Hierarchical Embodied Carbon Calculation Workflow and Verification for the Entire Building and Elements

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Abstract -

To support net-zero goals, greenhouse gas emissions from the civil engineering and construction industries are receiving increasing attention. Assessing and reducing embodied carbon during the design phase is crucial for achieving these goals. However, many commercial BIM-based LCA tools rely on international databases, which may not accurately reflect the material properties of Taiwan. Furthermore, results are typically presented at the building level, lacking the layer-by-layer visualization needed for single and composite elements. This limitation makes it difficult for designers to identify which materials contribute the most to the total embodied carbon.

This study utilizes Revit and Dynamo to develop an automated calculation and verification workflow for embodied carbon. The workflow applies emission factors for the product phase (A1–A3) based on the EN15978 standard and performs calculations on the entire building model. For composite elements, the workflow breaks them into different material layers, calculates the volume and embodied carbon for each material, and uses color-coded visualization to highlight high-impact and low-impact materials. The calculation results will be written back to Revit parameters and can be exported to Excel for further analysis.

Overall, this study presents a transparent and verifiable BIM-based framework of embodied carbon calculation. This approach supports overall consistency checks and individual discrepancy analysis, laying the foundation for future extensions of the workflow to other element types and life-cycle stages.

Keywords -

Building Elements; EN15978; N15804; Embodied Carbon; BIM

1 Introduction

Taiwan has proposed a path to achieving a net-zero goal by 2050 [1]. Therefore, embodied carbon emissions of the building product stage (A1–A3) in the civil engineering and construction industries have received increasing attention. Taiwan has established carbon databases for building materials, such as ABRI-LCC and P-LCC [2], and developed the Low Embodied-carbon Building Rating system (LEBR) [3]. However, in practice, embodied carbon for structural systems is still frequently estimated using regression-based formulas [4]. This approach makes it difficult to calculate for individual building elements and material layers, which limits clear comparisons between emission factors of different materials.

Various BIM-based LCA tools have been developed internationally [5][6] to estimate embodied carbon emission through commercial software or plug-ins. These tools typically integrate multinational databases and localized methods, enabling designers to evaluate design alternatives using BIM models. However, in Taiwan, embodied carbon assessment still focuses on the level of the entire building or element category. Detailed material-level analysis and layer-by-layer visualization of composite elements remain limited.

In summary, although integration BIM and LCA can support carbon emission calculation [7][8][9], Taiwan faces two major challenges: (1) the embodied carbon of composite elements (such as composite walls and slabs) are often estimated using regression formulas, which leads to limitation in element and hierarchical analysis; and (2) many international tools contain limited Taiwan-specific data, which may lead to discrepancies when applied locally. Therefore, it is necessary to develop a corresponding calculation and verification workflow that is suitable for Taiwan's actual situation.

To address these issues, this study developed a workflow for calculating the embodied carbon in the main structural system, using a floor of a university building as an example. This study specifically focuses on the primary RC structural system to evaluate the environmental impact of its core concrete components. This workflow integrates Revit and Taiwan's material databases using Dynamo. One Click LCA [10] was used as a benchmark tool for verification and comparison analysis. This study provides a practical, transparent framework that integrates directly into the existing architectural workflow by leveraging the open calculation logic of Revit and Dynamo. This approach effectively reduces the complexity of conducting embodied carbon assessments by leveraging widely accessible design tools, while supporting the feedback of results into Revit parameters and the export of data to Excel for further analysis. This workflow provides a practical reference for BIM-based carbon assessment in Taiwan.

2 System Framework

As shown in Figure 1, the framework consists of six main functions: material parameter setting, composite element layer extraction, A1–A3 carbon emission calculation, quality control, visualization, and result export. First, define the material and project parameters in Revit. Taiwan-specific data is mapped and entered into fields such as emission factor, density, and data source. Next, Dynamo extracts element information, including material layers, thicknesses, and quantities of individual and composite elements. According to EN 15978, calculation formulas are applied to obtain embodied carbon emission results at the element and category levels Dynamo has built-in. quality control functions to improve reliability, including checking for thickness appropriateness and missing carbon emission factors. If the value is outside the recommended range or a factor is missing, the system uses the Data-Shapes package to generate a pop-up dialog box reporting the problem and the corresponding element ID. Finally, the results are written back to Revit parameters, allowing them to be reviewed through elements or schedules. For composite elements, the system reports the contribution of each material layer. Additionally, it provides color-schema visualization to help users quickly identify high-carbon materials. All data can be exported to Excel for further analysis.

