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Case Report

BIM-Based Approach to Reduce GHG Emissions in Construction

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Abstract: The construction sector is responsible for a substantial portion of the country's total greenhouse gas (GHG) emissions. Several problems, such as global warming, environmental degradation, unpredictable weather patterns, etc., are caused by higher levels of carbon emission, which is a major cause for concern. Massive amounts of greenhouse gases are produced during the construction process due to the manufacturing, transportation, and utilization of materials as well as the high energy demands of the building's construction processes. The emission of these gases is a factor in climate change. In this study, the phases that release the most carbon into the atmosphere were analyzed alongside the sources of carbon dioxide emissions from construction materials. Building Information Modelling (BIM) has been used for several reasons in projects, including 3D visualization, the preparation of project requirements, and so on. In this research, a BIM-based approach has been conducted to model a proposed building. Then a software-based analysis has been used for the evaluation of carbon emission from the materials. The study's outcome satisfies its aim by assessing the carbon emissions of the entire structure, and the roof and walls as the maximum carbon emitting component with 4272.92 tons of CO_2 and 152.18 tCO_2. The findings of the research indicate a decrease in carbon emissions from the roof and wall by material modifications to C40/50-50% GGBS and Steel-Hollow Sections. Adopting such material modification will enable structures to be constructed successfully and becoming a lower ecological contributor to carbon emissions is achievable.

Keywords: GHG, BIM, Building

1. Introduction

The world is currently confronting the unanticipated challenge offered by the world's shifting climate. Human activity has had a major influence on the global climate and temperature since the start of the Industrial Revolution in the late 18th and early 19th centuries. Since the commencement of the industrial revolution, this has been the case [1]. The build-up of heat-trapping gases like carbon dioxide and other gases like methane and nitrous oxide, which were previously present in the atmosphere, has increased the greenhouse effect and global warming [2, 3]. From 2000-2010, yearly GHG emissions increased by an average of 1.0 $GtCO_2e$ per year, relative to 0.4 $GtCO_2e$ annually between 1970-2000, and overall anthropogenic GHG emissions reached a record-high 49.0 $GtCO_2e/y$ in 2010 [4]. Reducing carbon emissions hence has become a primary concern [5]. According to the findings of the Panel on Climatic Changes (2013), the construction industry is among the major sectors that possess significant potential for cutting carbon emissions shortly. Carbon emissions from construction materials are disproportionately high compared to other sources. Greenhouse gases are released in huge quantities during the construction of a structure due to the manufacturing, transporting, and use of materials and the high energy demands of the building's construction operations (GHGs).

Atmospheric greenhouse gases primarily consist of carbon dioxide, methane, nitrous oxide, ozone, water vapor, sulfur hexafluoride, chlorofluorocarbons, and hydrofluorocarbons. Hydrofluorocarbons and chlorofluorocarbons are two other examples of greenhouse gases [6]. A small number of research on environmental evaluation in Hong Kong have looked at buildings' GHG emissions [7-9]. Evidence from the studies of Chen et al. suggests that residences are responsible for a substantial amount of the world's total CO_2 emissions. According to Su and Zhang, the fact that residential buildings consume 45.9% of the total energy indicates that there is a substantial share of greenhouse gases in this sector [10]**.** In their presentation, Suzuki and Oka employed input/output data to calculate the total energy consumption and carbon dioxide emissions from new and renovated Japanese office buildings. In doing so, they hoped to get a deeper comprehension of the connections between the two variables [11]. Their research was centered on the evaluation of greenhouse gas emissions that were produced by the building sector. Embodied GHG emissions and operation GHG emissions are the two primary contributors to a building's total GHG output [12]. Based on a summary of their work from 2010, Yan et al. identified four main emission sources related to construction sites: the manufacturing and shipping of building materials; the operation of construction machinery; the processing of resources; and the removal of demolition waste [13].

There is empirical evidence that the transportation and usage of construction equipment generate significant amounts of carbon dioxide. CO_2 emissions throughout the traditional framing of a building have been estimated at around 45 tons [14]. Emissions from the mining and production of raw materials, the fabrication of building materials and components, the transportation of building materials, and the act of construction itself account for the vast majority of embodied greenhouse gas emissions [15]. The construction industry has been singled out as one having the highest possibilities for the efficient mitigation of greenhouse gas emissions, as indicated by Khaled A. Al-Sallal and colleagues from the outset [16]. According to research on the environmental impact of buildings during their lifespan, the building process is responsible for between 20 and 30 percent of the initial embodied carbon output and 6 to 10 percent of the overall output. The priority aims for lowering greenhouse gas emissions during the construction phase of a project might include enhancing transportation, construction machines, trash generation, and energy usage. In Bangladesh, the common construction materials for a building are concrete, bricks, sand, cement, glass, and wood. With the exception of wood, each of these materials has an adverse impact on the atmosphere because of the role it plays in the generation of greenhouse gases on a worldwide scale. There has been a shift in recent years toward the creation of low-emissions built environments and an increase in the prominence given to the use of low-emissions technology [17].

Building Information Modelling is one of the developed methods of designing with relevant data and sustainable solutions in the evolution of eco-friendly building practices. BIM is a tool that may be used to coordinate the many stages of a modern construction project. One of the technologies that are used to bring the BIM idea to life is a software called Autodesk Revit. Each of the 2D drawings, 3D views, and plans that are included in the Revit model are synced with one another. There are different kinds of BIM tools that, have integrated carbon emissions analysis models for buildings during different life phases. Using BIM, Matipa Wilfred et al. planned costs. A previous study concluded that BIM is useful for both the planning and administration of construction projects [18]. A BIM program's output data might be in IFC (Industry Foundation Class), aecXML, or gbXML format (green building extensible markup language). These are protocols that have been established to allow consistent data transmission and accessibility between numerous BIM applications including those for regulating energy usage in buildings which include geometry modelling, HVAC design, energy analysis, and facility management [19].

