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Evaluation of Energy Consumption in Construction

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Abstract:
Construction projects consume a large amount of energy during construction as well as operation Phases in various forms for transportation, manufacturing, labour and machinery in construction activities. Energy efficiency is a vital issue of any building project. In recent years, many energy optimization techniques have been used to raise the efficiency of energy utilization. Most of the research conducted towards quantifying the energy consumption in buildings focuses only on the operation phase and hence sidelines the opportunity to decrease other building-related energy consumption. This energy consumption in construction during the construction phase has large scale cumulative environmental impacts at the national level.

This paper demonstrates a method to automatically quantify the 'Embodied Energy of various raw materials' used in construction projects. And also we calculated transportation energy for construction material and personnel transportation energy involve in whole construction project. For this, BIM technology has been used and a convenient linkage between the BIM model and external energy databases has been established through plug-ins developed exclusively for this purpose.

Keywords:*BIM, Plug-in development, SQL , Embodied Energy.*

I. INTRODUCTION

The primary concern of now a day is energy use and the issues arising out of its use. Based on the International Energy Agency (IEA) data, the world's Total Primary Energy Supply (TPES) for 2017 peaked at 13651 Million Tonnes of Coal Equivalent (MTCE), releasing a whopping 32,316 Million Tonnes of energy-related CO_2 emissions in the atmosphere [1]. These figures are at all-time high and a dreadful concern for climate scientists. Out of this, building and building construction sectors combined be responsible for 36% of worldwide final energy expenditure and nearly 40% of total direct and indirect CO_2 emissions [2]. These figures indicate the urgent need to work towards actionable plan to bring down the energy consumption and attempt on a war-foot to reduce the environmental effect of our industry. Due to the highly complex and fragmented nature of the construction industry, every project is unique in itself. Due to this fact, it is a daunting task to study and identify the critical areas in a construction project which consume large amounts of energy and attempt to reduce the same by using traditional methods. In this context, the recent development in multi-dimensional CAD technology presents a good hope. Building Information Models (BIM) offer a 360º view by adding Time & Cost factors to a conventional 3D drawing, thus effectively transforming it into a 5D model. This helps the project stakeholders: owners, planners,designers, contractors and clients to have a

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holistic view and information about the real-time state of the project at any given time. Although BIM as technology is quite old, it has evolved since its inception into a much advanced and robust tool in the hands of the decision-makers more in the last decade and still in the continual development stage. So the vital project contributors and participants can make the optimum use of this robust skill to enhance their decisions and construct better working strategies in effecting long-lasting and sustainable projects. BIM has become a mainstream hand tool which enables collaboration, data sharing between all the crucial project players on one single platform. This is fast changing the face of AEC industry to achieve ecological goals and efficiency.

To study, identify and attempt to reduce significant energy-consuming materials and activities in a project, we need to effectively organize that energy statistics and store it in an intelligent repository that can hold and extract this data when required in the desired format. This is where BIM technology comes handy. A BIM model contains the geometrical data of a building along with the properties of the significant elements but lacks the energy data of the same. However, the BIM authoring tools are flexible enough to hold additional information and perform various tasks based on combined built-in and external data. But adding the massive energy values data manually to a BIM model would be a herculean task and there is a need to automate the process.

Hence, this research aims to find the total energy expenditure in a building, and suggest some options to reduce the same. The key objectives of this research study are:

1. Using BIM to study the total energy expenditure during the construction phase of a Building.
2. To quantify the initial energy content in the project, including embodied energies of materials and transportation energy consumed in construction activities.

II. LITERATURE REVIEW

Various literature has been referred to for this research and has been explained herewith.

IEA, Key World Energy Statistics [1], have compiled the Global Energy Data and published key energy statistics which are updated every year. Their study reveals crucial information about Energy sources, production, consumption and reserves of the world by region. This proves to be very useful for Research Scholars and Governments and policymakers of the world.

IEA, Energy Technology Perspectives, 2017 [2], is a compiled report of current global energy scenario, trends and future recommendations for a cleaner environment for global policymakers.