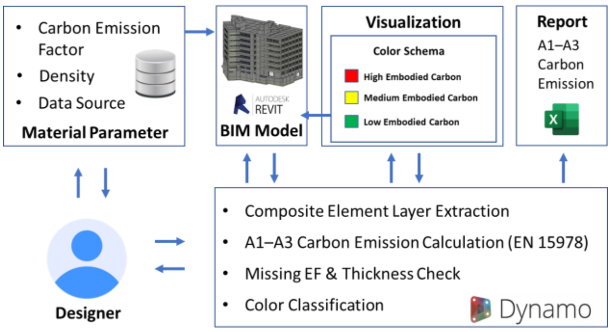

Figure 1. System Framework

2.1 Material Parameter Setting

This study focuses on the product stage (A1–A3) and prioritizes Taiwan-specific emission factors. While many commercial tools can assess life-cycle carbon emissions, their databases rely heavily on international data and may not accurately reflect the actual situation in Taiwan. Therefore, this study mainly collects factors for stages A1-A3 from the Architecture and Building Research Institute's (ABRI) "Low Embodied-carbon Building Rating System" Handbook (LEBR Handbook) and project data from the Highway Bureau, as shown in Figure 2. For missing data, the One Click LCA database is used as a supplement.

In addition, since some emission factors are expressed in kgCO2e/kg (kilograms of carbon dioxide equivalent), it is necessary to utilize material density to convert these factors need to be convert into volume units (kgCO2e/ m^3) or area units (kgCO2e/ m^2) for unit consistency. Density data is from are sourced from the "Technical Code for Building Energy Conservation Design". The missing parts were supplemented with reference to EN 1991-1-1 standard to ensure data consistency. Because the localization factors used in some commercial tools are not always transparent, architects may struggle to identify the source of differences.

To support the Dynamo-based framework, this study establishes material and shared parameters as data fields in Revit. Material parameters (such as emission factor, density, and data source) are mapped and filled according to the material names. This method improves data transparency and reduces manual input errors. Additionally, result parameters are also created for individual and composite elements (e.g., layer-specific results). This feature enables architects to directly select elements in Revit to view outputs or trace data sources, thereby enhancing verification and communication efficiency. The Material Parameters Setting dialog is shown in Figure 3.

Material name	Raw Material Supply (A1)	Transport (A2)	Manufacturing (A3)	Unit	Emission factor Source
1:1 Cement mortar finish (2cm thick)	0.1	0.27	19.02	kgco2e/m²	ABRI
1:2 Cement mortar finish (2cm thick)	0.095	0.29	12.37	kgco2e/m²	ABRI
1:3 Cement mortar finish (2cm thick)	0.089	0.29	8.57	kgco2e/m²	ABRI
Ready-mixed concrete (2000 psi)	5.13	19.24	214.84	kgco2e/m³	ABRI
Ready-mixed concrete (2500 psi)	285.77	285.77	285.77	kgco2e/m³	ABRI
Ready-mixed concrete (3000 psi)	4.89	17.95	300.34	kgco2e/m³	ABRI
Ready-mixed concrete (4000 psi)	4.8	17.42	343.09	kgco2e/m³	ABRI
Ready-mixed concrete (5000 psi)	4.74	16.93	407.21	kgco2e/m³	ABRI
Ready-mixed concrete (6000 psi)	4.71	16.53	471.34	kgco2e/m³	ABRI
Ready-mixed high-flow concrete (2000 psi)	181.74	181.74	181.74	kgco2e/m³	ABRI
Ready-mixed high-flow concrete (2500 psi)	194.06	194.06	194.06	kgco2e/m³	ABRI
Ready-mixed high-flow concrete (3000 psi)	4.5	21.62	175.68	kgco2e/m³	ABRI
Ready-mixed high-flow concrete (4000 psi)	4.35	21.46	200.62	kgco2e/m³	ABRI
Ready-mixed high-flow concrete (5000 psi)	4.3	22.08	238.03	kgco2e/m³	ABRI
Lightweight concrete	222.52	222.52	222.52	kgco2e/m³	ABRI