Autodesk Revit was chosen as the BIM software product by Y. Cang and colleagues. This program offers a robust coding system. Any “building element” (BE) may be given its unique identifier in the BIM model, and the "schedule" feature of the model can be used to produce a statistical bill of the quantities of the BEs [20]. Carbon emissions were promptly determined by using BIM technology and the Chenxi program. Four instances in Fujian Province, comprising both prefabricated and traditional cast-in-place structures, were researched to gain a deeper understanding of the carbon emissions that are produced by prefabricated buildings. Designers can finish the modelling process and calculate the carbon output from the materialization stage, all with the help of Revit. Analyses of the results and comparisons of the results were also carried out. In conclusion, suggestions on how to reduce emissions were offered for each phase of the materialization process [21].

Now, most developing country is getting into green construction and that’s why low-carbon projects have already been initiated. In Bangladesh, this initiative is far behind though, facing environmental issues as well. The amount of carbon emission according to the last statistics is 215,940.00, which means annually the increase rate is 3.82% (2019) [22]. In this assessment, the applicability of BIM tools for construction projects in Bangladesh has been conducted. A software-based solution for construction carbon emission from construction has been evaluated so that further improvement in embodied carbon reduction can be possible. The aims of this assessment are given below-

1) Initiating BIM tools and software-based carbon emission analysis for a practical project like the office building in Chittagong.
2) Analysing the contribution of roof and wall material variation in total embodied carbon reduction.

2. Materials and Methods

2.1. Building of Revit Model

As this research aims at utilizing BIM software, Autodesk Revit has been chosen to make the 3D model of the plan. For the 3D modelling of the plan Revit 2020 version has been used. For this purpose, the AutoCAD drawing file was imported into Revit software. Then with the help of different commands, the model has been built. From the properties panel, the elements like walls, windows, doors, floors, and roofs have been selected as per the specifications of the design plan. Figure 1 shows the 3D model perspective of the floor plan for the office building, and Figure 2 shows the interior of the model.

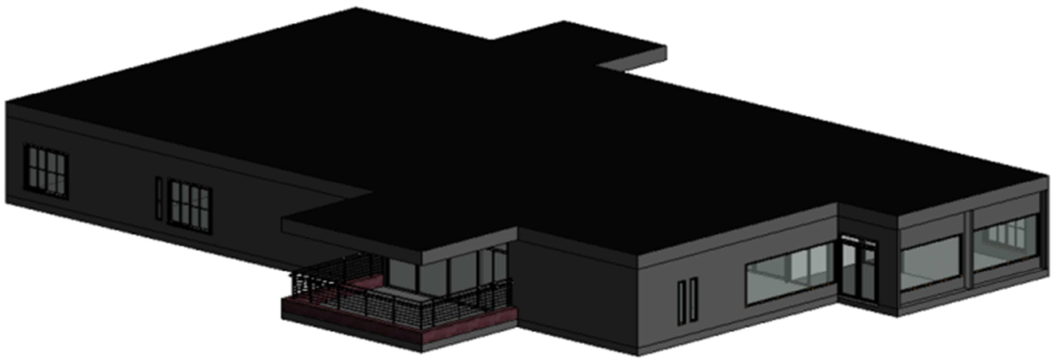


Figure 1. *3D view of the BIM model.*

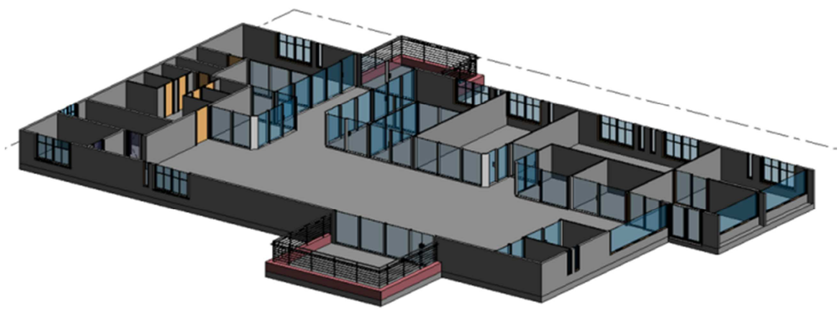


Figure 2. *The interior part of the building.*

2.2. Carbo Life Calculator

There are different ways of calculating carbon emissions. Some of the software that can be used for Carbon analysis of buildings are Autodesk ECOTECT Analysis, Graphisoft ArchiCAD, Graphisoft EcoDesigner, DesignBuilder, and so on. But most of the software is not user-friendly and a complex process has to follow for the analysis. The software that has been used in this research is Carbo Life Calculator. Carbo Life Calculator is a tool for figuring out how much carbon is already in a building. Carbo Life Calculator takes embodied carbon data from Environmental Product Declarations (EPDs) or other databases and maps it to the design [23]. To figure out the embodied carbon, the application has used quantities and materials from Revit. The materials in Revit are automatically mapped to the ones in Carbo Life Calc. This has given an instant answer about how much carbon is in the building.

2.3. Calculation of Carbon Emission

After launching the CarboLifeCalc to Revit 2020, got loaded to the Revit add-in template. The following Figure 3 shows that CarboLifeCalc has three options in the template. As the project of the research is new, so New Project has been selected for the analysis.

