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Enhancing Sustainability in Building Design: Optimizing Energy Efficiency and Reducing Carbon Footprint Using BIM Tools and Polymer Matrix Composites

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Abstract

Sustainable construction is an imperative that transcends the immediate and future horizons of the construction industry, propelled by the escalating recognition of the sector's ecological impact. Building Information Modelling (BIM) has firmly established itself as a pivotal instrument within the industry due to its unique capacity to seamlessly merge the physical and analytical dimensions of construction, thereby ushering in transformative practices. This research paper offers an all-encompassing exploration of the intersection between sustainable construction and BIM, with a specific emphasis on the application of BIM-centric tools such as REVIT, OneClick LCA, and Autodesk Insight for the quantification of the environmental impact of a chosen commercial building, with a focus on energy consumption and carbon emissions. Additionally, the study integrates the use of polymer-matrix composites (PMCs) in building design to evaluate their contribution to reducing the carbon footprint and enhancing energy efficiency. The primary aim of this study is to scrutinize the environmental consequences of a commercial building and to contrast the effects of altering various construction-related parameters, in accordance with the standards set forth by organizations like the Indian Green Building Council (IGBC). The findings underscore the favorable alignment of BIM with sustainability metrics, including analyses of energy efficiency, life-cycle assessments, and the environmental benefits of using PMCs. The BIM-based tools employed in the research offer comprehensive and dependable results. This research contributes significantly to the ongoing dialogue surrounding sustainable construction by substantiating that BIM acts as a transformative catalyst in the pursuit of environmental sustainability objectives, and highlights the potential of PMCs in achieving these goals. The conclusions drawn from this study advocate for the widespread adoption of BIM and PMCs within the realm of sustainable construction.

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INTRODUCTION

In an era defined by heightened environmental awareness and the urgent need for sustainable solutions, the construction industry is leading transformative change. With the world facing resource scarcity and climate change challenges, the need to design, construct, and manage commercial buildings with a strong emphasis on sustainability has never been more crucial.

This research paper delves into the fascinating realm of sustainability analysis, with a specific focus on a commercial building, and employs state-of-the-art Building Information Modeling (BIM) tools, Cumulative Energy Demand (CED), and Life Cycle Assessment (LCA).[10] These advanced technologies offer a holistic and insightful approach to scrutinizing the environmental impact and energy consumption of commercial structures over their entire lifespan. Through this exploration, we aim to shed light on how these tools can be harnessed to create environmentally responsible, efficient, and cost-effective commercial buildings, ultimately fostering a more sustainable future for the construction industry and the planet. It's evident that well-informed decision-making significantly influences the environment at every stage of a new construction project. [9] Surprisingly, the construction sector shoulders a substantial burden, contributing to a staggering 36% of global energy consumption and accounting for 40% of CO2 emissions. The manufacturing and transportation of materials play a pivotal role in influencing carbon emissions. Conventional construction practices have been associated with adverse environmental consequences, including substantial carbon emissions and significant energy consumption. Consequently, there is a growing imperative to adopt sustainable construction methods within the industry. Building Information Modeling (BIM) holds the potential to be a pivotal component in advancing sustainable construction. [10] Specifically, tools like CED and LCA, which are grounded in BIM principles, have been applied in the construction of extensive commercial projects. [1-2] BIM tools can assist in numerous aspects of sustainable design, including optimizing building orientation, analyzing building form, assessing day-lighting possibilities, evaluating water consumption, decreasing energy demand, exploring alternative renewable energy sources, reducing material usage through sustainable materials, and minimizing waste and carbon emissions."

The aim of this research is to conduct a Day Light Analysis, Cumulative Energy Demand (CED) and Life Cycle Assessment (LCA) on a Commercial building model using BIM tools such as Light-stanza, Autodesk Insight and One-click LCA respectively. The goal is to analyze the outcomes of the CED and LCA, make necessary adjustments to ensure the Commercial building model aligns with prominent green building rating systems, and pinpoint crucial performance metrics for sustainability analysis [3-5].