Figure 2 . Localized material emission factors (A1–A3)

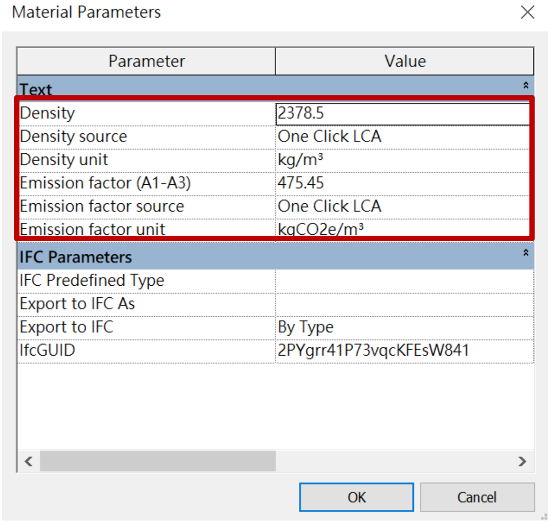

Figure 3. Material parameter setting in Revit

2.2 Layered Modeling of Composite Element

This study focuses on composite elements made of multiple materials, such as composite walls and floors. A layer-based approach is used to represent their structure, thereby supporting the extraction of material-level values, calculation of embodied carbon, and visualization. In this case study, the composite wall is a double-sided assembly. The material layers include structural, insulation, waterproofing, and finishing layers. This structural configuration can be easily adjusted to meet various project requirements, as illustrated in Figure 4.

Figure 4. Layer settings for composite elements

As shown in Figure 5, the Dynamo workflow of layer-based modeling of a composite element is as follows. First, input the element ID and read the structure information to obtain the name, order, and thickness of each layer. Next, the element's positioning line was extracted as the basis of geometric generation. Based on the order of the material layer, the offset direction and thickness are defined from the center toward both sides. The "Extrude" and "Thicken" node functions are used to create the solid geometry for each layer. The "Geometry.Translate" node function separates each layer and establishes a layer-by-layer representation. Finally, the geometry is written back to Revit using a "DirectShape" Dynamo package (Figure 6), generating a layered-composite element model that can be reviewed directly in BIM, as shown in Figures 7.