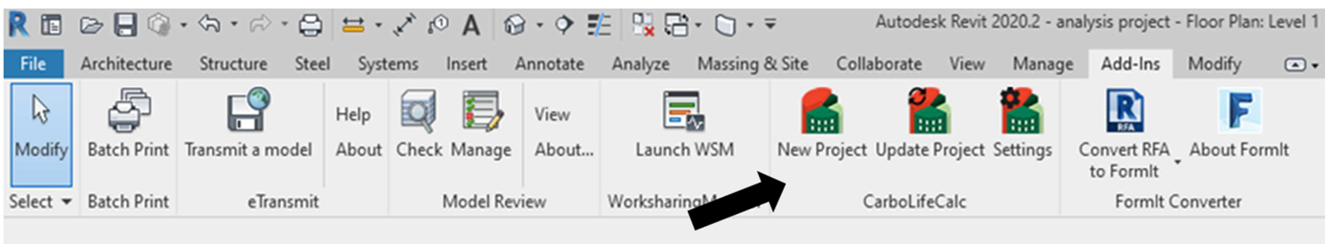


Figure 3. *CarboLifeCalc panel in Revit template.*

For initiating the work, the 3D view has been taken so that all the elemental data gets added to CarboLifeCalc.

After this, the next tab is opened, and a visual depiction of the building's embodied carbon is displayed. This section contains some of the most fundamental data on the project, including its name, number, classification, and monetary worth. Figure 4 is a bar chart showing the embodied carbon of the new project.

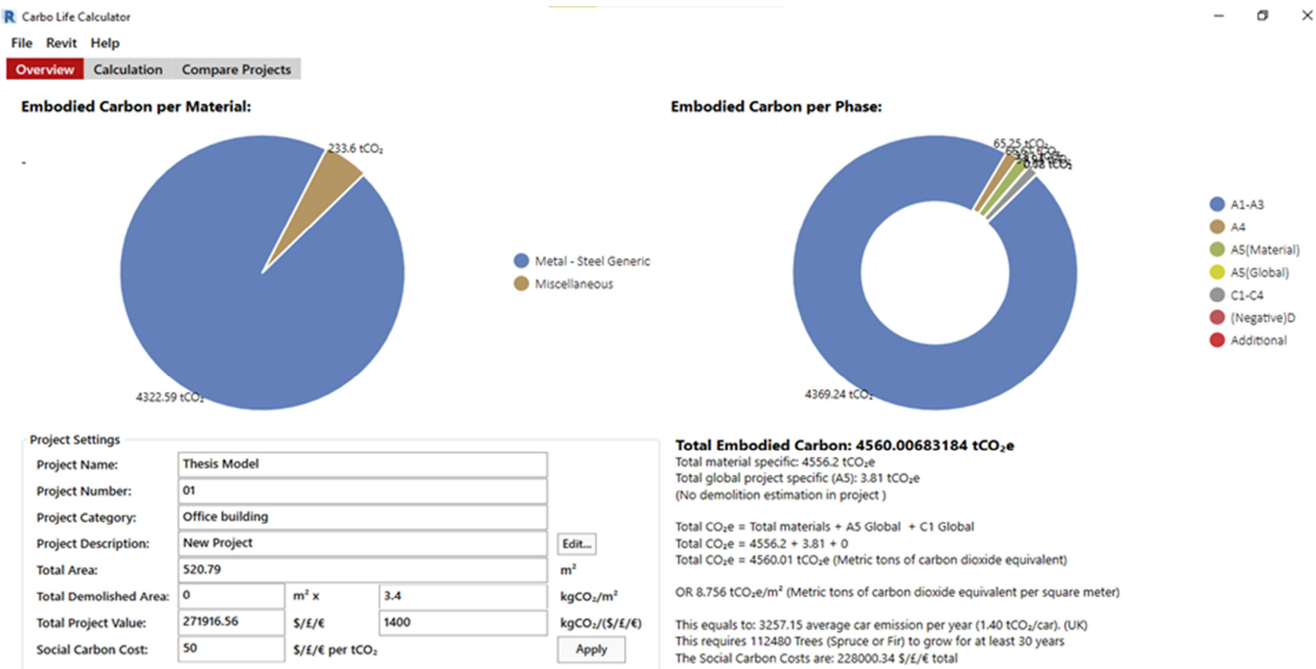
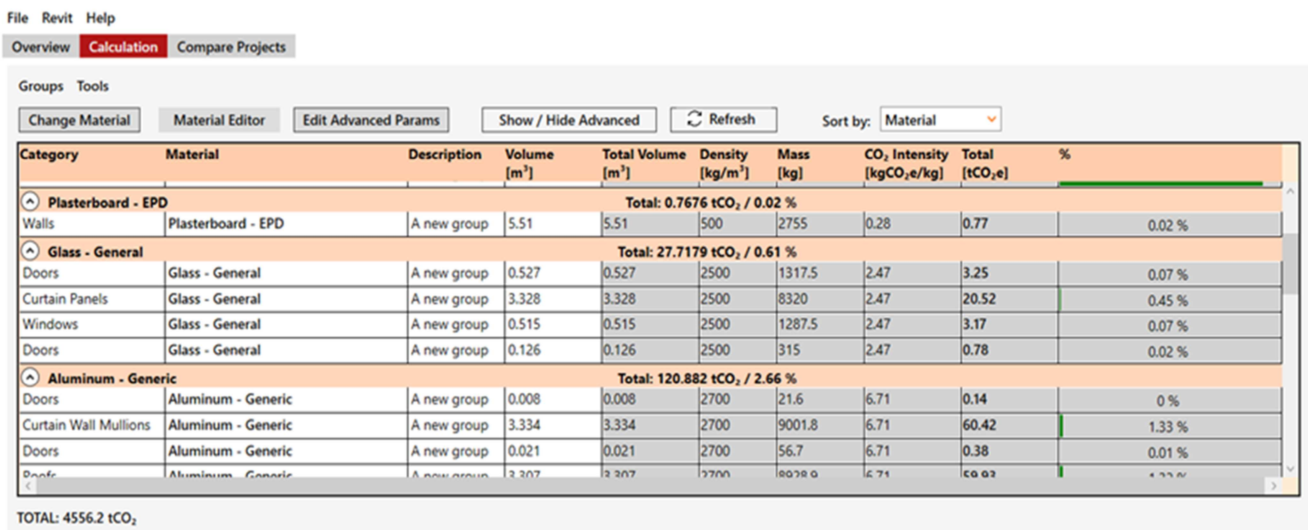


Figure 4. *Overview of the total embodied carbon.*

The calculation option displays a list-like breakdown of the calculations performed for each element's material type. Figure 5 shows the material calculation for each element.