Jones[3],https://www.igbc.ie/resources/inventory-of-carbon-and-energy/ developed a comprehensive database of embodied energy and embodied carbon of materials. *Inventory of Carbon and Energy (ICE)* is considered to be an international benchmark for all industries. It contains the embodied energy coefficients of various industrial raw materials and encompasses an exhaustive list of over 200 materials.

Co-Funded by the European Union [4], International finance corporation (IFC) has developed a database of environmental impacts of compressive set of materials used in construction within India and compiled a report on the same-named as India construction material database of embodied energy and global warming potential methodology report.

Zhang et al., [5] tried to examine the total energy consumption in delivering construction projects with the help of BIM technology and ran several simulation studies for the same. They created a BIM model in *Revit* and also created a *plug-in* to link BIM data with an external database. Finally, they also used energy simulation software *Simphony* to analyze the potential to reduce energy consumption. They found that embodied energy in construction materials accounts for 90% of the total energy utilization of the building. However, their study used

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simple simulation models and lacked professional effectiveness.

Nizam et al. [6] presented a structure to evaluate the embodied energy content inside the native BIM environment. They had deployed *Autodesk Revit 2016* as the BIM authoring tool and developed a *plug-in* to integrate the embodied energy data from an external database into the model and hence automate the energy estimation process.

Shadram et al. [7] proposed a framework for assessing the embodied energy in a building material supply chain and evaluated the same by the use of a prototype in a case study. The prototype of their proposed framework uses *Autodesk Revit* as the BIM authoring tool, *Feature Manipulation Engine (FME)* as the spatial ETL tool, *Google Maps (GM)* API as the map web service API, and *Power Pivot* – which is an add-in to *Microsoft Excel* – for implementing the rest parts of the proposed framework like setting up the database model and assessment of the embodied energy.

Rock et al. [8] proposed a methodology utilizing BIM to assess an extensive range of construction options and their embodied environmental impact. This will support decision making in the early design phase. They used *Autodesk Revit* to develop the BIM model, *MS Excel* to create an aggregated Life Cycle Analysis (LCA) database and the visual scripting software is *Autodesk Dynamo* for establishing an automated link between the other two.

Davies et al. [9] studied and demonstrated practical difficulties and opportunities for delivering improved initial embodied energy efficiency in a construction project. They found that material phase impacts represented a significant proportion (95.1%) of the total initial embodied energy consumption. They explored the practices followed by contractors on-site and improved them in an attempt to address the initial embodied energy issue.

Autodesk White Paper [10] One of the primary industry players in the engineering software domain and pioneering developers of BIM software environment, Autodesk, have published this White Paper on BIM technology, to explain the wonderful features of BIM and how it enables the AEC industry to achieve optimal solution to their existing challenges and also helps the professionals in their endeavour to avoid any future issues in advance.

Guan et al. [11] proposed a method to analyze the energy preservation of high rise buildings based on BIM technology. They found that BIM technology can be used effectively to optimize building design and hence improve the Green Building performance & decrease building energy consumption. Although they also found that while transferring the BIM data into an environmental energy analysis tool, there is loss of some data significant to the analysis process, hence there is a need to solve this issue.

From the literature review conducted herein, it was found that previous researchers have conducted extensive studies on both BIM and energy consumption, but the main focus of this study lies in integration and automation of the energy values. Eddy Krygiel et al,[12]"Green BIM: Successful Sustainable Design with Building Information Modelling." In this paper as an innovation, BIM is more than software but rather a new design paradigm and methodology using sophisticated computer tools. Chuck Eastman Paul et al., [13]"BIM Handbook A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Contractors, Second Edition. " John Wiley & Sons, Inc. Copyright © 2011 by John Wiley & Sons, Inc. All rights reserved. Published by John Wiley & Sons, Inc., Hoboken, New Jersey published simultaneously in Canada.