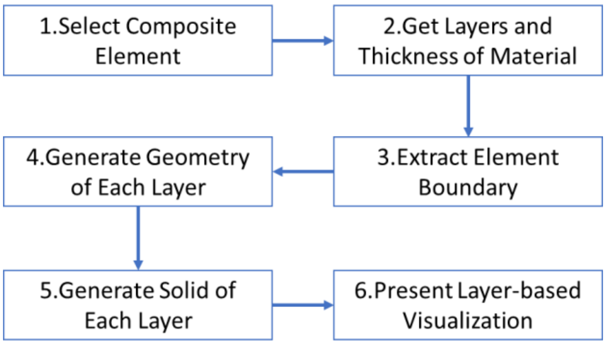

Figure 5. The workflow for layer-based modeling of a composite element in Dynamo

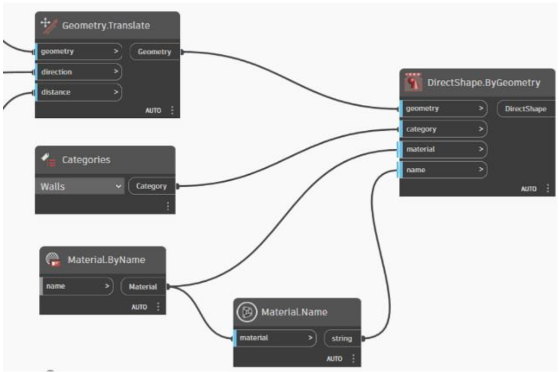

Figure 6. "DirectShape" Dynamo Package

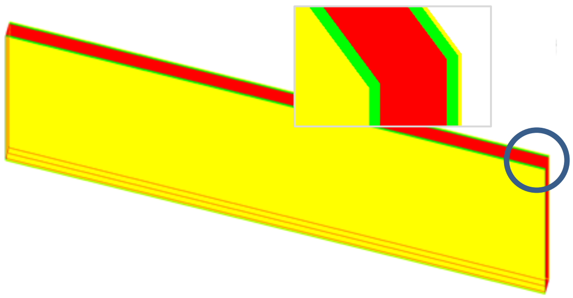

Figure 7. Layered visualization of a composite element

2.3 Quality Control

To enhance calculation reliability, this study utilizes Dynamo program to establish two checks: a thickness check and a missing emission factor check. For each material layer, the system first extracts the thickness and name, ensuring that units are consistent to prevent errors caused by unit mismatches. Specifically, all project units are standardized to centimetres within Revit to streamline the calculation process. Regarding the thickness check (Figure 8), the system first utilizes Code Block nodes to define a threshold range based on general engineering practices in Taiwan. Any material layer thickness that falls above or below this specified range is then filtered and identified through a combined screening process.

To perform emission factor checks, the system scans all individual and composite elements. In this workflow, embodied carbon coefficients are pre-assigned to each Revit material parameter, and the calculation process directly retrieves these values. However, to enable distinct color-coding for visual identification, the system utilizes the Material Name as a criterion during the missing value detection phase. By using 'Code Block' nodes to define null or empty criteria, the system then employs the 'List.FilterByBoolMask' node (Figure 9) to automatically flag any missing coefficients or unassigned materials as data gaps. While Dynamo nodes can show these results, manually searching for a specific element in an extensive list is very time-consuming. To address this issue, this study uses the "Data-Shapes" package to create a pop-up window. As shown in Figure 10, this window is divided into two parts: "Thickness Check" and "Missing Emission Factor", enabling architects to clearly identify problems and their locations.

In addition to showing the element type and ID, the pop-up window also identifies the specific material layer for composite elements. This significantly reduces manual checking time, making the correction process more efficient and ensuring the reliability of the carbon calculation results.

However, this study acknowledges certain limitations. The accuracy of quantity takeoff depends heavily on the completeness of the BIM model, and incomplete definitions of material layers or missing parameters may require manual corrections to ensure data integrity. Furthermore, the current geometric decomposition logic is optimized for standard building elements (e.g., walls, floors, and roofs). For highly complex or non-standard organic geometries, further refinement of the calculation methods will be necessary in future research.