File Revit Help

Overview Calculation Compare Projects

Groups Tools

Change Material | Material Editor | Edit Advanced Params | Show / Hide Advanced | Refresh | Sort by: Material

Category	Material	Description	Volume [m³]	Total Volume [m³]	Density [kg/m³]	Mass [kg]	CO₂ Intensity [kgCO₂e/kg]	Total [tCO₂e]	%
Plasterboard - EPD				Total: 0.7676 tCO₂ / 0.02 %					
Walls	Plasterboard - EPD	A new group	5.51	5.51	500	2755	0.28	0.77	0.02 %
Glass - General				Total: 27.7179 tCO₂ / 0.61 %					
Doors	Glass - General	A new group	0.527	0.527	2500	1317.5	2.47	3.25	0.07 %
Curtain Panels	Glass - General	A new group	3.328	3.328	2500	8320	2.47	20.52	0.45 %
Windows	Glass - General	A new group	0.515	0.515	2500	1287.5	2.47	3.17	0.07 %
Doors	Glass - General	A new group	0.126	0.126	2500	315	2.47	0.78	0.02 %
Aluminum - Generic				Total: 120.882 tCO₂ / 2.66 %					
Doors	Aluminum - Generic	A new group	0.008	0.008	2700	21.6	6.71	0.14	0 %
Curtain Wall Mullions	Aluminum - Generic	A new group	3.334	3.334	2700	9001.8	6.71	60.42	1.33 %
Doors	Aluminum - Generic	A new group	0.021	0.021	2700	56.7	6.71	0.38	0.01 %
Roofs	Aluminum - Generic	A new group	3.307	3.307	2700	[illegible]	6.71	[illegible]	[illegible]

TOTAL: 4556.2 tCO₂

Figure 5. *The material calculation for each element.*

The formula that is used by Carbo Life Calc for calculating the total volume is-

$$\text{Total Volume} = \text{Volume} \times \text{Correction Formula} \times \text{Waste factor} \times \text{Replacement Factor} \quad (1)$$

Where,

Total Volume: Total Volume in m^3

Volume: Extracted or manually given volume of a material

The Correction formula that is used for correcting the volume if there's any sort of error is:

+0.5: adds.5 m^3 to the Volume

×2: Multiplies the volume by 2

/3: Divide the volume into two

The waste factor in the formula is the percentage of waste added to the material.

Replacement Factor: If a material or part of a project has to be changed during its whole life, this needs to be added to the materials list.

The weight calculation details are given below-

$$\text{Mass} = \text{Total Volume} \times \text{Density} \quad (2)$$

Where,

Mass: Mass in kg
Total Volume: Total Volume in m^3
Density: Density in kg/m^3

Embodied carbon is a result of many processes that affect a material. Considerations include Production, transport, and construction, but also the deconstruction of elements.

$$\text{Total } kgCO_2/kg = A1-A3 + A4 + A5 + [B1-B7] + [C1-C4] + D + \text{Additional}\times[B4] \quad (3)$$

Where,
Total $kgCO_2/kg$: The Embodied Carbon Intensity (ECI)
[A1-A3]: Production
[A4]: Transport
[A5]: Construction
[B1-B7] (excluding [B4]): Life
[C1-C4]: End of Life
[D]: Out of Scope
Additional: Added value if needed.
[B4]: Replacement factor

The embodied carbon of a material group can be calculated when the Material Mass and Embodied Carbon Intensity have been calculated.

$$\text{Embodied Carbon}=\text{Mass} \times (\text{ECI} + \text{Additional}) \quad (4)$$

Where,
Embodied Carbon in $kgCO_2e$
Mass in kg
ECI in $kgCO_2/kg$
Additional: Any value that can be as per specified group.

The quantity of carbon stored in a set of materials is represented by the sum. The total amount of carbon that is embedded in each material will be calculated by adding together all the different categories.

$$\text{Total material-based embodied carbon} = \text{SUM (Embodied Carbon Groups)} \quad (5)$$

A5 (Construction) is calculated by assuming 1kgCO_2 per 1400 Euro or dollars. These are rough ballpark numbers assumed by the RICS (Royal Institution of Chartered Surveyors) guidelines. Using 1kgCO_2 for 1400£ or dollars yields an A5 (Construction) estimate. The value of C1 is considered to be 3.4$kgCO_2/m^2$. The RICS standards are used for the approximate estimate. When it is done, the total amount of carbon that has been integrated into the project may be calculated by,

$$\text{Total Embodied Carbon} = [\text{Total Material Based}] + [\text{A5 Global}] + [\text{C1 Global}] \quad (6)$$

2.4. Material Changes for Carbon Reduction

To fulfill the research purpose, the materials of walls and roofs have been changed. Comparatively, materials with lower embodied carbon have been selected.

2.4.1. Wall

For the exterior wall, concrete-precast material was selected. However, this material emits a large amount of carbon at different phases. So, the material with a lower ECI has been chosen. In terms of embodied carbon intensity, 40/50 graded concrete that contains 50% Ground Granulated Blast-furnace Slag (GGBS) has a far lower value than precast, which has a value of 0.12 $kgCO_2/kg$. The following Figure 6 shows the difference in carbon emission at different phases by these two materials.

