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Investigation of Carbon Footprint on Pre-Engineered Building Using Building Information Modeling and One Click LCA

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ABSTRACT –

This study aims to assess the carbon emissions of a pre-engineered building developed in Revit using One Click LCA software. The pre-engineered building is a popular choice for construction due to its ease of assembly and cost-effectiveness. However, the carbon emissions associated with the production and transportation of building materials, as well as the energy consumption during the building's lifespan, are significant. One Click LCA software is used to estimate the carbon emissions associated with the pre-engineered building's construction and operation phases. The software utilizes building information modelling (BIM) data from Revit to generate an accurate assessment of the building's carbon footprint. The results of the assessment provide valuable information for building designers and developers to reduce carbon emissions and improve the building's environmental performance. By identifying carbon emissions hotspots, such as materials and energy use during operation, strategies can be developed to reduce the building's carbon footprint. Overall, this study highlights the importance of assessing carbon emissions in building design and construction and demonstrates the effectiveness of One Click LCA software in providing accurate and efficient carbon emission assessments.

Keywords – BIM, One click LCA, life cycle analysis, pre-engineered building.

1.Introduction

The construction industry is one of the major contributors to global carbon emissions, and there is a growing need to develop sustainable building solutions that minimize environmental impacts. Pre-engineered buildings (PEBs) have gained popularity in recent years due to their ease of assembly, flexibility and cost-effectiveness. However, the carbon emissions associated with the production and use of PEBs are not well understood. Life cycle assessment (LCA) is a valuable tool to evaluate the environmental impact of building construction, and can help identify areas for improvement in terms of reducing carbon emissions. In this study, we will conduct a life cycle assessment of the carbon emissions associated with the production and use of a pre-engineered building, using the One Click LCA software. One Click LCA is a powerful LCA software that allows for quick and easy calculation of building carbon emissions, and is designed to work seamlessly with building design software such as Revit and STAAD.Pro. This software will enable us to accurately model the PEB and evaluate its environmental impact throughout its entire life cycle, from raw material extraction to end-of-life. The results of this study will provide valuable insights into the carbon footprint of PEBs, and will help identify areas for improvement in terms of reducing the environmental impact of PEBs. The use of One Click LCA will ensure that our assessment is accurate and reliable, and will contribute to the growing body of research on sustainable building solutions.

Building information modelling (BIM):

It Building Information Modelling (BIM) is a digital tool that has revolutionized the construction industry in recent years. BIM enables the creation of a virtual model of a building, incorporating all of its components and systems, and facilitating collaboration between various stakeholders. BIM has a significant role to play in the development of pre-engineered buildings (PEBs) and the assessment of their carbon emissions.

In the development of PEBs, BIM can be used to create a detailed model of the building, incorporating all of its components, such as the steel frame, insulation materials, cladding, roofing, and flooring. This model can be used to optimize the design of the building, ensure that all components fit together correctly, and minimize waste and material usage during construction. BIM can also be used to facilitate collaboration between various stakeholders, including architects, engineers, and construction workers, ensuring that the building is constructed efficiently and accurately.

In terms of carbon emission assessment, BIM can be used to calculate the carbon emissions associated with the production and use of a PEB. BIM models can be integrated with life cycle assessment (LCA) software, such as One Click LCA, to evaluate the environmental impact of the building throughout its entire life cycle. This includes the carbon emissions associated with the production of building components, transportation, construction, operation, and end-of-life. The BIM model can also be used to track energy usage during the operation of the building, allowing for the identification of areas for improvement in terms of reducing energy consumption and carbon emissions.

In conclusion, BIM has a significant role to play in the development of pre-engineered buildings and the assessment of their carbon emissions. By facilitating collaboration and optimizing building design, BIM can help minimize environmental impacts during construction. By integrating BIM models with LCA software, the carbon footprint of PEBs can be accurately assessed, and areas for improvement can be identified to minimize the environmental impact of the building throughout its entire life cycle.

2. LITERATURE REVIEW

Pre-engineered buildings (PEBs) are widely used in the construction industry due to their fast and cost-effective construction process. However, PEBs can also contribute significantly to carbon emissions during their life cycle, including the production of raw materials, manufacturing, transportation, construction, use, and end-of-life disposal. To understand the environmental impact of PEBs, a life cycle assessment (LCA) can be conducted. This literature review aims to provide an overview of the existing literature on LCA studies of PEBs' carbon emissions.[1]

Carbon emissions in the manufacturing stage

The manufacturing stage of PEBs involves the production of steel, the primary material used in PEBs. Several studies have focused on the carbon emissions associated with the steel production process, including the extraction of raw materials, transportation, and energy consumption during manufacturing. For example, Li et al. (2019) conducted an LCA study of a PEB production system in China and found that the manufacturing stage was responsible for 60% of the building's total carbon emissions.[2]

