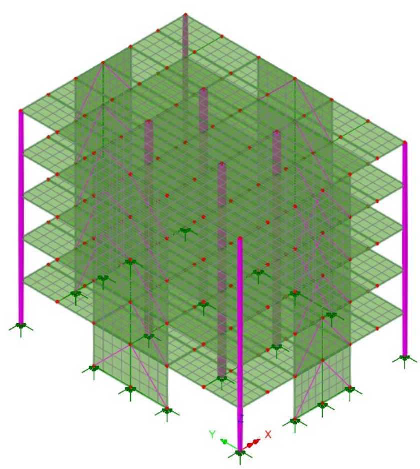
Embodied carbon calculator

For LUSAS version:	24.0
For software product(s):	All (except LT versions)
With product option(s):	None.

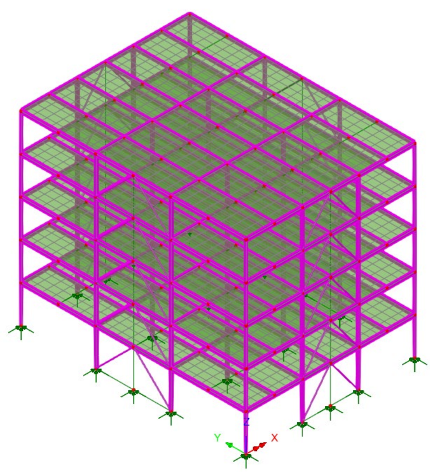
Description

This example shows how to extract a bill of material and how to quantify the embodied carbon of two conceptual structural schemes for a multi-storey building, namely a reinforced concrete (RC) frame and steel-composite frame. A refinement to the RC scheme to make use of a thinner slab with post-tensioning is explored to demonstrate its impact on carbon reduction.

Fleshed views of the reinforced concrete and steel-composite models are shown below.



RC frame (Loadcase 1)



Steel-composite frame (Loadcase 2)

Units used are N, m, kg, s, C throughout.

Objectives

The primary objective of this study is to evaluate and compare the embodied carbon of two structural schemes: a reinforced concrete (RC) frame and a steel-composite frame. This comparison is conducted during the early conceptual design stage to facilitate informed decision-making in achieving sustainable construction outcomes. The study aims to achieve the following objectives:

- **Material Quantification & Model Validation** - Extract a detailed *Bill of Materials* (BOM) for each structural scheme to validate the model.
- **Embodied Carbon Assessment** - Utilise the *Embodied Carbon Calculator* tool to estimate the carbon footprint associated with each scheme.
- **Hotspot Identification** - Identify carbon-intensive components within each scheme to prioritise areas for potential improvement.
- **Comparison of Design Alternatives** - Compare the embodied carbon of the two schemes to guide the selection of the more sustainable solution.
- **Refinement Exploration** - Propose and evaluate potential refinements to the RC scheme, such as incorporating post-tensioning, to reduce embodied carbon.

Keywords

Embodied Carbon Calculator, Bill of Materials, Steel-Composite, Reinforced Concrete, 3D.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

- **steel_vs_RC_frame.lvb** creates an initial model for further development.

Discussion

As the construction industry faces increasing pressure to address environmental concerns, reducing embodied carbon in building materials has become a key priority. Addressing this during the early stages of design offers a valuable opportunity to influence project sustainability and align with global carbon reduction targets.

The investigated model includes two analyses:

- **RC scheme.**
- **Steel-composite scheme**.

These represent the two conceptual schemes considered in this study.

Section sizing was carried out using simple hand calculations to adhere to BS EN 1992-1-1:2004 and BS EN 1993-1-1:2005. The loading assumed includes:

- Super-imposed load: 1.5kPa.

- Live load: 5.0kPa.
- Wind pressure: 1.0kN/m2.

Composite-steel scheme

Composite-steel scheme materials include S355 steel and C25/30 concrete in the composite slab. The model is composed of the following sections:

- ComFlor 60 with 170mm thickness for 90 min fire resistance, concrete C25/30, A252 mesh and 0.9mm profile decking.
- Secondary beams UKB 457x191x67, spaced at 3.0m.
- Primary beams UKB 457x191x74, spaced at 8.0m.
- Edge and internal columns UKC 254x254x73.
- Corner columns UKC 203x203x60.
- Chevron bracing CHS 139.7x5.

Note that the concrete volume for a 170mm thick ComFlor 60 slab is $0.138m^3/m^2$ (TATA, 2024). Therefore, the slab was modelled with 138mm thickness, so that the concrete weight is maintained. Edge columns resist wind loading from bracing and thus have the same section as the internal columns.

RC frame scheme

The RC scheme is made of in-situ C32/37 concrete. The model is composed of the following sections:

- Flat slab, 300mm thick.
- Internal columns of 0.5m × 0.5m.
- Corner columns of 0.3m × 0.3 m.
- Shear walls 0.2m thick along 24m side.
- Shear walls 0.25m thick along 18m side.

The members were preliminary sized using the *Economic Concrete Frame Elements to Eurocode 2* (Goodchild et al., 2009) manual.

In this example, only modules A1-A3 are considered when calculating embodied carbon. UK average values of the **Embodied Carbon Factors** (ECFs) taken from IStructE (2022) are used.

Embodied carbon is normalised by dividing the total carbon by the **functional area** (FA) or **gross-internal area** (GIA). For a building, this typically excludes the roof area. FA for both schemes can be calculated as 5 × 24m × 18m = 2160m^2.

The findings aim to provide actionable insights for designers, emphasising how early-stage assessments can identify carbon hotspots and inform sustainable construction practices. This approach underscores the role of structural engineering in meeting sustainability goals while maintaining economic and functional viability.

Modelling

Running LUSAS Modeller

For details of how to run LUSAS Modeller, see the heading ***Running LUSAS Modeller*** in the *Introduction to LUSAS Worked Examples* document.

Note. This example is written assuming a new LUSAS Modeller session has been started. If continuing from an existing Modeller session select the menu command **File>New** to start a new model file. Modeller will prompt for any unsaved data and display the New Model dialog.