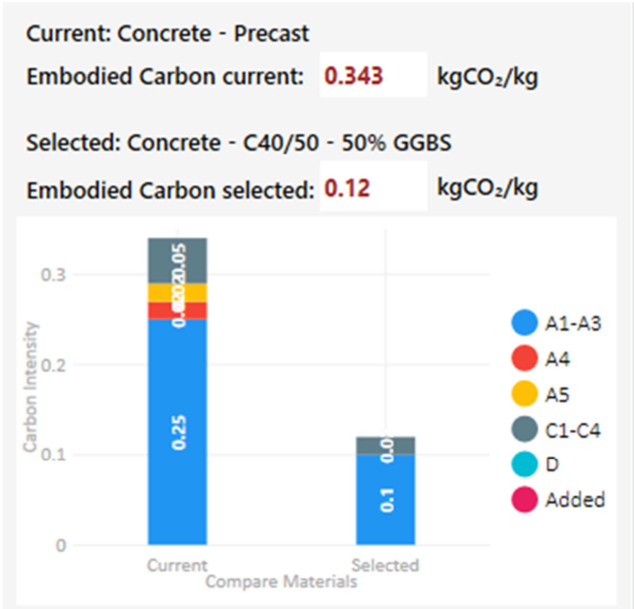


Figure 6. *Embodied carbon intensity variance of the concrete wall by material.*

The metal stud layer of the partition wall has to be changed for the carbon emission. The material for this metal steel generic was selected which has a carbon intensity of 2.53 $kgCO_2/kg$. For this purpose, steel Hollow Sections EPD has been selected. It has the lowest ECI which is 0.995 $kgCO_2/kg$. In Figure 7 difference in carbon emission is shown.

Figure 7. *Material-based ECI variance for metal stud layer.*

2.4.2. Roof

Roof materials are selected based on two parts. For the metal deck part concrete was selected and for the steel bar joist layer metal usual steel was selected. Both of these materials are great contributors to carbon emissions. In Figure 8 and Figure 9, the material variation is shown.

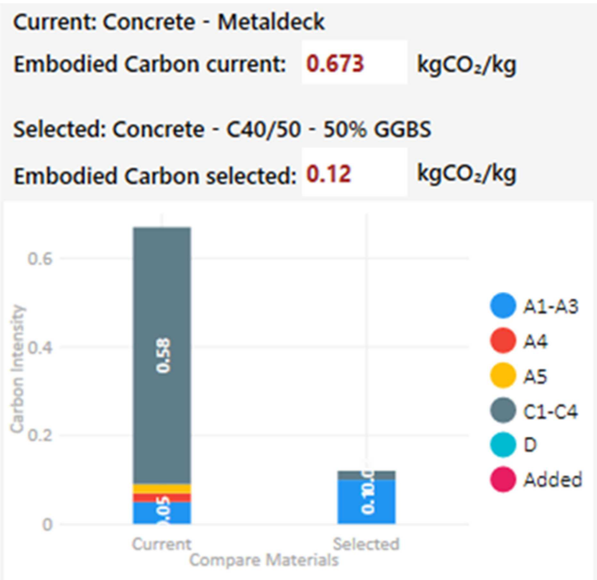


Figure 8. *Material-based ECI variance for the metal deck.*

Figure 9. *Material-based ECI variance for steel bar joist layer.*

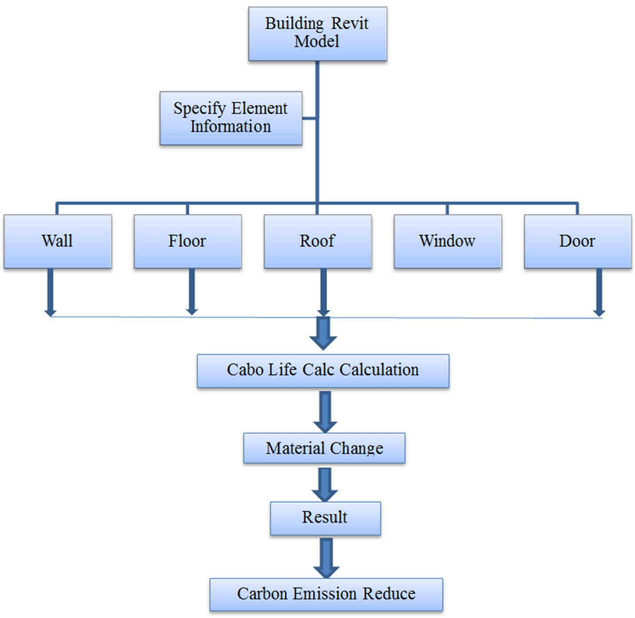


Figure 10. *Workflow diagram of the research.*

The steps that are followed for the entire research process are given below with a workflow diagram in Figure 10.

3. Results and Discussions

The result of the initial building model before any changes of material was estimated by Carbo Life Calculator. Based on the data provided by the software, the total embodied carbon emission of the construction material is calculated to be 4556.2 tons of CO_2. After the final calculation added with global project specific (A5), this amount is 4560.01 tCO_2e globally. Which is alarming. So, the environmentally it's enough harmful. Table 1 lists the total embodied carbon (EC) by building elements. Among all the elements, the list shows that maximum carbon emission occurs from roofs and walls which are 4272.92 tCO_2 and 152.18 tCO_2. So, the roof and wall materials have been changed to reduce the carbon emission of this huge amount.

Table 1. *EC list of building elements.*

Category	**EC tCO_2**
Curtain Panels	20.52
Curtain Wall Mullions	60.42
Doors	5.40
Floors	41.27
Generic Models	0.13
Roofs	4272.92
Walls	152.18
Windows	3.36
Grand Total	4556.2

Figure 11 shows the embodied carbon emission chart from curtain panels, curtain wall mullions, doors, floors, generic models, roofs, walls, and windows. In the chart, the contribution of roofs to carbon emission is the highest because of the roof material.