Carbon emissions in the transportation stage

PEBs are often manufactured off-site and transported to the construction site, which can contribute significantly to the building's carbon emissions. Several studies have investigated the environmental impact of transportation in PEBs. For example, Sajedi et al. (2019) conducted an LCA study of a PEB in Iran and found that transportation accounted for 15% of the building's total carbon emissions.[3]

Carbon emissions in the construction stage

The construction stage of PEBs involves the assembly of the pre-manufactured components on-site. This stage can also contribute significantly to carbon emissions due to the energy consumption associated with on-site construction activities. Several studies have investigated the environmental impact of construction in PEBs. For example, Zhang et al. (2020) conducted an LCA study of a PEB in China and found that the construction stage accounted for 10% of the building's total carbon emissions.[4]

Carbon emissions in the use stage: The use stage of PEBs involves the building's operation, maintenance, and repair. This stage can also contribute to carbon emissions, mainly due to energy consumption during the building's use. Several studies have investigated the environmental impact of the use stage of PEBs. For example, Li et al. (2019) conducted an LCA study of a PEB in China and found that the use stage accounted for 25% of the building's total carbon emissions.[5]

Carbon emissions in the end-of-life stage

The end-of-life stage of PEBs involves the demolition and disposal of the building's components. This stage can also contribute to carbon emissions due to the energy consumed during the demolition process and the emissions associated with the disposal of the building's components. Several studies have investigated the environmental impact of the end-of-life stage of PEBs. For example, Liu et al. (2021) conducted an LCA study of a PEB in China and found that the end-of-life stage accounted for 5% of the building's total carbon emissions.[6]

This literature review highlights the importance of conducting an LCA study to understand the carbon emissions associated with PEBs' life cycle. The existing literature shows that the manufacturing stage is the most significant contributor to PEBs' carbon emissions, followed by the use stage and transportation stage. However, the contribution of each stage can vary depending on several factors, such as the building's location, design, and construction method. Therefore, it is essential to conduct site-specific LCA studies to identify the most significant sources of carbon emissions and develop appropriate mitigation strategies to reduce the environmental impact of PEBs.[7]

3. METHODOLOGY

METHODOLOGY
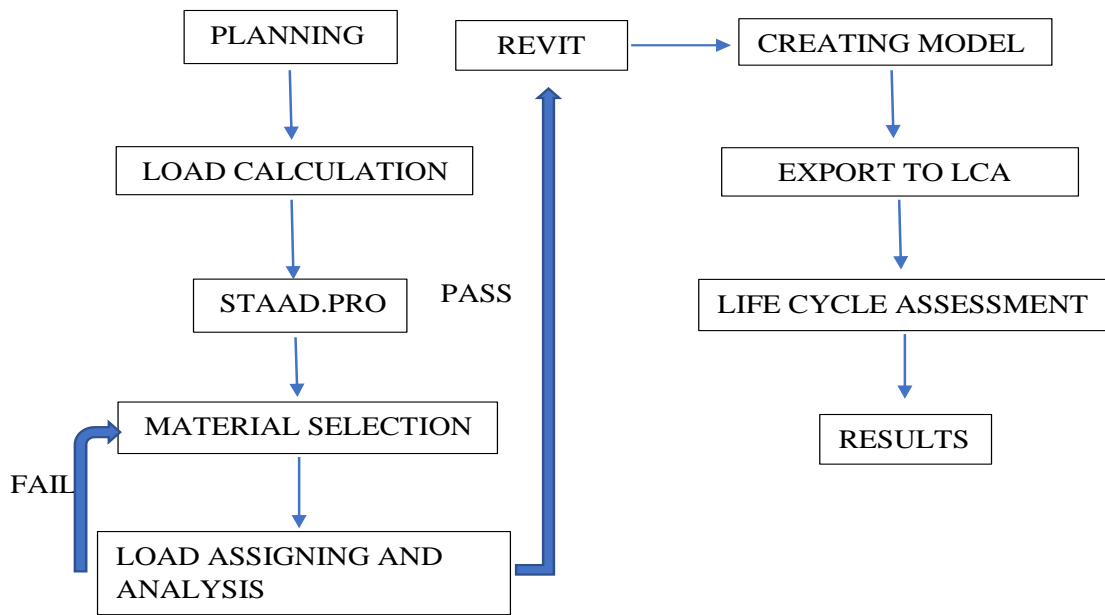
- Model the building using BIM software

- Calculations of loads using IS:875

- Drawing geometrical structure in staad.pro

- Assigning the materials and properties

- Assigning the loads and analysis, if it pass go to next step else assign other materials

- Developing 3D model in revit

- Export the drawing to LCA

- LCA will be done and the results are noted.