Creating a New Model

File
New…

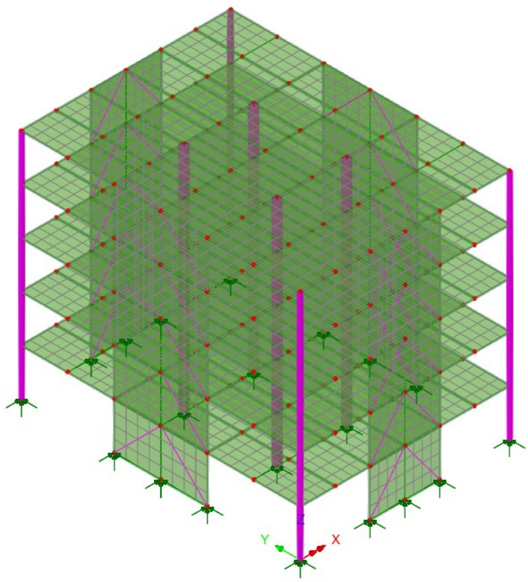
- Enter a file name of **steel_vs_RC_frame**.
- Use the default **User-defined** working folder.
- Ensure an Analysis category of **3D** is set.
- Click the **OK** button.

Note. There is no need to enter any other new model details when the intention is to run a script to build an initial model, since the contents of the script will overwrite any other settings made.

File
Script >
Run Script…

To create the model, open the read-only file **steel_vs_RC_frame.lvb** that was downloaded and placed in a folder of your choosing.

The model for the RC scheme will be displayed initially because Loadcase 1 is set active by default.



 If necessary, select the isometric button to view the frame in 3D.

 Toggling the Fleshing button on and off will show the steelwork arrangement.

 **Note.** No structural loading has been defined in this model, as only its structural type and features are relevant for the embodied carbon study.

Model validation using Bill of Materials (BOM)

When carrying out finite element analysis it is possible to make some unintentional modelling errors, for instance, by overlapping beam elements. Such duplication can artificially increase the material tonnage and subsequently the embodied carbon. Additionally, incorrect materials or geometric attributes may also be assigned to incorrect analyses, leading to incorrect calculation of effects and embodied carbon.

As a result it is recommended first to validate the model by investigating the **Bill of Materials**. This tool provides a summary of the materials in a given loadcase, and saves an entry to the Utilities  treeview for each loadcase considered. By studying its entries, you can verify whether all the features were correctly considered.

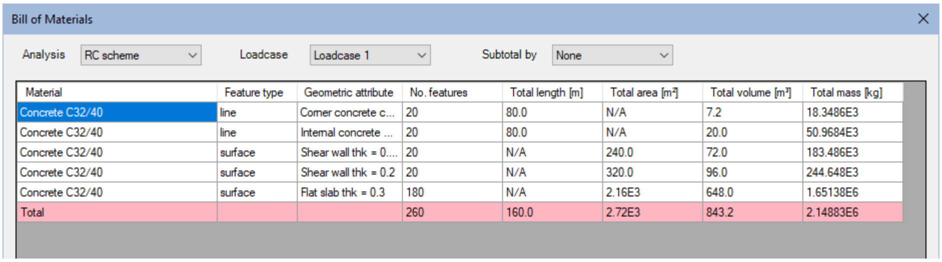
RC Frame

Utilities
Material Summary
Bill of Materials…

On the Bill of Materials dialog:

- In the Analysis droplist select **RC scheme**

- In the Loadcase droplist select **Loadcase 1**
- In the Subtotal by droplist select **None**
- Enter a name of **BOM RC scheme** and click **Apply**.



Material	Feature type	Geometric attribute	No. features	Total length [m]	Total area [m²]	Total volume [m³]	Total mass [kg]
Concrete C32/40	line	Corner concrete c...	20	80.0	N/A	7.2	18.3486E3
Concrete C32/40	line	Internal concrete ...	20	80.0	N/A	20.0	50.9684E3
Concrete C32/40	surface	Shear wall thk = 0....	20	N/A	240.0	72.0	183.486E3
Concrete C32/40	surface	Shear wall thk = 0.2	20	N/A	320.0	96.0	244.648E3
Concrete C32/40	surface	Flat slab thk = 0.3	180	N/A	2.16E3	648.0	1.65138E6
Total			260	160.0	2.72E3	843.2	2.14883E6

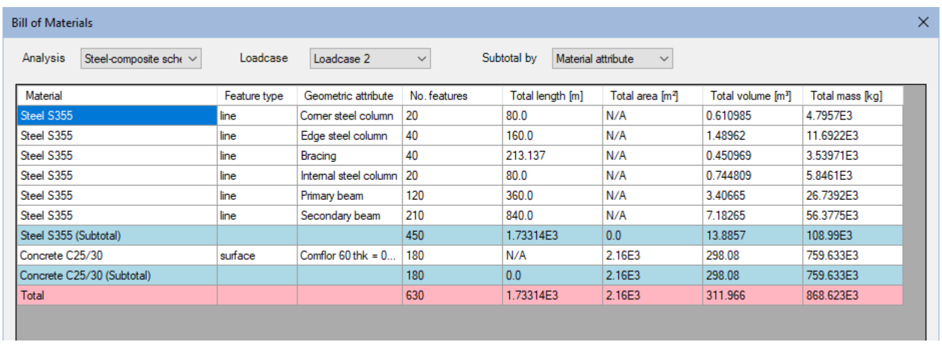
Note. The optional **Subtotal by** droplist provides additional **(Subtotal)** entries for either materials or features.

Note. The Bill of Materials provides output only relevant for the given feature type. For instance, **Total length** values are only available for lines, and **Total area** values are only available for surfaces. All features output **Total volume** and **Total mass**.

Note. Materials that are deactivated in a given loadcase are ignored in the **Bill of Materials**.

Steel-composite frame

- With the Bill of Materials dialog still active, in the Analysis droplist select **Steel-composite scheme**
- In the Subtotal droplist select **Material attribute**
- Enter a name of **BOM steel-composite scheme** and click **OK**.



