A framework for enhancing the eco-efficiency and sustainability in the construction sector using BIM

FINAL YEAR PROJECT UG-2019

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This is to certify that the Final Year Project titled

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Abstract

The world is moving towards sustainable, eco-friendly, recyclable materials to enhance the circular economy and mitigate the issues of carbon footprint, overburdened landfills, and waste of natural resources. As increasing greenhouse gas (GHG) emissions are a major contributor to climate change and global warming, and the construction sector is one of the prominent sources of GHG emissions, it is essential to precisely quantify and reduce the GHG emissions of this sector. This research presents a novel framework by combining advanced tools i.e., building information modeling (BIM), Life cycle assessment (LCA), Geographic Information System (GIS), and mathematical analysis of embodied emissions to obtain accurate results. The accuracy and effectiveness of the proposed approach has been validated on a real case study in Islamabad, Pakistan. Building model has been generated using BIM, and a complete LCA has been conducted. With the selected route, embodied emissions have been calculated with mathematical formulae. Targeted mitigation strategies have been proposed and an optimized route has been designed using GIS tools along the suggested facility centers in the Islamabad region. The case study has been re-assessed with alleviation strategies. The results show that 29.35% of the materialization stage and 14.77% of the operational stage GHG emissions have been reduced. 11.53% of the end-of-life phase GHG emissions have been reduced. Hence, pre-evaluating the environmental degradation caused by construction projects at the design stage might offer an opportunity to comprehend and reduce prospective environmental impacts. This study proposes a distinctive framework for the construction sector to enhance its sustainability and eco-efficiency.

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LIST OF ABBREVIATIONS

LCA	Life Cycle Assessment
GIS	Geographic Information System
GHG	Green House Gases
BIM	Building Information Modeling
CDW	Construction and Demolition waste
LCI	Life Cycle Inventories
CC	Classification Centre
SMS	Second-Materials store
RP	Recycling Plant
LS	landfill Site

1. Introduction:

The construction sector is one of the paramount sources of environmental depredation owing to the manufacturing of construction materials and direct or indirect energy use throughout the construction, operation, and end-of-life phase. The construction industry contributes over 39% of the annual global carbon emissions [1,2]. This industry generates approximately 50% of greenhouse gas (GHG) emissions in member nations of the European Union [3]. Annual production on the European continent is close to 890 million tons [4]. While only China almost produces 1.13 billion tons of construction waste [5]. Additionally, numerous construction activities in Pakistan are affecting about 67.5% of the ecosystem and 34% of the natural energy resources [6]. There is a lack of a holistic approach that promotes a circular economy [7]. and lowers energy consumption, greenhouse gas (GHG) emissions, and waste production, all of which are still severely lacking in developing nations [8-10]. It is evident with a growing number of publications on the issue of minimization of waste production and ecological impacts in these nations [11-16] and also life cycle assessment (LCA) results vary greatly because of different regional conditions, such as climates, laws, and technological advancements [17]. The world is moving towards sustainable, recyclable, economical, and environment-friendly approaches to strengthen the circular economy and to alleviate the issues of surging waste generation, GHG emissions, overburdened landfills, and degradation of natural resources. Therefore, a sustainable and ecologically sound framework should be adopted to utilize and integrate innovative construction materials, advanced methods, modern designs, and digital technologies that will revamp the environment.

The rising environmental degradation posed a critical threat, and it has gained significant attention around the globe. Approaches available in the literature i.e., using the life cycle assessment (LCA) which is a systematic method for assessing the inputs, outputs, and possible environmental impact of a project or product [18] . LCA has been used often to evaluate the impact of buildings on the environment and it provides promising results for formulating mitigation strategies. Adalbert et al. assessed phases of the life cycle of buildings to identify the phase having the highest environmental impact [19]. Norman et al. studied the energy use and greenhouse gas emissions of high and low-populated buildings to demonstrate the effects of urban density [20]. Guggemos et al. compared the ecological impacts of steel and concrete framed buildings utilizing the LCA [21]. Blengini et al. evaluated the controlled blasting demolition of building using LCA [22]. Furthermore, various other types of buildings were also analyzed using LCA [23]. In addition to this, with growing technology more modern tools are available in the construction sector that has enhanced and optimized the industry. Building information modeling (BIM) has been systematically explored in sustainability assessments [24-26]. BIM is a digital representation of an actual structure that works as a database for data from several disciplines. Additionally, it has the innate ability to generate and manage the data necessary for a variety of building assessments [27-29].

In recent studies, there has been a significant amount of research on the integration of BIM and LCA of buildings. The limitations of the traditional LCA methods, which are time-consuming, expensive, and require manual data entry, can be minimized by using BIM-based LCA [30-36]. Moreover, mathematical formulae that incorporate a variety of GHG emission parameters into account are generated in order to facilitate the ability to accurately quantify the construction and demolition (CDW) GHG emissions [37]. The proposed mathematical equations with a BIM-based approach were discovered to identify the GHG emissions effectively and precisely to offer crucial strategies for minimizing the major damage to the ecosystem caused by the disposal of CDW. Meanwhile, the embedded impacts of buildings can also be significantly reduced by combining transportation and end-of-life phase approaches [38]. Geomatics-based spatial systems form the basis of geographic information science (GIS) which is used to design waste transportation routes and provides geographic information on trash treatment facilities and landfill locations [39]. Therefore, there is still a gap to integrate and implement the above-mentioned advanced tools and develop an approach to enhance the eco-efficiency and sustainability of the construction sector.

This paper proposes an innovative approach to integrate BIM, LCA, disposal GHG emissions quantification with mathematical formulae, and GIS to develop an estimation and evaluation approach containing all life cycle phases i.e., construction phase, use phase, and end- of-life phase to identify all the critical parameters and processes that cause the deterioration of the environment and proposes strategies to ameliorate the critical materials and processes for reducing the ecological degradation. The effectiveness and efficiency of the developed approachare illustrated through a real-world case study from Pakistan. Initially, the model of the building was developed using the special BIM software Revit and the dataset for assessments was extracted. The life cycle assessment was conducted using One Click LCA cloud version and the CDW disposal GHG emissions are then precisely quantified using mathematical estimation formulas with integrated CDW GHG emission factors for CO_2. The critical parameters and processes are then obtained by evaluating the LCA and disposal GHG emissions quantification. Mitigation strategies to reduce environmental depredations were proposed and implemented in the case study to validate the approach. Furthermore, an optimized route has been designed for transporting the waste is also incorporated using the GIS network analyst tool. Therefore, a re-evaluation of all phases with improved material and process was conducted to compare the impacts. Moreover, this approach also paves the way for designers and construction managers to conduct a pre-evaluation of environmental damage caused by materials, processes, and waste thatenables the construction of sustainable and eco-friendly structures.

2. Literature review:

2.1 Life cycle assessment (LCA) in construction:

LCA focuses primarily on social and environmental impacts [40], and it is frequently used in sectors like automotive design, production of equipment, and designing consumer goods [41]. LCA has been implemented in the construction industry since the 1980s [42], and in the 1990s it was further standardized with multiple workshops, research and handbook publications [43-45] often to assess the environmental effects of a specific building over the course of its lifetime, which generally contains the extraction of raw materials, industrial production, construction, execution, maintenance, restoration, substitution, and demolition [46]. Architects can also get information on which approach is optimal by comparing the environmental impact of numerous choices and making the changes in designs accordingly. for instance, structural designers can choose more sustainable materials having less carbon footprint rather than selecting materials having high carbon emissions [47]. life cycle inventories (LCI) of buildings are diverse and complex due to the variety of elements and procedures involved [48]. The input flows and output flows of the different stages of a building's LCI are influenced by a wide range of variables [49]. Each LCA database is specific to a particular nation or area [50-51]. Despite the outcomes being less reliable and significantly subjective but it is simpler to make conclusions. Hence LCA has been rapidly growing in the construction sector around the globe [52-62].

2.2 GHG emissions of buildings:

GHG emissions of buildings can be broken down into two main categories: embodied GHG emissions and operating GHG emissions [63]. The primary sources of embodied GHG emissions are the extraction of raw materials, production and transportation of building materials and components, on-site construction activities, demolition, and landfill emissions [64]. The daily energy use ultimately produces the operating GHG emissions i.e., heating, lighting, air conditioning, and water supply [65]. The evaluation of building GHG emissions in the past mostly focused on energy consumption in operation. [66-68], and embodied GHG emissions were hardly taken into account. Recent research successfully lowered operational energy demand and associated greenhouse gas emissions by enhancing the energy efficiency of buildings has been coupled with a rise in embodied GHG emissions [69].

2.3 Building information modeling in sustainability assessments:

Building information modeling (BIM) is described as a collection of policy frameworks, processes, and technologies that develop a systematic method for maintaining essential project data and structure design information in digital form over the course of a building's life cycle [70]. Environmental performance assessments and sustainability-improving activities can be carried out precisely and successfully using BIM since it enables multidisciplinary information to be integrated inside a single model [71-72]. Over the past few years, the concept of "green BIM" has gained enormous popularity in the architecture and construction industry. Green BIM is the use of BIM tools to accomplish sustainability or enhanced building performance [73]. Regardless of increasing knowledge and understanding of BIM, and its ability for environmental sustainability, the rate of adoption of BIM in green construction projects is still quite low and its full potential has not yet been explored [74].

2.4 Integration of BIM and LCA:

BIM has the capability to significantly ease LCA throughout the building [75]. The use of BIM and LCA software would reduce the need for manual entry of information and quickens the development of LCA models [76]. Shadram et al created a framework for evaluating the embodied energy of materials by implementing BIM [77]. Han et al developed a methodology for optimizing building systems with the goal of reducing life cycle costs while taking into account energy consumption analyses based on BIM [78]. BIM-enabled LCA offers a great opportunity to accelerate the process of collecting life cycle inventory data while also enhancing the simulation accuracy of the LCA research for the particular building. However, there is still a need for improvement and harmonization of the current BIM and LCA technologies [79].