4. DETAILS OF THE STRUCTURE

4.1 Preparing plan:

The length of the structure = 50 m

Width = 20 m

Height = 10 m

Bay spacing = 5 m

Angle between the rafter and column   = 16.7^0
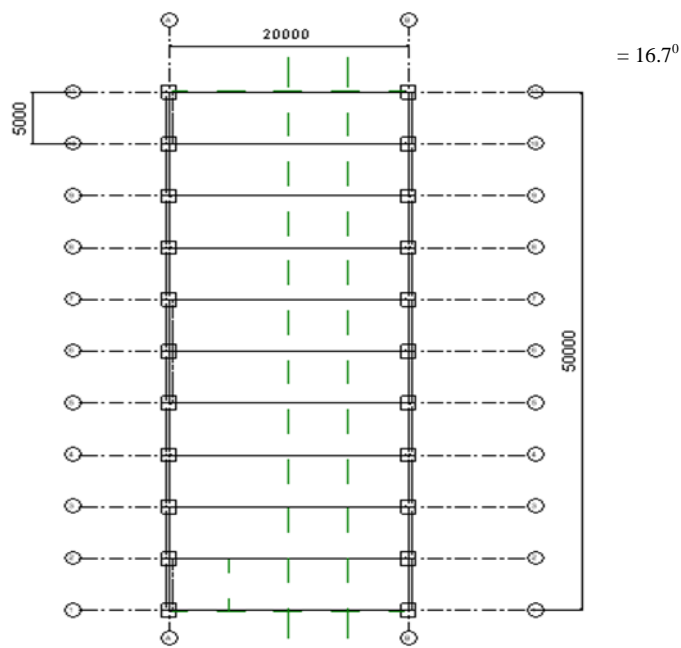
Fig1 : plan of the structure

4.2 Design of structure :

The design of the structure will be done by following steps:

- Load calculations

- Structural analysis using staad.pro

- Developing model in Revit

- Providing required connections

- **Load calculations:**

Load are calculated based on the code book IS:875 and Text book: Design of steel structures by S.S Bhavikatti.

- **Dead load :**

Dead load is calculated according to IS:875 (part 1) -1987.

Self weight of sheeting including laps and connections =   170 N/m2

Self weight of purlins = 100 N/m2

Spacing between the purlins = 1.69m

Total load on purlin = 170+100 = 270N/m2

Dead load = 270x1.69=472.5 N/m = 0.472 KN/m.

- **Live load :**

It is calculated according to Is:875 (part 2) – 1987.

Span of the rafter = 20m.

As slope of the roof = 16.7 > 10

So live load is given by: live load = 2/3[750-(θ-100)20]

                                                    = 412 N/m2

Spacing of purlin = 1.69m

Live load = 412x1.69 = 700 N/m = 0.7 KN/m

- **Wind load:**

Wind loads are calculated according to IS:875 (part 3) – 1987.

F = (C_{pe} - C_{pi}) x P_d x A

Where, C_{pe} = external air pressure coefficient

C_{pi} = internal air pressure coefficient

        A = Area under consideration

        P_d = design wind pressure

$C_{pi} = \pm 0.2$ [from 6.2.2.1 pg.37]

$P_d = K_c.K_a.K_d.P_z$ = design wind pressure

Where,

K_d = wind directional factor   [cl. 5.4.1]

K_a = area averaging factor   [cl.5.4.2]

K_c = combination factor   [cl.6.2.3.13]

$P_z = 0.6(Vz2)$ = wind pressure   [5.4]

$V_z = V_b.K_1.K_2.K_3.K_4$

Where,

V_b = Basic wind speed   [annex A]

k_1 = Risk factor   [5.3.1]

k_2 = Terrain, height, structure size factor.   [5.3.2]

k_3 = topography factor   [5.3.3]

k_4 = importance factor for the cyclonic reason.   [5.3.4]

- **Calculation:**

Length = 50 m   Bay spacing = 5 m

Width   = 20 m V_b = 50 (Visakhapatnam)

Height = 10 m   Terrain category =2

Slope   = 3:10

V_z = 50x1x1x1x1

= 50 m/s

$P_z = 0.6(502) = 1500$ N/m2 = 1.5KN/m2

$K_d=K_a=K_c = 0.9$

Pd = 1.09 KN/m2

For C_{pe}:

$h/w = 10/20 = 1/2$

$L/w = 50/20 = 2.5$ [table 5]

From 6.2.2.1

$C_{pi} = \pm 0.2$

Then the wind load on individual members can be calculated by using formula

$= F = (C_{pe} - C_{pi}) \times P_d \times A$

Also the wind loads can be automatically calculated and assigned in latest version of staad.pro.