Polymer Matrix Composites (PMCs), reinforced with carbon, glass, or aramid fibers, significantly enhance structural integrity and durability in construction. Their high strength-to-weight ratio makes them ideal for load-bearing structures, reducing overall weight and lowering transportation and installation costs. PMCs resist corrosion and environmental wear, extending the lifespan of structures and promoting sustainability by minimizing repairs and replacements. Their recyclability and superior thermal insulation contribute to resource efficiency and energy savings, making PMCs a key component in sustainable construction practices [6-8].

METHODOLOGY

The methodology involves the creation of two revision models using traditional and sustainable approaches. The analysis of these models is mainly performed using three major software or tools: Autodesk Revit, Autodesk Insight, and One-Click LCA. Revit aids in the design process and provides easy access to the thermal and physical properties of the materials used in construction. The BIM capabilities of Revit enable us to make spontaneous changes throughout the model for the selected elements and materials.

Autodesk Insight on the other hand is an analysis tool which provides a wide range of parameters which can be manipulated for changing the energy efficiency of the model. These parameters help change the energy efficiency of a building.

One-click LCA is a life-cycle assessment tool that has been used to obtain the overall carbon footprint of the model throughout its life span, that is, cradle to grave. The creation of a green building model involves the use of green materials, whose thermal transmittance values are defined according to the guidelines set by the Indian Green Building Council (IGBC). The following Figures show the values of various building parameters used for performance analysis of conventional building and green building Figure 1 and 2).

Category	Override	Analytic construction
Roofs	☐	4 in lightweight concrete (U=1.2750 W/(m²K))
Exterior walls	☐	4 in heavyweight concrete with 2 in insulation (U=0.6391 W/(m²K))
Interior walls	☐	Frame partition with 3/4 in gypsum board (U=1.4733 W/(m²K))
Ceilings	☐	8 in lightweight concrete ceiling (U=1.3610 W/(m²K))
Floors	☐	Passive floor, no insulation, tile or vinyl (U-2.9582 W/(m²K))
Slabs	☐	Un-insulated solid (U=0.7059 W/(m²K))
Doors	☐	Metal (U=3.7021 W/(m²K))
Exterior windows	☐	Large, double-glazed windows (reflective coating) - industry (U=2
Interior windows	☐	Large single-glazed windows (U=3.6898 W/(m²K), SHGC=0.86
Skylights	☐	Large, double-glazed windows (reflective coating) - industry (U-3.

Figure 1. Parameters of traditional buildings.

Category	Override	Analytic construction
Roofs	☑	4 in heavyweight concrete with 2 in insulation (U=0.5181 W/(m²K)
Exterior walls	☑	2 in face brick 2 in insulation and 8 in clay tile (U=0.5362 W/(m²K)
Interior walls	☑	Frame construction, R-11 insulation, wood studs (U=0.5507 W/(m²
Ceilings	☑	Wood blocks, concrete, batting, gypsum (U=0.7457 W/(m²K)
Floors	☑	Passive floor, R-8 board insulation, any cover (U=0.5507 W/(m²K)
Slabs	☑	Standard slab construction - A (U=0.2499 W/(m²K)
Doors	☑	Solid core wood, wood storm (U=1.6466 W/(m²K)
Exterior windows	☑	Large, double-glazed windows (reflective coating) - industry (U=2
Interior windows	☑	Large, double-glazed windows - reflective coating (U=2.3130 W/
Skylights	☑	Double glazing 1/4 in thick clear/low-E (e = 0.2) glass (U=1.987

Figure 2. Parameters of green buildings.

Creation of Energy Model

The first step in this study is the creation of 3D and energy model for traditional and green building in Revit. The line plan and development plans for the selected building are acquired from the contractor and then 3D model for traditional building is created first in Revit. Revit allows for creation of an energy model from the 3D model that is created (Figure.3)

Figure 3. 3D model created in Revit.

