total		**25.74**		
C5(28 month construction period)	Loader	2	180	Disel	1.253	ton	3.18	3.99	37195.12	3.18
	truck	4	20km	Disel	3.481	ton	3.18	11.07	37195.12	3.18
	Mixture Machine	1	350	Disel	0.305	ton	3.18	0.97	37195.12	3.18
	Vibrator 2.2 hp	1	350	Electricity	0.574	Mwhr	0.68	0.39	3600.00	0.68
	water pump 2 hp	1	2520	Electricity	3.760	Mwhr	0.68	2.56	3600.00	0.68
	for cooking	56		LPG	0.795	ton	3.09	2.45	1510.00	3.09
	Lightining				18.200	Mwhr	0.68	12.39	3600.00	0.68
						Total		**33.82**		
C6(24 month construction period)	Loader	2	42	Disel	0.292	ton	3.18	0.93	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	240	Disel	0.209	ton	3.18	0.66	37195.12	3.18
	Vibrator 2.2 hp	1	240	Electricity	0.394	Mwhr	0.68	0.27	3600.00	0.68
	water pump 2 hp	1	2160	Electricity	3.223	Mwhr	0.68	2.19	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				13.200	Mwhr	0.68	8.99	3600.00	0.68
						Total		**19.57**		
C7 (18 month construc	Loader	2	30	Disel	0.209	ton	3.18	0.66	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	230	Disel	0.200	ton	3.18	0.64	37195.12	3.18

tion period)	Vibrator 2.2 hp	1	230	Electricity	0.377	Mwhr	0.68	0.26	3600.00	0.68
	water pump 2 hp	1	1350	Electricity	2.014	Mwhr	0.68	1.37	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				8.100	Mwhr	0.68	5.51	3600.00	0.68
						Total		**14.45**		
C8(24 month construction period)	Loader	2	36	Disel	0.251	ton	3.18	0.80	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	260	Disel	0.226	ton	3.18	0.72	37195.12	3.18
	Vibrator 2.2 hp	1	260	Electricity	0.427	Mwhr	0.68	0.29	3600.00	0.68
	water pump 2 hp	1	2160	Electricity	3.223	Mwhr	0.68	2.19	3600.00	0.68
	for cooking	48		firewood	10.080	ton	1.46	14.74	1510.00	1.46
	Lightining				15.600	Mwhr	0.68	10.62	3600.00	0.68
						Total		**33.79**		
O1(24 month construction period)	Loader	2	40	Disel	0.279	ton	3.18	0.89	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	275	Disel	0.239	ton	3.18	0.76	37195.12	3.18
	Vibrator 2.2 hp	1	265	Electricity	0.435	Mwhr	0.68	0.30	3600.00	0.68
	water pump 2 hp	1	260	Electricity	0.388	Mwhr	0.68	0.26	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				10.800	Mwhr	0.68	7.35	3600.00	0.68
						Total		**16.09**		
O2 (30 month construction period)	Loader	2	40	Disel	0.279	ton	3.18	0.89	37195.12	3.18
	truck	4	10km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	300	Disel	0.261	ton	3.18	0.83	37195.12	3.18
	Vibrator 2.2 hp	1	300	Electricity	0.492	Mwhr	0.68	0.34	3600.00	0.68
	water pump 2 hp	1	2700	Electricity	4.028	Mwhr	0.68	2.74	3600.00	0.68
	for cooking	60		LPG	0.852	ton	3.09	2.63	1510.00	3.09
	Lightining				15.000	Mwhr	0.68	10.21	3600.00	0.68
						Total		**19.85**		
O3 (28 month construction period)	Loader	2	30	Disel	0.209	ton	3.18	0.66	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	336	Disel	0.292	ton	3.18	0.93	37195.12	3.18
	Vibrator 2.2 hp	1	336	Electricity	0.551	Mwhr	0.68	0.38	3600.00	0.68
	water pump 2 hp	1	2520	Electricity	3.760	Mwhr	0.68	2.56	3600.00	0.68