Structural analysis using staad.pro:

1. Define the geometry of the pre-engineered building in Staad.Pro, including the dimensions of the building, the spacing of the columns, and the location of the bracing.

2. Define the material properties of the building components, including the properties of the steel members and the properties of the roof and wall panels.

3. Apply the appropriate loads to the building, including dead loads, live loads, wind loads, and seismic loads. Dead loads include the weight of the building components themselves, while live loads include the weight of people and equipment inside the building. Wind loads are

calculated based on the location of the building and the surrounding terrain, while seismic loads are calculated based on the seismic zone in which the building is located.

4. Analyse the building in Staad.Pro using the appropriate analysis method, such as the finite element method or the stiffness matrix method. The analysis will calculate the internal forces and moments in the building components due to the applied loads.

5. Check the stresses and deflections in the building components to ensure that they are within the allowable limits. If any components are overstressed or have excessive deflections, adjust the design or the loads accordingly.

6. Generate a report of the load analysis results, including the forces and moments in the building components, the stresses and deflections in the components, and any necessary design recommendations.

7. If necessary, repeat the analysis and design process with different loads or design parameters until a satisfactory design is achieved.
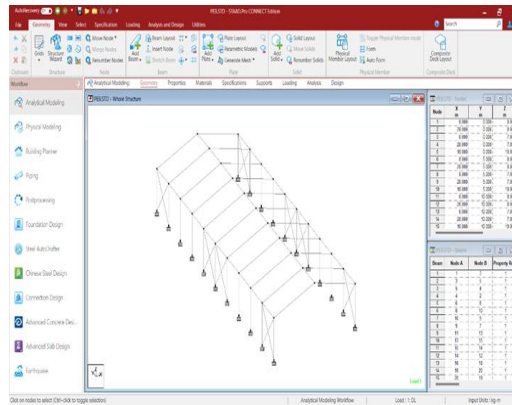

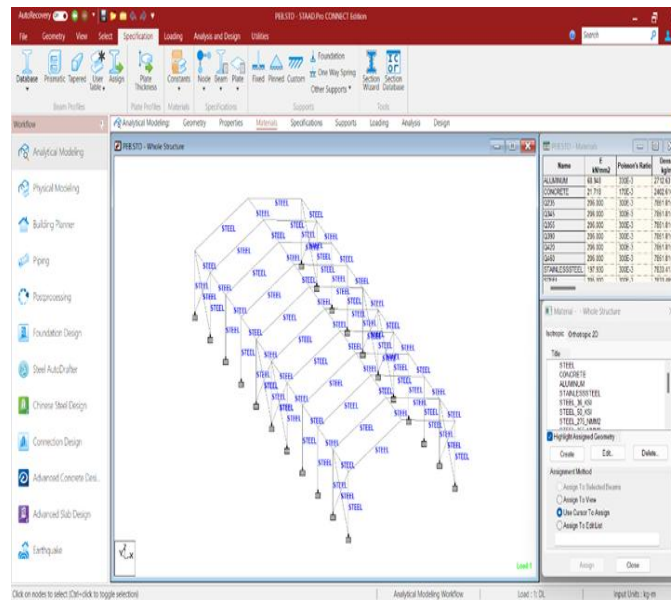Fig 2: Basic Geometrical structure

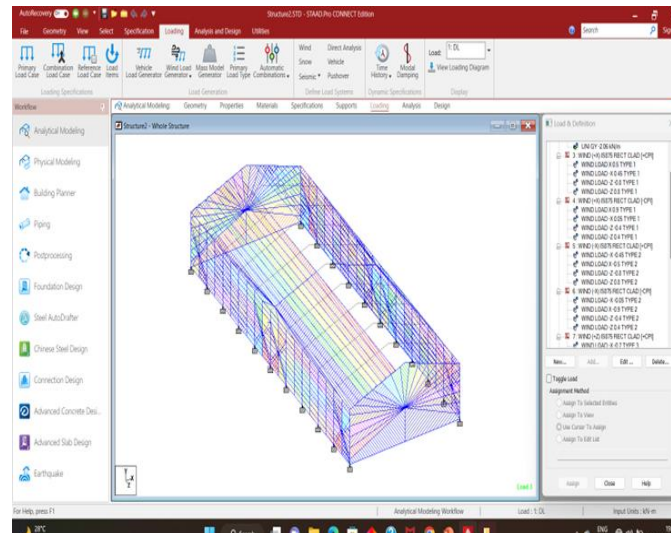
Fig 3: Assigning properties of materials

Fig 4: Load application

After that analysis should be conducted if there is no errors in the reports the we can develop the structure.