2.5 GIS for optimized route design:

GIS is used in numerous sectors, including urban planning, transportation, resource management, forestry, managing natural disasters, ecological modeling, and engineering [80]. Developing nations are becoming more and more concerned with inadequate waste management [81]. Hence, the development of essential infrastructure and instruments on the basis of an effective management framework is necessary for proper waste management [81]. Using GIS multiple extensions are developed such as ArcGIS Network Analyst which is an advanced tool that is being used in the solid waste management sector efficiently and provides network-based analysis, encompassing routes, travel directions, nearby facilities, and service area analysis [82]. it offers users to model a variety of realistic network circumstances, such as turn limitations, speed restrictions, height constraints, and traffic patterns at various times of the day [82].

3. Methodology:

A framework has been developed that integrates BIM, LCA, disposal GHG quantification, and GIS followed by implementation on the real-time case study. The methodology primarily focuses on operationalizing the framework and reduce the GHGs emission produced by the construction sector. The integration of these technologies not only makes the evaluation easy but also promotes the adoption of sustainable methodologies. The framework of the proposed model is illustrated in figure 1.

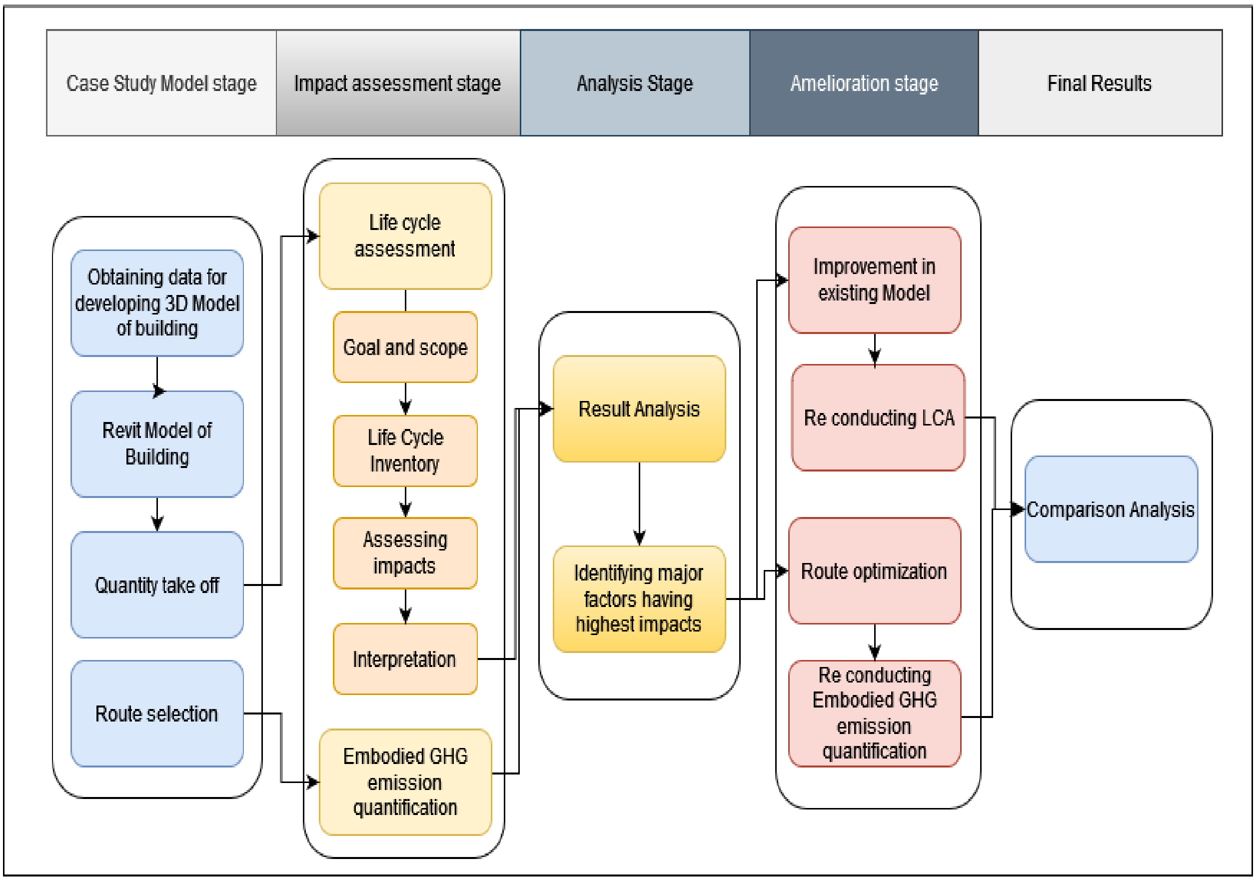


Figure 1: Proposed framework

3.1 BIM modeling:

Due to its built-in characteristics to assist the creation of the effective estimation model and overcome interface problems, the BIM tool Autodesk Revit was adopted. The first stage is creating a BIM model that has both functional and physical properties. Geometries and layout configurations make up physical properties, whereas element and component zoning, and material specifications make up functional characteristics. To provide an accurate LCA result, it's critical to develop a consistent modeling approach with the same naming conventions in the created materialdatabase. The Revit platform allows users to amend the whole building data. A building model isdeveloped using 3D objects to create walls, floors, roofs, structures, windows, doors, etc. Theseparametric items, which include 3D architectural elements like windows and doors, are referred to as "families." By altering specified properties like height, width, and material type, users maymodify the alter a particular segment. Thus, the case study model is generated on the Revit Software. Furthermore, the procedure has been illustrated in figure 2.

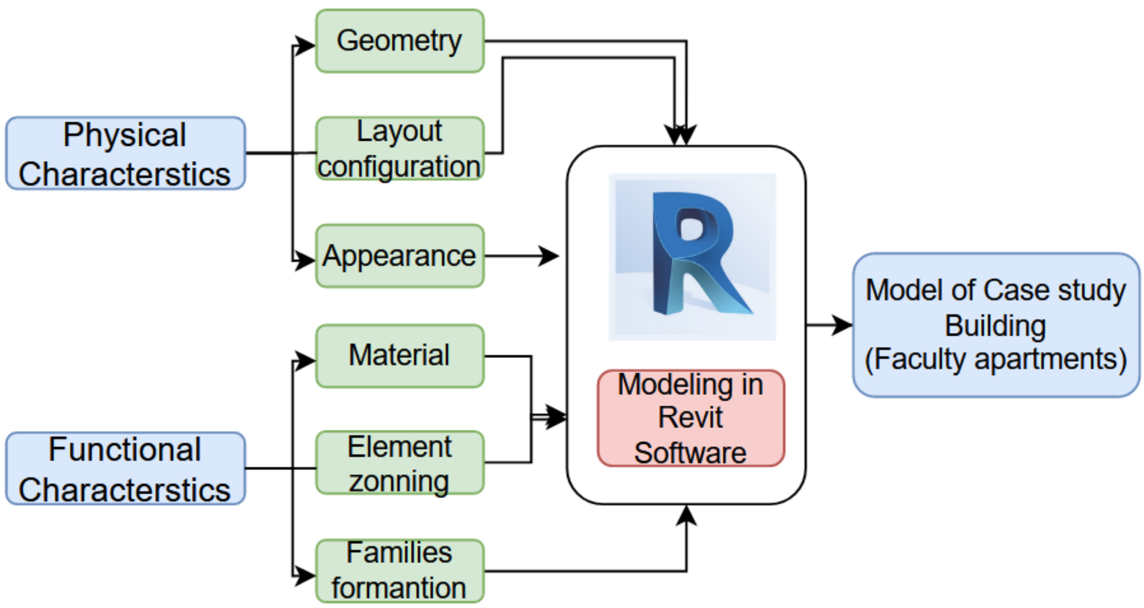


Figure 2: Procedure for developing Case Study model in Revit

3.2 Life cycle assessment:

3.2.1 Goal and scope of the proposed approach:

This LCA aims to integrate many assessment levels to undertake a systematic environmental evaluation of a building structure. Using all building life cycle phases i.e., material production, construction, usage, and end-of-life, a cradle-to-grave strategy is employed. In order to reduce embodied effects during the design phase, attention is also given to the superstructure's structural and architectural aspects, as well as its mechanical and electrical components.

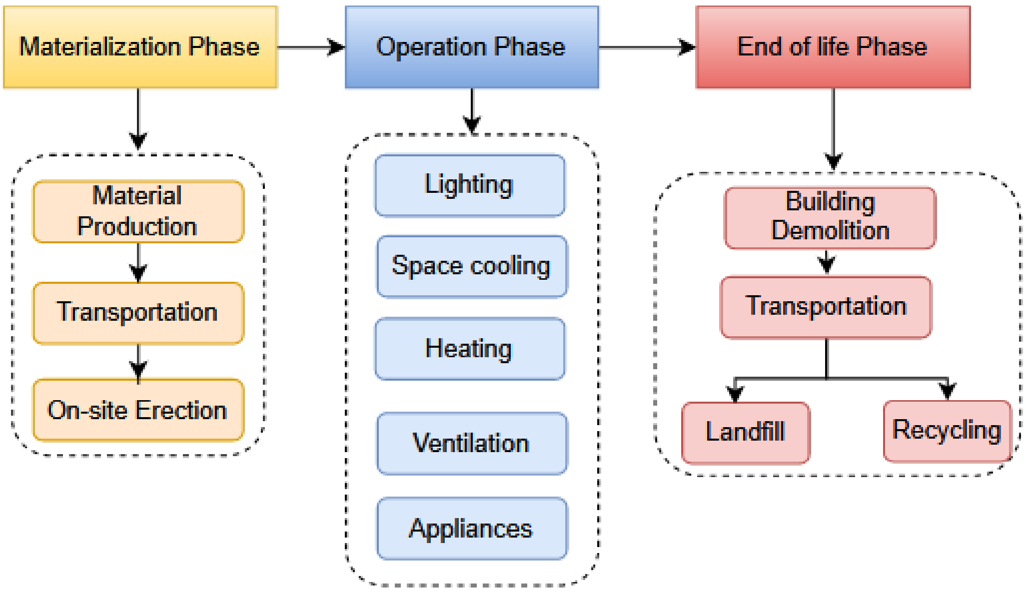


Figure 3: Stages included in Life cycle assessments

3.2.2 Lifecycle inventory:

The process of creating a lifecycle inventory encompasses compiling all input and output flows related to the defined goal and scope. For obtaining an effective LCA outcome, this stage is essential. All of the data needed for the lifespan inventory analysis is incorporated into the BIM environment since the primary objective of the project is to establish a BIM-based LCA approach for building structures. This stage also combines the recommended levels of evaluations for the breakdown and classification of building components. Information on data processing and integration within the BIM environment is illustrated in figure 2.