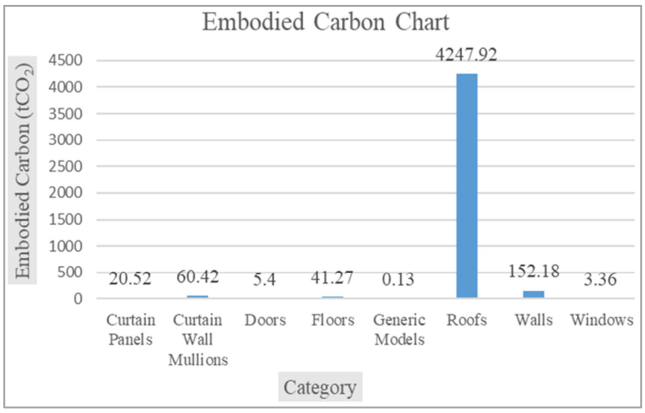


Figure 11. *Embodied carbon chart before material changes.*

Table 2 shows the overall carbon emission from roof material. As in this research, embodied carbon has been considered, and the calculation focuses on its production, transportation, construction, and end-of-life. From steel around 4204.013 tCO_2 was emitted. A large amount of fossil fuel has to be burned for the processing of steel which is environmentally not safe. On the roof, for metal decking, if concrete is used, it also emits around 5.34 tCO_2. Each pound of concrete emits 0.93 pounds of CO_2, based on the National Ready Mixed Concrete Association [24]. But changing the material to Concrete - C40/50 - 50% GGBS reduces this amount.

Table 2. *Embodied carbon of roof materials.*

Material	ECI $kgCO_2/kg$	EC tCO_2	Changed Material	ECI $kgCO_2/kg$	EC tCO_2
Concrete– Metal deck	0.67	5.34	Concrete - C40/50 - 50% GGBS	0.12	0.95
Metal-Steel Generic	2.53	4204.013	Metal - Steel - Hollow Sections EPD	0.99	1652.54

Again, the second highest carbon-emitting material is from walls. The materials that emit the maximum carbon are precast concrete and metal steel. The processing of these 2 materials requires a lot of combustion of fuel. Moreover, concrete production goes through chemical reactions which also produce carbon dioxide. During construction, concrete can even absorb CO_2 which increases the embodied carbon of the products. From Table 3 the embodied carbon from precast concrete is 31.18 tCO_2 and from metal, steel is 118.58 tCO_2.

Table 3. *Embodied carbon of wall materials.*

Material	ECI $kgCO_2/kg$	EC tCO_2	Changed Material	ECI $kgCO_2/kg$	EC tCO_2
Concrete - Precast	0.34	31.18	Concrete - C40/50 - 50% GGBS	0.12	0.95
Metal-Steel Generic	2.53	118.58	Metal - Steel - Hollow Sections EPD	0.99	1652.54

After making the changes of materials another analysis has been run through the Carbo Life Calc and the embodied carbon that has been counted by the software is 1908.04 for the office building. After adding the values of A5 and C1 the total gets 1911.85 tCO_2. This amount is much less than before changing the material specification. Table 4 lists the total embodied carbon by building elements. Among all the elements, the list shows that carbon emissions from roofs are 1717.06 tCO_2 and from walls are 59.88 tCO_2. But before making any changes in the material these values were 4272.92 tCO_2 and 152.18 tCO_2. So, around 60% of carbon has been reduced in the roof and 60.7% of carbon has been reduced in the wall. So, the changes in materials have made a huge difference in carbon reduction.

Table 4. *EC list of building elements after making changes.*

Category	EC tCO_2
Curtain Panels	20.52
Curtain Wall Mullions	60.42
Doors	5.40
Floors	41.27
Generic Models	0.13
Roofs	1717.06
Walls	59.88
Windows	3.36
Grand Total	1908.04

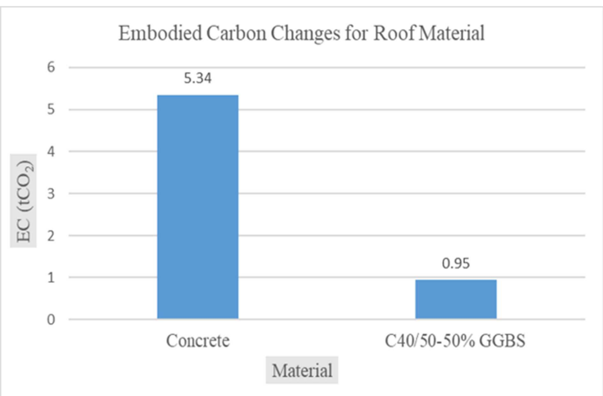


Figure 12. *Embodied carbon variation for Concrete and C40/50 - 50% GGBS (Roof).*

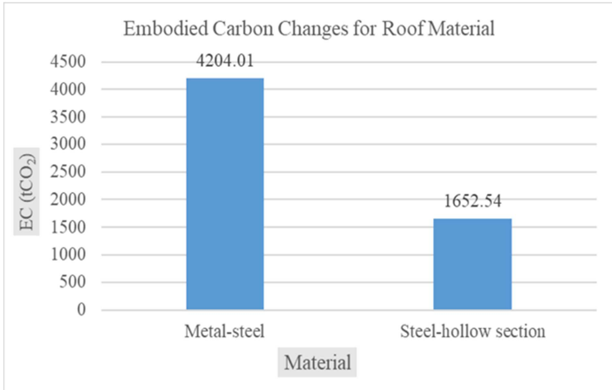


Figure 13. *Embodied carbon variation for Metal-steel and Steel-hollow section (Roof).*

Figures 12 and 13 represents the variation in embodied carbon due to the change in roof material as a chart. There's a huge difference in embodied carbon of metal steel.