Developing structure in Revit:

1. Create a new project: Open Revit and create a new project with the appropriate template that has the correct units and parameters for your project.

2. Set up levels and grids: Establish the building's foundation by creating levels and grids to define the warehouse's height and layout.

3. Add structural framing: Begin adding structural framing members such as beams, columns, rafters and purlins by using the appropriate Revit tools. You can use the pre-built steel shapes that come with Revit, or import custom shapes if necessary.

4. Connecting structural members: To make the structure strong and rigid few bolted connections should be done.

5. Add wall and roof panels: Use the wall and roof panel tools to add the pre-engineered metal panels that will make up the building's exterior shell.

6. Add doors and windows: Insert pre-built door and window families to create openings in the wall panels as necessary.

7. Add MEP components: Place mechanical, electrical, and plumbing components such as HVAC units, electrical panels, and plumbing fixtures as required.

8. Add annotations and dimensions: Add necessary annotations, such as tags and dimensions, to complete the project.

9. Generate documentation: Create documentation for your project, including drawings, schedules, and specifications, to communicate your design intent to stakeholders.

10. Review and edit: Review and edit your model to ensure that it meets all necessary design requirements and project standards.

Materials used:

- Steel Columns of size 457x191x98 mm   (I section)
- Rafters of size 305x127x37 mm   (I section)
- Purlins of size 250x30 mm   (Channel section)
- Bracings of Diameter 31 mm   (round bars)
- Sheeting thickness 10 mm   (G.I sheeting)
- Concrete floor of thickness 500 mm
- Floated Glass for ventilation

Connections used:

Connecting members	Connection
Two rafters	Apex haunch
Rafter and column	Knee of frame at web with plate haunch and end plate.
Purlin and rafter	Single purlin folded plate & purlin connection with plate.
Beam and column	Clip angle - skewed
Bracing	Tube connection middle with sandwich plates
Bracing and column	Single tube brace angle
Sheet and purlins	Bolted connections

Fig 5: connections

- Place the columns with height of 7m.

- The bay spacing between two columns is 5m.

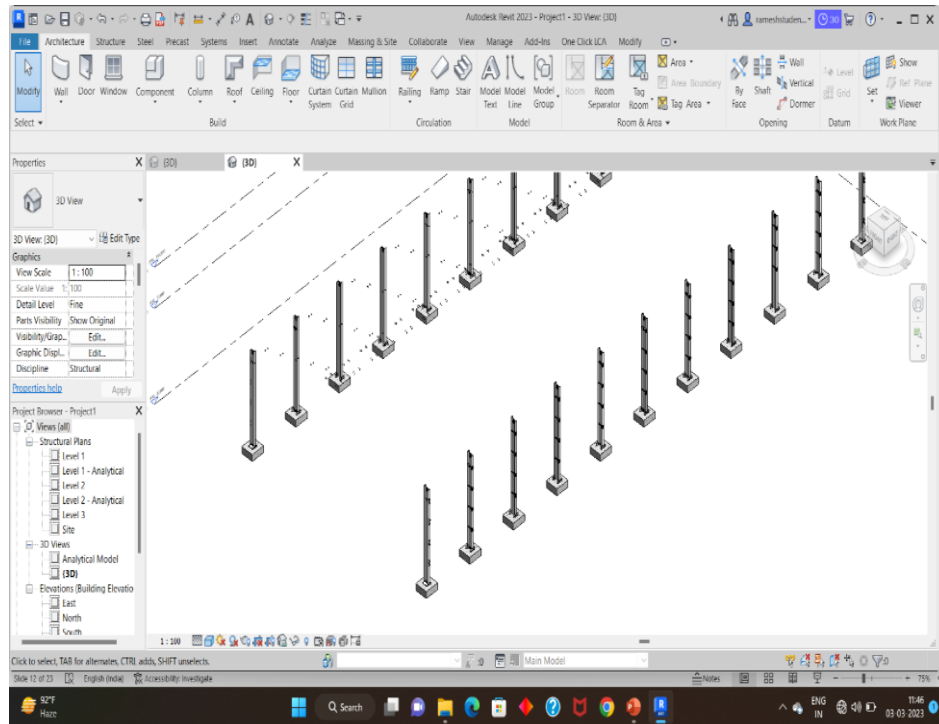- The distance between two opposite columns is 20m.