Material	Feature type	Geometric attribute	No. features	Total length [m]	Total area [m²]	Total volume [m³]	Total mass [kg]
Steel S355	line	Corner steel column	20	80.0	N/A	0.610985	4.7957E3
Steel S355	line	Edge steel column	40	160.0	N/A	1.48962	11.6922E3
Steel S355	line	Bracing	40	213.137	N/A	0.450969	3.53971E3
Steel S355	line	Internal steel column	20	80.0	N/A	0.744809	5.8461E3
Steel S355	line	Primary beam	120	360.0	N/A	3.40665	26.7392E3
Steel S355	line	Secondary beam	210	840.0	N/A	7.18265	56.3775E3
Steel S355 (Subtotal)			450	1.73314E3	0.0	13.8857	108.99E3
Concrete C25/30	surface	Comflor 60 thk = 0...	180	N/A	2.16E3	298.08	759.633E3
Concrete C25/30 (Subtotal)			180	0.0	2.16E3	298.08	759.633E3
Total			630	1.73314E3	2.16E3	311.966	868.623E3

Validating the model

The two BOM entries in the Utilities treeview can be used to validate the model, if the number of individual features is known.

This is illustrated by checking the number of columns in the RC frame scheme. On each floor there are four internal (0.5m × 0.5m) and four corner (0.3m × 0.3m) columns. For a five-storey structure this gives 5 × 4 = 20 columns. This matches the number displayed in **BOM RC scheme** under **No. features** header for the 'Corner concrete column' and 'Internal concrete column' entries.

The same exercise can be done for each individual combination of geometric attribute and material attribute for both analyses. Other properties can be also used. For instance, the total area of the slab shells is 5 × 24m × 18m = 2160m^2, which is the number in **BOM RC scheme** under **Total area [m^2]** column for the 'Flat slab thk = 0.3' entry.

Note. Although the **Total area** (of surface features) coincides with the **gross-internal area**, conceptually it is different. Gross internal area considers the ground floor area, (where the slab was not explicitly modelled) but it does not consider the roof.

Having checked the number of features, and their length, area, volume and mass are as expected, embodied carbon calculations can be carried out.

Embodied carbon calculations

Steel-composite frame scheme

First, the composite-steel frame scheme is analysed.

- ComFlor 60 shells only capture the correct amount of concrete. The A252 mesh and 0.9mm thk deck profile need to be added separately by calculating their density relative to the parent feature volume.
- Mesh embodied carbon factor (ECF) can be taken as 0.76kgCO_2e/kg, just like reinforcement bars (IStructE, 2022).
- ECF of the steel profile is taken as 2.83kgCO_2e/kg (IStructE, 2022).
- From TATA ComFlor manual (TATA, 2024), the weight of the profile is 0.1kN/m^2, which for 138 mm thick slab can be converted to 72kg/m^3.
- A252 mesh weight is about 3.9kg/m^2, which for 138mm thick slab gives the density of 28kg/m^3.
- Steel hot-rolled section ECF can be taken as 0.1740kgCO_2e/kg, whilst the ECF of concrete C25/30 is 0.10kgCO_2e/kg (IStructE, 2022).

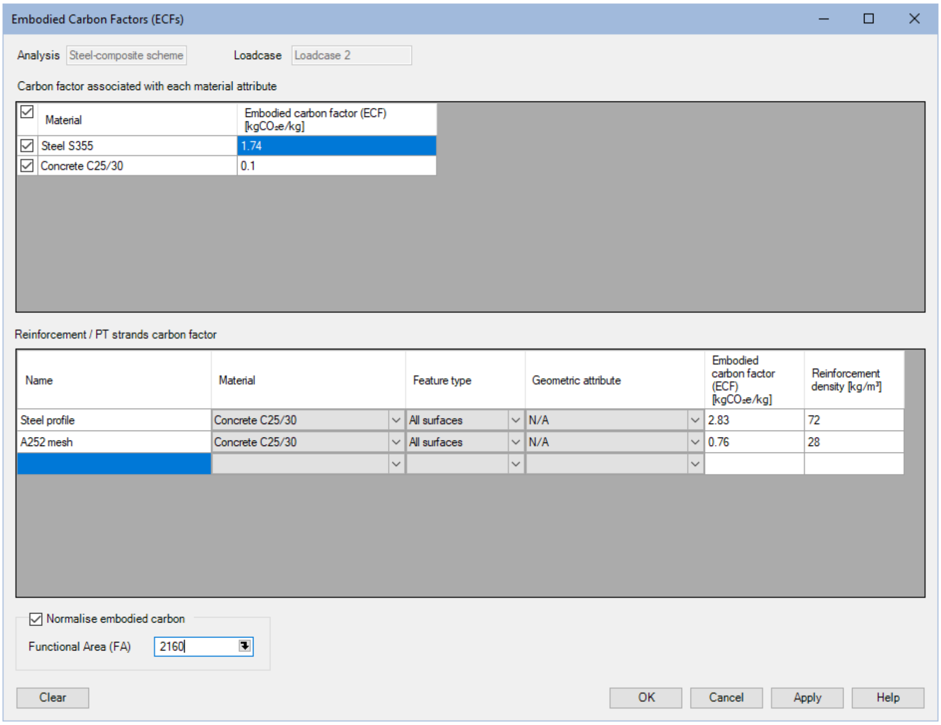
This data can now be input into LUSAS.

Utilities
Material Summary
Embodied Carbon Calculator…

On the Embodied Carbon Calculator dialog:

- In the Analysis droplist select **Steel-composite scheme**
- In the Loadcase droplist select **Loadcase 2**
- In the Subtotal by droplist select **Geometric attribute**
- Click the **Define / Edit ECFs** button.