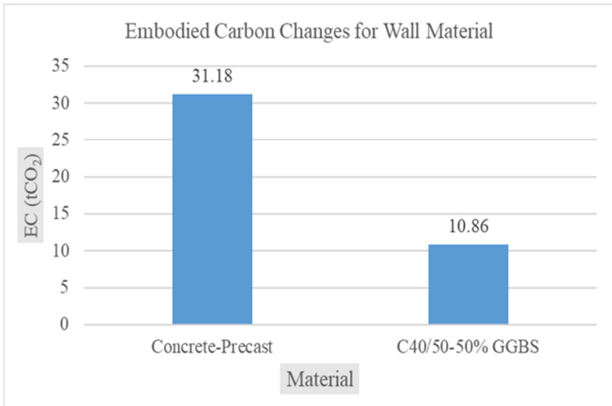


Figure 14. *Embodied carbon variation for Concrete and C40/50 - 50% GGBS (Wall).*

For the exterior wall purpose, C40/50 - 50% GGBS was selected which reduced the embodied carbon to 10.86 tCO_2 which has decreased from 31.18 tCO_2. Another change that is made is by selecting steel with a hollow section. It reduces carbon emissions from the stud layer of the partition wall.

Using this type of steel reduces the carbon intensity from 2.53 to 0.99 kgCO_2/kg and overall embodied carbon gets 46.61 tCO_2. Figures 14 and 15 represents the variation in embodied carbon due to the change in wall material as a chart.

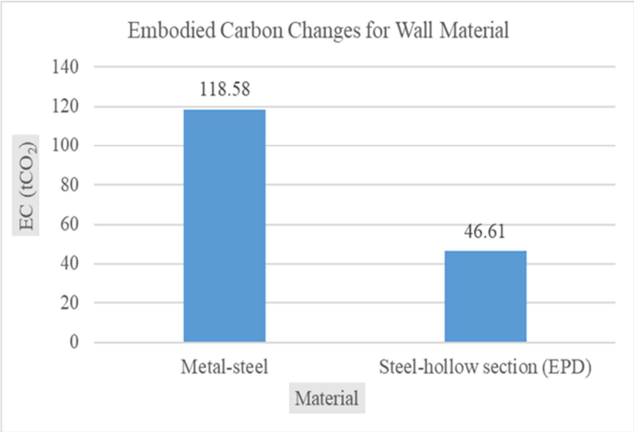


Figure 15. *Embodied carbon variation for Metal-steel and Steel-hollow section (Wall).*

The embodied carbon of the structure that is evaluated is presented in the form of a pie chart in Figure 16. The pie chart shows that among the total embodied carbon of 4556.2 tCO_2, the maximum portion comes from steel-type material. So, the graph here signifies steel embodied carbon with 4322.59 tCO_2, and the remaining carbon is mixed with the emission from other materials which is 233.6 tCO_2.

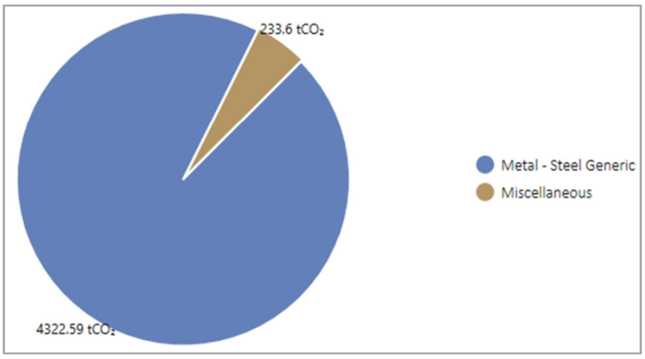


Figure 16. *Embodied carbon per material (before material change).*

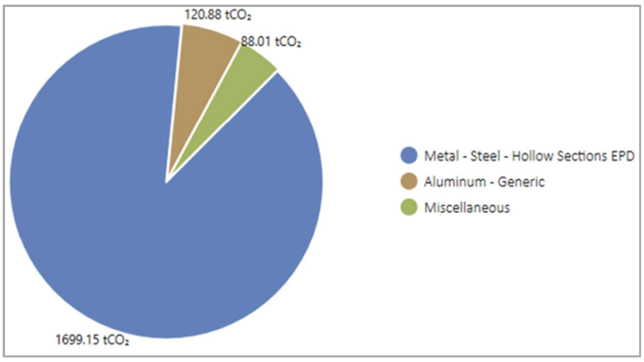


Figure 17. *Embodied carbon per material (after material change).*

Carbon "embodied" in various components is displayed as a proportion in Figure 17. Steel-type materials are responsible for the greatest proportion of the total embodied carbon, which is 1908.04 tCO_2, followed by aluminum, and the rest comes from a variety of sources. This graph shows that hollow section steel has 1699.15 tCO_2 of carbon embedded in it, while aluminum-type materials emit 120.88 tCO_2 and other materials emit 88.01 tCO_2. As a whole, carbon emissions decreased from the preceding period.

4. Conclusion

The importance of lowering carbon emissions in the AEC sector has grown in recent years. The design and construction phases of a structure's life cycle are the primary applications of building information modelling (BIM). It has limited functionality in other phases of a building's existence. This study explores the use of BIM technology in connection with strategies for lowering carbon emissions generated by the use of technology to modify materials to create a system for real-time carbon estimation. The objective of this thesis was to initiate a BIM tool and a software-based analysis for carbon emission. With the help of Autodesk Revit, a 3D model of the office building was possible to make with material detailing, and embodied carbon for the entire building was calculated to be 4560.01 tCO_2 using the Carbo Life Calc software. Along with this carbon emission reduction was another purpose of this research through material changes in roofs and walls. Through the changes in these two structural elements, the carbon has been reduced for the roof by 60% and the wall by 60.7%. So, the outcome satisfies the objective of this project. Still, there were some limitations while initiating the methodology which has been followed for this research process. The carbon emission due to repair, refurbishment, or maintenance of the material on its whole hasn't been considered for estimation. The outcome of this thesis can be used for such kinds of office building projects at the early stage. It will be possible to successfully contribute to carbon emission reduction from building materials and as well globally a less contributor to carbon emission.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] R. Chandrappa, S. Gupta, and U. C. Kulshrestha, *Coping with Climate Change: Principles and Asian Context*. Springer Science & Business Media, 2011.

[2] K. Halsnæs *et al.*, "Framing issues," in *Climate change 2007: Mitigation. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, 2007.

