A Comparative Study of Traditional vs. Automated BIM-LCA Methods for Embodied Carbon Assessment

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Abstract. This study explores the integration of Building Information Modeling (BIM) and Life Cycle Assessment (LCA) to improve the assessment of Embodied Carbon (EC) in building materials, aiming to enhance sustainability in the construction industry. The research compares traditional manual LCA (Type I) with an automated BIM-LCA approach (Type II), utilizing Autodesk Revit and Python programming for enhanced accuracy and efficiency. The methodology is demonstrated through a case study of The London College, a 2500 m² educational building. Results show that the Type II integration method significantly reduces assessment time while maintaining high accuracy, with discrepancies between the methods being less than 1%. This automation enables detailed EC assessments early in the design process, facilitating informed decision-making and optimizing material choices to reduce carbon emissions.

Keywords: Building Information Modelling, Life Cycle Assessment, BIM-LCA approach, Python programming, Revit.

1. Introduction

Dealing with climate change and its consequences for the environment has been one of the biggest challenges of modern life (Fenner *et al.,* 2018). In fact, most current sustainable strategies are intrinsically associated with the intention of reducing greenhouse gas (GHG) emissions. According to the Report of the Intergovernmental Panel on Climate Change (IPCC), global GHG emissions should be reduced by 45% by 2030 compared to 2010 and achieve a 100% reduction by 2050 (Chen et al., 2020; Xu et al., 2021). This target is crucial to limit global warming to no more than 1.5°C, as outlined in the Paris Agreement and emphasised by various international organisations and scientific assessments. Similarly, GHG emissions in the UK must decrease by approximately 68% by 2030 and reach net zero by 2050. Net zero means that emissions of GHGs are balanced by removals from the atmosphere (Gregg and Morecraft, 2021). GHG emissions are measured in million tonnes of carbon dioxide equivalent, or Mt CO_2e – a measure covering the seven main GHG emissions which weights each gas based on its potential to cause global warming. Fig. 1 illustrates the GHG emissions in the UK spanning the years 1990 to 2021. As carbon emissions (CO_2) accounts for the majority of GHG emissions (80% on average over the years 2017 to 2021), changes in CO_2 tend to be reflected in changes in GHG emissions overall (Climate Change, 2023). Therefore, accurate assessment of CO_2 emissions is crucial.

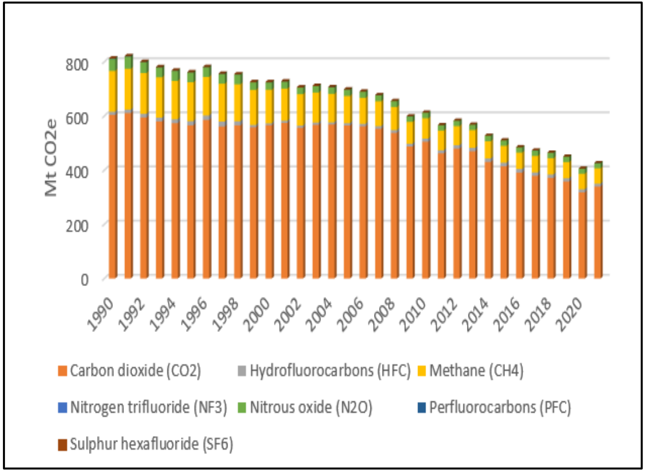


Fig. 1 GHG emissions in the UK spanning the years 1990 to 2021

In the building sector, Operational Carbon (OC) (carbon emitted during the heating, cooling, lighting, etc.) accounts for 28% of carbon emissions, whereas EC (carbon emissions emitted throughout the extraction, manufacture, transportation, construction, and demolition of a building) accounts for 11%, according to a report by The World Green Building Council (World GBC) (Adams, Burrows and Richardson, 2019).

Unlike OC which only relates to energy used to keep the building running when in-use, EC is associated with different

doi: 10.1006/efs.xxxx.xxxx ISSN: 2753-4693

phases of the building's life cycle (Ekundayo et al., 2019).

The focus of carbon reduction is shifting from OC to EC as a result of improved operational energy efficiency in buildings (Victoria and Perera, 2018). During a building's full life cycle, OC plays a vital role in total carbon emissions because of the long period of the use stage, whereas EC generated from construction has been increasingly emphasised owing to the promotion of low/zero carbon building design (Pan and Pan, 2018; Ansah, Chen and Yang, 2022) and advances in renewable energy (Liu and Rodriguez, 2021; Zhang et al., 2022). This means that EC can represent a higher proportion of Whole Life Carbon (WLC) than it used to. Thus, EC has become significant and can represent 40-70% of WLC in a new building. Fig. 2 shows the magnitude and breakdown of WLC (London Energy Transformation Initiative, 2020).

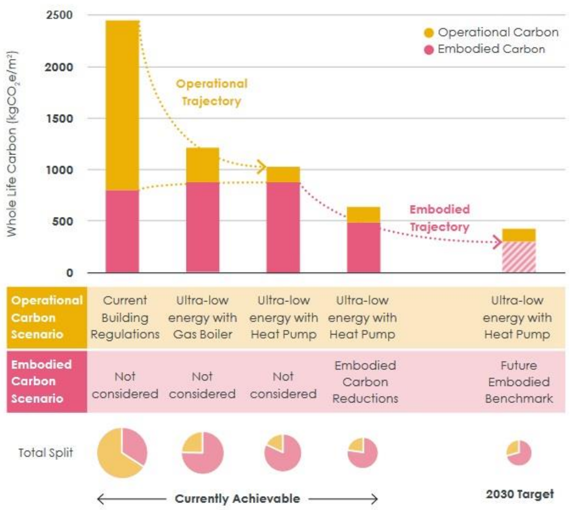


Fig. 2 The magnitude and breakdown of WLC emissions (London Energy Transformation Initiative, 2020)