A good practice before creating an energy model is to assign spaces to each room allowing for an accurate differentiation between various analytical spaces and surfaces. Next step is to create systems loop for HVAC in the building which is done using System browser window in Analyze tab. Now the energy model can be created using from the ‘Energy Analysis’ section of the ‘Analyze’ tab. The analytical spaces and analytical surfaces in the energy model are used to calculate energy performance of the building in AUTODESK INSIGHT. These analytical spaces are assigned to each room and the parameters like occupancy number and occupancy schedule etc (Figure 4) can be varied as per the use of the room or the space. The created model is then checked for the completeness and gaps [11-14].

Daylight Analysis in Light-Stanza

The daylight analysis is a preliminary step in energy analysis as optimizing the available daylight to the maximum can reduce energy consumption of the building in the long run. The process is quite simple as the Light-stanza plugin for Revit allows for direct export of the 3D model into the Light-stanza web tool. Using Light-stanza web tool plugin for Revit we can get the UDI values for each floor of the building. These UDI values are then checked for their adherence to the recommended values in the ISHRAE-IEQ code (Figure 5)

Energy Analysis in Autodesk Insight

Once the energy model is created and checked the next step is to export it to the AUTODESK INSIGHT web tool for analysis. The Insight web tool calculates the energy performance of the model based on various parameters. These parameters can be varied by the user to optimize the energy performance of the building. The following Table 1 shows the list of parameters that can be changed to optimize the energy usage of the model.

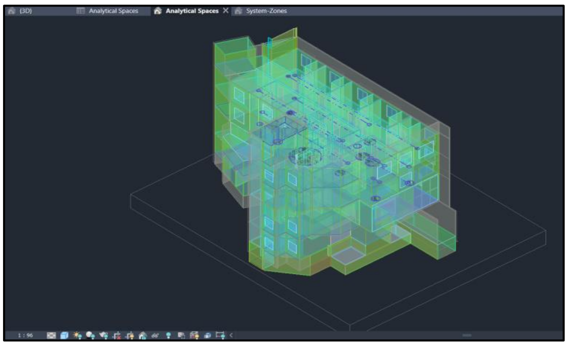

Figure 4. Energy model and system zones for the building in revit.

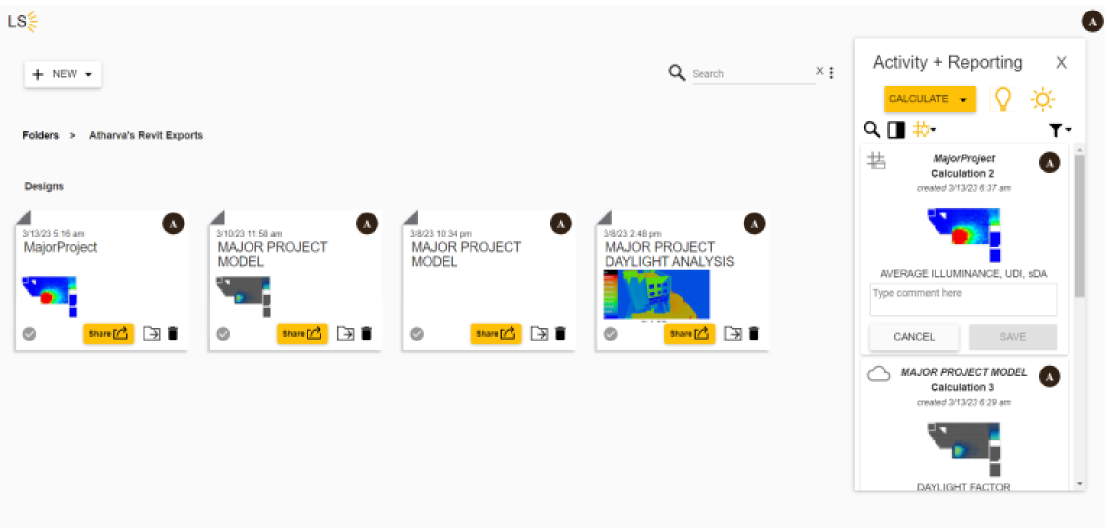

Figure 5. Daylight analysis in light-stanza.