	for cooking	56		LPG	0.795	ton	3.09	2.45	1510.00	3.09
	Lightining				15.400	Mwhr	0.68	10.48	3600.00	0.68
						Total		**21.89**		
O4 (18 month construction period)	Loader	2	24	Disel	0.167	ton	3.18	0.53	37195.12	3.18
	truck	4	20km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	120	Disel	0.104	ton	3.18	0.33	37195.12	3.18
	Vibrator 2.2 hp	1	120	Electricity	0.197	Mwhr	0.68	0.13	3600.00	0.68
	water pump 2 hp	1	1620	Electricity	2.417	Mwhr	0.68	1.65	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				8.400	Mwhr	0.68	5.72	3600.00	0.68
						Total		**12.15**		
O5(18 month construction period)	Loader	1	24	Disel	0.084	ton	3.18	0.27	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	136	Disel	0.118	ton	3.18	0.38	37195.12	3.18
	Vibrator 2.2 hp	1	136	Electricity	0.223	Mwhr	0.68	0.15	3600.00	0.68
	water pump 2 hp	1	1350	Electricity	2.014	Mwhr	0.68	1.37	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				8.100	Mwhr	0.68	5.51	3600.00	0.68
						Total		**13.69**		
O6 (24 month construction period)	Loader	1	36	Disel	0.125	ton	3.18	0.40	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	240	Disel	0.209	ton	3.18	0.66	37195.12	3.18
	Vibrator 2.2 hp	1	240	Electricity	0.394	Mwhr	0.68	0.27	3600.00	0.68
	water pump 2 hp	1	2160	Electricity	3.223	Mwhr	0.68	2.19	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				10.800	Mwhr	0.68	7.35	3600.00	0.68
						Total		**17.41**		
O7 (15month construction period)	Loader	1	24	Disel	0.084	ton	3.18	0.27	37195.12	3.18
	truck	4	20km	Disel	1.393	ton	3.18	4.43	37195.12	3.18
	Mixture Machine	1	180	Disel	0.157	ton	3.18	0.50	37195.12	3.18
	Vibrator 2.2 hp	1	180	Electricity	0.295	Mwhr	0.68	0.20	3600.00	0.68
	water pump 2 hp	1	900	Electricity	1.343	Mwhr	0.68	0.91	3600.00	0.68
	for cooking	30		LPG	0.426	ton	3.09	1.31	1510.00	3.09
	Lightining				8.400	Mwhr	0.68	5.72	3600.00	0.68
						Total		**13.34**		
	Loader	1	30	Disel	0.104	ton	3.18	0.33	37195.12	3.18

O8(18 month construction period)	truck	2	20km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	120	Disel	0.104	ton	3.18	0.33	37195.12	3.18
	Vibrator 2.2 hp	1	120	Electricity	0.197	Mwhr	0.68	0.13	3600.00	0.68
	water pump 2 hp	1	1350	Electricity	2.014	Mwhr	0.68	1.37	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				4.500	Mwhr	0.68	3.06	3600.00	0.68
						Total		**9.02**		
O9 (18 month construction period)	Loader	1	20	Disel	0.070	ton	3.18	0.22	37195.12	3.18
	truck	2	20km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	100	Disel	0.087	ton	3.18	0.28	37195.12	3.18
	Vibrator 2.2 hp	1	100	Electricity	0.164	Mwhr	0.68	0.11	3600.00	0.68
	water pump 2 hp	1	1350	Electricity	2.014	Mwhr	0.68	1.37	3600.00	0.68
	for cooking	36		LPG	0.511	ton	3.09	1.58	1510.00	3.09
	Lightining				4.500	Mwhr	0.68	3.06	3600.00	0.68
						Total		**8.84**		
O10 (24 month construction period)	Loader	1	36	Disel	0.125	ton	3.18	0.40	37195.12	3.18
	truck	2	20km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	150	Disel	0.131	ton	3.18	0.42	37195.12	3.18
	Vibrator 2.2 hp	1	150	Electricity	0.246	Mwhr	0.68	0.17	3600.00	0.68
	water pump 2 hp	1	1800	Electricity	2.686	Mwhr	0.68	1.83	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				6.000	Mwhr	0.68	4.08	3600.00	0.68
						Total		**11.21**		
O11 (24 month construction period)	Loader	1	30	Disel	0.104	ton	3.18	0.33	37195.12	3.18
	truck	2	20km	Disel	0.696	ton	3.18	2.21	37195.12	3.18
	Mixture Machine	1	120	Disel	0.104	ton	3.18	0.33	37195.12	3.18
	Vibrator 2.2 hp	1	130	Electricity	0.213	Mwhr	0.68	0.15	3600.00	0.68
	water pump 2 hp	1	1080	Electricity	1.611	Mwhr	0.68	1.10	3600.00	0.68
	for cooking	48		LPG	0.682	ton	3.09	2.10	1510.00	3.09
	Lightining				4.500	Mwhr	0.68	3.06	3600.00	0.68
						Total		**9.29**		
						Total		**385.65**		
						N		**31.00**		
						Avg		**12.44**		