3.2.3 Assessment of impacts:

The outcome of the inventory study is utilized to calculate the building's environmental impacts. For the following case study, LCIA technique from the Ecoinvent and GABI database were mainly used. Those often used and offers a solid platform for comparing findings with those from another research. Additionally, those database categories are not aggregated by weight for transparency. The carbon emissions have been assessed and obtained in tonsCO_2 via considering all phases and materials used in the building. Furthermore, it has provided the impacts of each material separately and also determined the total emissions of each phase and operation.

3.3.4 Interpretation:

Life cycle interpretation is a comprehensive and systematic process for assessing outcomes. At this phase, the result is organized in a way that is in line with the objectives and scope of the research. In order to incorporate scenarios and variability in input data to improve building performance, the findings should be presented in a way that is simple to understand. Finally, for decision-making, goal-oriented conclusions, constraints, suggestions, and guidelines are presented.

3.3 Disposal GHG emission quantification:

The life cycle assessment mainly focused on the operational phase, neglecting the embodied GHG emissions which have also immense impact on ecology. CO_2 emissions is also embodied GHG emissions mentioned in this section because they cause the most environmental harm. First, the classification center (CC) separates the materials into recyclable and non-recyclable components. The recyclable components are then sent to the second materials store (SMS) to be roughly separated into smaller parts, after which they are sent to the recycling plant (RP) to be remanufactured and reused. The non-recyclable components are then sent directly to landfill locations (LS). When the construction site (CS) waste is transported from the CS to the CC, the CC to the SMS, the SMS to the RP, and the CC to the LS, transportation emissions (CO_2) are emitted. The CO_2 is produced at the LS, RP recycling, SMS sorting, and CC classification. Additionally, throughout the extensive decomposition process in the waste dump, emissions from breakdown are emitted. The actual parameter information was gathered before using the formulas to determine the embodied emissions for each kind of material based on Islamabad route distances. The embodied emission factor values were taken from Bok et al. [83] and Turner et al.[84]. CO2 emission calculation formulae for the source separated CDW including transportation emissions and the CDW handling emissions at each disposal center are mentioned below.

$$E_{CO2} = Etr + E_h$$

Transportation and handling emissions are added to determine the overall CO2 emissions, as seen in the formulae above. Here E_{tr} are the CDW transportation emissions and E_h are the CDW handling emissions.

E_{tr} = transportation emissions from th CS to the CC + transportation emissions from the CC to the SMS + transportation emissions from the SMS to the RP + transportation emissions from the CC to the LP.
E_h = classification emissions in the CC and SMS + recycling emissions in the RP + landfill emissions in the LS.

Moreover, details and calculations of CO_2 are as follows:

3.3.1 CO2 transportation emissions:

Given that both big and small diesel vehicles are recognized as means of transportation and that diesel is used in both, the transportation CO2 emissions are [85]

Equation 1

$$E_{tr} = \sum_{k=1}^{K}\sum_{j=1}^{J} Q_{bs,k}\cdot e_{d,j}\cdot D_{bs} + \sum_{k=1}^{K}\sum_{j=1}^{J} Q_{sc,k}\cdot e_{d,j}\cdot D_{sc} + \sum_{k=1}^{K}\sum_{j=1}^{J} Q_{cr,k}\cdot e_{d,j}\cdot D_{cr} + \sum_{k=1}^{K}\sum_{j=1}^{J} Q_{sl,k}\cdot e_{d,j}\cdot D_{sl}$$

Where $Q_{bs,k}$ Quantity of mixed waste k transported from the building site to the CC (unit: tonne), $e_{d,j}$CO2 transportation emissions for mode j per unit (unit: tonne/tonne-km), D_{bs} Distance from the CS to the CC

(unit: km), $Q_{sc,k}$ Quantity of source-separated waste k transported from the CC to the SMS (unit: tonne), D_{sc} Distance from the CC to the SMS (unit: km), $Q_{cr,k}$ Quantity of source-separated waste k transported from the SMS to the RP (unit: tonne), D_{cr} Distance from the SMS to the RP (unit: km), $Q_{sl,k\ t}$ Quantity of source-separated waste k transported from the CC to the LP (unit: tonne), Dsl Distance from the CC to the landfill site(LS) (unit: km), site to the CC (unit: tonne)

3.3.2: CO2 handling emissions:

The CO2 handling emissions are comprised of the landfill emissions in the LS, the CC, the SMS, the recycling emissions at the RP, and the classification emissions at the CC, hence disposal CDW handling CO2 emissions are [86]

Equation 2 $$\sum_{k=1}^{k} \boldsymbol{Q}sl,k \times \boldsymbol{P}l,k$$

Where $Q_{sc,k}$ Quantity of source-separated waste k transported from the CC to the SMS (unit: tonne), $P_{r,k}$ recycling emission factor, $Q_{sl,k\ t}$ Quantity of source-separated waste k transported from

the CC to the LP (unit: tonne), $P_{l,k}$ landfill emission factor.

Instead of the chemical biogenic CO2 emissions produced by the organic matter digestion, which are not considered in these greenhouse gases, the landfill emissions in this context relate to the physical emissions produced during the disposal process.

3.4. GIS for design of optimized route:

Geographic information system (GIS) technique was used in this research to create a design of optimized route transport system encompassing all the primary facilities i.e., classification center, second material store, recycling plant, and landfill site. GIS technology offers decision and policy makers an advanced modelling framework to analyze and simulate a variety of spatial material management issues, including waste collection. Using a popular commercial GIS platform (ESRI, ArcGIS), a spatial geodatabase was developed and applied for the designing the route of the collection operation and transportation. Furthermore, ArcGIS Network Analyst modelling package was used to perform vehicle routing. This program has to be altered in order to work with real-world limitations like one-way streets, forbidden turns (such as U-turns), demand at junctions (nodes), along the roadways, and side-of-street limits while reducing a user-specified cost characteristic.

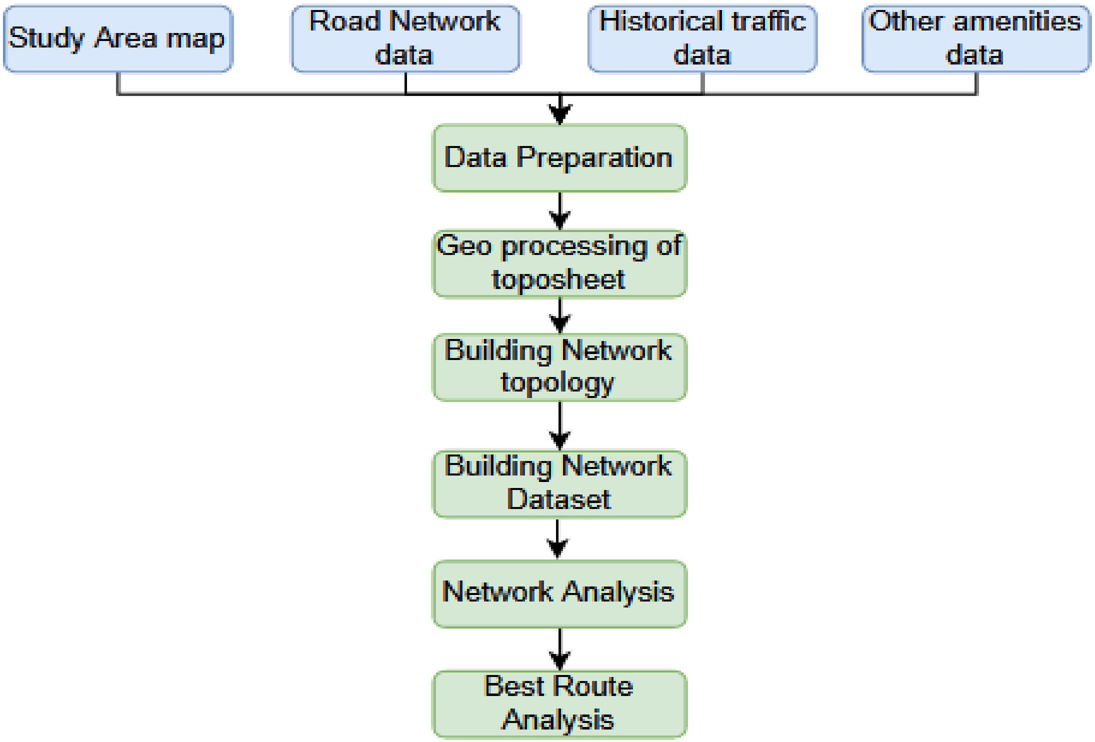


Figure 4: Procedure applied in designing the optimized route

4. Case study

4.1 Case Description:

The case study used for this research work is a building apartment located in National university of sciences and technology NUST, sector H-12, Islamabad. The building has total four floors, each floor has two apartments with multiple rooms and other amenities. It has frame structure with area of 540 m^2.

4.2 Application of the methodology:

The proposed framework in section 3 has been implemented to evaluate the efficiency of the given approach. Each step of the algorithm has been calculated with precise details with real-time data using the specially designed respective databases for each module.