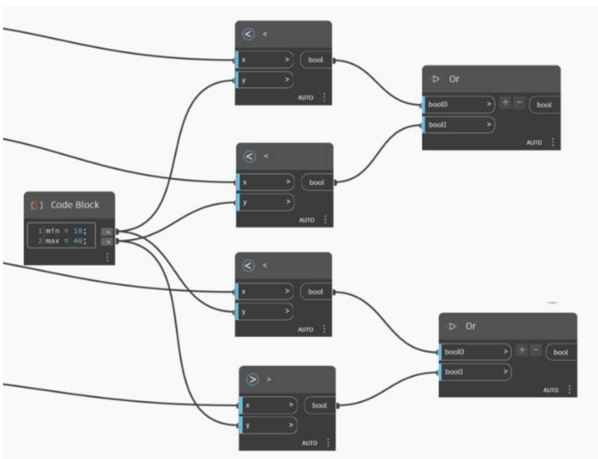

Figure 8. Emission factors check

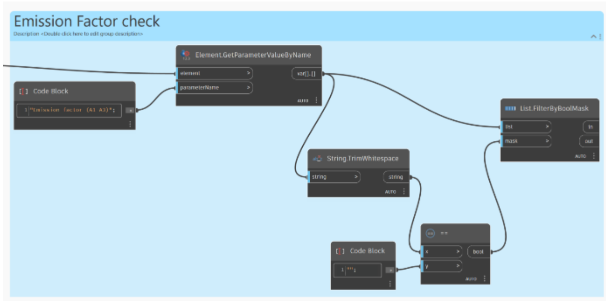

Figure 9. Thickness check

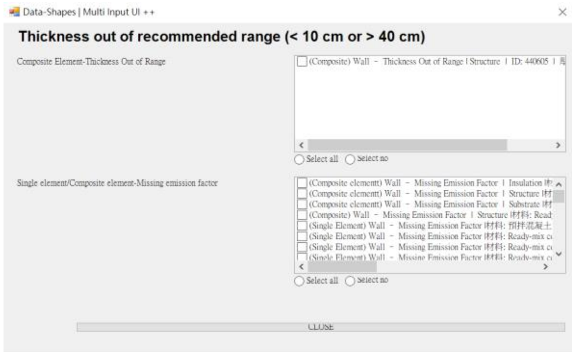

Figure 10. Detection of missing emission factors and thickness

2.4 A1–A3 Carbon Emission Calculation

This study focuses its embodied carbon assessment on the product stage (A1–A3). The building-level calculation framework adheres to the EN 15978 standard, while the definitions of modules and indicators A1–A3 are based on EN 15804 (EPD rules). Specifically, these modules represent the 'Cradle-to-Gate' scope, encompassing raw material supply (A1), transportation to the manufacturer (A2), and the manufacturing process (A3). This establishes an integrated workflow that links material quantity with carbon emission factors. The process is automated in Dynamo, which calculates element-level embodied carbon by reading the emission factors and material densities defined in Revit, as well as quantitative data (such as area and volume). The EN15978 formula is established as formula (1). This value is used to calculate total greenhouse gas emissions (carbon dioxide equivalent, CO_2e) to assess the impacts of climate change.

$$\mathrm{GWP}_i = a_{1,i} \times \mathrm{GWP}_{a1,i} + a_{2,i} \times \mathrm{GWP}_{a2,i} + a_{3,i} \times \mathrm{GWP}_{a3,i} + \cdots + a_{N,i} \times \mathrm{GWP}_{aN,i} \quad (1)$$

- GWP_i: The quantified result of Global Warming Potential for the building in the module;
- $a_{n,i}$: The total quantity of the n-th product or service used in the building within module i (N=1, 2, 3, …, N);

- $GWP_{an,i}$: The Global Warming Potential (GWP) factor of the n-th product or service in the building within module i (n=1, 2, 3, …, N)。

To ensure the accuracy of the proposed automated workflow that integrates Taiwan-specific localized embodied carbon factors, a preliminary verification was conducted using One Click LCA. Selected single and composite elements from the case model were utilized to validate the calculation process. Table 1 summarizes the detailed key parameters between the proposed system and One Click LCA.

To maintain a consistent logic, the verification stage adopted identical emission factors, volumes, and areas as One Click LCA. Thicknesses were predefined in Revit and subsequently retrieved via both Dynamo nodes and the One Click LCA plugin. Regarding indicator selection, this study focuses on GWP-fossil during the product stage (A1–A3) for comparison. The reason is that the environmental impact of construction materials during manufacturing is predominantly driven by fossil fuel combustion, and One Click LCA's localization adjustments (e.g., regional electricity grid factors) are primarily reflected in this indicator; thus, these localized factors were used as the calculation basis to ensure consistency.

Furthermore, regarding thickness data, in addition to extraction based on the model geometry, thicknesses of material layers were applied during the calculation. As shown in Table 2, the Dynamo outputs are fundamentally consistent with One Click LCA values, confirming the reliability of the workflow. Minor discrepancies are primarily due to differences in internal numerical precision and rounding algorithms during data extraction. Currently, the workflow has been expanded to the entire building for comprehensive analysis and verification.

Table 1. Comparison of the Proposed System and One Click LCA Plugin

Item	Proposed System	One Click LCA Plugin	Description
Embodied Carbon	A1–A3 Product Stage	A1–A3 Product Stage	To ensure identical assessment stages.
GWP Indicator	GWP-fossil	GWP-fossil	Primarily targeting GHGs from fossil fuel combustion.
BIM Model	Revit Model	Revit Model	To verify the accuracy of the model area/volume.
Data Extraction (Area / Volume)	Dynamo Node Extraction	One Click LCA Plugin Extraction	Thicknesses are extracted from the model, and the accurate volume is then calculated based on the corresponding material's properties.
Emission Factor Source	One Click LCA Material (EF)	One Click LCA Material (EF)	To ensure the correctness of the calculation workflow.
Unit Setting	International System of Units (SI)	International System of Units (SI)	To ensure consistent unit standards.