On the resulting Embodied Carbon Factors (ECFs) dialog:



- In the 'Carbon factor associated with each material' datagrid, ensure **Steel S355** is selected and set Embodied carbon factor (ECF) (kgCO_2e/kg)' to **1.74**
- Ensure **Concrete C25/30** is selected and set 'Embodied carbon factor (ECF) (kgCO_2e/kg)' to **0.1**

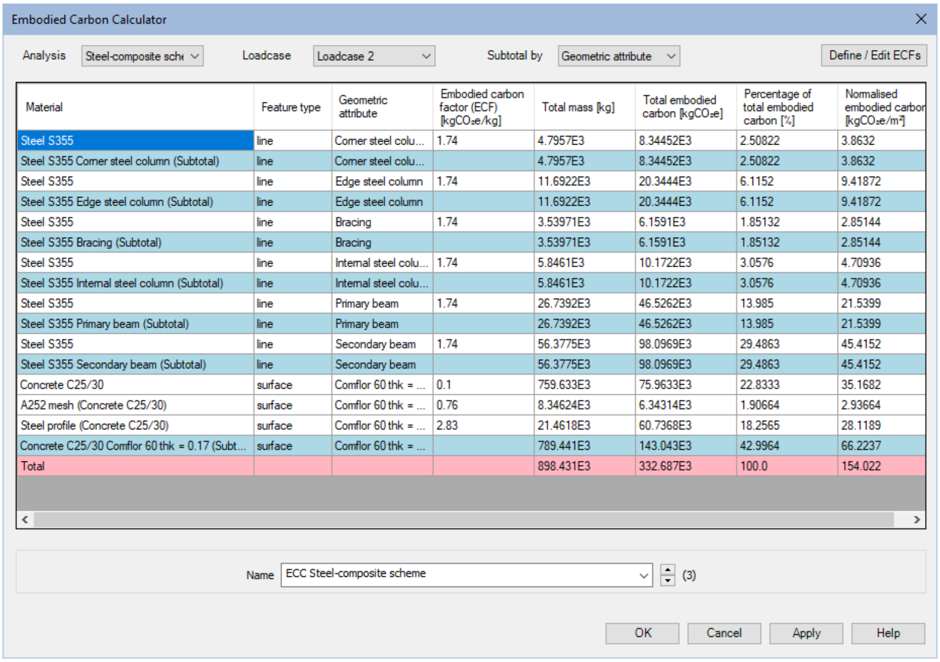
In the 'Reinforcement / PT strands carbon factor' datagrid add the following entries:

- Name: **Steel profile**, Material: **Concrete 25/30,** Feature type: **All Surfaces**, Geometric attribute: **N/A**, Embodied carbon factor (ECF) (kgCO_2e/kg): **2.83**, Reinforcement density (kg/m^3): **72**

- Name: **A252 mesh**, Material **Concrete 25/30**, Feature type: **All Surfaces**, Geometric attribute: **N/A**, Embodied carbon factor (ECF): **0.76** ($kgCO_2e/kg$), Reinforcement density: **28** (kg/m^3).

- Tick the **Normalise embodied carbon** checkbox. Set the Functional Area (FA) to **2160** (m^2). Ticking this box adds a column 'Normalised embodied carbon' column to the datagrid of the main dialog.

- Click **OK** to close the Embodied Carbon Factors (ECFs) dialog.



Material	Feature type	Geometric attribute	Embodied carbon factor (ECF) [kgCO₂e/kg]	Total mass [kg]	Total embodied carbon [kgCO₂e]	Percentage of total embodied carbon [%]	Normalised embodied carbon [kgCO₂e/m²]
Steel S355	line	Corner steel colu...	1.74	4.7957E3	8.34452E3	2.50822	3.8632
Steel S355 Corner steel column (Subtotal)	line	Corner steel colu...		4.7957E3	8.34452E3	2.50822	3.8632
Steel S355	line	Edge steel column	1.74	11.6922E3	20.3444E3	6.1152	9.41872
Steel S355 Edge steel column (Subtotal)	line	Edge steel column		11.6922E3	20.3444E3	6.1152	9.41872
Steel S355	line	Bracing	1.74	3.53971E3	6.1591E3	1.85132	2.85144
Steel S355 Bracing (Subtotal)	line	Bracing		3.53971E3	6.1591E3	1.85132	2.85144
Steel S355	line	Internal steel colu...	1.74	5.8461E3	10.1722E3	3.0576	4.70936
Steel S355 Internal steel column (Subtotal)	line	Internal steel colu...		5.8461E3	10.1722E3	3.0576	4.70936
Steel S355	line	Primary beam	1.74	26.7392E3	46.5262E3	13.985	21.5399
Steel S355 Primary beam (Subtotal)	line	Primary beam		26.7392E3	46.5262E3	13.985	21.5399
Steel S355	line	Secondary beam	1.74	56.3775E3	98.0969E3	29.4863	45.4152
Steel S355 Secondary beam (Subtotal)	line	Secondary beam		56.3775E3	98.0969E3	29.4863	45.4152
Concrete C25/30	surface	Comflor 60 thk = ...	0.1	759.633E3	75.9633E3	22.8333	35.1682
A252 mesh (Concrete C25/30)	surface	Comflor 60 thk = ...	0.76	8.34624E3	6.34314E3	1.90664	2.93664
Steel profile (Concrete C25/30)	surface	Comflor 60 thk = ...	2.83	21.4618E3	60.7368E3	18.2565	28.1189
Concrete C25/30 Comflor 60 thk = 0.17 (Subt...	surface	Comflor 60 thk = ...		789.441E3	143.043E3	42.9964	66.2237
Total				898.431E3	332.687E3	100.0	154.022

- Back on the parent dialog, rename the utility to **ECC Steel-composite scheme** and click **OK**.

Note. Selecting 'Geometric attribute' in the 'Subtotal by' droplist is particularly useful for entries, where potentially multiple reinforcement layers are defined, such as composite decking (concrete, mesh, steel profile) or RC members with reinforcement and post-tensioning.

Note. As for the Bill of Materials, the materials that are deactivated in the given loadcase are ignored in the Embodied Carbon Calculator.

Note. For the 'Steel profile' and 'A252 mesh' reinforcement entries, the Feature type was set to 'All surfaces', as ComFlor slabs are the only active shell elements for this loadcase.

From the ‘Total’ row (highlighted in pink) it can be seen that the total embodied carbon of the structure is about 330.5 tons of CO_2. This number is difficult to interpret so a normalised embodied carbon value is used, which is 153.0 $kgCO_2e/m^2$. Note that this number includes only the superstructure, but excludes the foundations, which need a separate analysis.