Embodied carbon assessment (ECA) is a method used to quantify the total EC emissions associated with the entire life cycle of a building, considering all stages from production of building materials (A1-A3) until end-of-life of the building (C1-C4). Demonstrating commitment to reducing embodied emissions is quickly becoming a key consideration in obtaining planning permission. Several local authorities - including Westminster City Council, Brighton, Oxford, Hammersmith and Fulham, Camden and City of London - have started to enquire about the EC emissions of developments. Having an EC assessment may soon make all the difference in the planning process. One of the ways that can reduce EC significantly is ECA early in design stage before the building is built. LCA is a systematic method for evaluating environmental impact (such as EC emissions) of a product throughout its entire life cycle, from raw material extraction to disposal. There are three typical LCA methods, namely Process-Based Life Cycle Assessment (PLCA), Input-Output Life Cycle Assessment (I–O LCA) and Hybrid Life Cycle Assessment (HLCA) (Pan and Teng, 2021). These three LCA methods offer distinct perspectives and levels of detail in assessing the environmental impacts of products, processes, or services throughout their life cycles. PLCA focuses on analyzing the environmental impacts associated with individual processes within a product's life cycle. I-O LCA takes a more macroeconomic approach, examining the interactions between different sectors of the economy and assessing the environmental impacts associated with the entire supply chain. HLCA combines elements of both PLCA and I-O LCA, leveraging their respective strengths to provide a more comprehensive and accurate assessment by integrating detailed process-level data with macroeconomic considerations (Pan and Teng, 2021). PLCA is frequently employed to evaluate the environmental impact within the building sector and is often simply referred to as LCA in research studies. Combining LCA with digital design tools like BIM allows for the identification and mitigation of environmental hotspots during the design process (Potrč Obrecht *et al.,* 2020). BIM is a three-dimensional virtual model that incorporates building data (Cheng et al., 2022). As a comprehensive digital representation of project-related information (Zhao, Deng, and Lai, 2021), BIM can significantly reduce the time and labor required to manage building data (Lu *et al.,* 2021). BIM facilitates decision-making for architects and designers in the sustainable material selection (for example, the material with low energy content) during the building design process (Lee and Jun, 2016; Raza, Kumar and Nawab, 2018). Previous research has identified Revit® as the most widely used BIM tool (Carvalho, Bragança, & Mateus, 2020; Eleftheriadis et al., 2017). In 2020, Revit® software was employed in nearly 78% of BIM-LCA articles, up from 73% in 2017.

To calculate EC, BIM-integrated LCA approaches can be classified into three types based on data exchange flow. The Type I approach involves exporting BIM data and combining it with emission factors from various databases, usually in spreadsheet format (Hunt and Osorio-Sandoval, 2023). This assessment is conducted outside the BIM environment and is susceptible to errors due to manual processing. Type I is also known as traditional manual LCA. Several of the reviewed studies applied LCA during the early design stage, utilizing type I integration between BIM models and LCA tools. In most cases, contemporary BIM-LCA workflows relied on conventional spreadsheets (e.g., Excel sheets) (Potrč Obrecht et al., 2020). This method requires a significant time investment, reducing their efficiency and potentially delaying decision-making in the early design stages. Type I method often necessitates external data management, as the analysis is performed outside the BIM environment, creating additional complexity in data handling. In contrast, the benefits of automated integration between LCA and BIM are now clear, such integration streamlines the assessment of EC in buildings, significantly improving both the speed and accuracy of the process. The Type II approach integrates carbon emission factors directly into BIM tools, utilizing BIM technology as both a data source and a visualization platform (Hunt and Osorio-Sandoval, 2023). This method frequently uses LCA plug-in tools, which offer quick results but often depend on generic data (Potrč Obrecht et al., 2020). Although Type II automated BIM-LCA approaches streamline workflows and save considerable time, the dependence on pre-existing databases can limit the accuracy of embodied carbon assessments. This reliance can lead to a

doi: 10.1006/efs.xxxx.xxxx ISSN: 2753-4693

generalized carbon profile, which may fail to fully account for the unique characteristics of a project's materials and environmental context. Most studies employing the plug-in approach have utilized the Tally tool (Najjar et al., 2017; Najjar et al., 2019; Raposo, Rodrigues, and Rodrigues, 2019; Bueno and Fabricio, 2018), a Revit plug-in that conducts LCA analysis using the Gabi database. However, some researchers have developed their own plug-ins to extend BIM capabilities. For example, (Lee, Kim and Yu, 2014) created a Revit plug-in that generates results for six impact categories. Similarly, (Jalaei, Zoghi and Khoshand, 2021) developed a plug-in that integrates BIM with LCA for assessing EC, conducting energy analysis, and performing lighting simulations. Another study by (Parece, Resende and Rato, 2024) aimed to assess EC in buildings by integrating BIM and LCA with a Construction Classification System (CCS) and a Python add-on for Autodesk Revit. This research extracts material quantities from BIM models, links them to environmental data in LCA databases, and calculates EC. Case studies demonstrate the tool's effectiveness in accurately assessing EC and optimizing design choices. The Type III approach involves importing BIM data into dedicated LCA software tools, allowing the assessment to be performed directly within these specialized tools (Hunt and Osorio-Sandoval, 2023). This approach utilizes BIM data as input for LCA software. However, a significant limitation is that stakeholders with limited budgets may not have access to these specialized LCA tools, hindering comprehensive EC assessments, particularly in the crucial early design phases. Research conducted by (Xu et al., 2022) used an Industry Foundation Classes (IFC)-enabled data transfer tool to integrate BIM data with the LCA software SimaPro for a prefabricated residential building in Hong Kong. This integration resulted in only a 1% discrepancy compared to traditional LCA methods and significantly reduced LCA modeling time from 729 minutes to 62 minutes, achieving a 91.5% efficiency improvement. Another study conducted by (Resch *et al.,* 2020), introduces a method for evaluating and visualizing buildings' EC emissions by linking material inventory data with LCAs. Utilizing the building LCA database tool (bLCAd-tool) for organizing and analyzing LCA data, the study demonstrates the method's effectiveness through a case study, highlighting its ability to identify key emission drivers and support low-carbon building design. However, using specialized LCA tools can be expensive and out of reach for many stakeholders, especially in the crucial early design phases. This limitation restricts broader adoption and prevents many professionals from leveraging these tools for real-time carbon assessments. The main differences between these integration processes and calculation approaches are based on how the data were collected and used, as well as the process of data exchange and type of computation (Vandervaeren et al., 2022). This research addresses a key research question identified by the IEA Annex 57: " How can new calculation methods and 3D models better account for embodied impacts from the early stages of construction?".