Table 2. Verification of results

Category	Dynamo Result ($kgCO_2e$)	One Click LCA Result ($kgCO_2e$)	Difference(%)
Walls (Single/Composite)	779.750	780	-0.03%
Columns (Single)	881.105	881	+ 0.01%
Floors (Single/Composite)	1771.376	1770	+0.078%
Structural Framing (Single)	2113.500	2110	+0.165%

2.5 Visualization

To assist architects in rapidly identifying high-intensity carbon emission components within a BIM model, this study developed an automated color-graded visualization method. Due to the complexity of building elements, this study prioritizes the primary structural system of RC educational buildings. The assessment logic is grounded in the 'Carbon Heroes Benchmark' report by One Click LCA (Figure 11), which indicates that concrete represents the largest proportion (41%) of embodied carbon in educational buildings. This focus is further justified by global industry data from the IEA [12], which highlights that the manufacturing of building materials—particularly cement and steel—accounts for approximately 10% of global emissions. Considering that concrete remains the predominant construction material in Taiwan, focusing on these core structural elements (columns, beams, slabs, and walls) ensures a highly representative assessment while streamlining the verification workflow. The process begins by converting the embodied carbon values from kgCO2e to metric tonCO2e and calculating the "percentage contribution" of each element and material layer relative to the total building emissions. To provide intuitive design guidance, the results are categorized into five intensity levels based on a quintile distribution (each level accounting for 20% of the data), visualized through a color-coded system:

- Very-Low (0-20%, Dark Green): 'Optimal Selections' — Represents the materials with the lowest carbon footprint in the project, serving as the top 20% low-carbon examples to be maintained or expanded.
- Low (21-40%, Light Green): 'Low-Carbon Materials' — Represents materials performing better than the project median, aligning with carbon reduction design goals.
- Medium (41-60%, Yellow): 'Project Baseline' — Corresponds to the median range of internal emissions, reflecting the average material intensity and serving as a reference point for further optimizations.
- High (61-80%, Orange): 'High-Emission Range' — Identifies materials with higher-than-average impacts, prompting designers to evaluate alternative low-carbon solutions.
- Very-High (81-100%, Red): 'Primary Optimization Targets' — Identifies the highest-impact 20% of materials. This range acts as a visual warning, guiding designers to immediately review and replace material types, thicknesses, or structural forms.

By using layer-based visualization, architects can more efficiently view carbon emission results and identify which material layers in composite elements have the greatest impact on emissions. This facilitates material selection and reduces the time required for checking. In which Red represents high-intensity carbon emission results, Yellow signifies medium-intensity results, and Green represents low-intensity results.

Regarding the technical setup, after establishing the layered model, the color is applied using Dynamo's "Element.OverrideColorInView" node. The Revit model will then update automatically. If users change the value of the numerical range or emission factor, simply re-execute the Dynamo workflow to update the results and the colors (Figure 12).

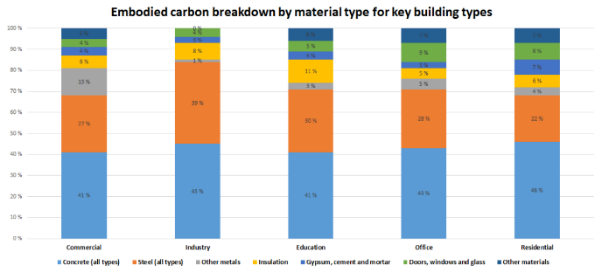

Figure 11. Embodied carbon breakdown by material type for key building types[11]

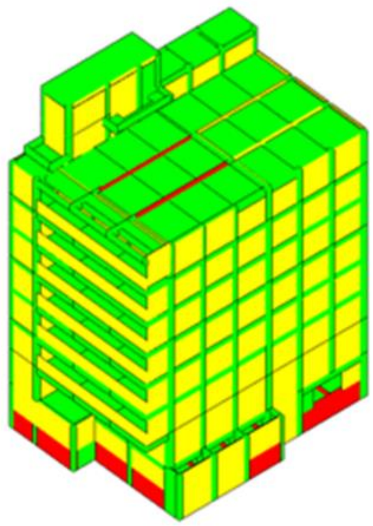

Figure 12. Visualization of building embodied carbon results (A1–A3)

2.6 Result Export to Excel

To improve the efficiency of reviewing calculation results, this study writes the Dynamo outputs back into Revit Shared Parameters. Architects can simply select an element to view its carbon assessment results—including individual material layers, composite totals, and category summaries—directly in the Revit Properties panel as shown in Figure 13. This eliminates the need to manually trace nodes within Dynamo, significantly streamlining the verification process.