[3] O. US EPA, “Causes of Climate Change,” Apr. 15, 2021. https://www.epa.gov/climatechange-science/causes-climate-change (accessed Sep. 14, 2022).

[4] L. Meyer, S. Brinkman, L. van Kesteren, N. Leprince-Ringuet, and F. van Boxmeer, “Technical Support Unit for the Synthesis Report,” p. 169.

[5] C. K. Chau, T. M. Leung, and W. Y. Ng, “A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings,” *Appl. Energy*, vol. 143, pp. 395–413, Apr. 2015, doi: 10.1016/j.apenergy.2015.01.023.

[6] S. Anowar, Md. F. Rakib, R. Hasan, and M. Rahman, “Assessment of greenhouse gas emissions in building construction: A case study of SWC building at Kuet in Bangladesh,” *J. Constr. Eng. Manag. Innov.*, vol. 2, pp. 215–229, Dec. 2019, doi: 10.31462/jcemi.2019.04215229.

[7] Y. H. Dong and S. T. Ng, “A life cycle assessment model for evaluating the environmental impacts of building construction in Hong Kong,” *Build. Environ.*, vol. 89, pp. 183–191, Jul. 2015, doi: 10.1016/j.buildenv.2015.02.020.

[8] Y. H. Dong and S. T. Ng, “Comparing the midpoint and endpoint approaches based on ReCiPe—a study of commercial buildings in Hong Kong,” *Int. J. Life Cycle Assess.*, vol. 19, no. 7, pp. 1409–1423, Jul. 2014, doi: 10.1007/s11367-014-0743-0.

[9] V. J. L. Gan, J. C. P. Cheng, I. M. C. Lo, and C. M. Chan, “Developing a CO_2-e accounting method for quantification and analysis of embodied carbon in high-rise buildings,” *J. Clean. Prod.*, vol. 141, pp. 825–836, Jan. 2017, doi: 10.1016/j.jclepro.2016.09.126.

[10] S. Xing, Z. Xu, and G. Jun, “Inventory analysis of LCA on steel- and concrete-construction office buildings,” *Energy Build.*, vol. 40, no. 7, pp. 1188–1193, Jan. 2008, doi: 10.1016/j.enbuild.2007.10.016.

[11] M. Suzuki and T. Oka, “Estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan,” *Energy Build.*, vol. 28, no. 1, pp. 33–41, Aug. 1998, doi: 10.1016/S0378-7788(98)00010-3.

[12] N. Shafiq, Muhd. F. Nurrudin, S. S. S. Gardezi, and A. B. Kamaruzzaman, “Carbon footprint assessment of a typical low rise office building in Malaysia using building information modelling (BIM),” *Int. J. Sustain. Build. Technol. Urban Dev.*, vol. 6, no. 3, pp. 157–172, Jul. 2015, doi: 10.1080/2093761X.2015.1057876.

[13] H. Yan, Q. Shen, L. C. H. Fan, Y. Wang, and L. Zhang, “Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong,” *Build. Environ.*, vol. 45, no. 4, pp. 949–955, Apr. 2010, doi: 10.1016/j.buildenv.2009.09.014.

[14] M. J. González and J. García Navarro, “Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact,” *Build. Environ.*, vol. 41, no. 7, pp. 902–909, Jul. 2006, doi: 10.1016/j.buildenv.2005.04.006.

[15] W.-M.-S. Wan Omar, J.-H. Doh, and K. Panuwatwanich, “Variations in embodied energy and carbon emission intensities of construction materials,” *Environ. Impact Assess. Rev.*, vol. 49, pp. 31–48, Nov. 2014, doi: 10.1016/j.eiar.2014.06.003.

[16] K. A. Al-Sallal, “Energy and carbon emissions of buildings,” in *Low Energy Low Carbon Architecture*, CRC Press, 2016.

[17] “Decision criteria for selecting air source heat pump technology in UK low carbon housing: Technology Analysis & Strategic Management: Vol 23, No 6.” https://www.tandfonline.com/doi/abs/10.1080/09537325.2011.585030 (accessed Sep. 07, 2022).

[18] W. M. Matipa, P. Cunnigham, and B. Naik, “Assessing the impact of new rules of cost planning on BIM schema pertinent to quantity surveying practice,” in *Proceedings 26th Annual ARCOM Conference*, Leeds, UK, Sep. 2010, vol. 1, pp. 625–632. Accessed: Sep. 14, 2022. [Online]. Available: http://researchonline.ljmu.ac.uk/id/eprint/3346/

[19] I. Motawa and K. Carter, “Sustainable BIM-based Evaluation of Buildings,” *Procedia - Soc. Behav. Sci.*, vol. 74, pp. 419–428, Mar. 2013, doi: 10.1016/j.sbspro.2013.03.015.

[20] Z. Luo, L. Yang, and J. Liu, “Embodied carbon emissions of office building: A case study of China’s 78 office buildings,” *Build. Environ.*, vol. 95, pp. 365–371, Jan. 2016, doi: 10.1016/j.buildenv.2015.09.018.

[21] X.-J. Li, J. Lai, C. Ma, and C. Wang, “Using BIM to research carbon footprint during the materialization phase of prefabricated concrete buildings: A China study,” *J. Clean. Prod.*, vol. 279, p. 123454, Jan. 2021, doi: 10.1016/j.jclepro.2020.123454.

[22] “CO_2 emissions (metric tons per capita) - Bangladesh | Data.” https://data.worldbank.org/indicator/EN.ATM.CO$_2$E.PC?locations=BD (accessed Sep. 14, 2022).

[23] DavidVeld, “CarboLifeCalc.” Jul. 06, 2022. Accessed: Sep. 15, 2022. [Online]. Available: https://github.com/DavidVeld/CarboLifeCalc

[24] “Cement and Concrete: The Environmental Impact,” *PSCI.* https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact (accessed Sep. 15, 2022).