4.2.1 BIM Model of Building:

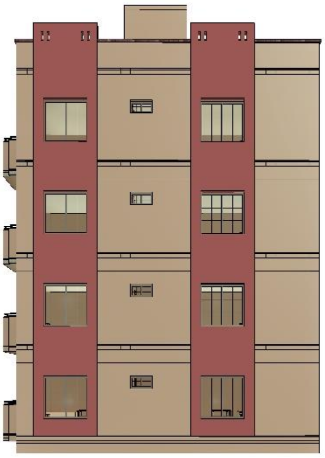
The 3D model of the building taken for the case study has been developed using the Autodesk Revit software with fine details. The elements of the building model have been grouped into families that make calculations immensely easy and precise. Furthermore, each element has been designed by conducting in-depth analysis of available 2d drawing plans and the actual existing building. All the materials and operations are included in the database according to the specification of the building and its usage, and nomenclature has been set in a way that life cycle assessment could easily be conducted. The building model has been illustrated figure.

Figure 5: Front View of Building

Figure 6: Rear View of Building

Figure 7: Angled View of Building

Figure 8: Side View of Building



4.2.2 LCA of the building:

The four fundamental phases of the LCA technique are aim and scope, inventory, impact assessment, and interpretation are incorporated to evaluate the impacts of our case study. The purpose, audiences, and system limits must first be defined before the aim and scope can be determined. The second step in assessing the inventory is gathering information on all pertinent energy and mass flow inputs and outputs as well as emissions to the air, water, and land for each stage of the operation. Calculating a building system's material and energy intake and output is a part of this step. Third, based on the inventory analysis, the impact assessment assesses possible environmental effects, and then impacts are arranged in an orderly manner in their respective phases.The data has been extracted directly from the BIM and then normalized for further usage in the cloud version of One Click LCA. Furthermore, some part of database formation for conducting LCA has been depicted in the figure below which shows the critical information of each element of the building has been taken into consideration. The automation in database formation has significantly reduced the effort and time, and also helps to quantify the materials digitally.

CLASS	MATERIAL	QUANTITY	QTY_TYPE	AREA_M2	VOLUME_M3	UNIT_PCS	COMMENT	CATEGORY	FAMILY	TYPE
SYSTEMS	Furniture_Coalesse_Await - Upholstery	16	unit	113.49	9.9	16	021_COALESSE_AWAIT_-_Four-Seat_Sof	Furniture	021_COALESSE_AWAIT_-_Four-Seat_Sof	021_COALESSE_AWAIT_-_Four-Seat_Sof
SYSTEMS	Furniture_Coalesse_Await - Upholstery (Back)	16	unit	33.04	1.77	16	021_COALESSE_AWAIT_-_Four-Seat_Sof	Furniture	021_COALESSE_AWAIT_-_Four-Seat_Sof	021_COALESSE_AWAIT_-_Four-Seat_Sof
SYSTEMS	1.Mahogny wood	16	unit	1.02	0.01	16	021_COALESSE_AWAIT_-_Four-Seat_Sof	Furniture	021_COALESSE_AWAIT_-_Four-Seat_Sof	021_COALESSE_AWAIT_-_Four-Seat_Sof
SYSTEMS	branco	24	unit	172.95	9.74	24	094_sink__mirror_1	Furniture	094_sink__mirror_1	094_sink__mirror_1
SYSTEMS	metal	24	unit	11.42	0.03	24	094_sink__mirror_1	Furniture	094_sink__mirror_1	094_sink__mirror_1
SYSTEMS	metal 2	24	unit	43.87	0.41	24	094_sink__mirror_1	Furniture	094_sink__mirror_1	094_sink__mirror_1
SYSTEMS	espelho	24	unit	72.78	0.35	24	094_sink__mirror_1	Furniture	094_sink__mirror_1	094_sink__mirror_1
SYSTEMS	painel fosco	24	unit	5.78	0.03	24	094_sink__mirror_1	Furniture	094_sink__mirror_1	094_sink__mirror_1
SLAB	1.Concrete, Lightweight (PCC)	3977.22	m2	3977.22	151.53	8	Floor	Floors	Floor	1 1/2" Thick PCC (1,2,4)
SLAB	1.WALL PAINT	3494.37	m2	3494.37	0	8	Floor	Floors	Floor	1 1/2" Thick PCC (1,2,4)
SLAB	1.Marble	505.09	m2	505.09	0	1	Floor	Floors	Floor	1 1/2" Thick PCC (1,2,4)
SLAB	Default Floor	474.38	m2	474.38	18.07	1	Floor	Floors	Floor	1.5" PCC 1,2,4
SLAB	1.Marble	522.59	m2	522.59	13.27	1	Floor	Floors	Floor	1/2" Th (Terrazo /Marble /Poralain Tiles)
SLAB	1.WALL PAINT	2.01	m2	2.01	0	1	Floor	Floors	Floor	1/2" Th (Terrazo /Marble /Poralain Tiles)
SLAB	1.Tile, Porcelain	408.63	m2	408.63	5.19	15	Floor	Floors	Floor	12"x12" Non Skid Tiles
COLUMN	1.WALL PAINT	60.14	m2	60.14	0	118	Rectangular Column	Columns	Rectangular Column	1'4" x 10"
COLUMN	1.Concrete, Cast-in-Place gray	4.58	m3	115.91	4.58	76	Rectangular Column	Columns	Rectangular Column	1'4" x 10"
COLUMN	1.WALL PAINT	16.52	m2	16.52	0	28	Rectangular Column	Columns	Rectangular Column	1'6" x 10"
COLUMN	1.Concrete, Cast-in-Place gray	1.04	m3	21.84	1.04	16	Rectangular Column	Columns	Rectangular Column	1'6" x 10"
COLUMN	1.WALL PAINT	79.32	m2	79.32	0	168	Concrete L Shaped	Columns	Concrete L Shaped	1'6" x 1'6"
COLUMN	1.Concrete, Cast-in-Place gray	4.59	m3	133.94	4.59	58	Concrete L Shaped	Columns	Concrete L Shaped	1'6" x 1'6"
COLUMN	1.WALL PAINT	26.32	m2	26.32	0	25	Rectangular Column	Columns	Rectangular Column	2' 3" x 10"
COLUMN	1.Concrete, Cast-in-Place gray	1.34	m3	23.92	1.34	10	Rectangular Column	Columns	Rectangular Column	2' 3" x 10"
COLUMN	1.WALL PAINT	20.22	m2	20.22	0	21	Rectangular Column	Columns	Rectangular Column	2' x 10"
COLUMN	1.Concrete, Cast-in-Place gray	1.01	m3	17.3	1.01	8	Rectangular Column	Columns	Rectangular Column	2' x 10"
SLAB	1.Brick Bat	522.59	m2	522.59	53.1	1	Floor	Floors	Floor	4" thick Ghera/Brick Bats
SLAB	1.WALL PAINT	1053.23	m2	1053.23	0	1	Floor	Floors	Floor	4" thick Ghera/Brick Bats
SLAB	1.Sand	522.59	m2	522.59	53.1	1	Floor	Floors	Floor	4" thick Sand Filling
SLAB	1.WALL PAINT	1053.23	m2	1053.23	0	1	Floor	Floors	Floor	4" thick Sand Filling
SLAB	Default Floor	435.6	m2	435.6	66.39	4	Floor	Floors	Floor	6" RCC Slab (2 coat bitumen+1/2" plaster)
SYSTEMS	Laminate, Ivory, Matte	24	unit	133.15	9.1	24	Desk	Furniture	Desk	60" x 30"
SYSTEMS	Cherry	24	unit	64.31	1.14	24	Desk	Furniture	Desk	60" x 30"
SYSTEMS	Steel, Chrome Plated	24	unit	7.58	0.12	24	Desk	Furniture	Desk	60" x 30"
SLAB	Default Floor	435.6	m2	435.6	99.58	4	Floor	Floors	Floor	9" thick Brick Bats
SYSTEMS	Glass - Clear, Grey	16	unit	68.09	0.6	16	Table - Dining (2)	Furniture	Table - Dining (2)	900 x 2400mm Glass Top
SYSTEMS	1.Mahogny wood	16	unit	21.05	0.23	16	Table - Dining (2)	Furniture	Table - Dining (2)	900 x 2400mm Glass Top
BEAM	1.WALL PAINT	245.19	m2	245.19	0	97	Concrete-Rectangular Beam	Structural Framing	Concrete-Rectangular Beam	Beam- 8" x 18"
BEAM	1.Concrete, Cast-in-Place gray	104.3102832	m3	1278.98	104.31	292	Concrete-Rectangular Beam	Structural Framing	Concrete-Rectangular Beam	Beam- 8" x 18"
BEAM	1.WALL PAINT	158.1	m2	158.1	0	28	Concrete-Rectangular Beam	Structural Framing	Concrete-Rectangular Beam	Beam- 8" x 24"
BEAM	1.Concrete, Cast-in-Place gray	32.77	m3	277.06	32.77	32	Concrete-Rectangular Beam	Structural Framing	Concrete-Rectangular Beam	Beam- 8" x 24"
SYSTEMS	Textile - White	24	unit	200.76	14.8	24	Bed (1)	Furniture	Bed (1)	Bed Twin
SYSTEMS	1.Mahogny wood	24	unit	100.05	1.08	24	Bed (1)	Furniture	Bed (1)	Bed Twin
SYSTEMS	Bed01	8	unit	0	0	8	Bed01	Furniture	Bed01	Bed01
SYSTEMS	Book Shelf	24	unit	0	0	24	Book Shelving06	Furniture	Book Shelving06	Book Shelf
SYSTEMS	cream	8	unit	33.22	0.4	8	complete_kitchen4	Furniture	complete_kitchen4	complete_kitchen4
SYSTEMS	black granite	8	unit	37.42	0.73	8	complete_kitchen4	Furniture	complete_kitchen4	complete_kitchen4
SYSTEMS	brown	8	unit	274.16	4.57	8	complete_kitchen4	Furniture	complete_kitchen4	complete_kitchen4
SYSTEMS	Laminate - Ivory, Matte	8	unit	9.63	0.1	8	complete_kitchen4	Furniture	complete_kitchen4	complete_kitchen4
SYSTEMS	translucent glass	8	unit	8.07	0.11	8	complete_kitchen4	Furniture	complete_kitchen4	complete_kitchen4
DOOR	Door - Frame	44.75	m2	44.75	0.85	40	Single-Flush	Doors	Single-Flush	D-2
DOOR	1.Door - Panel	97.55	m2	97.55	4.63	40	Single-Flush	Doors	Single-Flush	D-2
DOOR	Door - Frame	17.4	m2	17.4	0.33	16	Single-Flush	Doors	Single-Flush	D-3
DOOR	1.Door - Panel	33.69	m2	33.69	1.59	16	Single-Flush	Doors	Single-Flush	D-3
DOOR	Door - Frame	59.18	m2	59.18	1.12	56	Single-Flush	Doors	Single-Flush	D-6
DOOR	1.Door - Panel	99.28	m2	99.28	4.63	56	Single-Flush	Doors	Single-Flush	D-6
SYSTEMS	Pelle Bianca	8	unit	162.22	9.01	8	033_Couch_-_Diagonal_Divani_amp_Divan	Casework	033_Couch_-_Diagonal_Divani_amp_Divan	Divano_Diagonal
SYSTEMS	Pelle Marrone	8	unit	221.14	15.84	8	033_Couch_-_Diagonal_Divani_amp_Divan	Casework	033_Couch_-_Diagonal_Divani_amp_Divan	Divano_Diagonal
DOOR	Dark Wood	6.92	m2	6.92	0.24	8	Double Shutter Double Panel	Doors	Double Shutter Double Panel	DOUBLE DOOR
DOOR	Light Wood	11.18	m2	11.18	0.29	8	Double Shutter Double Panel	Doors	Double Shutter Double Panel	DOUBLE DOOR
DOOR	Glass 2	10.7	m2	10.7	0.04	8	Double Shutter Double Panel	Doors	Double Shutter Double Panel	DOUBLE DOOR
EXTERNAL WALL	1.Brick, Common	147.57	m2	147.57	14.99	70	Basic Wall	Interior Walls	Basic Wall	Generic - 4"
EXTERNAL WALL	1.WALL PAINT	152.43	m2	152.43	0	70	Basic Wall	Interior Walls	Basic Wall	Generic - 4"
EXTERNAL WALL	1.Brick, Common	160.16	m2	160.16	18.31	204	Basic Wall	Interior Walls	Basic Wall	Generic - 4.5"
EXTERNAL WALL	1.WALL PAINT	311.6	m2	311.6	0	196	Basic Wall	Interior Walls	Basic Wall	Generic - 4.5"
EXTERNAL WALL	1.Brick, Common	260.89	m2	260.89	39.76	52	Basic Wall	Exterior Walls	Basic Wall	Generic - 6"
EXTERNAL WALL	1.WALL PAINT	534.68	m2	534.68	0	52	Basic Wall	Exterior Walls	Basic Wall	Generic - 6"
EXTERNAL WALL	1.Brick, Common	2648.86	m2	2648.86	538.25	168	Basic Wall	Exterior Walls	Basic Wall	Generic - 8"
EXTERNAL WALL	1.WALL PAINT	5517.63	m2	5517.63	0	164	Basic Wall	Exterior Walls	Basic Wall	Generic - 8"
SLAB	Default Floor	10.33	m2	10.33	0.79	8	Floor	Floors	Floor	kitchen raised deck
SLAB	1.WALL PAINT	0.52	m2	0.52	0	4	Floor	Floors	Floor	kitchen raised deck
SLAB	1.Tile, Mosaic, Gray	3454.63	m2	3454.63	43.87	7	Floor	Floors	Floor	MOSAIC TILES 300X300X13mm Th
SLAB	1.WALL PAINT	3461.01	m2	3461.01	0	7	Floor	Floors	Floor	MOSAIC TILES 300X300X13mm Th
SLAB	1.Concrete, Cast-in-Place gray	22.54	m2	22.54	2.29	1	Floor	Floors	Floor	Mumty Slab - 4" thick