Table 1. Insight Parameters for Energy Optimization.

S N.	Insight Parameters
1	Operating Schedule
2	Window Wall Ratio
3	Plug Load Efficiency
4	Lighting efficiency
5	HVAC
6	Wall Construction
7	Window Glass
8	Panel Efficiency
9	Daylight Occupancy and Controls
10	Surface Coverage
11	Infiltration
12	Roof Construction
13	Building Orientation
14	Window Shades

It is important to note that Insight allows users to select different values of these parameters allowing users to create and compare the effect of changing each parameter value. For this study we changed the values for each of the above mentioned parameters as per the IGBC code to minimize the annual energy demand which is the energy intensity of the building expressed in KWH/m2/year. Once the annual energy demand for both the traditional and green building model are generated the next step is to calculate the EPI which is the ratio of annual energy demand of traditional building model to the green building model. This ratio is a metric used to quantify the energy consumption of a building or space. The changes made in the green building model should be such that the EPI calculated is falling in the EPI range specified by IGBC (Figure 6)

Carbon Analysis in One-Click LCA

The carbon analysis refers to the assessment of a building`s environmental impact in terms of carbon emissions. The unit used to measure carbon emissions is metric ton or tonne of CO2 equivalent (tCO2e). One-click LCA is a life-cycle assessment tool which helps calculate the overall carbon emissions throughout the life-cycle of a building. The first step is to upload the gbxml file of the model from revit which contains all the information regarding the materials of the model (Figure7) Next we add the energy consumption values from the energy analysis and after defining other parameters like calculation period for analysis we can get the results in terms of (tCO2e).

RESULTS

In this research paper, we have undertaken a thorough sustainability analysis of a commercial building by harnessing the power of Building Information Modeling (BIM) tools, Cumulative Energy Demand (CED), and Life Cycle Assessment (LCA). This study marks a pivotal stride towards understanding and optimizing the environmental performance of commercial buildings. Through the utilization of BIM, we have created a comprehensive digital model of the building, allowing for precise examination of its various facets throughout its life-cycle. The incorporation of CED and LCA data has provided an encompassing view of the building's cumulative energy demands and overall Carbon embodied footprint through its life span. Our findings underscore the critical importance of sustainable practices in the construction industry and the imperative need to reduce energy consumption and environmental impact. With a commitment to reducing cumulative energy demands and enhancing overall sustainability, this research contributes to the broader mission of creating a more ecologically sound and resilient built environment.