In this study, Autodesk Revit is employed as the BIM software, and the EC assessment is automated via a Type II integration of BIM and LCA facilitated by Python programming. The feasibility and effectiveness of this approach are evaluated through a comprehensive case study. The study is specifically delimited to include college buildings. The choice to limit the scope to this category is driven by two key reasons. One reason is the recognition of their significant contributions to EC emissions and the other one is the availability of the necessary data for our assessment. A major analysis of the carbon emissions of universities and further education colleges has revealed that they emitted more than 18 million tonnes of carbon dioxide equivalent (CO_2e) into the environment in 2020/21, which represents around 2.3% of the UK's overall carbon footprint (Priestley Centre for Climate Futures, 2023).

2. Methodology

2.1 Life Cycle Assessment

LCA is a method for evaluating the environmental impact of products and procedures throughout their entire life cycle. It seeks to identify environmental impacts at all stages of a product's life cycle and generates data representing the environmental burden of the product (Kumanayake, Luo and Paulusz, 2018). BS EN 15978 divides the life cycle of a building into the following modules: product (A1-A3), construction (A4-A5), use (B), end-of-life (C), and re-use/recovery potential (D), with the latter accounting for advantages outside the system boundary. As more of these steps are considered, a more complete picture of the environmental effect emerges (Papakosta and Sturgis, 2017). Fig. 3 shows the life cycle stages of an asset (Gibbons et al., 2022).

According to the International Organization for Standardization (ISO), the LCA procedure consists of the following steps: 1. Goal and Scope: In this phase, the boundary, functional unit, assumptions, and purpose are mentioned (Ortiz, Castells and Sonnemann, 2009). 2. Life cycle inventory (LCI): collection of input data needed for assessment. 3. Life cycle impact assessment (LCIA): Evaluation of the size and significance of the environmental impacts of a product throughout its life cycle. 4. Life cycle Interpretation: Analysis of the results of the LCI and LCIA within the goal and scope. Fig. 4 shows the description of LCA methodology in the ISO standards (ISO, 2006).

2.1.1 Embodied Carbon Definition

Cradle-to-grave carbon is the carbon released during material extraction, processing, manufacturing, demolition, transportation, waste processing, and final disposal. The fundamental principle of an EC calculation is to multiply the quantity of each material by a carbon factor for the life cycle modules being considered (Gibbons et al., 2022).

Product stage Embodied Carbon (A1-A3)

This stage involves the processing of raw materials and the manufacturing of building materials. The emissions are primarily caused by chemical reactions and energy consumption (e.g., diesel, gasoline, and electricity) during the manufacturing of a product from raw materials. The total amount of carbon emissions associated with the product stage (A1-A3) is calculated by equation 1 (Gibbons et al., 2022).

$$\mathrm{EC_{A13}} = \sum_{i=1}^{n}\left[\mathrm{Q_i}\left(\mathrm{ECF_{A13,i}}\right)\right] \quad (1)$$

Where Q_i is the weight of i^{th} material, $\mathrm{ECF_{A13,i}}$ is the ECF associated with i^{th} material.

2.3 System Boundary

The system boundary of the case study in this research follows the modularity approach defined by the EN 15804:2012+A2:2019. The system boundary is cradle-to-gate. This boundary includes all associated processes and activities, from the extraction of raw materials to the point when the product leaves the manufacturer.

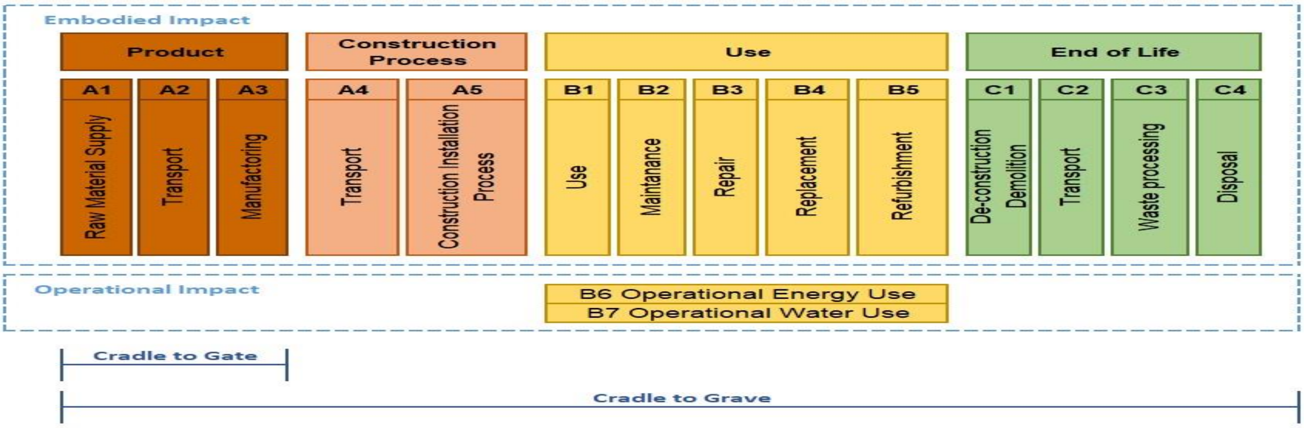


Fig. 3 WLC emissions of a building reproduced from IStructE 'How to Calculate Embodied Carbon' (Gibbons et al., 2022)

Fig. 4 Description of LCA methodology in the ISO standards

2.2 Case Study

As a case study, this investigation used The London College, which is a large, detached educational building. This building is coated in red bricks and has double glazed windows of a dark brown colour. The total floor area of the building is around 2500 m^2 and it is constructed in three levels (Fig. 5).

Fig. 5 Revit 3D model of the college building

2.4 BIM-Integrated LCA

This research conducted an EC assessment comparison between Type I and Type II BIM-integrated LCA approaches to highlight the differences and demonstrate the benefits of automating EC assessment. In a previous study, Type I, the most widely used method for assessing EC in buildings, was employed for the EC assessment in the case study. In this approach, the initial step involved conducting a comprehensive site visit to gather essential data, marking the preliminary phase of the simulation process. During this phase, a thorough survey of the actual buildings was carried out to collect crucial information. This includes obtaining AutoCAD plans and details on the building's construction such as the year and materials used. AutoCAD drawings were employed to extract precise measurements of doors and windows, including their quantities, as well as to determine floor height. These drawings have the necessary zones, such as bedrooms, bathrooms, offices, kitchen, laundry etc. Following this, the case study was modelled using the BIM software Autodesk® Revit®. The modelling process relies on the design plan data provided by the constructor to precisely determine the quantity of materials used in the construction of the building. Subsequently, a diverse set of Embodied Carbon Factor (ECF), including Environmental Product Declarations (EPDs) and the Inventory of Carbon and Energy (ICE) database were applied. These factors were multiplied by the respective quantities of materials, showing comprehensive insights into the EC emissions associated with various building materials across their life stages (Fig. 6).