Table 30 Building Notation Details

Building Notation	Name of owner	Location	Name of contractor	Period(month)
R1	Sanjaya Agrawal	Kuleshowr	Bright Future Construction Pvt.Ltd	6
R2	NJA Faculty Building	Manamaiju	Mahakaya Construction Pvt.Ltd	7
R3	Padma Colony Type A	Ramkot	Bright Future Construction Pvt.Ltd	6.5
R4	Padma Colony Type B	Ramkot	Bright Future Construction Pvt.Ltd	8
R5	Padma Colony Type C	Ramkot	Bright Future Construction Pvt.Ltd	7
R6	Padma Colony Type D	Ramkot	Bright Future Construction Pvt.Ltd	7.5
R7	Bindu Pradhan	Budanilkantha	Mahakaya Construction Pvt.Ltd	7.5
R8	Rohan Shrestha	Gokarna	Pashupatinath Construction Pvt.Ltd	7
R9	Niraj Shing Rathor	Hepali Height	Mahakaya Construction Pvt.Ltd	9
R10	Guest House	Gongabu	Mahakaya Construction Pvt.Ltd	8.5
R11	Waiting and security	Tokha	Mahakaya Construction Pvt.Ltd	10
R12	Rakhi Chaudhary	Gaushala	Bright Future Construction Pvt.Ltd	9
C1	Mina kumari Agrawal	Tripureshwor	Pashupatinath Construction Pvt.Ltd	18
C2	Binaya Kumar Shah	Ganabal	Synergy Builders Pvt.Ltd	20
C3	Shrawan kumar Agrawal	Tripureshwor	Bright Future Construction Pvt.Ltd	19
C4	Devine Bless	Swayambhu	Synergy Builders Pvt.Ltd	24
C5	Hotel Eastern	Lazimpat	Pashupatinath Construction Pvt.Ltd	28
C6	Hotel Ryne fitness block	Kathmandu	Synergy Builders Pvt.Ltd	24
C7	Hotel Ryne banqute block	Kathmandu	Synergy Builders Pvt.Ltd	18
C8	Badijaya Bank	Kathmandu	Synergy Builders Pvt.Ltd	24
O1	Nja Hostel	Manamaiju	Synergy Builders Pvt.Ltd	24
O2	Nja Admin Block	Manamaiju	Pashupatinath Construction Pvt.Ltd	30

O3	Tarkeshowr Municipality building	Dharmasthali	Pashupatinath Construction Pvt.Ltd	28
O4	KMC College	Kathmandu	Synergy Builders Pvt.Ltd	18
O5	MAX Building	Putalisadak	Synergy Builders Pvt.Ltd	18
O6	Triten Norbutse Institution	Ichange	Synergy Builders Pvt.Ltd	24
O7	Himalayan College Auditorium Hall	Sankhamul	Synergy Builders Pvt.Ltd	15
O8	Manka Khala Building	Dallu	Pashupatinath Construction Pvt.Ltd	18
O9	Police Building	Samakhushi	Mahakaya Construction Pvt.Ltd	19
O10	shankharapur municipality	shankhu	Synergy Builders Pvt.Ltd	24
O11	Gokerneshowr Municipality	Gorkarna	Pashupatinath Construction Pvt.Ltd	24