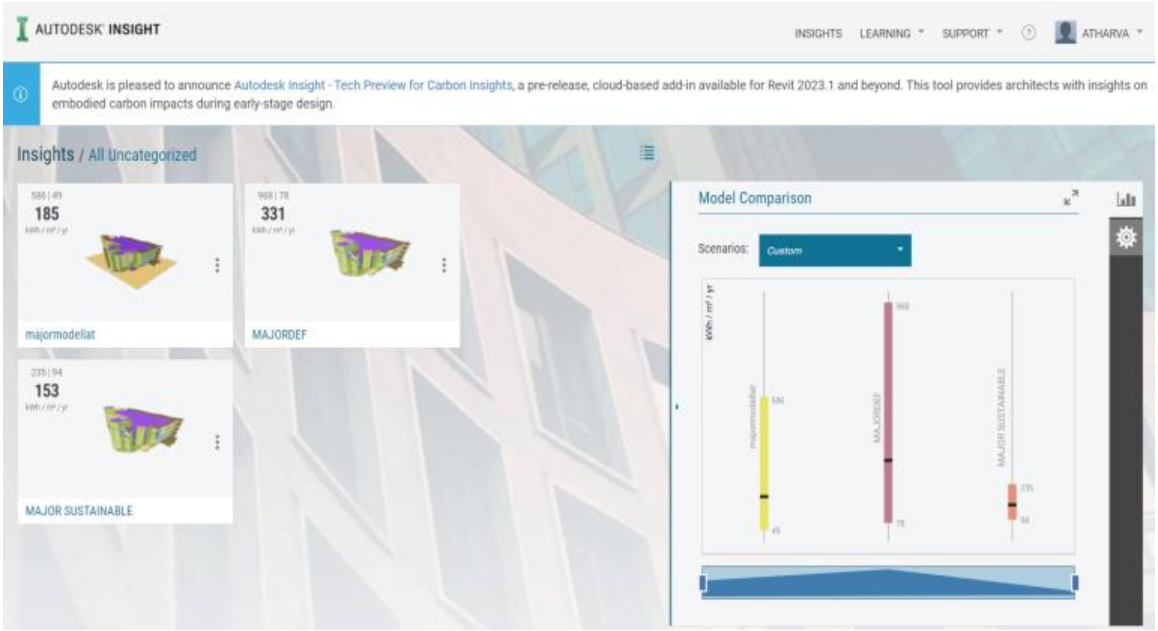

Figure 6. Autodesk insight energy analysis.

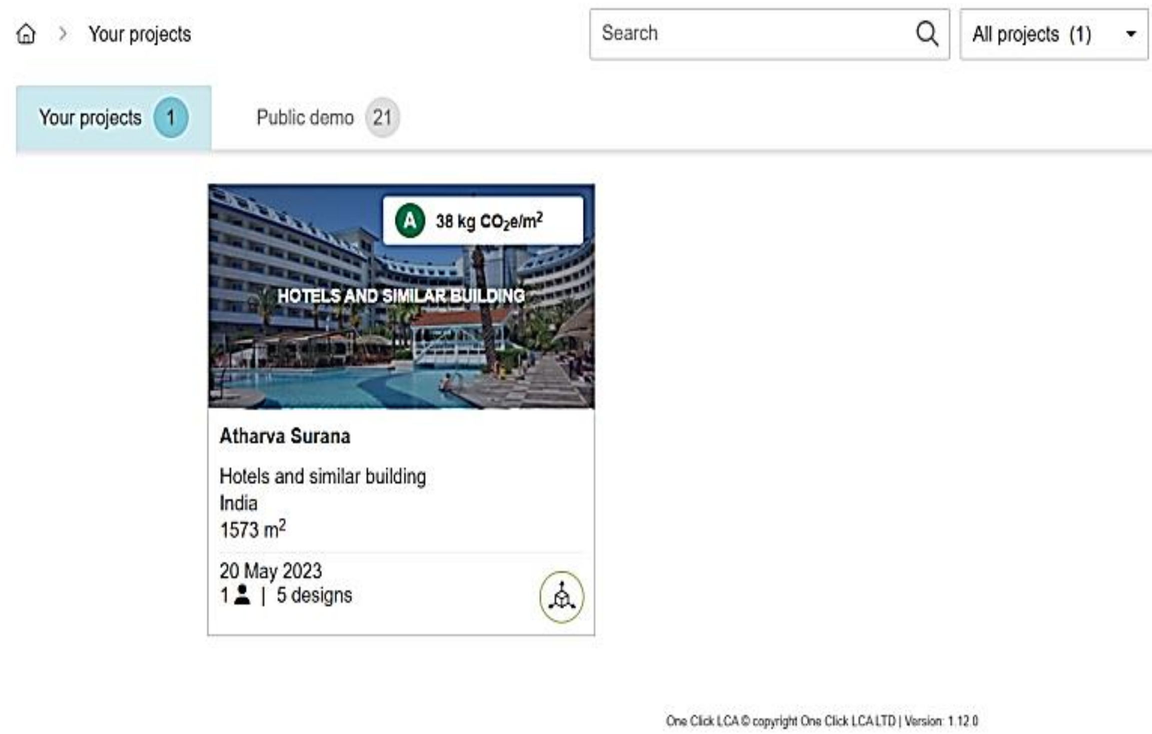

Figure 7. Carbon analysis using one-click Lca.