By referring to the ‘Percentage of total embodied carbon [%]’ column, carbon hotspots can be identified. Composite decking accounts for 43% of the total carbon. Interestingly, concrete accounts for only 23%, whilst steel decking contributes further 18% due to its high ECF value. Much of the remaining carbon is locked in the secondary (29%) and primary (14%) beams.

RC frame scheme

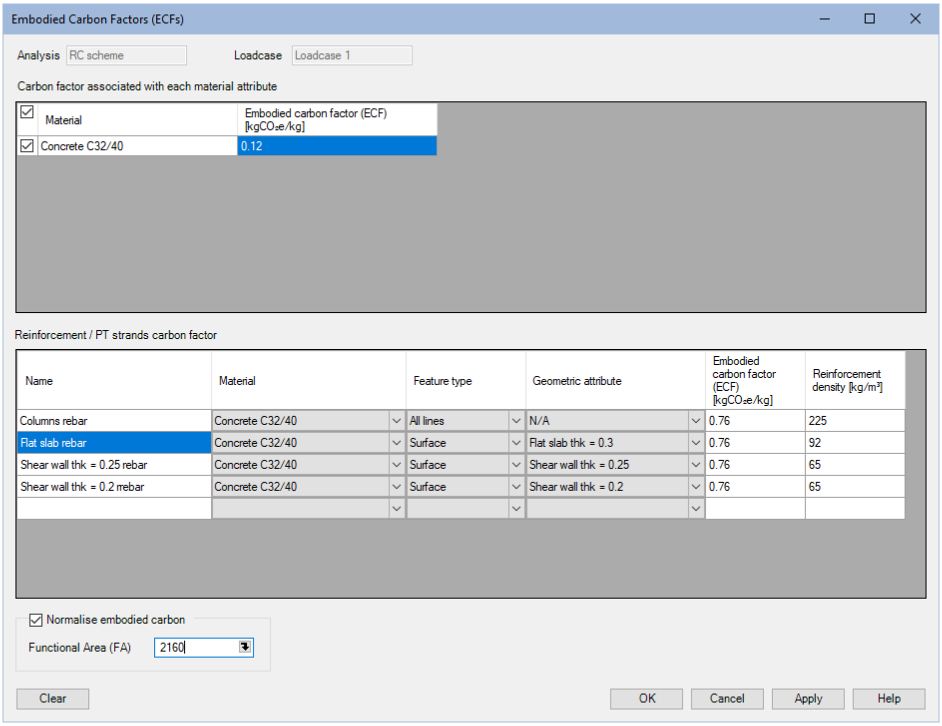
- ❑ The reinforcement for this building is approximated using the *Structural Engineer’s Pocket Book* (Cobb, 2011).
- ❑ For the flat slab the *Economic Concrete Frame Elements to Eurocode 2* (Goodchild et al., 2009) manual offers the reinforcement density for different spans, loads and thicknesses, which was adopted in this example.
- ❑ ECF factors can be taken as 0.12 $kgCO_2e/kg$ for concrete C32/37 and 0.76 $kgCO_2e/kg$ for reinforcement bars (IStructE, 2022).

Utilities
Material Summary
Embodied Carbon Calculator…

On the Embodied Carbon Calculator dialog:

- In the Analysis droplist select **RC scheme**
- In the Loadcase droplist select **Loadcase 1**.
- In the Subtotal by droplist select **Geometric attribute**
- Click the **Define / Edit ECFs** button.

On the resulting Embodied Carbon Factors (ECFs) dialog:



- Tick and set **Concrete C32/40** and Embodied carbon factor (ECF) ($kgCO_2e/kg$.) to **0.12**

In the 'Reinforcement / PT strands carbon factor' datagrid add the following entries:

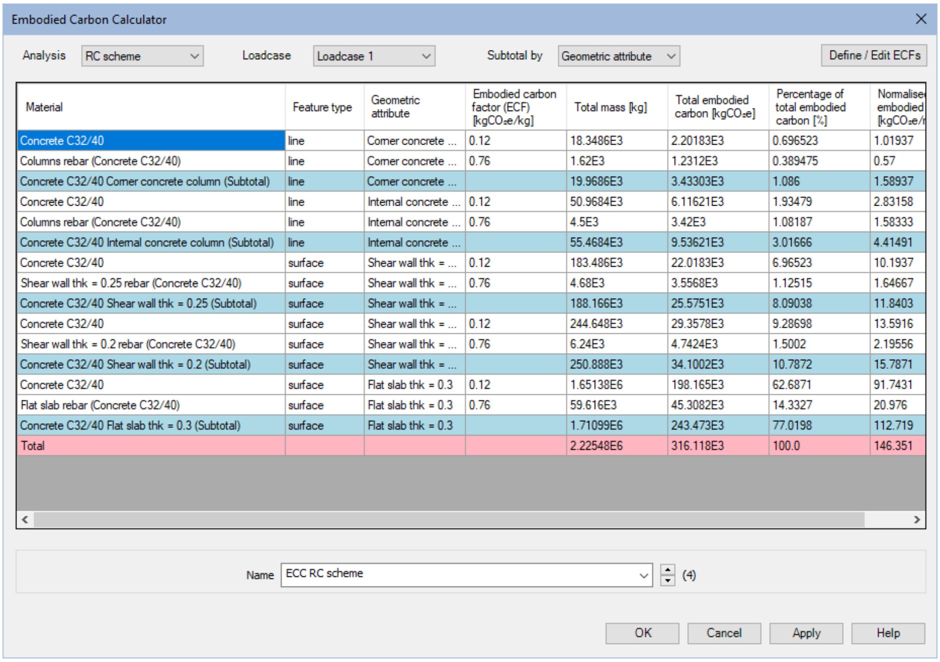
- Name: **Columns rebar**, Material: **Concrete C32/40**, Feature type: **All lines**, Geometric attribute: **N/A**, Embodied carbon factor (ECF)($kgCO_2e/kg$): **0.76**, Reinforcement density (kg/m^3)**:** **225.**