doi: 10.1006/efs.xxxx.xxxx
ISSN: 2753-4693

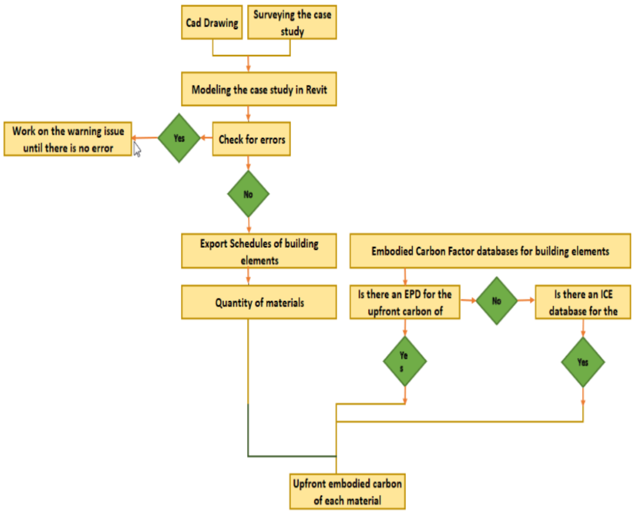


Fig. 6 Workflow for Modelling and Calculating EC in Building Elements

2.4.1 Type II BIM- LCA Approach

Type II BIM-integrated LCA is a solution to accelerate ECA and minimize potential errors. By employing Python programming, the LCA database was effectively linked with Autodesk Revit. Fig. 7 presents a workflow that automates ECA within Autodesk Revit using this integrated approach. This integration allows Revit to perform assessments internally, thereby enhancing both efficiency and accuracy.

Fig. 7 demonstrates the simplicity of assessing EC in a building using only the LCA database and the selected building elements for which EC is to be calculated.

An Excel spreadsheet has been created as LCA database containing detailed information on a wide range of building materials in the UK, including their density, ECF, and all necessary data for conducting ECAs. The EPDs and ICE database have been employed as sources for ECFs and are recognized as the most reliable database in the UK.

This document is then imported into Dynamo, a visual programming language within Revit, allowing us to perform assessments directly within the Revit environment.

A significant challenge in automating ECA is the variability in the declared units of ECF for different materials. To accurately calculate the EC of a single element comprising multiple materials with differing units, it is essential for Revit to correctly identify and apply the appropriate formula for each material. Subsequently, the software must aggregate the EC values of all materials within the element to provide a comprehensive assessment.

To address this issue, this research employed Python scripts to accurately calculate the EC of UK building materials. Python scripts were developed to automate the extraction of material properties directly from the Revit model, such as material volumes, areas, and densities. These scripts enable the collection of necessary data without manual intervention, streamlining the assessment process and reducing the potential for human error. The Python programming approach categorizes materials based on their embodied carbon factors (ECFs), which are expressed in various units such as $kgCO_2e/kg$, $kgCO_2e/m^2$, and $kgCO_2e/m^3$. Custom formulas are implemented within the Python script to accommodate these differences, ensuring that the appropriate calculations are applied to each material type. Then, Python scripts were integrated within Dynamo, a visual programming interface in Autodesk Revit. This connection allows Python to manipulate Revit's material data, performing real-time updates and calculations. This integration ensures that any design changes are automatically reflected in the embodied carbon assessment, offering a dynamic and responsive analysis tool.

The script iterates over each element ID, retrieves associated material IDs, and calculates the EC based on predefined factors. The script begins by initializing a list to store the calculated EC values for each element. It then iterates over each element ID in the input list. For each element, it initializes a variable to store the calculated EC. For each element, If the material is valid, the script fetches the material name for further processing (Fig. 8).

Initialization and Setup

```
calculation Output = [ ]
for elementId in ElementIds:
    elementCalculatedValue = 0
    element = doc. GetElement (ElementId(elementId))
    materialIds = element. GetMaterialIds(False)
    if materialIds:
        for materialId in materialIds:
            if materialId != ElementId.InvalidElementId:
                material = doc.GetElement(materialId)
                if material:
                    materialName = material.Name
```

Fig. 8 Initialization and Setup for EC Calculation in Revit Elements

For materials with ECFs measured in $kgCO_2e/kg$, the input data required for the EC assessment is defined in Dynamo, as shown in Fig. 9. The material names, densities, and EC factors are organized into separate lists, which are then linked to the Python script node.

The script processes each material by checking if the material name is present in predefined lists that categorize materials by their EC factors. For materials with EC factors in $kgCO_2e/kg$, it retrieves the material density and EC factor, then calculates the EC of the materials using equation 2.

$$EC_{A13-\text{kg based materials}} = \sum_{i=1}^{n}\left[V_i * D_i * \left(ECF_{A13,i}\right)\right] \quad (2)$$

Where V_i and D_i is the volume and density of i^{th} material, $ECF_{A13,i}$ is the ECF associated with i^{th} material. The script also handles special cases for materials like stainless steel and concrete with rebar (Fig. 10).