The result of this study are:

1. We were able to increase the UDI value up to the required standard which should be greater than 100 as per the ISHRAE guideline (Figure.8)
2. The EPI for the traditional building after analysis was found to be 331 KWH/m2/year and the EPI for the proposed Green Building was found to be 185 KWH/m2/year. This resulted in an EPI ratio of 0.55 which falls well within the criteria set by IGBC(Figure9)
3. The embodied carbon of traditional buildings from Carbon analysis was found to be 294 tonnes and for Green Building is found to be 96 tonnes (Figure 10 and 11)

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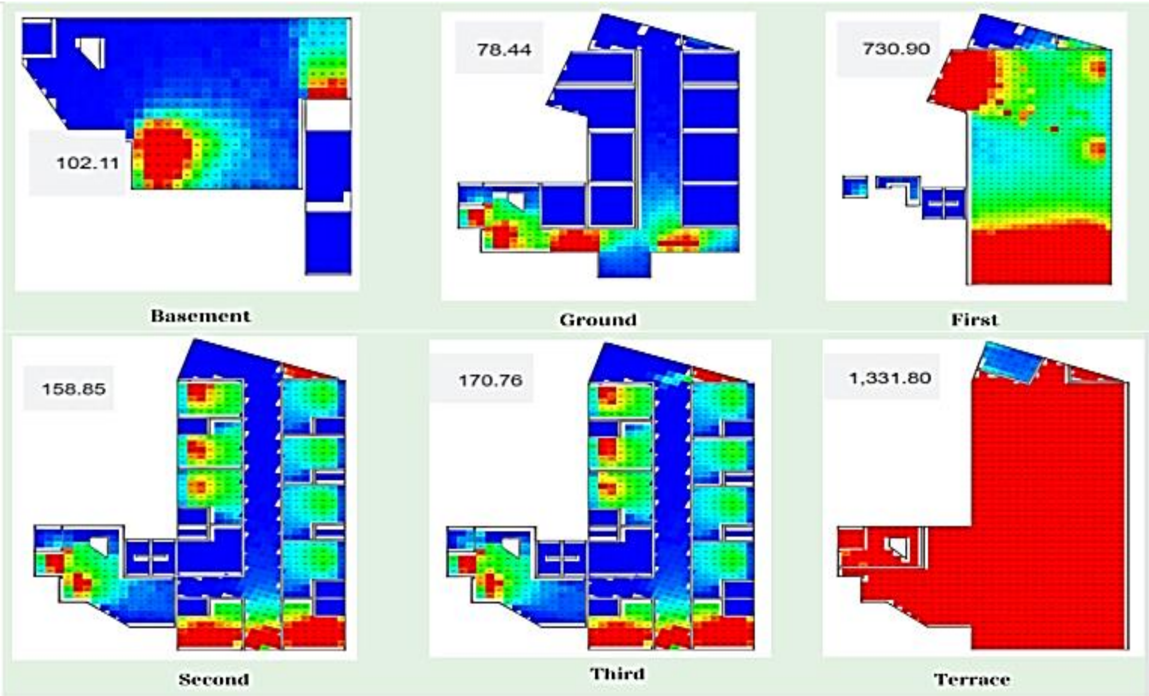

Figure 8. Udi Values for each floor in the model by daylight analysis.