- Name: **Flat slab rebar**, Material **Concrete C32/40**, Feature type: **Surface**, Geometric attribute: **Flat slab thk = 0.3**, Embodied carbon factor (ECF) ($kgCO_2e/kg$): **0.76**, Reinforcement density(kg/m^3): **92**,

- Name: **Shear wall thk = 0.25 rebar**, Material: **Concrete C32/40**, Feature type: **Surface**, Geometric attribute: **Shear wall thk = 0.25**, Embodied carbon factor (ECF) ($kgCO_2e/kg$): **0.76**, Reinforcement density (kg/m^3): **65**

- Name: **Shear wall thk = 0.2 rebar**, Material: **Concrete C32/40**, Feature type: **Surface**, Geometric attribute: **Shear wall thk = 0.2**, Embodied carbon factor (ECF) ($kgCO_2e/kg$): **0.76**, Reinforcement density (kg/m^3): **65**

- Ensure that the **Normalise embodied carbon** checkbox is ticked. Set the Functional Area (FA) to **2160** (m^2). Ticking this box adds a column **Normalised embodied carbon** column to the datagrid of the main dialog.
- Click **OK** to apply ECF factors and close the Embodied Carbon Factors (ECFs) dialog.
- Back on the parent dialog, name the utility **ECC RC scheme** and click **OK**.



Material	Feature type	Geometric attribute	Embodied carbon factor (ECF) [kgCO₂e/kg]	Total mass [kg]	Total embodied carbon [kgCO₂e]	Percentage of total embodied carbon [%]	Normalise embodied [kgCO₂e/
Concrete C32/40	line	Corner concrete ...	0.12	18.3486E3	2.20183E3	0.696523	1.01937
Columns rebar (Concrete C32/40)	line	Corner concrete ...	0.76	1.62E3	1.2312E3	0.389475	0.57
Concrete C32/40 Corner concrete column (Subtotal)	line	Corner concrete ...		19.9686E3	3.43303E3	1.086	1.58937
Concrete C32/40	line	Internal concrete ...	0.12	50.9684E3	6.11621E3	1.93479	2.83158
Columns rebar (Concrete C32/40)	line	Internal concrete ...	0.76	4.5E3	3.42E3	1.08187	1.58333
Concrete C32/40 Internal concrete column (Subtotal)	line	Internal concrete ...		55.4684E3	9.53621E3	3.01666	4.41491
Concrete C32/40	surface	Shear wall thk = ...	0.12	183.486E3	22.0183E3	6.96523	10.1937
Shear wall thk = 0.25 rebar (Concrete C32/40)	surface	Shear wall thk = ...	0.76	4.68E3	3.5568E3	1.12515	1.64667
Concrete C32/40 Shear wall thk = 0.25 (Subtotal)	surface	Shear wall thk = ...		188.166E3	25.5751E3	8.09038	11.8403
Concrete C32/40	surface	Shear wall thk = ...	0.12	244.648E3	29.3578E3	9.28698	13.5916
Shear wall thk = 0.2 rebar (Concrete C32/40)	surface	Shear wall thk = ...	0.76	6.24E3	4.7424E3	1.5002	2.19556
Concrete C32/40 Shear wall thk = 0.2 (Subtotal)	surface	Shear wall thk = ...		250.888E3	34.1002E3	10.7872	15.7871
Concrete C32/40	surface	Flat slab thk = 0.3	0.12	1.65138E6	198.165E3	62.6871	91.7431
Flat slab rebar (Concrete C32/40)	surface	Flat slab thk = 0.3	0.76	59.616E3	45.3082E3	14.3327	20.976
Concrete C32/40 Flat slab thk = 0.3 (Subtotal)	surface	Flat slab thk = 0.3		1.71099E6	243.473E3	77.0198	112.719
Total				2.22548E6	316.118E3	100.0	146.351

Note. Since the columns are the only structural lines in the model and they are assumed to have the same reinforcement density, the entry ‘All lines’ for the ‘Feature type’ could be set for the Columns rebar entry on the Embedded Carbon Factors (ECFs) dialog. Otherwise, if the entry ‘Line Feature type’ was selected, each geometric attribute would need a separate entry.

From the ‘Total’ row (highlighted in pink) it can be seen that the total embodied carbon of the structure is about 316 tons of CO_2. The normalised embodied carbon is 146.4 $kgCO_2e/m^2$. This is very similar to the steel-composite scheme.

By referring to the ‘Percentage of total embodied carbon [%]’ column it becomes immediately apparent that the slab is responsible for over 77% of the total embodied carbon. Hence, a further refinement is proposed on how this can be reduced.

RC frame scheme: refinement using post-tensioning in slab

A refinement to the RC scheme is investigated by reducing the thickness of the flat slab and introducing post-tensioning.

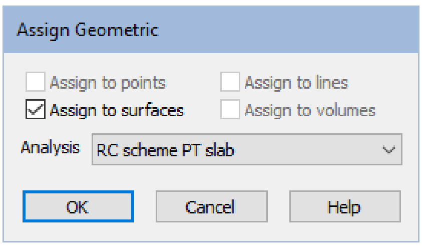
- ❑ With reference to *Economic Concrete Frame Elements to Eurocode 2* (Goodchild et al., 2009), for a multi-span floor with 5 kPa live load, the thickness of the slab can be reduced to 230 mm with tendon density of 11 kg/m^3.

A new analysis is created to represent this refined third scheme.