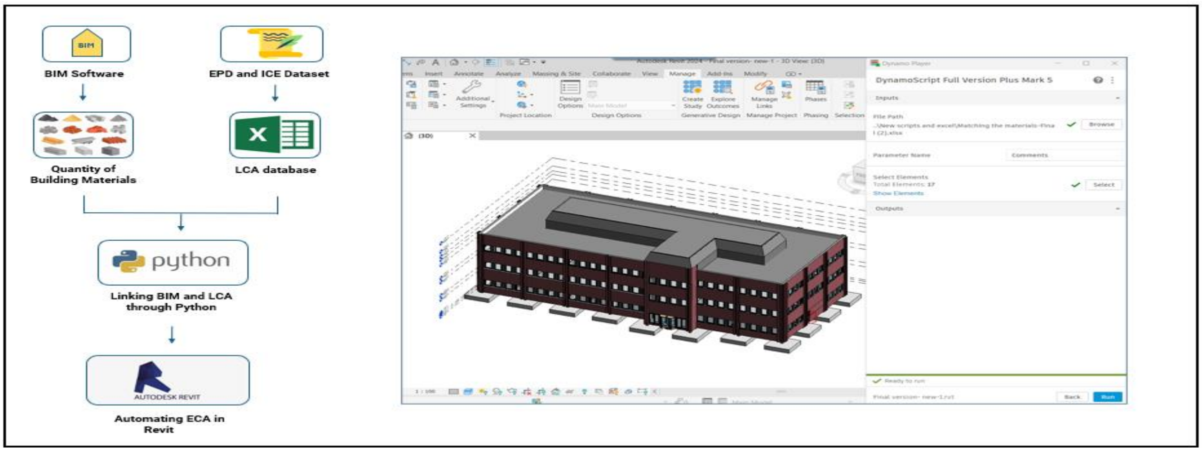


Fig. 7 Automating ECA in Revit Using BIM, LCA Databases, and Python

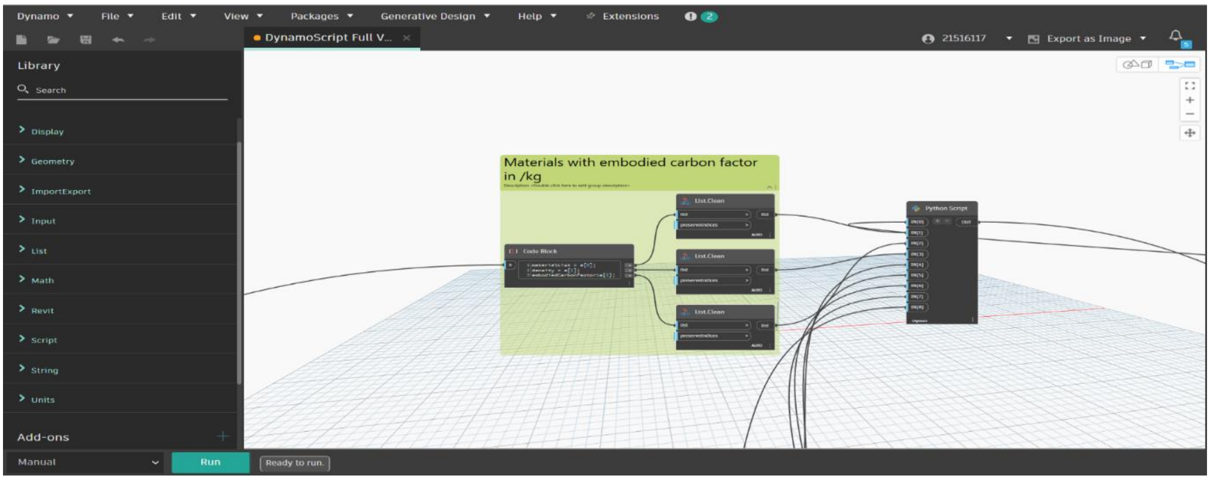


Fig. 9 Dynamo nodes for materials in $kgCO_2e/kg$

EC Assessment for materials with kgCO2e/kg declared unit

```
if materialName in kgMaterialList:
        indexInkgList = kgMaterialList.index(materialName)
        densityString = densityMaterialList[indexInkgList]
        kgFactorString = kgFactors[indexInkgList]
        density = float(densityString) #density of material for KG
        kgFactor = float(kgFactorString) # embodied carbon factor for KG
        materialVolume = UnitUtils.ConvertFromInternalUnits(element.GetMaterialVolume(materialId), UnitTypeId.CubicMeters)
        if materialName == "Steel, Stainless":
            materialVolume = round (materialVolume, 5)
        else:
            materialVolume = round (materialVolume, 3)
        rebarCalculationIfKg = 0
        if "concrete" in materialName.lower() and "block" not in materialName.lower() and "cement" not in materialName.lower():
            rebarVolume = round (materialVolume * rebarPercentage, 3)
            rebarIndexInkgList = kgMaterialList.index("Rebar")
            rebarDensityString = densityMaterialList[rebarIndexInkgList]
            rebarKgFactorString = kgFactors[rebarIndexInkgList]
            rebarDensity = float(rebarDensityString)
            rebarKgFactor = float(rebarKgFactorString)
            rebarCalculationIfKg = round (rebarDensity * rebarVolume * rebarKgFactor, 5)
        numberIfInKg = round (density * materialVolume * kgFactor, 5)
        if rebarCalculationIfKg == 0:
            elementCalculatedValue += numberIfInKg
        else:
            elementCalculatedValue += numberIfInKg + rebarCalculationIfKg
```