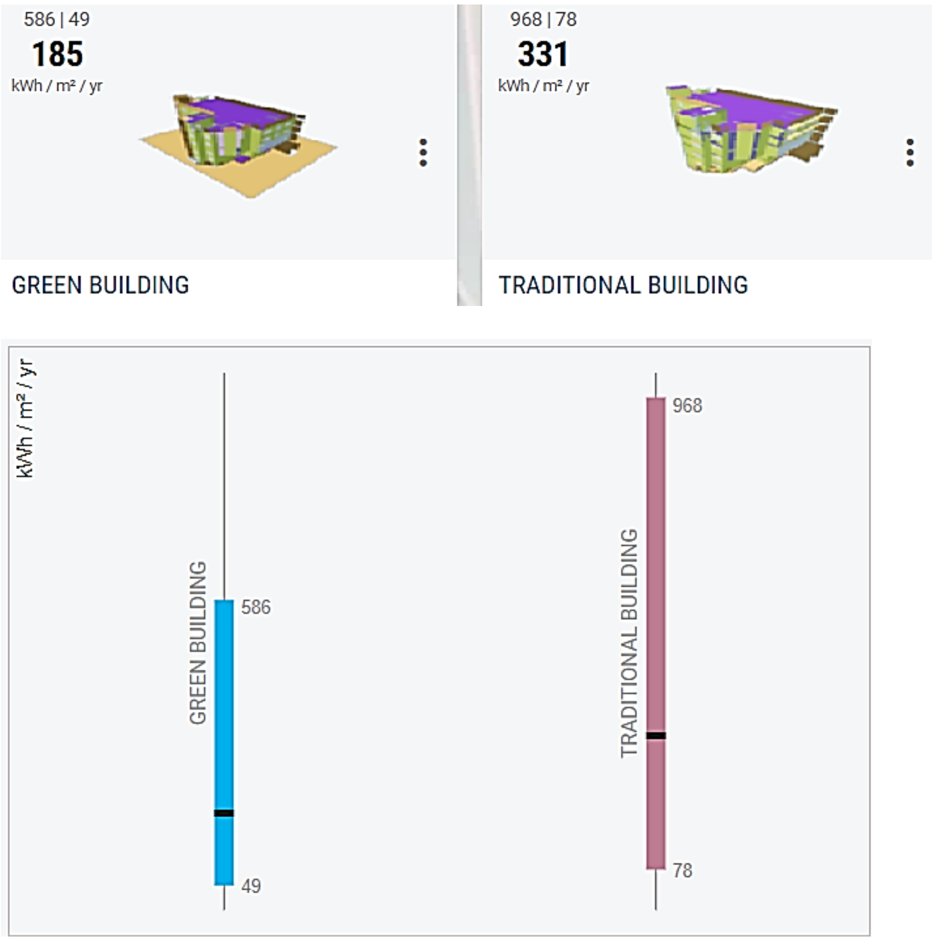

Figure 9. Graphical Comparison Between Mean Eui Values of the Traditional and Green Building Models.

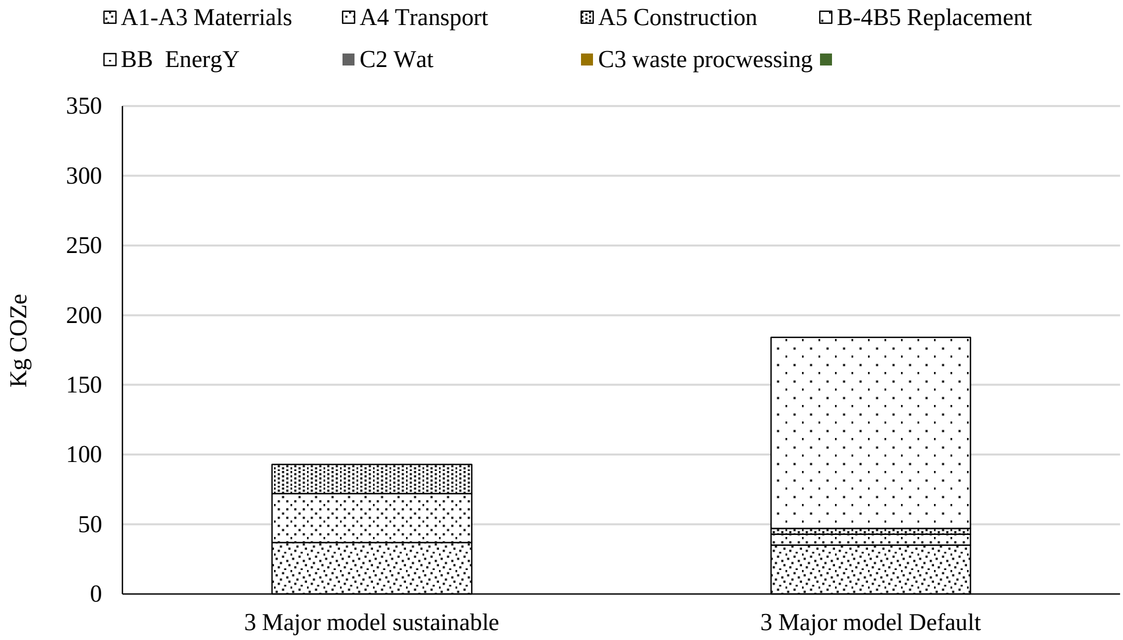

Figure 10. Graph showing comparison between the traditional and green building models for contribution of each building parameter in the carbon emissions.