- In the Analysis treeview, select **RC scheme**. Right-click on it and select **Copy**, then right-click again and select **Paste**.
- Rename **RC scheme (Copy 1)** to be **RC scheme PT slab**
- Rename **Loadcase 1 (Copy 1)** to be **Loadcase 3**

Attributes
Geometric
Surface…

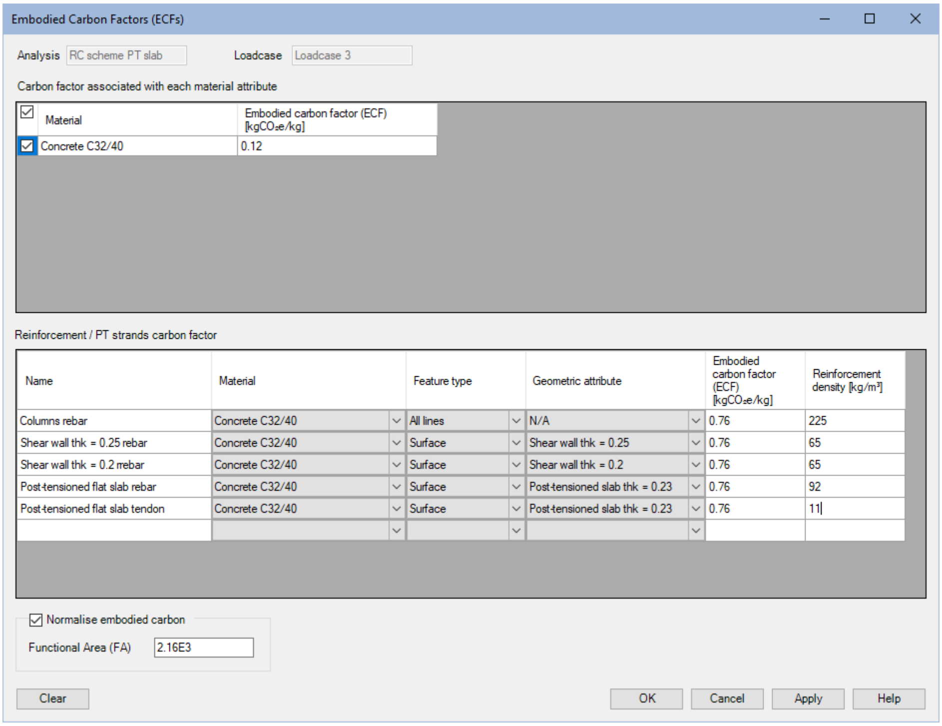
- Set the thickness t to **0.23**, name it **Post-tensioned slab thk = 0.23** and click **OK**.
- In the Attributes treeview, right-click on **Slab mesh** and from the context menu click on **Select Assignments**.
- From the Attributes treeview drag and drop **Post-tensioned slab thk = 0.23** onto the selected features, ensuring that **Assign to surfaces** is selected.
- In the **Analysis** droplist select **RC scheme PT slab** and click **OK**.



Now the embodied carbon can be re-calculated for this scheme.

- From the Utilities treeview open **ECC RC scheme**
- From the Analysis droplist select **RC scheme PT slab**.
- Click **Define / Edit ECFs**.

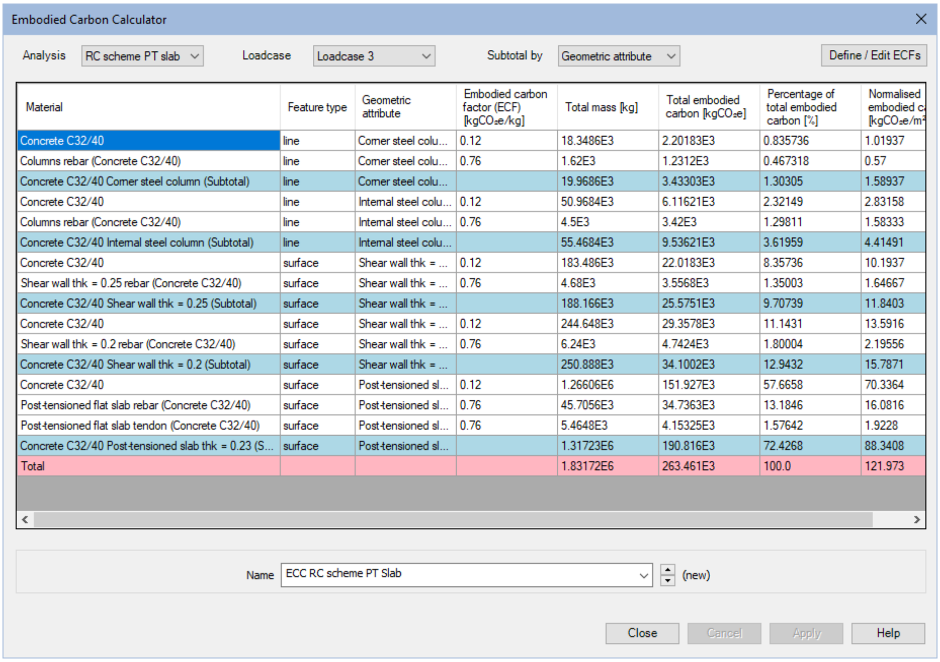
On the resulting Embodied Carbon Factors (ECFs) dialog:



In the Reinforcement / PT strands carbon factor datagrid add the following entries:

- Name: **Post-tensioned flat slab rebar**, Material: **Concrete C32/40**, Feature type: **Surface**, Geometric attribute: **Post-tensioned slab thk = 0.23**, Embodied carbon factor (ECF) ($kgCO_2e/kg$): **0.76**, Reinforcement density (kg/m^3): **92**
- Name: **Post-tensioned flat slab tendon,** Material: **Concrete C32/40**, Feature type: **Surface**, Geometric attribute: **Post-tensioned slab thk = 0.23**, Embodied carbon factor (ECF) ($kgCO_2e/kg$): **0.76**, Reinforcement density (kg/m^3): **11**.
- Click **OK** to close the Embodied Carbon Factors (ECFs) dialog.
- Back on the parent dialog, rename the utility to be **ECC RC scheme PT slab** and click **Apply**. (This creates the utility and retains the view of the table of results)

Note. Reinforcement entries can be deleted by selecting the desired row(s) that need to be removed, then right-clicking in a different column of the selected row(s) to open a context menu and selecting 'Delete row'.