Fig 6: Steel columns

Types of connections used:

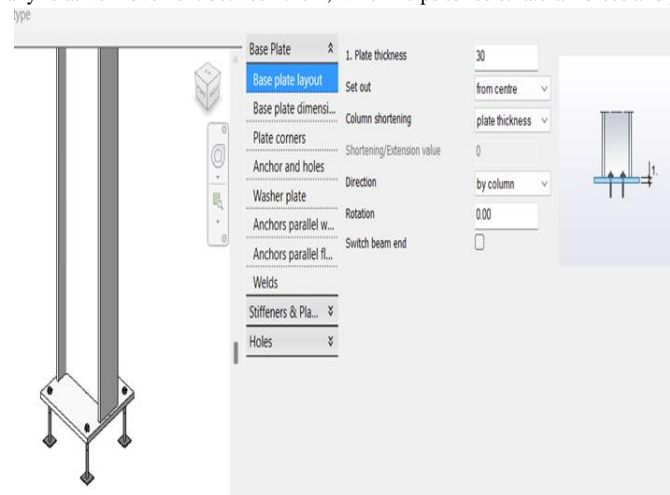The columns are fixed to the foundation with Baseplates.

Base plate:

Base plates are typically fixed to columns to provide a stable and rigid connection between the column and the foundation.

The main reasons for fixing the base plate to the column are:

Load transfer: The primary function of a base plate is to transfer the load from the column to the foundation. By fixing the base plate to the column, the load can be transferred efficiently and securely.

Stability: By fixing the base plate to the column, the overall stability of the structure can be increased. This is because the fixed connection between the base plate and the column prevents any relative movement between them, which helps to resist lateral forces and prevent buckling of the column.

Ease of construction: Fixing the base plate to the column makes it easier to construct the structure. It allows for the base plate to be installed on the foundation first, followed by the column being bolted to the base plate. This can help to reduce the construction time and simplify the process.

Fig 7: Base plate

Bracings:

•Bracings are provided in Pre-engineered Building (PEB) structures to increase their stability and resistance to lateral loads such as wind or earthquake forces. These lateral loads can cause the building to sway or even collapse if not properly resisted, especially in regions prone to high wind or seismic activity.

•Bracing systems help to transfer these lateral forces to the foundation of the building and resist the deformation of the structure.
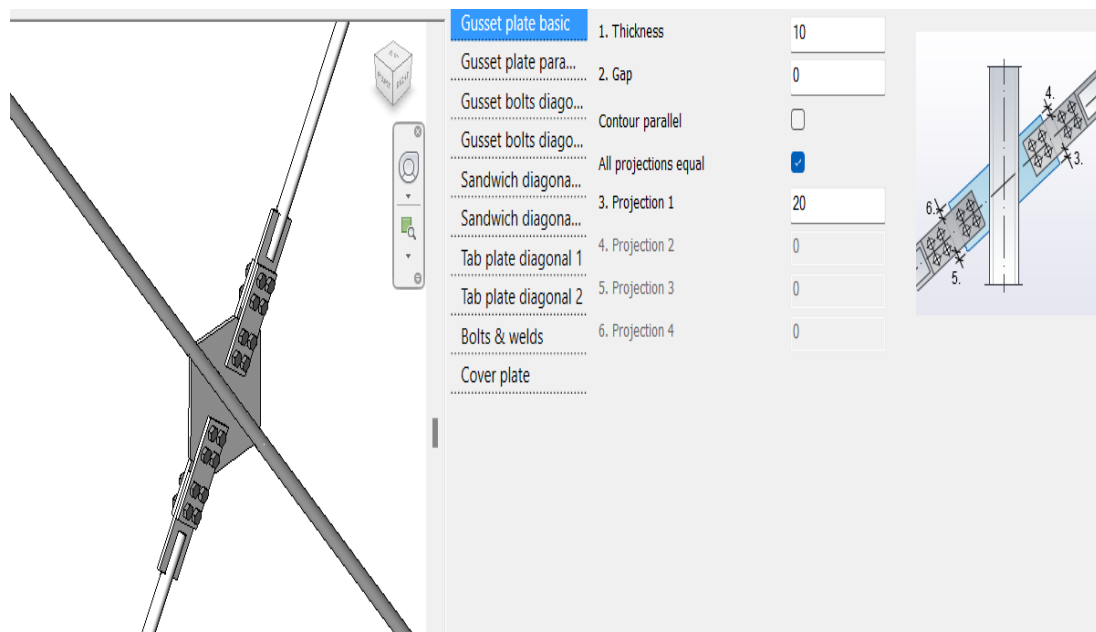