Furthermore, the results are exported to Excel to support further analysis. The exported data includes element categories, element IDs, material names (including specific layers), emission factors, quantities (area/volume), and total embodied carbon results. This allows designers to perform statistical analysis and filtering in Excel for reporting purposes, while maintaining a fully traceable record of the carbon assessment. The results are shown in Figure 14.

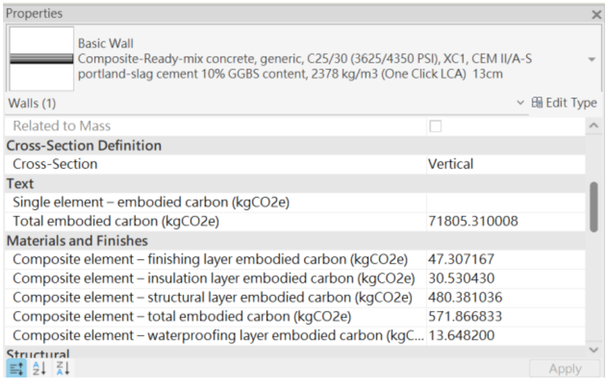

Figure 13. Writing calculation results back to Revit parameters

NO.	Category	Element ID	Material	Volumn	Ec factor	Total Carbon Results
1	Structural Columns	265465	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.894056	203.093852
2	Structural Columns	265539	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.9	204.444
3	Structural Columns	265937	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.899587	204.35024
4	Structural Columns	265976	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.890443	202.273089
5	Structural Columns	266013	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.9	204.444
6	Structural Columns	266174	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.798574	181.404025
7	Structural Columns	266231	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.9	204.444
8	Structural Columns	266384	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.899917	204.425248
9	Structural Columns	266419	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.9	204.444
10	Structural Columns	266454	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.9	204.444
11	Structural Columns	266509	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.8454	192.041064
12	Structural Columns	266742	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	0.820656	186.420217
13	Structural Columns	268109	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.3303	302.191057
14	Structural Columns	268223	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.44	327.1104
15	Structural Columns	268266	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.43986	327.078507
16	Structural Columns	268497	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.369625	311.123901
17	Structural Columns	268628	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.423656	323.397697
18	Structural Columns	268685	Ready-mix concrete, 50 MPa, 2265 kg/m3, WGS5020-1 (Western Suburbs Concrete, North Penrith Facility)	340	1.413687	480.65341
19	Structural Columns	268853	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.07967	245.257792
20	Structural Columns	268931	Ready-mix concrete, 40-50 Mpa, 2410 kg/m3, 40MPA40065 (Readymix Abu Dhabi)	227.16	1.0798	245.287323

Figure 14. Example of A1–A3 Results to Excel

3 Conclusions

This study utilizes BIM (Revit) and Dynamo to establish a material layering framework for composite building elements, integrating the calculation and visualization of embodied carbon (A1–A3) into a single workflow. This method can automatically calculate engineering quantities, assign coefficients, and present results for composite elements. Compared to traditional manual methods, this workflow reduces repetitive work, ensures consistency in calculation, and makes the results easier to check. Additionally, the color-graded visualization enables designers to intuitively identify elements with higher embodied carbon emissions, facilitating faster design adjustments.

Future work will focus on expanding the material database and utilizing Taiwan-specific data for embodied carbon calculations. Such as embodied carbon emission factors and material densities, can be gradually added and organized in a consistent data format (e.g., units, A1–A3 scope, and data sources) to facilitate future updates. To enhance maintenance efficiency, an external database retrieval mechanism will be implemented, utilizing Dynamo to synchronize data between external Excel tables and the Revit model. This automated update process will further improve system stability for large-scale projects.

Additionally, to improve technical scalability, future research could leverage the Revit API to enable in-place geometry modification. This approach would optimize computational performance and prevent Revit file bloating, particularly in complex or massive models. Furthermore, the Dynamo system can be packaged into reusable modules with example templates, allowing it to be applied more quickly across various projects or design stages. As the database continues to improve, the system can also support comparisons of low-carbon alternatives in similar material categories, helping designers identify elements with higher embodied carbon emissions and determine the priority of improvements.

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