Sergio Pinheiroa et al, [14]; "MVD based information exchange between BIM and building energy performance simulation." This paper proposes a standardized method of information exchange between Building Information Modelling (BIM) and BEPS tools using the Information Delivery Manual (IDM) and Model View Definition

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(MVD) methodologies. Through the development of a specific MVD that defines a subset of the IFC data model that deals with building energy performance simulation. By doing so, the potential of BIM-based simulation can be fully unlocked, and a reliable and consistent IFC subset is provided as an input for energy simulation software.

The conclusions of the literature review study have been summarized below:

1. BIM technology has existed for a few decades now but remained in the shadows until lately. BIM offers an excellent tool in the hands of the project stakeholders and enables a share-able, multi-dimensional real-time view of the project.
2. Energy consumption in general and especially in the construction industry is a major challenge faced by global policymakers. Hence, major studies have been conducted by researchers till now in an attempt to reduce the energy usage on construction projects.
3. Most of the studies conducted till now have focused majorly on energy saving during the occupational phase only and very little attention has been paid to reducing the embodied content of materials and construction activities during the construction phase.
4. Even if the study was done with the help of BIM, the energy data was used from outside and the computation of energy consumption had to be done manually.

III. METHODOLOGY

The entire process of this research has been divided into FIVE parts: Data Collection, External Energy Database, BIM Model, Development of Plug-in, and Embodied Energy Calculation. The main aim of this research is to demonstrate a method to quantify the Embodied Energy in Construction Project during construction phase. In the present study, first a BIM model of a building used in the present case study is developed using Revit software. Revit stores and integrates the data regarding quantity of each material used in construction automatically. Revit is an intelligent software but lacks the energy content values of various construction materials. Fortunately, it has a feature to link and integrate external data sets within the model. The International Finance Corporation (IFC) has developed a database of environmental impacts of comprehensive set of materials used in construction industry within India. The same has been used in the present study and a master database has been compiled and named as External Database. This external database cannot in and by itself help in our computations, and there is a need to bridge the gap to link the External Database with the BIM Model. For this purpose, a plug-in has been developed using Structured Query Language (SQL). So once the BIM model is ready the Embodied Energy content in any desired material used in the structure can be easily and automatically found by running the query on that particular material. The entire flow of the research has been shown below. In the present study, embodied energy content in construction materials and the transportation of materials & personnel have been considered, but the same can be easily scaled up to encompass the entire spectrum of Embodied Energy including that by machines during construction activities.

The flow of the study:- All in all, the entire process flow will be divided into the following steps:

Step#1: Development of 2D CAD Model → Autodesk AutoCAD 2016

Step#2: Development of 3D BIM Model → Autodesk Revit 2018

Step#3: Acquiring Embodied Energy Database → IFC Database

Step#4: Developing a Plug-in (Bridge between → Programming Language C#
BIM and External Database)

Step#5: Finding Energy Consumption Values

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IV. DATA COLLECTION

TWO databases were identified to acquire the values of embodied energy coefficients of different construction materials:

(1.) *Inventory of Carbon and Energy (ICE)* [1]which is considered to be an international benchmark for all industries. It contains the embodied energy coefficients of various industrial materials and encompasses an exhaustive list of over 200 materials.

(2.) *India Construction Materials Database for Embodied Energy and Global warming Potential* (*ICMDEEGWP*) [3]which is an embodied energy database prepared by the International Finance Corporation (a World Bank Initiative) with support from the European Union, especially prepared for Indian conditions. This database is used to collect the embodied energy coefficients data in this project.

Out of the two selected databases, the ***India Construction Materials Database of Embodied Energy and Global Warming Potential*** published by International Finance Corporation (IFC) is considered to be more relevant to Indian conditions and hence referred to for the purpose of calculations. A sample excerpt from the same is presented herewith (with due permission of IFC).

ANNEX A: EMBODIED ENERGY AND GLOBAL WARMING POTENTIAL RESULTS

Table 14: below presents the embodied energy and global warming potential results for the materials included in the India Construction Materials Database. Embodied energy results represent the total primary energy demand from renewable and non-renewable resources based on the net calorific value (lower heating value) and excluding any renewable feedstock energy. Global warming potential is calculated using the IPCC AR5 characterization factors over a 100-year time horizon and including biogenic carbon emissions - IPCC AR5 GWP100, including biogenic carbon (IPCC, 2014).