Figure 9: Database Formation from Revit to Microsoft Excel

The data base of all materials has been inserted to do the material mapping for which Ecoinvent and Gabi databases has been effectively utilized from the inventory. Each material has been employed with their respective materials according to the specifications of the case study building. Furthermore, other essential data of water usage, electrical appliances, and waste on site has been inserted to evaluate the impacts the of the overall operational phase of the building. The results obtained in detail for each of the material and process, which were further classified into their respective categories. Life assessment provided results of mass classifications and emissions of stages, material resource and family based classification which have been illustrated below.

Table 1: Classification of components as per mass

Mass kg - Classifications

Item	Value	Unit	Percentage %
Not defined	19	kg	0.0 %
21-01 40 10. Standard Slabs-on-Grade	2 400 000	kg	77.21 %
21-02 10 10 10 01. Floor Structural Frame - Beam	160 000	kg	5.14 %
21-02 10 10 10 02. Floor Structural Frame - Column	71 000	kg	2.3 %
21-02 10 80. Stairs	14 000	kg	0.47 %
21-02 20 10. Exterior Walls	360 000	kg	11.74 %
21-02 20 20. Exterior Windows	52 000	kg	1.69 %
21-02 20 50. Exterior Doors and Grilles	45 000	kg	1.44 %

Table 2: Emission of various resource type

Global warming kg CO_2e - Resource types

Item	Value	Unit	Percentage %
Electricity	1 400 000	kg CO_2e	56.56 %
Water	630 000	kg CO_2e	24.77 %
Ready-mix concrete for structures (beams, columns, piling)	96 000	kg CO_2e	3.78 %
Paints, coatings and lacquers	85 000	kg CO_2e	3.34 %
Regular glass panes	79 000	kg CO_2e	3.12 %
Concrete masonry units (CMU)	62 000	kg CO_2e	2.46 %
Refrigerant fluids	61 000	kg CO_2e	2.4 %
Aluminium-framed glass doors	50 000	kg CO_2e	1.99 %
Aluminium frame windows	30 000	kg CO_2e	1.18 %
Other resource types	9 900	kg CO_2e	0.39 %

Table 3: Emission as classified per families of various components

Global warming kg CO_2e - Classifications

Item	Value	Unit	Percentage %
21-01 40 10. Standard Slabs-on-Grade	150 000	kg CO_2e	6.1 %
21-02 10 10 10 01. Floor Structural Frame - Beam	23 000	kg CO_2e	0.89 %
21-02 10 10 10 02. Floor Structural Frame - Column	15 000	kg CO_2e	0.61 %
21-02 20 10. Exterior Walls	89 000	kg CO_2e	3.49 %
21-02 20 20. Exterior Windows	110 000	kg CO_2e	4.29 %
21-02 20 50. Exterior Doors and Grilles	65 000	kg CO_2e	2.57 %
Electricity use	1 400 000	kg CO_2e	55.99 %
Total water consumption	630 000	kg CO_2e	24.76 %
Refrigerant leakages	61 000	kg CO_2e	2.4 %

Figure 10: Emissions from various resource types.

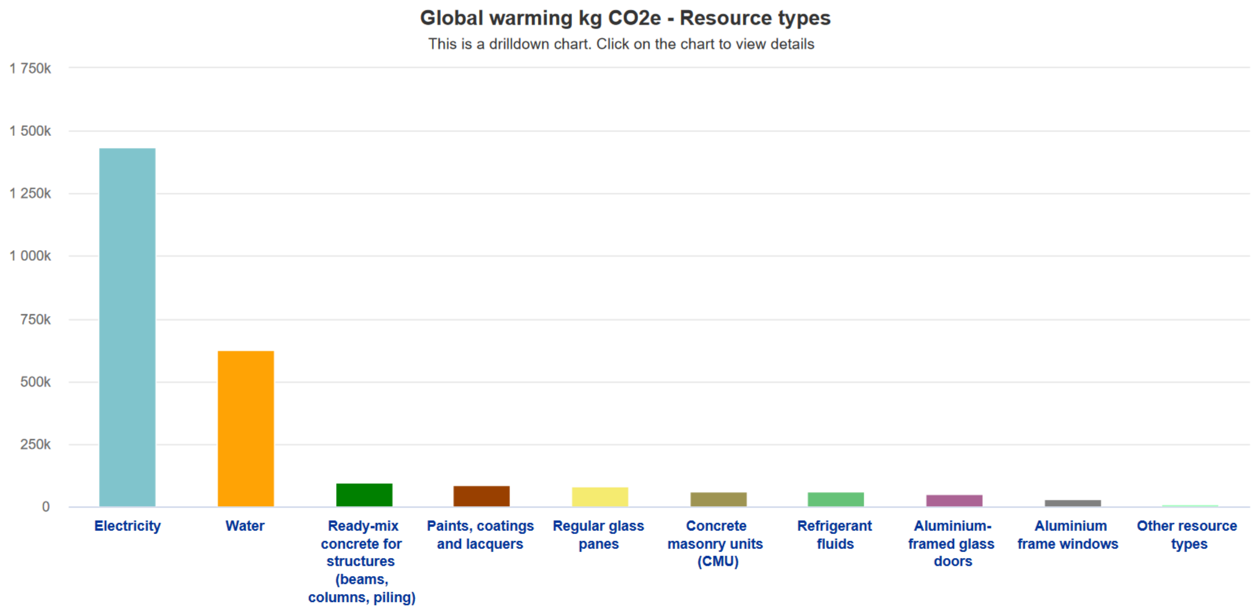


Table 4: Emission from materialization and operational stage

Life cycle stage	Result category	Carbon emission (ton CO_2e)
Materialization stage	Materials used	402
Operational stage	Energy and use	2030
Total carbon emissions		2432

The impacts of the apartments have been assessed over the span of 50 years after assigning the materials and necessary datasets, it produces construction and operational carbon emissions of 2432 tonC02e. From the figure, it is evident that use of less eco-friendly electrical appliances and usage materials have a major chunk in the overall emissions of the building.