Fig.10 Python Script for Calculating EC for Materials in $kgCO_2e/kg$

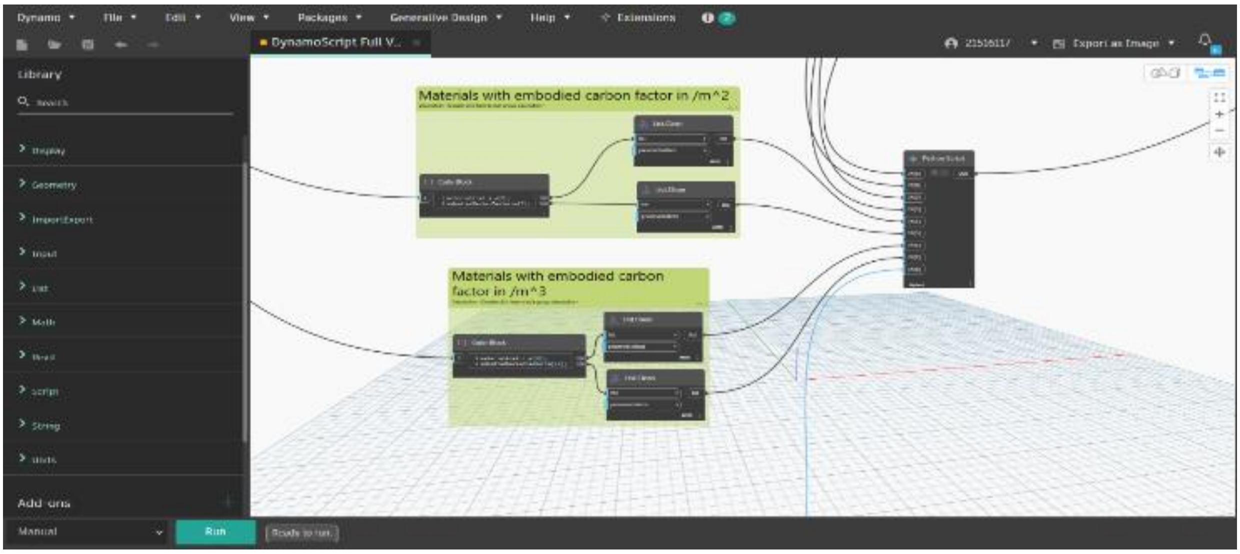


Fig. 11 Dynamo nodes for materials in $kgCO_2e/m^2$ and $kgCO_2e/m^3$

EC Assessment for materials with $kgCO_2e/m^2$ and $kgCO_2e/m^3$ declared unit

```
            elif materialName in m2MaterialList:
                indexInm2List = m2MaterialList.index(materialName)
                m2FactorString = m2Factors[indexInm2List]
                m2Factor = float(m2FactorString)
                materialArea=UnitUtils.ConvertFromInternalUnits(element.GetMaterialArea(materialId,False),
UnitTypeId.SquareMeters)
                materialArea = round (materialArea, 3)
                numberIfInm2 = round (materialArea * m2Factor, 5)
                elementCalculatedValue += numberIfInm2
            elif materialName in m3MaterialList:
                indexInm3List = m3MaterialList.index(materialName)
                m3FactorString = m3Factors[indexInm3List]
                m3Factor = float(m3FactorString)
                materialVolume = UnitUtils.ConvertFromInternalUnits(element.GetMaterialVolume(materialId),
UnitTypeId.CubicMeters)
                materialVolume = round(materialVolume, 3)
                numberIfInm3 = round(materialVolume * m3Factor, 5)
                elementCalculatedValue += numberIfInm3
        elementCalculatedValue = round(elementCalculatedValue, 3)
        calculationOutput.append(elementCalculatedValue)
        if materialIds:
    OUT = calculationOutput
```

Fig. 12 Python Script for Calculating EC for Materials in $kgCO_2e/m^2$ and $kgCO_2e/m^3$

doi: 10.1006/efs.xxxx.xxxx ISSN: 2753-4693

The script also accommodates materials with emission factors expressed in $kgCO_2e/m^2$ and $kgCO_2e/m^3$. For these materials, density is not required, as the EC is calculated directly from their volume and area measurements. (Fig. 11).

The formula for the EC calculation for materials in $kgCO_2e/m^2$ and $kgCO_2e/m^3$ is shown below.

$$\mathrm{EC}_{\mathrm{A13-Volume\ based\ materials}} = \sum_{j=1}^{n}\left[\mathrm{V}_j * \left(\mathrm{ECF}_{\mathrm{A13,j}}\right)\right] \quad (3)$$
$$\mathrm{EC}_{\mathrm{A13-Area\ based\ materials}} = \sum_{k=1}^{n}\left[\mathrm{A}_k * \left(\mathrm{ECF}_{\mathrm{A13,k}}\right)\right] \quad (4)$$

Where V_j and A_k is the volume and area of j^{th} and k^{th} materials, $\mathrm{ECF}_{\mathrm{A13}}$ is the ECF associated with them.

Python script in Fig. 12 calculates the EC of materials based on their emission factors in either square meters (m^2) or cubic meters (m^3). The results are then added to the total calculated value for an element. The Python script dynamically calculates embodied carbon during the design process, offering designers real-time feedback on the impact of material choices. This allows for more informed decision-making aimed at reducing carbon emissions from the outset of the design and is applicable to all structures throughout the UK.

3. Results

In a prior study, the EC results for the case building were determined using Type I. This paper advances the LCA approach by automating its integration with BIM technology. Consequently, the accuracy and efficiency of the proposed solution can be validated through comparison with a reference case. The study validated the accuracy of the automated BIM-LCA method (Type II) by comparing it to the results from the traditional manual LCA method (Type I). In this research EC results for the London College building were computed using both methods. The study reported that the discrepancies between the manual and automated approaches were less than 1%, which indicates high reliability for the automated process.

The radar chart displays the efficiency comparison for various structural elements using two methods (Fig. 13). Each axis represents a different element: Ceiling, Door, Floor, Roof, Stair, Structural Column, Structural Foundation, Wall, and Window. Most elements showed almost identical outcomes, with the greatest difference being around 1% (Table 1).

Door, Floor, Roof and Structural Foundation have the highest efficiency at 100%. Other elements like the ceiling, stair, structural column, wall, and window have efficiencies between 99% and 100%. This highlights the high accuracy of Type II BIM-LCA integration in this research. In addition, the bar chart in Fig. 13 shows the time disparity between Type I and Type II BIM-LCA integration for various elements. The x-axis represents time in minutes, ranging from 0 to 1800 minutes. Fig. 13 illustrates that the time required for conducting an ECA using Type I method is significantly higher compared to Type II method, indicating substantial time savings. The Type II method benefits from a comprehensive collection of ECFs for UK building materials, eliminating the need for additional time to locate these values.

These visualizations effectively highlight the efficiency and time-saving benefits of integrating BIM and LCA compared to Type I method.

The comparative analysis indicates that while both methods maintain high efficiency, the Type II BIM-LCA integration offers a marked advantage in terms of time savings. This integration not only accelerates the LCA process but also maintains, if not enhances, the reliability and accuracy of the assessments. Adopting BIM-integrated LCA can thus be highly beneficial for sustainable building practices, enabling faster and more efficient EC assessments.

Fig. 14 illustrates an example of the output for the wall materials category. It includes details such as Family and Type, Material Name, Material Area, Material Volume, and Comments, which represent the EC associated with each building material. Similar material take-offs can be generated for each category in the building. This output can be exported as an Excel file for further analysis of the building's environmental impact.

Fig. 15 represents the quantity and EC of building materials used in the college building according to the second method. The findings reveal that concrete materials have the highest quantity, leading to a substantial EC potential. In contrast, metal materials, despite their relatively low quantity, contribute the highest EC emissions due to their high ECF. This highlights the importance of reducing the EC of concrete because of its large volume and metal materials due to their high ECF, to achieve more sustainable buildings.

Materials, such as insulation and glass, also exhibit high EC potential. Although they are used in smaller quantities in this building, their impact on EC could be significant if used more extensively.

Therefore, they should be included in EC reduction strategies to effectively lower overall EC levels. Other materials, such as timber and brick, have both low quantities and low EC potential, making them suitable for use in sustainable buildings.