Material	Feature type	Geometric attribute	Embodied carbon factor (ECF) [kgCO₂e/kg]	Total mass [kg]	Total embodied carbon [kgCO₂e]	Percentage of total embodied carbon [%]	Normalised embodied c... [kgCO₂e/m²
Concrete C32/40	line	Corner steel colu...	0.12	18.3486E3	2.20183E3	0.835736	1.01937
Columns rebar (Concrete C32/40)	line	Corner steel colu...	0.76	1.62E3	1.2312E3	0.467318	0.57
Concrete C32/40 Corner steel column (Subtotal)	line	Corner steel colu...		19.9686E3	3.43303E3	1.30305	1.58937
Concrete C32/40	line	Internal steel colu...	0.12	50.9684E3	6.11621E3	2.32149	2.83158
Columns rebar (Concrete C32/40)	line	Internal steel colu...	0.76	4.5E3	3.42E3	1.29811	1.58333
Concrete C32/40 Internal steel column (Subtotal)	line	Internal steel colu...		55.4684E3	9.53621E3	3.61959	4.41491
Concrete C32/40	surface	Shear wall thk = ...	0.12	183.486E3	22.0183E3	8.35736	10.1937
Shear wall thk = 0.25 rebar (Concrete C32/40)	surface	Shear wall thk = ...	0.76	4.68E3	3.5568E3	1.35003	1.64667
Concrete C32/40 Shear wall thk = 0.25 (Subtotal)	surface	Shear wall thk = ...		188.166E3	25.5751E3	9.70739	11.8403
Concrete C32/40	surface	Shear wall thk = ...	0.12	244.648E3	29.3578E3	11.1431	13.5916
Shear wall thk = 0.2 rebar (Concrete C32/40)	surface	Shear wall thk = ...	0.76	6.24E3	4.7424E3	1.80004	2.19556
Concrete C32/40 Shear wall thk = 0.2 (Subtotal)	surface	Shear wall thk = ...		250.888E3	34.1002E3	12.9432	15.7871
Concrete C32/40	surface	Post-tensioned sl...	0.12	1.26606E6	151.927E3	57.6658	70.3364
Post-tensioned flat slab rebar (Concrete C32/40)	surface	Post-tensioned sl...	0.76	45.7056E3	34.7363E3	13.1846	16.0816
Post-tensioned flat slab tendon (Concrete C32/40)	surface	Post-tensioned sl...	0.76	5.4648E3	4.15325E3	1.57642	1.9228
Concrete C32/40 Post-tensioned slab thk = 0.23 (S...	surface	Post-tensioned sl...		1.31723E6	190.816E3	72.4268	88.3408
Total				1.83172E6	263.461E3	100.0	121.973

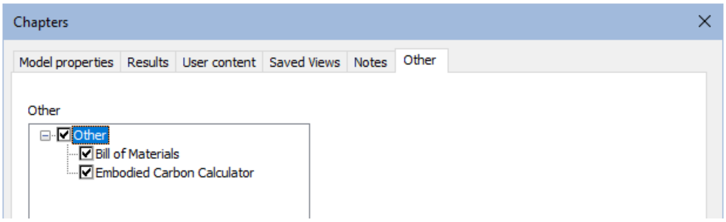
From the 'Total' row it can be seen that the normalised embodied carbon is now reduced from 146.4 to 122.0 $kgCO_2e/m^2$. This is a significant improvement. However, the potential increased cost associated with hiring a specialised subcontractor to carry out the post-tensioning would need to be considered and discussed with the client.

- **Close** the table of results.

Creating a report

The results obtained may also be output and included in a report.

- In the Reports treeview, right-click on the **Reports** folder and choose **New report.**
- Enter a report title of **Steel vs RC frame builiding**, change the name from Rpt1 to **Carbon Calculations** and click **OK**.
- Once renamed, right-click and select **Add Chapter**



- Select the **Other** tab and tick the **Other** checkbox to select the **Bill of Materials** and **Embodied Carbon Calculator** entries, then click **OK**.

Note. Other Chapters showing model properties, structural results and saved views of the model may be added by selecting the 'Add Chapter' context menu item. This is not covered here.

- In the Reports treeview, right-click on **Carbon Calculations** and select **View Report**

A Word document will be created containing results listing for all selected options.

Note that an **Export…** option permits outputting of results to PDF and other file formats.

Conclusions

This study demonstrates the use of the Embodied Carbon Calculator to evaluate and compare the carbon footprint of different structural design schemes. The analysis shows that the embodied carbon values for the steel-composite frame and the reinforced concrete (RC) frame are similar. However, further refinements, such as incorporating post-tensioning in the RC frame, can be effective in significantly reducing its embodied carbon. This highlights the significance of material selection and design optimisation in minimising environmental impact.

While the steel-composite frame offers potential advantages in structural performance and ease of assembly, the RC frame, when optimised, presents a comparable carbon footprint. This underscores the importance of early-stage design evaluation and refinement to explore all viable options for achieving carbon reduction goals.

Future detailed design phases should incorporate precise reinforcement detailing, including longitudinal bars, links, laps, and sacrificial reinforcement, to refine the embodied carbon calculations further. More targeted section assignment for individual structural members can also be employed to maximise their utilisation and minimise the material used.

By continuing to refine material usage and exploring alternative construction techniques, the structural engineering field can contribute substantially to reducing the carbon footprint of building projects. These measures, when aligned with client goals and cost considerations, can pave the way for more sustainable construction practices.

Final remarks

The 'Bill of Materials' and 'Embodied Carbon Calculator' tools work in a similar manner. They both read the features in the model to quantify the materials in the model. For a feature to be considered in the tools it needs to meet the following criteria:

- Be active for the selected loadcase.
- It needs to have assigned mesh, material and geometric attributes.
- Material assigned needs to be either: Isotropic, Orthotropic, Anisotropic or Concrete (RC Frame/slab design).

Note that the following are not currently considered:

- Non-structural masses and joints.
- The reinforcement component of RC materials.
- Axisymmetric models
- Rigid zones
- Load contribution to mass.

References

Cobb F. (2011) *Structural Engineer's Pocket Book: Eurocodes*. Taylor & Francis. London, United Kingdom.

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Goodchild, C. H., Webster, R. M. and Elliott K. S. (2009) *Economic Concrete Frame Elements to Eurocode 2*. The Concrete Centre, part of the Mineral Products Association. Blackwater, United Kingdom.

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