4.2.3 Transportation of Material:

The transportation route is critical in determining the disposal emissions as the case study building is located in Islamabad which does not have all the facilities of waste management i.e., classification center, second material store, and recycling plant. The unavailability of these facilities leads to dumping whole construction demolition waste into the landfill site. Hence, for this case study, the Rawalpindi waste management company (RWPC) landfill has been taken into account. The distance from the building site to the landfill site is 36.3 Km that has been obtained using Google maps which is depicted below in the figure.

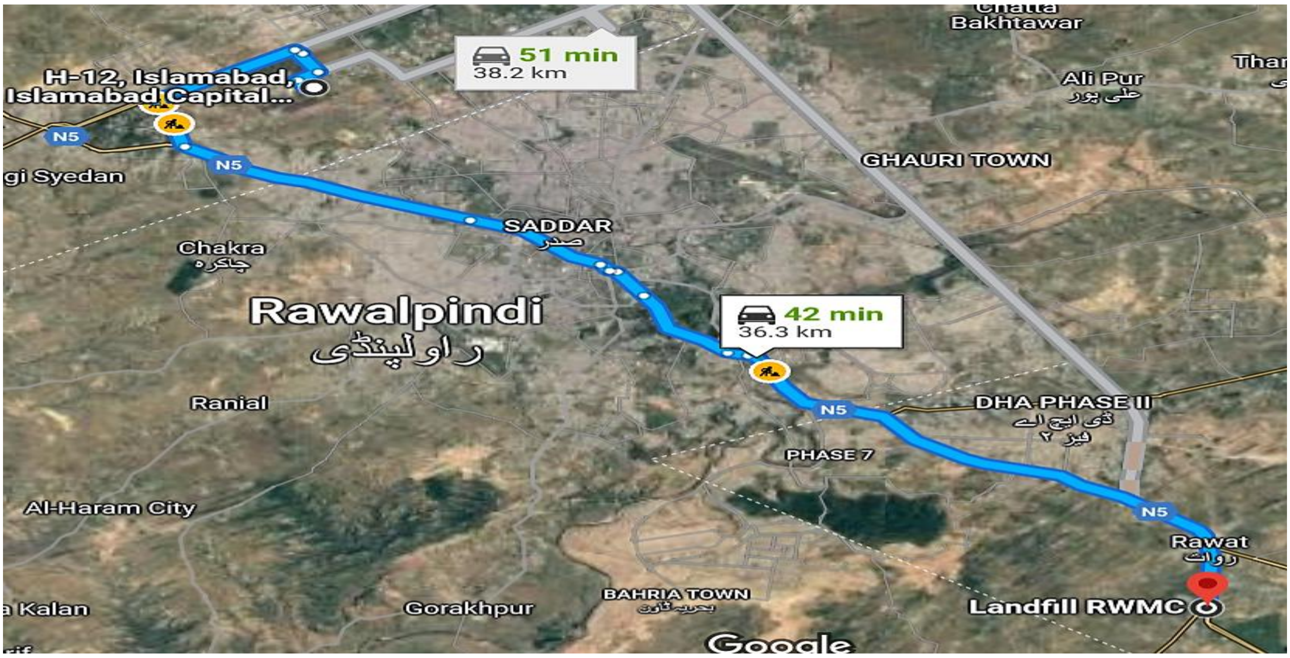


Figure 11: Transportation route between the building site and landfill

4.2.4 Quantification of disposal GHG emissions:

As the disposal GHG emission also has crucial impact on the environmental degradation, in order to address the issue of disposal emission measurement of the CDW, a new approach is required as the majority of current methods utilized to extract CDW information have proven to be time-consuming, incorrect, and difficult. Hence, a method of quantifying the emission with mathematical formulae has been proposed which provides accurate results as mentioned in section 3.3. 11 types of CDW have been considered for assessing the impacts and their respective quantities are mentioned in the table below.

Table 5: Quantities of waste materials

S.no	Material resource	Data	Units	Density (tonne/m3)	Change factor	Calculated quantities (tonne)
1	Concrete	864	m3	2.42	1.1	2299.968
2	Brick	986	m3	1.9	1.2	2248.08
3	cement	404.25	m3	2	1.2	970.2
4	lime	1.25	m3	3.3	1.2	4.95
5	steel	1138.23	t	-	1.1	1252.053
6	ceramic tile	328.2	m3	2.7	1.1	974.754
7	paint	291.18	kg	-	1.1	0.320298
8	plastic	12.5	m3	1.6	1.1	22
9	wood	15.43	t	-	1.15	17.7445
10	paper	244	kg	-	1.15	0.2806
11	plaster	64.1	m3	0.9	1.2	69.228

Using the route mentioned in 4.2.3, having the distance directly from the case study building site to the landfill site for calculating initial GHG disposal emissions. The results have been obtained by using the table and distance between the building and the landfill site which is presented in the table below.

Table 6: CO_2 disposal emissions from transportation

S.no	Material resource	Calculated quantities (tonne)	emission factor (tonne/tonne-km)	distance (km)	Transportation emission (tonne)
1	Concrete	2299.968	0.000168	36.3	14.02612485
2	Brick	2248.08	0.000168	36.3	13.70969107
3	cement	970.2	0.000168	36.3	5.91666768
4	lime	4.95	0.000168	36.3	0.03018708
5	steel	1252.053	0.000168	36.3	7.635520015
6	ceramic tile	974.754	0.000168	36.3	5.944439794
7	paint	0.3201	0.000168	36.3	0.001952098
8	plastic	22	0.000168	36.3	0.1341648
9	wood	17.7445	0.000168	36.3	0.108213059
10	paper	0.2806	0.000168	36.3	0.001711211
11	plaster	69.228	0.000168	36.3	0.422180035
				Total	47.93085

Table 7: CO_2 landfill emission from handling waste

S.no	Material resource	Calculated quantities (tonne)	Handling emission factors (tonne/tonne)	Landfill emissions (tonne)
1	Concrete	2299.968	0.13	298.99684
2	Brick	2248.08	0.03	67.4424
3	cement	970.2	0.02	19.404
4	lime	4.95	0.02	0.099
5	steel	1252.053	0.03	37.56159
6	ceramic tile	974.754	0.018	17.545572
7	paint	0.3201	2.25	0.720225
8	plastic	22	0.02	0.44
9	wood	17.7445	0.05	0.887225
10	paper	0.2806	2.25	0.63135
11	plaster	69.228	0.02	1.38456
			Total	445.1128

Therefore, the total amount of end-of-life phase emissions is 493.0453 tonsC02.

4.3 Analyses of Results:

The results of the Life cycle assessment have shown the impact of each element on the environment and have elaborated that the operational phase is the most critical in the degradation of ecology. It indicated all the materials which are unsustainable and non-friendly to use in the building and also provided an accurate carbon emission value so that engineer and architects could modify their designs and incorporate more eco-efficient materials to mitigate the impacts. Electricity consumption and usage materials are paramount factors in intensifying emissions. The primary energy uses during operation are those for space heating, residential hot water, and household electricity. In addition to this, the disposal emissions produced are also high due to the unavailability of major facilities in the region. The three phases collectively construction, operation, and disposal of CDW have a higher carbon footprint that not only damages the environment but also abates the sustainability of the construction sector. The total amount of CO_2 emissions from the construction and operation phase is 2432 tonsC02, and the total amount of CO_2 emissions from the end-of-life phase including primarily transportation and demolition waste CDW is 493.04365 tonsC02. Furthermore, most contributing materials have been mentioned below.

Figure 12: Most Contributing materials

Most contributing materials (Global warming) Compare data

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives	
1.	Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 10% (typical) recycled binders in cement (400 kg/m3 / 24.97 lbs/ft3) ?	70 tonnes CO_2e	27.3 %	Show sustainable alternatives	Add to compare
2.	Concrete masonry unit (CMU), 7 7/8in x 7 5/8in x 15 5/8in ?	59 tonnes CO_2e	23.2 %	Show sustainable alternatives	Add to compare
3.	Aluminium frame sliding doors, per m2, 14 kg/m2 ?	25 tonnes CO_2e	9.9 %	Show sustainable alternatives	Add to compare
4.	Ready-mix concrete, normal strength, generic, C25/30 (3600/4400 PSI) with CEM III/A, 60% GGBS content (280 kg/m3; 18.7 lbs/ft3 total cement) ?	24 tonnes CO_2e	9.5 %	Show sustainable alternatives	Add to compare
5.	Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 50% recycled binders in cement (400 kg/m3 / 24.97 lbs/ft3) ?	17 tonnes CO_2e	6.5 %	Show sustainable alternatives	Add to compare
6.	Aluminium framed hung and horizontal slider windows, 36.4 kg/m2 ?	15 tonnes CO_2e	5.8 %	Show sustainable alternatives	Add to compare
7.	Writing surface from glass with steel frame, magnetic, 1.88 m2, 33.5 kg/m2 ?	14 tonnes CO_2e	5.4 %	Show sustainable alternatives	Add to compare
8.	Ready-mix concrete, high strength, generic, C45/55 (6527/7977 PSI) with CEM II/A-S, 10% GGBS in cement (400 kg/m3; 25.0 lbs/ft3 total cement) ?	12 tonnes CO_2e	4.5 %	Show sustainable alternatives	Add to compare
9.	Exterior paints and enamels, 0.24 kg/m2 ?	8,3 tonnes CO_2e	3.2 %	Show sustainable alternatives	Add to compare
10.	Structural composite lumber core doors, per m2, 57.77 kg/unit, 914 x 2134 x 44.45 mm (1-3/4 in), 1.95 m2/unit (21 ft2/unit) ?	7,1 tonnes CO_2e	2.8 %	Show sustainable alternatives	Add to compare
11.	Writing surface from glass with steel frame, non magnetic, 1.88 m2, 31.1 kg/m2 ?	1,8 tonnes CO_2e	0.7 %	Show sustainable alternatives	Add to compare
12.	Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 0% recycled binders in cement (400 kg/m3 / 24.97 lbs/ft3) ?	1,6 tonnes CO_2e	0.6 %	Show sustainable alternatives	Add to compare
13.	Exterior paints and enamels, 0.236 kg/m2 ?	1 tonnes CO_2e	0.4 %	Show sustainable alternatives	Add to compare
14.	Steel sheets, generic, 0% recycled content (only virgin materials), S235, S275 and S355 ?	0,3 tonnes CO_2e	0.1 %	Show sustainable alternatives	Add to compare
15.	Stainless steel handrail, 1.15 kg/m ?	0,13 tonnes CO_2e	0.1 %	Show sustainable alternatives	Add to compare
16.	Writing surface from glass with wood frame, magnetic, 1.88 m2, 34.5 kg/m2 ?	93 kg CO_2e	0.0 %	Show sustainable alternatives	Add to compare
17.	Exterior primer, ?	kg CO_2e	0.0 %	Show sustainable alternatives	Add to compare
18.	Exterior primers, 1.06 kg/m2 ?	38 kg CO_2e	0.0 %	Show sustainable alternatives	Add to compare
19.	Float glass, single pane, generic, 3-12 mm (0.12-0.47 in), 10 kg/m2 (2.05 lbs/ft2) (for 4 mm/0.16 in), 2500 kg/m3 (156 lbs/ft3) ?	26 kg CO_2e	0.0 %	Show sustainable alternatives	Add to compare