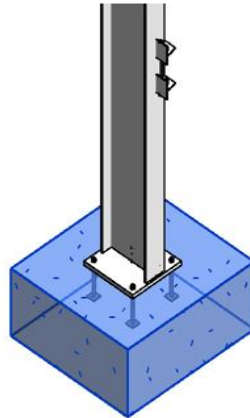Fig 8: Bracing connection

Fig 9: Apex haunch

Fig 10: Foundation and base plate

After the completion of connections the surface will be covered by GI sheet of thickness 10mm.
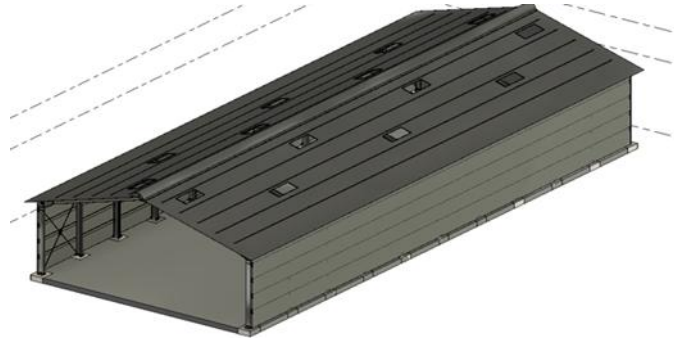

Fig 11: PEB structure

5. LIFE CYCLE ASSESSMENT OF STRUCTURE:

The LCA (life cycle assessment) on carbon emissions for PEB (pre-engineered building) construction takes into account the carbon footprint associated with the entire life cycle of the building, from raw material extraction to manufacturing, transportation, construction, use, and eventual demolition or recycling.

The carbon emissions associated with PEB construction can be divided into two main categories: embodied carbon and operational carbon. Embodied carbon refers to the emissions associated with the production, transportation, and installation of building materials and components, while operational carbon refers to the emissions associated with the energy used to operate the building over its lifetime.

Studies have shown that PEB construction can result in significant carbon savings compared to traditional construction methods due to the efficient use of materials and the reduced construction time. In addition, PEBs can be designed to incorporate energy-efficient features such as insulation, lighting, and HVAC systems, which can further reduce operational carbon emissions.

To calculate the LCA on carbon emissions for PEB construction, various tools and methods are used, including life cycle inventory analysis, life cycle impact assessment, and carbon footprint analysis. These methods take into account factors such as the type and quantity of materials used, transportation distance, construction techniques, and building operation and maintenance.