Table 14: Embodied energy and global warming potential results for India Construction Materials Database

Material Name	Embodied Energy (MJ)	GWP (kg CO_2 eq.)
Adhesive for parquet	130	6.7
Aggregate (mixed gravel/crushed stone)	0.11	0.0090
Aircrete (autoclaved aerated concrete)	3.7	0.50
Air-dried sawn timber	4.1	-1.3
Aluminum extruded profile	330	33
Aluminum extruded profile (window frame)	280	26
Aluminum ingot	310	31
Aluminum profiled cladding	360	35
Aluminum sheet	330	32

Figure 1 - Annex A : Embodied Energy Coefficient

A. Development of the Embodied Energy Database:-

The Embodied Energy coefficients as obtained from the Indian Construction Material Database were entered in SQL tool to create an External Energy Database. The following figure shows a sample screenshot of the Embodied Energy record created for a CLC Block.

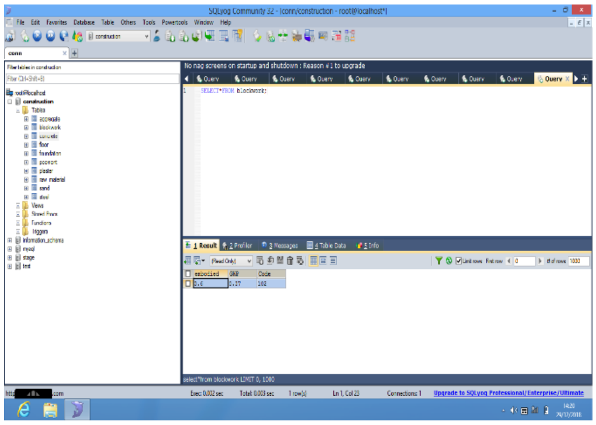

Figure 2- Embodied Energy Database (SQL Software)

B. Development of Plug-in:-

Finally, a plug-in was developed to fetch embodied energy data for various construction materials as recorded in the External Database (as shown above in Fig No 5.4.1). The software programming of the plug-in was done in C#. It acts as an intelligent bridge between the BIM data and the External Database to automatically calculate the values of Embodied Energy for various construction activities.

Net Beans software information:- Net Beans is an integrated development environment (IDE) for Java. Net Beans allows applications to be developed from a set of modular software components called modules. Net Beans runs on Windows, macOS, Linux and Solaris. In addition to Java development, it has extensions for other languages like PHP, C, C++, HTML5,[4] and JavaScript. Applications based on Net Beans, including the Net Beans IDE, can be extended by third party developers.

Net Beans IDE 8.2 was released on 3 October 2016.

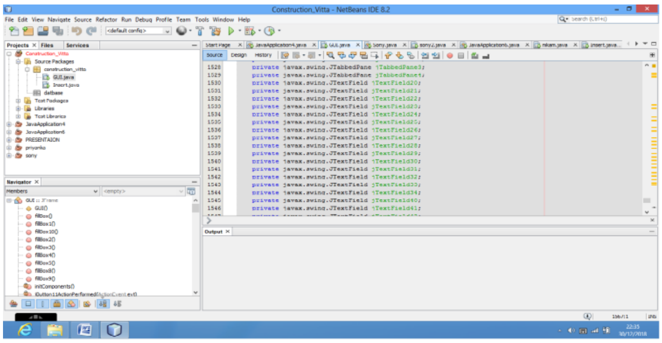

Figure 3-Net Beans IDE 8.2 software programmed

C. Embodied energy Calculation:-

(I.) Embodied Energy in Materials:

The BIM Model can be queried to obtain the material consumption values of various materials used in the building, and the Embodied Energy Coefficients data of materials can be fetched from the External Energy Database linked to the BIM Model through the plug-in. From this, the Embodied energy Content of various construction materials are directly obtained on screen.