4.4 Suggestions for Improvements:

The results indicated the most critical materials and operations, those aggravating CO_2 emissions and are barriers to sustainable buildings. The country's engineering and construction industry is experiencing a smart transition, driven by the rising use of green and sustainable materials to promote low-carbon building design. Therefore, all those materials should be replaced with more eco-friendly materials having less carbon footprint. Moreover, the disposal emissions are also high owing to the dearth of facilities, since there has already been a large rise in CDW due to growing urbanization, industrialization, and the construction sector. Therefore, a classification center, second-material store, and recycling plant should be established in Islamabad, particularly for the construction industry which will not only reduce the burden on the landfills but also recycles materials that could be saved for future use. For the establishment of these facility centers, the most feasible sites should be selected. An optimized route would be required to solve the transportation issues of CDW to these facility centers. In order to resolve the issue, a new optimized route should be designed using an advanced GIS platform containing all the existing essential information of the region. Implementation of the above mitigation strategies would lessen the overall CO_2 emissions and stimulate the eco-efficiency and sustainability of the construction sector.

4.5 Design of optimized Route for transportation:

The optimal path for collecting solid trash was determined using the network analyst tool provided in ArcGIS while taking into account all necessary factors for construction and demolition waste effectively. These factors include the locations of sites, the road system, slope, water of lakes or rivers and built area. In order to get the reduced disposal CO_2 emissions The two key criteria used to evaluate the route optimization model were economic costs along with environmental safety and sustainability. The financial and ecological impacts associated with the design of the route in the Islamabad-

Rawalpindi region, are the foundation parameters for the optimal route model. Fuel consumption and placement of centers away from populated areas makes the model a more environmentally friendly system while also improving its cost-effectiveness. The most important requirement for lowering fuel usage is the shortest distance with least degradation of environment. Moreover, the built area analysis depicted in figure 13, site suitability analysis in presented in figure 14, and the optimized route has been illustrated in the figure 15, and the distances between the facility centers are presented in table 8.

Figure 13: Built area analysis.

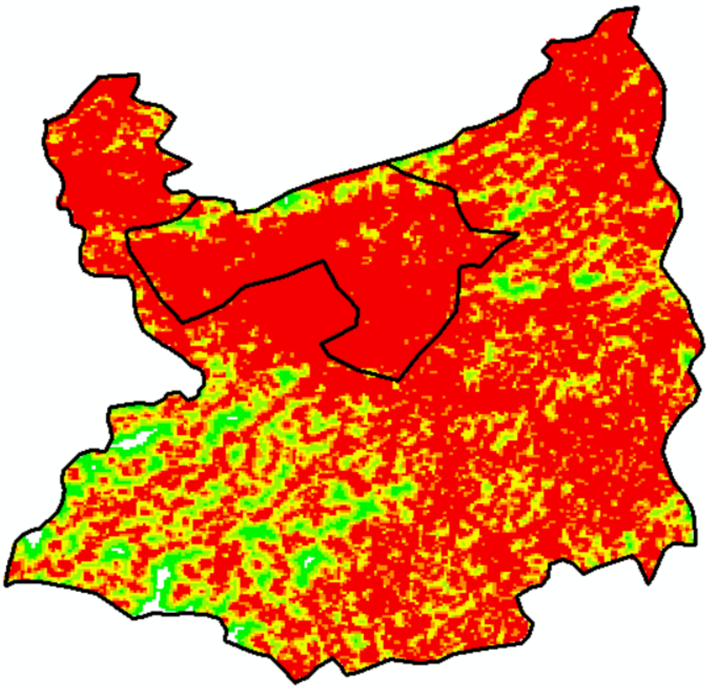


Figure 14: site suitability analysis

Figure 14.1: site suitability for classification center

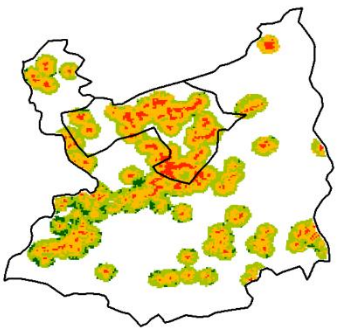


Figure14.2: Site suitablility for material store

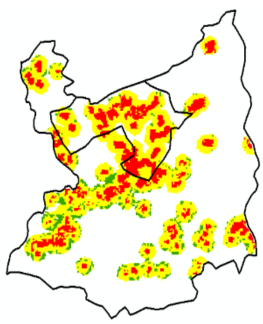
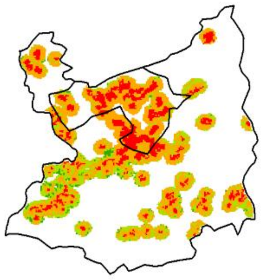


Figure 14.3: Site suitability for recycling plant   Figure 14.4: Site suitablility for landfill



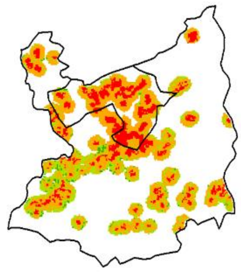


Figure 15: Design of the optimized route including all the facility centers.

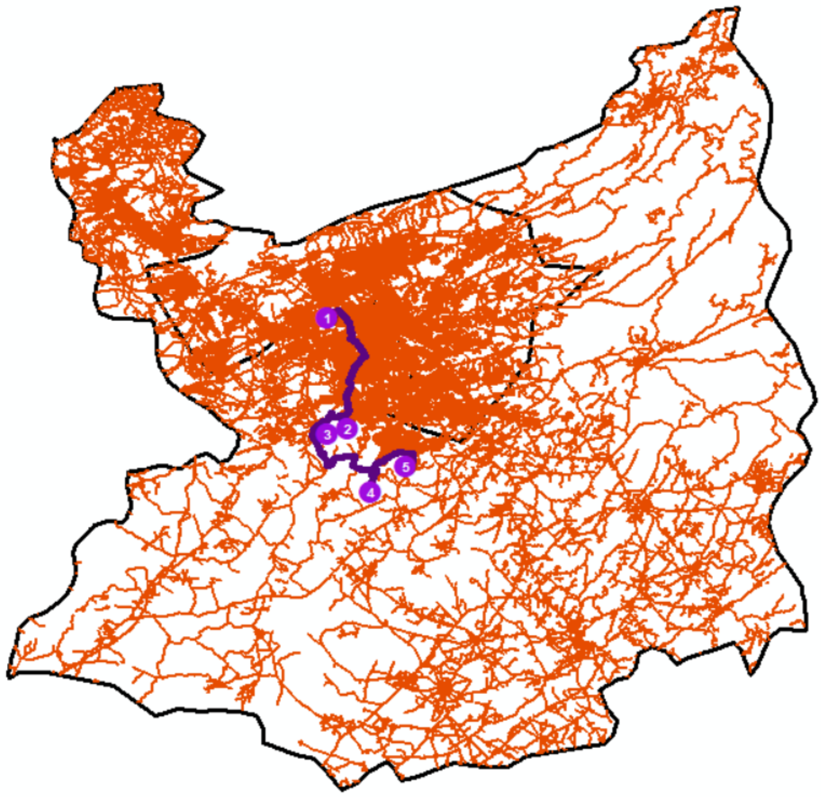


Table 8: distance between the facility centers

Distances (km)	CS	CC	SMS	RP	LS
CS	-	32.38	-	-	-
CC	32.38	-	9.11	-	
SMS	-	9.91	-	25.16	-
RP	-	-	25.16	-	-
LS	-	26.78	-	-	-

4.6 Re-evaluating the improved model:

Applying the mitigation strategies discussed in section 4.4 and implementing the distance between the facility centers obtained from section 4.5. A re-evaluation of the whole framework is conducted in order to compare the new sustainable design with the previous design and also quantify the percentage reduction in CO_2 operational as well as disposal emissions including all the phases i.e., construction, operational, and end-of-life of the case study building. By conducting the re-evaluation, the effectiveness and efficiency of all proposed mitigation strategies would also be evaluated. Therefore, the results of re-evaluation after the implementation of mitigation strategies are mentioned below.