4. Conclusion

This study highlights the importance of Type II BIM-LCA integration to evaluate and optimize the EC of building materials. The research employs Autodesk Revit, LCA databases and Python programming to automate EC assessments, enhancing both efficiency and accuracy. The comparison between Type I and Type II BIM-LCA integration approach shows nearly identical results, with a maximum discrepancy of around 1%. The Type II BIM-LCA integration method significantly reduces the time required for EC assessments, making the process more efficient. It provides a robust platform for assessing and mitigating the environmental impact of buildings from the early design stages. It also improves decision-making in building design by enabling faster, more accurately embodied carbon assessments, reducing costs and human error. It supports regulatory compliance and helps optimize material choices for sustainability, making it valuable for the construction industry in meeting environmental goals.

doi: 10.1006/efs.xxxx.xxxx ISSN: 2753-4693

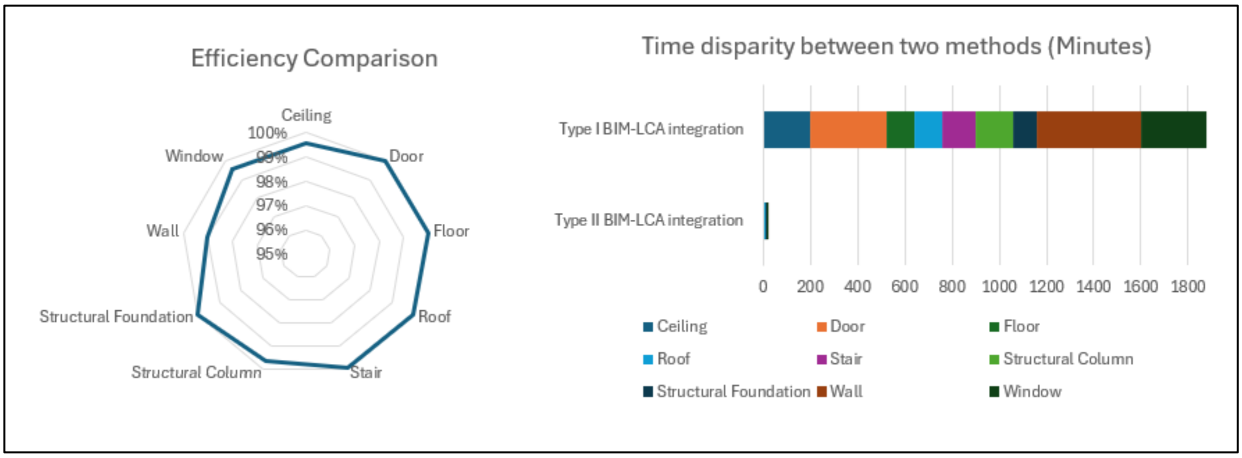
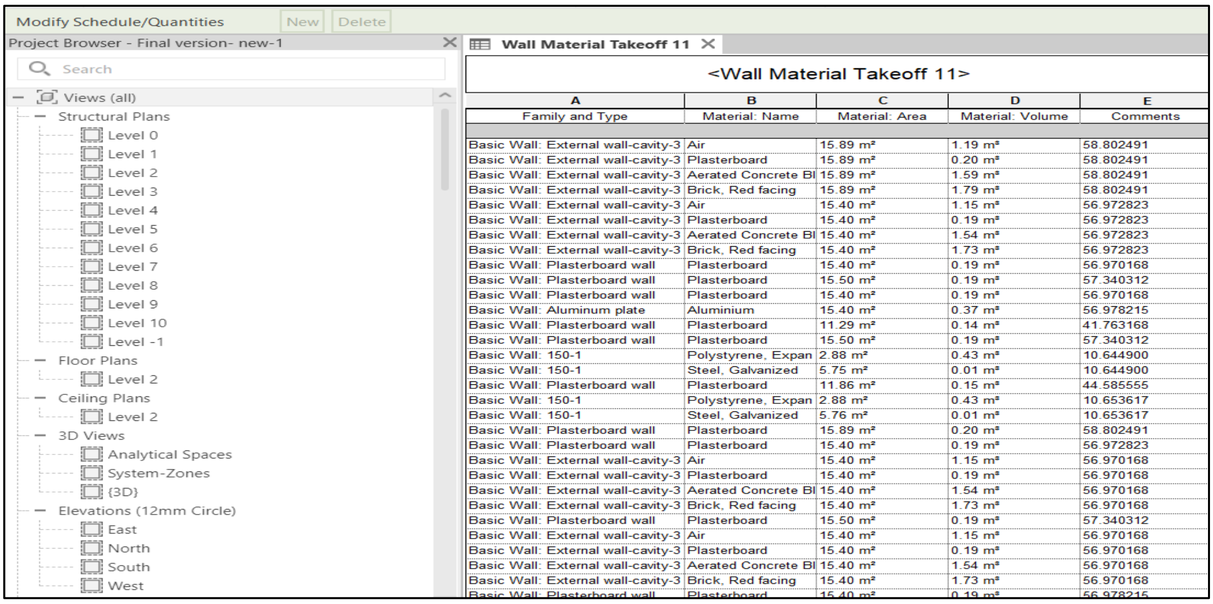


Fig. 13 Comparison of Efficiency and Time Disparity Between Type I and Type II BIM-LCA integration Methods

Table 1. Embodied carbon results of Type I and Type II BIM-LCA integration Methods

Component	Type II BIM-LCA Integration ($kgCO_2e$)	Type I BIM-LCA Integration ($kgCO_2e$)	Difference (%)
Ceiling	58234.64	58506.94	0.5%
Door	27826.15	27826.15	0
Floor	366697.22	366697.22	0
Roof	134667.98	134667.98	0
Stair	7110.26	7114.17	0.1%
Structural Column	26204.41	26284.67	0.3%
Structural Foundation	184308.20	184308.20	0
Wall	164483.84	166118.11	1%
Window	74125.45	74442.38	0.4%