(II.) Embodied Energy in Transportation:

One of the main categories of Embodied content apart from the materials consumption is that of 'Transportation of Materials & Personnel'.

Various construction materials are brought to site through various types of vehicles which consume fuel energy. This data is collected from the material inward register from site store. The data is recorded in a systematic manner in the specially designed data collection form. For the vehicle fuel efficiencies, average values were taken by interviewing the material suppliers from their usage pattern.

The second type of transportation data to be collected was that of 'Personnel Transportation' to and from the site. Personnel include Staff and Labour. Through onsite enquiries it was known that there were labour colonies established onsite to avoid daily transportation costs of the daily wages labour. Hence, the personnel transportation data contains only that of direct employees of the developer and contractor. Also it was known that the employer was not providing any common transport service to the site staff and the personnel were reaching the site with their own private vehicles.

This data contains information about the daily fuel energy consumption for transportation of working staff for travelling to and from the site and is obtained through onsite interviews. A structured data collection form was designed and distributed to the staff and they were requested to fill in the data pertaining to their daily travel to the site.

A. Case Study:

The ongoing project of Jaikumar Construction is a high-rise residential mass-housing project being developed by PARKSYDE HOMES at Adgaon, Nasik. The project comprises of a total of Five Construction Phases. Out of the total Five Phases, Three Phases have been already handed over. The fourth phase is about 90 percent complete, while the last phase is under construction. Masonry work is done in Autoclaved Aerated Concrete (AAC) Blocks and the developer has established their own RMC plant on site.

Figure 4 - Uunder–construction Multi-storey Bbuilding at Parksyde Homes

B. Site details:

1. Name Of Company: Jaikumar Construction LLP. Nasik
2. Project Name: Parksyde Homes
3. Owner: Mr. Gopal Atal and Mr. Manoj Tibriwala
4. Location: Parksyde Homes, Hanuman Nagar, Opp. Rasbihari High School, Adgaon, Nasik.
5. Area Of Site : 25 acres
6. Type of Building : High-Rise Structure
7. Type of Structure : G+ 15 RCC Constructions
8. RCC consultants : J.W. Consultants
9. Architect Name : Mr. Umesh Bagul

The above picture shows actual material consumption data for RCC components for Building I of the project which is a 15 storey building comprising of 3-BHK Flats. Due to insufficient availability of data, some values needed to be assumed to account for the material consumption for the entire building.

The material consumption data obtained as above was in raw form and not directly usable for the calculations of Embodied Energy. Hence the same was converted in unified unit (Kg) by using suitable conversion factors from their unit weights

V. RESEARCH WORK

A. Model:-

From the collected data, various analysis were performed and the details of the same along with the results and discussions thereof are presented in this chapter.

First, the 2D Drawings were prepared in AutoCAD 2016 from the data obtained from site and then these drawings were imported in the BIM software and a 3D Model of the same was prepared. Autodesk Revit 2018 was used as the BIM authoring tool for the purpose of modeling of the building. The developed 3D BIM Model is shown in the figure below.

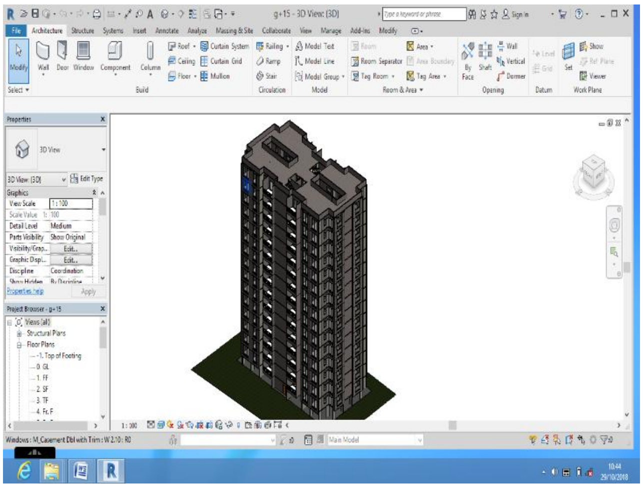

Figure 5 - BIM Model of the building under study

B. Material Consumption Data Analysis

The raw data about material consumption as obtained from site interviews was very crude and incomplete. So to make it usable it had to be converted into standard and uniform units. The following tables show the raw data first converted into standard metric units and then converted into unified unit of “Kg” by using various standard conversion factors. This was required as the Embodied energy Coefficients of various materials are available in the form of MJ/ Kg.