Table 9: Classification of components as per mass after re-evaluation

Mass kg - Classifications

Item	Value	Unit	Percentage %
Not defined	19	kg	0.0 %
21-01 40 10. Standard Slabs-on-Grade	2 400 000	kg	77.21 %
21-02 10 10 10 01. Floor Structural Frame - Beam	160 000	kg	5.14 %
21-02 10 10 10 02. Floor Structural Frame - Column	71 000	kg	2.3 %
21-02 10 80. Stairs	14 000	kg	0.47 %
21-02 20 10. Exterior Walls	360 000	kg	11.74 %
21-02 20 20. Exterior Windows	52 000	kg	1.69 %
21-02 20 50. Exterior Doors and Grilles	45 000	kg	1.44 %

Table 10: Emissions from various resource types after re-evaluation

Global warming kg CO_2e - Resource types

Item	Value	Unit	Percentage %
Electricity	1 100 000	kg CO_2e	53.38 %
Water	630 000	kg CO_2e	31.19 %
Ready-mix concrete for structures (beams, columns, piling)	74 000	kg CO_2e	3.68 %
Paints, coatings and lacquers	51 000	kg CO_2e	2.54 %
Ready-mix concrete for external walls and floors	46 000	kg CO_2e	2.27 %
Concrete masonry units (CMU)	44 000	kg CO_2e	2.2 %
Aluminium frame windows	41 000	kg CO_2e	2.06 %
Refrigerant fluids	34 000	kg CO_2e	1.7 %
Ready-mix concrete for foundations and internal walls	28 000	kg CO_2e	1.4 %

Table 11: Emissions as classified per families of various components after re-evaluation

Global warming kg CO_2e - Classifications

Item	Value	Unit	Percentage %
21-01 40 10. Standard Slabs-on-Grade	170 000	kg CO_2e	8.26 %
21-02 10 10 10 01. Floor Structural Frame - Beam	20 000	kg CO_2e	0.97 %
21-02 10 10 10 02. Floor Structural Frame - Column	10 000	kg CO_2e	0.52 %
21-02 20 10. Exterior Walls	69 000	kg CO_2e	3.4 %
21-02 20 20. Exterior Windows	44 000	kg CO_2e	2.18 %
Electricity use	1 100 000	kg CO_2e	52.87 %
Total water consumption	630 000	kg CO_2e	31.18 %
Refrigerant leakages	34 000	kg CO_2e	1.7 %
Site electricity consumption	10 000	kg CO_2e	0.5 %

Figure 16: Emissions from various resource types after re-evaluation

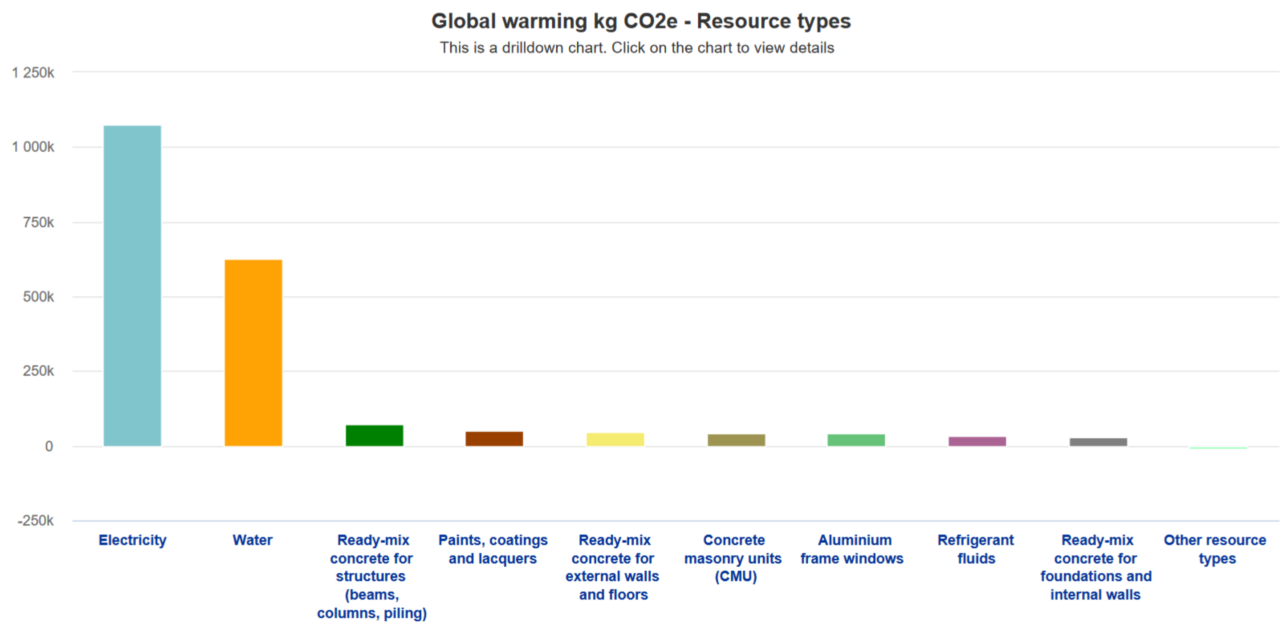


Table 12: Emission from materialization and operational stage after re-evaluation

Life cycle stage	Result category	Carbon emission (ton CO_2e)
Materialization stage	Materials used	284
Operational stage	Energy and water use	1730
Total carbon emissions		2014

Table 13: Disposal quantities for transportation and handling emissions after re-evaluation

S.no	Material resource	Calculated quantities (tonne)	Recycling quantities	Landfill quantities
1	Concrete	2299.968	229.968	2069.971
2	Brick	2248.08	224.808	2023.272
3	cement	970.2	97.02	873.18
4	lime	4.95	0.495	4.455
5	steel	1252.053	125.2053	1126.847
6	ceramic tile	974.754	97.4754	877.278
7	paint	0.3201	0.03201	0.288
8	plastic	22	2.2	19.800
9	wood	17.7445	1.77445	15.970
10	paper	0.2806	0.02806	0.252
11	plaster	69.228	6.9228	62.305

Table 14: CO_2 Transportation emission after re-evaluation

$Q_{bs,k}$	$e_{d,j}CO2$	D_{bs}	$Q_{sc;k}$	D_{sc}	$Q_{cr;k}$	D_{cr}	$Q_{sl;k}$	D_{sl}	Transporation Emission
2299.968	0.000168	32.38	459.9936	9.11	459.9936	25.16	1839.974	26.78	23.43793
2248.08	0.000168	32.38	449.616	9.11	449.616	25.16	1798.464	26.78	22.90916
970.2	0.000168	32.38	194.04	9.11	194.04	25.16	776.16	26.78	9.886866
4.95	0.000168	32.38	0.99	9.11	0.99	25.16	3.96	26.78	0.050443
1252.053	0.000168	32.38	250.4106	9.11	250.4106	25.16	1001.642	26.78	12.7591
974.754	0.000168	32.38	194.9508	9.11	194.9508	25.16	779.8032	26.78	9.933274
0.3201	0.000168	32.38	0.06402	9.11	0.06402	25.16	0.25608	26.78	0.003262
22	0.000168	32.38	4.4	9.11	4.4	25.16	17.6	26.78	0.224192
17.7445	0.000168	32.38	3.5489	9.11	3.5489	25.16	14.1956	26.78	0.180826
0.2806	0.000168	32.38	0.05612	9.11	0.05612	25.16	0.22448	26.78	0.002859
69.228	0.000168	32.38	13.8456	9.11	13.8456	25.16	55.3824	26.78	0.705471
								Total	80.0934

Table 15: CO_2 Handling emissions after re-evaluation:

Material resource	Calculated quantities (tonne)	Handling emission factors (tonne/tonne)	Landfill emissions (tonne)
Concrete	1839.974	0.13	239.1967
Brick	1798.464	0.03	53.95392
cement	776.16	0.02	15.5232
lime	3.96	0.02	0.0792
steel	1001.642	0.03	30.04927
ceramic tile	779.8032	0.018	14.03646
paint	0.25608	2.25	0.57618
plastic	17.6	0.02	0.352
wood	14.1956	0.05	0.70978
paper	0.22448	2.25	0.50508
plaster	55.3824	0.02	1.107648
		Total	356.0894

The impacts of the apartments have been re-assessed over the span of 50 years after assigning the materials and necessary datasets with mitigation strategies, producing materialization and operational stage carbon emissions are 284 and 1730 tonC02 respectively and the total amount of transportation and demolition stage emissions are 436.18 tonsC02. From the above results, it is evident that 29.35% and 14.77% reduction has been achieved in materialization and operational GHG emissions respectively by implementing the mitigation strategies. End-of-life phase emission has been reduced up to 11.53% respectively.

5. Conclusion and recommendations

This study has developed an integration between the BIM, LCA, GIS, and mathematical calculation of disposal GHG emissions provided significant advantages i.e., BIM could generate material data directly, which efficiently simplifies the data-collecting, and lessens the laborious task of manual data processing, and the associated possibility for inaccuracy. Through BIM, the features and design aspects of the building are represented digitally. Because of this, the building information obtained by BIM is more precise and comprehensive than the information obtained from conventional estimating techniques. A detailed evaluation of the lifecycle performance of buildings is achieved by incorporating the entire lifecycle assessment into the proposed technique. In-depth analyses and the identification of unsustainable materials and procedures are achieved by the automated generation of more comprehensive and comparable LCA data. To ensure the development of targeted reduction strategies, precise CDW information estimate and CDW disposal GHG emission measurement are also essential, which have been integrated into the framework using mathematical formulae calculations. Furthermore, as all the essential facilities that are not established in Islamabad region have been proposed and an optimized route along the facility centers has been designed using GIS to enhance the recycling of waste, and to lower the burden on the landfills. The whole framework has been critically validated on a case study in order to find its effectiveness and efficiency of the framework. From the results presented in section 4, 29.35% and 14.77% reduction has been achieved in materialization and operational GHG emissions respectively. End-of-life stage emission has been reduced up to 11.53%.

Hence, it is apparent that the framework has enhanced eco-efficiency and sustainability in the construction sector by reducing the GHG emissions of buildings.

However, there are multiple opportunities present for future research as this framework has integrated four aspects i.e., BIM, LCA, GIS, and mathematical calculation of disposal GHG emissions, other sustainable design methodologies and software could be integrated into the framework for more increment in sustainability and environmental safety. Secondly, this framework is more focused on the calculation and reduction of CO_2 emissions so other GHG gases could be evaluated for further enhancement of eco-efficiency. Thirdly, this research proposed CDW disposal methods from an environmental protection perspective. However, since handling certain CDW has no environmental risk, other handling considerations including financial advantages could be made. Thus, future research might include an evaluation of the trade-offs between the environment and the economy, as well as a CDW economic benefits analysis.

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