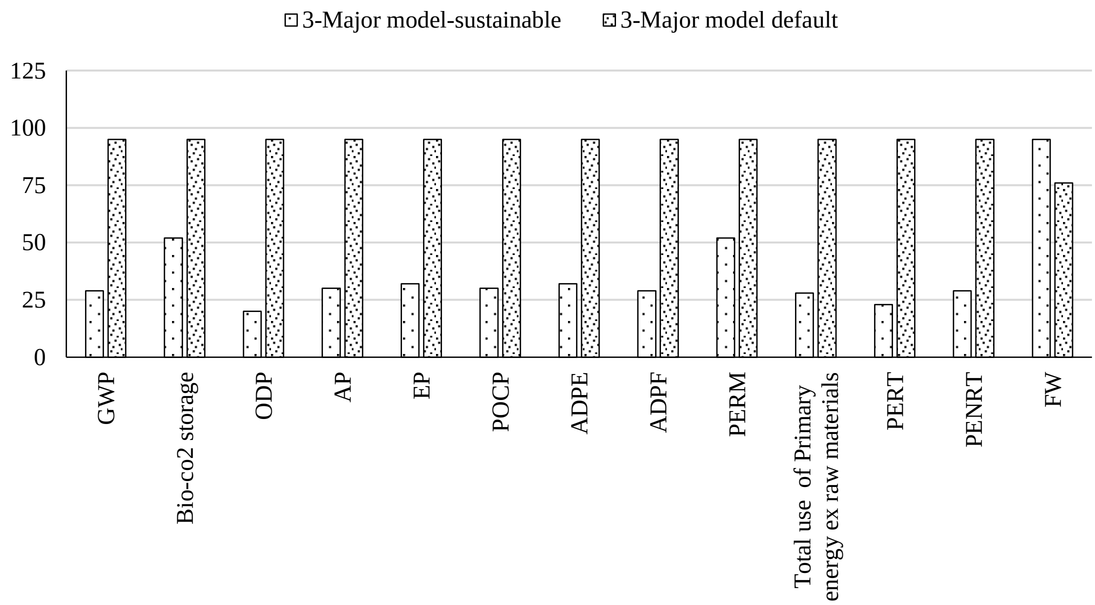

Figure 11. Graph Showing the contribution of each measurement parameter towards the co2 emission of the traditional and green building. (higher values are considered as 100%)

The insights generated from this research can guide stakeholders in making informed decisions aimed at constructing and managing commercial buildings that are not only economically viable but also environmentally responsible.

CONCLUSION

In conclusion, this research paper has addressed a comprehensive set of objectives aimed at promoting sustainable building practices and reducing the environmental impact of construction. Using a chosen building model, the research first conducted Life Cycle Assessment (LCA) and Cumulative

Energy Demand (CED) evaluations to provide a comprehensive picture of the structure's environmental impact and energy consumption during its lifetime. The identification of difficulties that arose throughout these studies gave important new light on the complexities and constraints of sustainability evaluations. This research clarified the environmental and energy consequences related to the chosen building model by carefully examining the findings from the CED and LCA assessments. This allowed for a more nuanced understanding of the building model's performance.

Moreover, by critically analyzing the results and comprehending the limitations, the study opens the door for well-informed decision-making and policy formulation. This research is a useful tool for stakeholders in the construction industry, architects, policymakers, and environmentalists, as it provides a road-map for implementing sustainable changes in building design and construction. By working to create a more sustainable and eco-friendly built environment, this research contributes to a future.

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