doi: 10.1006/efs.xxxx.xxxx ISSN: 2753-4693



<Wall Material Takeoff 11>

A	B	C	D	E
Family and Type	Material: Name	Material: Area	Material: Volume	Comments
Basic Wall: External wall-cavity-3	Air	15.89 m^2	1.19 m^3	58.802491
Basic Wall: External wall-cavity-3	Plasterboard	15.89 m^2	0.20 m^3	58.802491
Basic Wall: External wall-cavity-3	Aerated Concrete Bl	15.89 m^2	1.59 m^3	58.802491
Basic Wall: External wall-cavity-3	Brick, Red facing	15.89 m^2	1.79 m^3	58.802491
Basic Wall: External wall-cavity-3	Air	15.40 m^2	1.15 m^3	56.972823
Basic Wall: External wall-cavity-3	Plasterboard	15.40 m^2	0.19 m^3	56.972823
Basic Wall: External wall-cavity-3	Aerated Concrete Bl	15.40 m^2	1.54 m^3	56.972823
Basic Wall: External wall-cavity-3	Brick, Red facing	15.40 m^2	1.73 m^3	56.972823
Basic Wall: Plasterboard wall	Plasterboard	15.40 m^2	0.19 m^3	56.970168
Basic Wall: Plasterboard wall	Plasterboard	15.50 m^2	0.19 m^3	57.340312
Basic Wall: Plasterboard wall	Plasterboard	15.40 m^2	0.19 m^3	56.970168
Basic Wall: Aluminum plate	Aluminium	15.40 m^2	0.37 m^3	56.978215
Basic Wall: Plasterboard wall	Plasterboard	11.29 m^2	0.14 m^3	41.763168
Basic Wall: Plasterboard wall	Plasterboard	15.50 m^2	0.19 m^3	57.340312
Basic Wall: 150-1	Polystyrene, Expan	2.88 m^2	0.43 m^3	10.644900
Basic Wall: 150-1	Steel, Galvanized	5.75 m^2	0.01 m^3	10.644900
Basic Wall: Plasterboard wall	Plasterboard	11.86 m^2	0.15 m^3	44.585555
Basic Wall: 150-1	Polystyrene, Expan	2.88 m^2	0.43 m^3	10.653617
Basic Wall: 150-1	Steel, Galvanized	5.76 m^2	0.01 m^3	10.653617
Basic Wall: Plasterboard wall	Plasterboard	15.89 m^2	0.20 m^3	58.802491
Basic Wall: Plasterboard wall	Plasterboard	15.40 m^2	0.19 m^3	56.972823
Basic Wall: External wall-cavity-3	Air	15.40 m^2	1.15 m^3	56.970168
Basic Wall: External wall-cavity-3	Plasterboard	15.40 m^2	0.19 m^3	56.970168
Basic Wall: External wall-cavity-3	Aerated Concrete Bl	15.40 m^2	1.54 m^3	56.970168
Basic Wall: External wall-cavity-3	Brick, Red facing	15.40 m^2	1.73 m^3	56.970168
Basic Wall: Plasterboard wall	Plasterboard	15.50 m^2	0.19 m^3	57.340312
Basic Wall: External wall-cavity-3	Air	15.40 m^2	1.15 m^3	56.970168
Basic Wall: External wall-cavity-3	Plasterboard	15.40 m^2	0.19 m^3	56.970168
Basic Wall: External wall-cavity-3	Aerated Concrete Bl	15.40 m^2	1.54 m^3	56.970168
Basic Wall: External wall-cavity-3	Brick, Red facing	15.40 m^2	1.73 m^3	56.970168
Basic Wall: Plasterboard wall	Plasterboard	15.40 m^2	0.19 m^3	56.978215

Fig. 14 Wall Material Take-off and Quantity Schedule in Revit

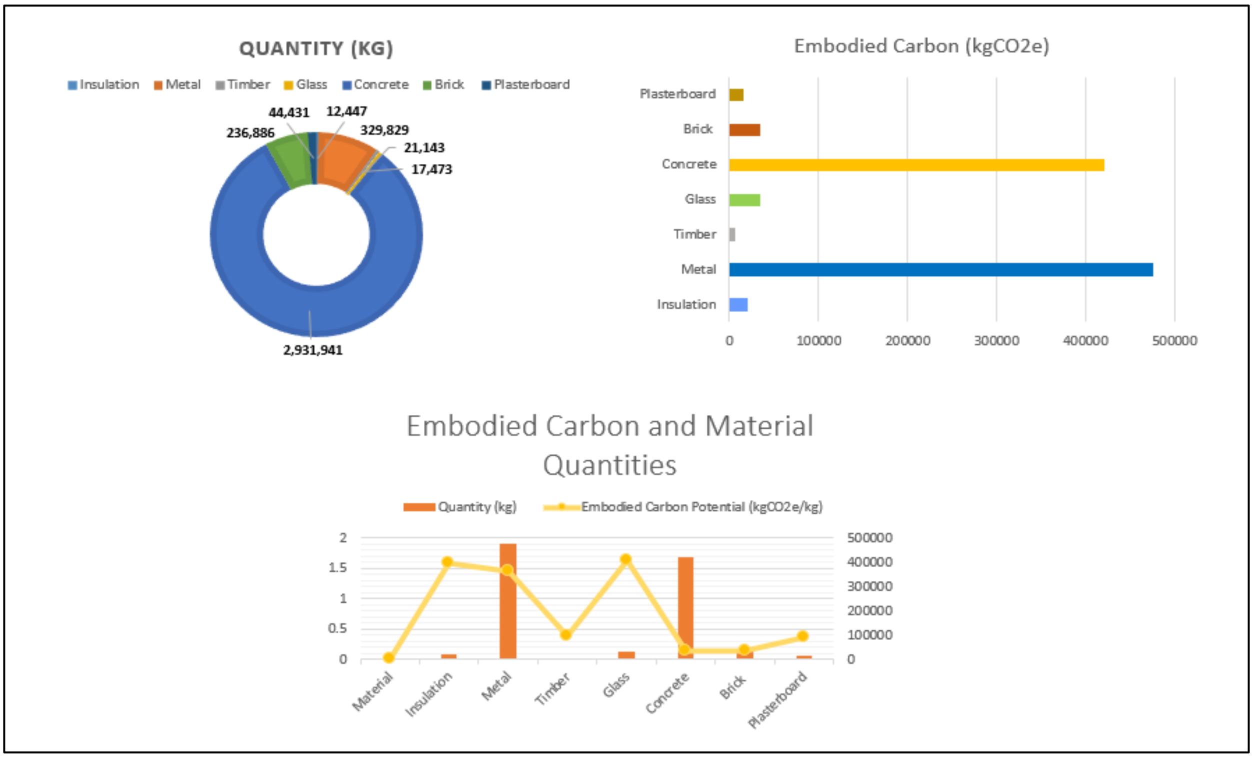


Fig. 15 Material Quantities and EC Analysis

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