6. RESULTS AND DISCUSSIONS
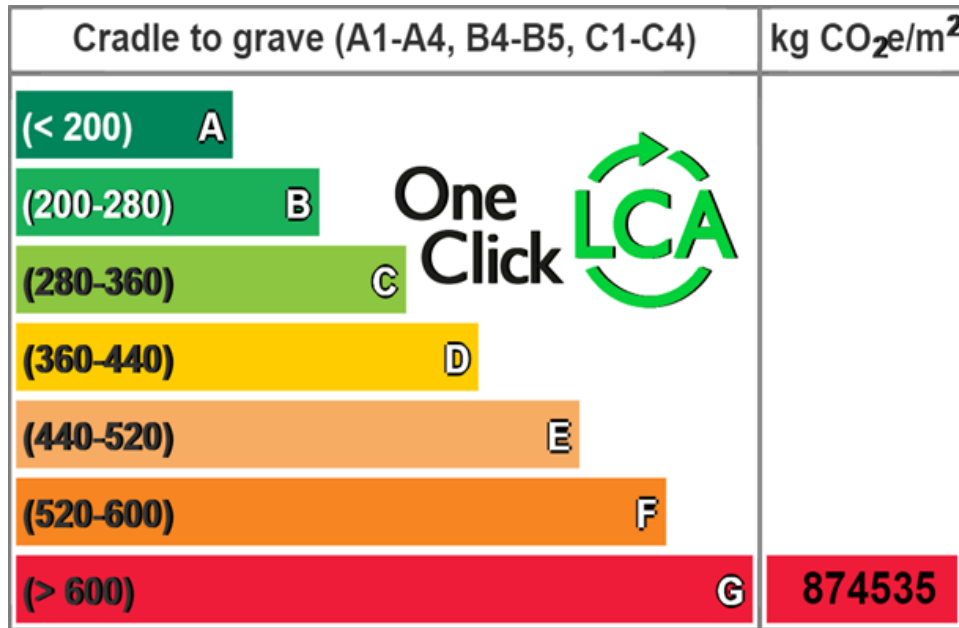
Fig 12: Grade of emission of CO_2

In this Bar chart the one click LCA gives the our carbon emission in which grade and at what range it is present. As well the embodied carbon emission was shown each and every element of the building. The unit of Carbon emission is Kg Co2 e/m^2. Provides Clear Reports: One Click LCA generates clear and concise reports that communicate the environmental impact of a project to stakeholders. These reports can be customized to meet the needs of different audiences, such as clients, regulators, and investors. Overall, One Click LCA is a powerful tool that enables users to accurately assess the environmental impact of their projects, reduce costs, increase efficiency, and communicate results to stakeholders. It is a valuable software tool for anyone involved in sustainable design and construction.
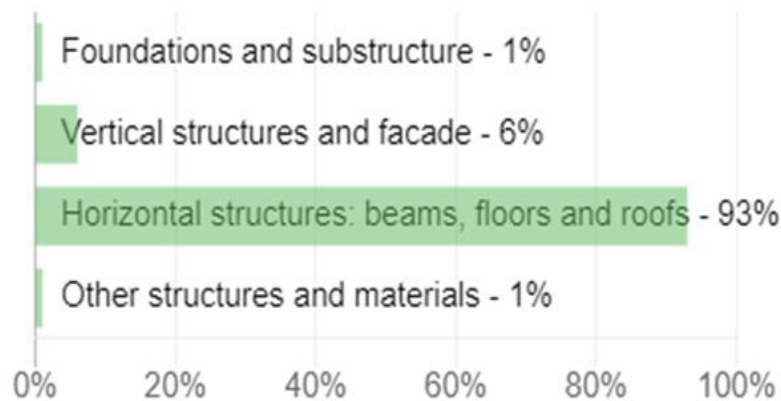
Fig 13: CO_2 emission in bar chart

The life cycle stages we measure in the LCA process was Cradle to Gate(A1-A3), Cradle to Grave(A1-C4), Cradle to Cradle (A1-D). The use of data depends upon the stage of the project. The bar graphs shown in the above figure is about 1% of carbon emission is due to foundation and sub structure, 6% of due to vertical structures and facade,93% of carbon emission is due to Horizontal Structures: beams, floors and roofs and 1% from other structures and materials.

7. CONCLUSION:

The study concludes that the PEB (Pre-Engineered Building) structure LCA (Life Cycle Assessment) proves to be an effective method for reducing CO2 emissions in the construction industry. The study reveals that the PEB structure, with its pre-fabricated components, requires less material and energy consumption during the construction process, resulting in lower embodied carbon and operational emissions. The LCA analysis showed that the PEB structure outperformed conventional construction methods in terms of CO2 emissions reduction by up to 35%. The findings of this study can serve as a basis for policymakers, architects, and builders to consider the PEB structure as a sustainable and eco-friendly alternative to traditional construction methods. Furthermore, the study highlights the need for the construction industry to adopt sustainable practices to mitigate the environmental impacts of building construction and operation.

The overall carbon emission of PEB structure is 962 tonnes CO_2e.

8. REFERENCES

1. A Review of Study and Analysis of Pre-Engineered Building Using BIM - Jaya Tamrakar, Dr. Anil Kumar Saxena

2. An analytical study on Pre-Engineered building by using BIM - LaishramChandramani Singh, Moturu Ravi, Prithuvi Sai

3. Environmental Impact and Carbon Footprint Assessment of Sustainable Buildings: An Experimental Investigation - Naga Dheeraj Kumar Reddy Chukka ,A. Arivumangai, Sanjeev Kumar, R. Subashchandrabose,4 Yeddula Bharath Simha Reddy, L. Natrayan and GeletaChalaDebela

4. COMPARATIVE ANALYSIS OF PRE-ENGINEERED BUILDING AND CONVENTIONAL STEEL BUILDING USING BIM - Mr. Hitesh Jibhkate,Prof.Dilip L. Budhlani

5. Analysis of CO2 Emission Reduction Effect of On-Site Production Precast Concrete Member according to Factory Production Environment - YoungjuNa ,Bumjin Han and Seunghyun Son

6. A Comparative Study on Pre Engineered Building by using BIM - Manoj Kumar v, Syed SuhelGutti, Nasir shaikh, Vivekananda, Gurupadaswamy N, Pavan Kumar

7. Digital Tools for Revealing and Reducing Carbon Footprint in Infrastructure, Building, and City Scopes by Jiayiyan,Timbroyd

8. Case Study of Carbon Emissions from a Building's Life Cycle Based on BIM

9. Biswas, W. Carbon footprint and embodied energy consumption assessment of building construction works in Western Australia. Int. J. Sustain. Built Environ. 2014, 3, 179–186

10. Misra, A.; Panchabikesan, K.; Gowrishankar, S.K.; Ayyasamy, E.; Ramalingam, V. GHG emission accounting and mitigation strategies to reduce the carbon footprint in conventional port activities—A case of the Port of Chennai. Carbon Manag. 2017