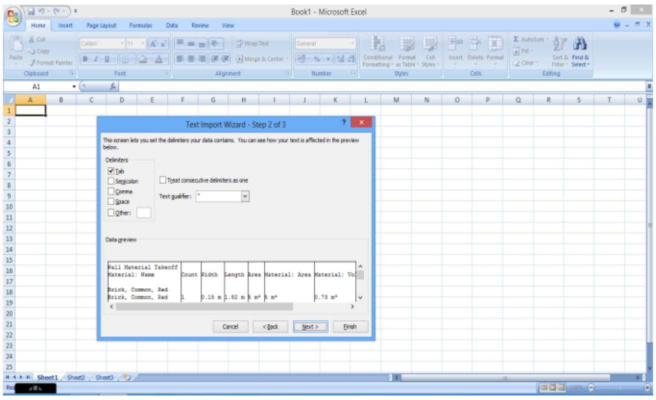

Fig 6 Material Quantities exported to Excel

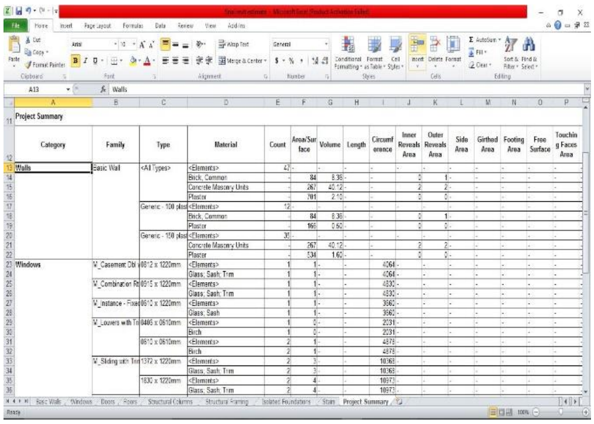

Fig 7 Material Quantities imported in Excel

Table No-1 On-site Material Consumption Data (Converted in Kg)

Work Item	Qty	Unit	Cement (kg)	F.A (A.S) (kg)	C.A (20 Mm) (kg)	R/F Steel (kg)	Clc Blocks
Concreting (1:2.8:2.94)	2497.79	cum	892956	2508620	260162		
Plastering	2772	Sq.M	13860	46957.30			
Blockwork		Sq.M					

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110 mm thk (630 x 230 x 100)	3052.5	Sq.M				21300	21300
150 mm thk (630 x 230 x 150)	4134.45	Sq.M				27900	27900
Reinforcement	348.04	M.T			351.52		
Total Quantity			**906816**	**2555578**		**49200**	49200

The above data was now finally ready to be fed into our Database for Embodied Energy Calculations.

The following figure shows a sample calculation of the Embodied Energy for Concreting activity in one entire Fifteen storey building (Wing-I) of the project comprising of all 3-BHK Flats.

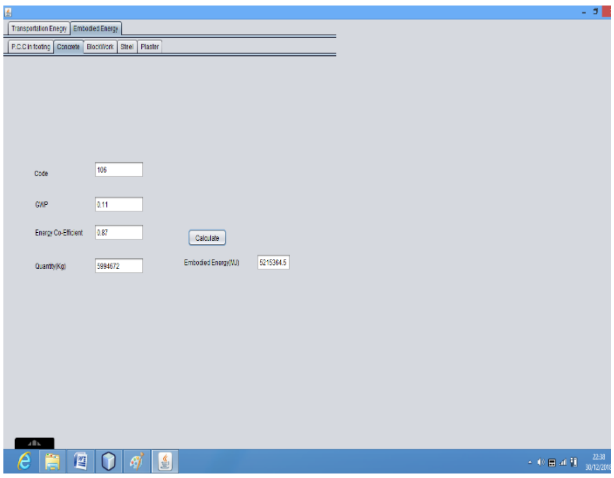

Figure 8 Final Energy values of different materials

C. Transportation Data Analysis

(i.) Material Transportation:

As shown here, the transportation data of different materials was obtained from site and fed into the standard form in our software. A few values like number of round-trips of the vehicles, distance per trip and vehicle mileage etc. need to be input by the user and the software automatically calculates the Embodied Energy content in the transportation of the material in consideration. The records tab in the end shows the record of all the data entered till date in a consolidated format.

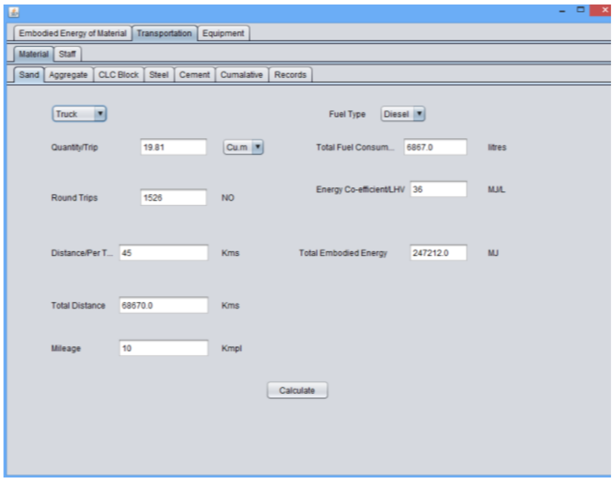

Figure 9. Embodied Energy of Transportation Of Material

(ii.) Personnel Transportation:

This data involves a separate form similar to the material transportation data above, where user can input the transportation data of site personnel like vehicle type, round-trip distance, number of working days and mileage of vehicle etc.

The data obtained from the site about staff transportation was raw and mixed. So a separate table was first prepared to segregate the vehicles data according to 4 wheelers and 2 wheelers and also according to the type of fuel like Diesel & Petrol.

This segregated data was ready to be fed into our software individually according to the vehicles.

After entering the information, the software calculates the Embodied Energy content in the transportation of the site personnel individually. In the records tab, the entire data input till date can be seen.

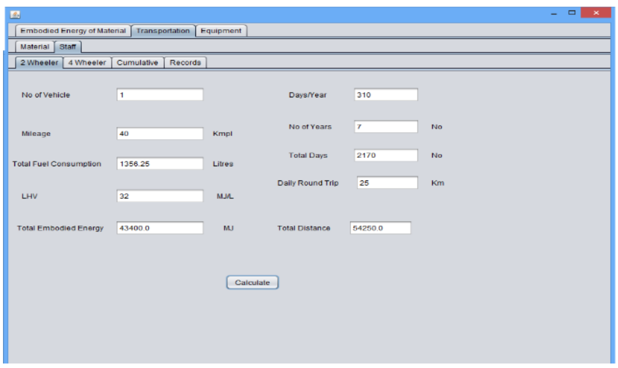

Figure 10 Personnel Transportation

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VI. RESULTS AND DISCUSSIONS

.) *Embodied Energy in Material Consumption*:

The following results regarding the Embodied Energy Quantification have been compiled from the work done till date. These results show the Embodied Energy consumed for One 15 Storey Building.

Table No-2 Results of Total Energy consumption ofmaterial

Sr. No.	Activity	Total Quantity	Unit	Embodied Energy (MJ)
1	**Concreting**	**2497.78**	**Cum**	**521536.5**
2	**Plastering**	**2772**	**Sq.M**	**93277.8**
3	**Block work**	**7186.95**	**Sq.M**	**1976493.5**
4	**Reinforceme nt**	**348.04**	**M.T**	**16441200**
	Total Embodied Energy		MJ	19032507.8

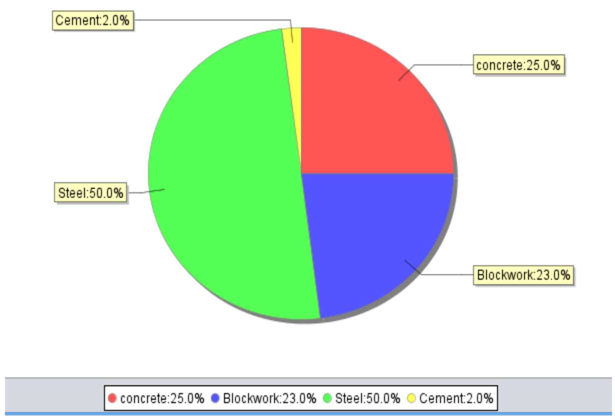

Figure 11 Result Graphs of Total Embodied Energy of Materials

(B.) *Embodied Energy in Transportation*:

The embodied energy in the transportation category consists of that consumed in transporting materials and personnel. This energy is used in the form of fuel consumed by the material carrying trucks like petrol and diesel.

The below Table 3 shows the values of embodied content in transportation of materials through trucks. The logic behind the calculation is to find out the average fuel consumption of the carrying vehicle and multiply it with the total distance travelled to get the total fuel consumption on the entire project for the transportation of that material. Finally, multiplying the total fuel consumed with the LHV of that fuel to get the embodied content.

Table No 3 Energy Consumption In Transporting Construction Materials.

Sr. No .	Material	Quantity/ Trip	Unit	Embodied Energy (MJ)
1	Cement	500.00	Bags	2026800
2	Sand	19.81	Cu.M	247212
3	Aggregate	19.81	Cu.M	301644
4	Steel	20.00	M.T	170755.2
5	CLC Blocks	1200.00	No.	466200
	Total			**3212611.2**

Similar to the above logic, fuel consumed in the transporting of personnel is calculated and multiplied with the fuel's LHV to get the total embodied energy in the transportation of personnel on the site

Table No 4 Energy Consumption Of Personnel Transportation

Sr. No.	Veh. Type	Fuel	Total Consumption	Embodied Energy
	2W/ 4W	Pet/Die/Gas	(L)	(MJ)
1	4W	Diesel	14225.56	512120.16
2	2W	Petrol	26796.74	857495.68
Total				**1369615.84**

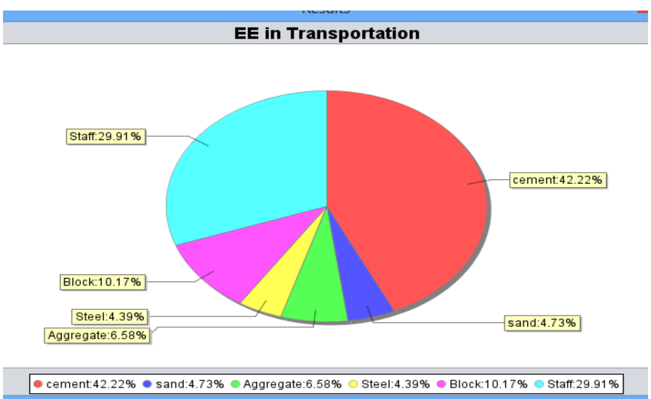

Figure 12. Result Graphs for Total Energy Consumption in Transportation.

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VII. CONCLUSION

(1.) In this work, the Embodied Energy of a fifteen storey residential apartment building project for four major activities viz.Concreting, Reinforcement, Block work and Plastering is computed by using construction material data and by applying the standard Embodied Energy Coefficients to the respective quantities of different materials consumed during the construction phase.

(2.) The calculated Embodied Energy for the building in the present case study is found to be 19.032 TJ (Tera Joules)

(3.) The combined Embodied Energy content in the transportation of Materials & Personnel was found to be 4.582 TJ (Tera Joules).

(4.) By developing Simulation Models for energy consumption in materials for different scenarios, the energy efficiency of the building project could be largely increased.

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