STEEL CONSTRUCTION
Embodied Carbon
Tata Steel and the British Constructional Steelwork Association (BCSA) have worked closely together for many years to promote the effective use of structural steelwork. This collaborative effort ensures that advances in the knowledge of the constructional use of steel are shared with construction professionals.

Steel is the most popular framing material for multi-storey buildings in the UK and has a long track record of delivering high quality and cost-effective structures with proven sustainability benefits. Steel can be naturally recycled and re-used continuously, and offers a wide range of additional advantages such as health and safety benefits, speed of construction, quality, efficiency, innovation, offsite manufacture and service and support.

The steel sector is renowned for keeping specifiers abreast of the latest advances in areas such as fire protection of structural steelwork and achieving buildings with the highest sustainability ratings. Recent publications have provided detailed guidance on CE Marking, Fire Protection, Cost and Thermal Mass and what it means for the construction sector. Guidance is provided on all relevant technical developments as quickly as is possible.

The sector’s go to resource website – www.steelconstruction.info – is a free online encyclopedia for UK construction that shares a wealth of up-to-date, reliable information with the construction industry in one easily accessible place.

**Tata Steel Europe**
The European operations of Tata Steel comprise Europe’s second largest steel producer. With the main steelmaking operations in the UK and Netherlands, they supply steel and related services to the construction, automotive, packaging, lifting and excavating, energy and power, aerospace and other demanding markets worldwide. The combined Tata Steel group is one of the world’s largest steel producers, with an aggregate crude steel capacity of more than 28 million tonnes and approximately 80,000 employees across four continents.

**British Constructional Steelwork Association**
BCSA is the national organisation for the steel construction industry: its Member companies undertake the design, fabrication and erection of steelwork for all forms of construction in building and civil engineering. Associate Members are those principal companies involved in the direct supply to all or some Members of components, materials or products. Corporate Members are clients, professional offices, educational establishments etc which support the development of national specifications, quality, fabrication and erection techniques, overall industry efficiency and good practice.
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Introduction

What is Embodied Carbon?

The term ‘embodied carbon’ refers to the lifecycle greenhouse gas emissions (expressed as carbon dioxide equivalents – CO$_2$e$^1$) that occur during the manufacture and transport of construction materials and components, as well as the construction process itself and end of life aspects of the building.

In recent years, the embodied carbon of construction materials has become synonymous with the term ‘carbon footprint’.

Operational carbon is the term used to describe the emissions of carbon dioxide during the operational or in-use phase of a building, including heating, cooling, ventilation and lighting of the building.

Together, embodied and operational carbon comprise the total emissions of a building throughout its lifecycle.

1 Climate change is caused by a number of different greenhouse gases each which have a greater or lesser impact on the climate over time. In robust embodied carbon studies, climate change characterisation factors are used to combine the global warming potential of different greenhouse gases to derive a single metric, in this case CO$_2$e or carbon dioxide equivalents. So, for example, methane has 25 times the global warming potential of CO$_2$ and so a process that emits 1kg of CO$_2$ and 1kg of methane emits 26kg CO$_2$e.
For construction materials, embodied carbon should include the impacts from the whole lifecycle of the building that they contribute to. The lifecycle aspects that should be considered are shown on page 4. Usually, construction materials do not contribute to the operational impacts of a building (operation, maintenance and refurbishment), though the design that includes them can have a significant effect on the operational performance of the building.

**Why is Embodied Carbon Significant?**

Reduction of operational carbon emissions from buildings is the primary sustainable construction driver in the UK. The Government has set ambitious and legally binding targets\(^2\) to reduce national greenhouse gas emissions and, as the operation of buildings currently accounts for nearly half of these, significant improvement in new and existing building performance is required if these targets are to be met.

As the operational energy efficiency of buildings is improved, the relative importance of the embodied carbon impact is increasing. As a consequence, it is receiving more attention by designers.

The purpose of this guide is to give designers an overview of how embodied carbon should be considered, some practical guidance on how to assess embodied carbon on individual projects and some case studies on how structural steelwork compares with other framing materials.

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\(^2\) The Climate Change Act commits the UK to an 80% reduction in CO\(_2\) emissions by 2050 from 1990 levels. It includes an interim target of a 34% reduction by 2020.
How Should Embodied Carbon Be Calculated?

The most straightforward way to determine the embodied carbon impact of different materials and products in a building is to calculate it in a similar way to a cost model but using rates of kgCO₂e/kg rather than £/kg. The key of course is in identifying the correct rates to use.

Lifecycle assessment (LCA) should be used to determine the embodied carbon impacts of construction products. LCA as a methodology is in itself flexible so that it can be used in any sphere of life. To ensure robustness, the scope of the LCA and aspects that it considers must be consistent and rigorous to enable comparability of one product against another. Within construction, this is usually achieved with a LCA that follows all of the lifecycle stages set out in BS EN 15804.

Designers must also ensure that they are assessing different options using consistent data. This is an obvious statement to make but, where embodied carbon is concerned, careful background checking of the scope of any data needs to be carried out.
Some manufacturers present data for their products based on some but not all of the lifecycle stages to BS EN 15804. Most frequently this will be ‘cradle to gate’ data that consider only the impacts from the extraction and manufacturing processes.

Other manufacturers will present data for their products considering all of the lifecycle stages to BS EN 15804. This is ‘cradle to cradle’ data (sometimes also called ‘cradle to grave’).

A brief look at the scope of cradle to gate assessment compared to the scope of cradle to cradle shows the significant difference between them. Comparing one material or product’s cradle to gate data against another’s cradle to cradle data will result in a flawed analysis and an incorrect conclusion. Again, an obvious statement to make but actually a mistake that can easily be made inadvertently since the scope of the embodied carbon number presented is not always apparent.

Designers should therefore ensure that they confirm with a manufacturer on what basis the number has been derived (cradle to gate, cradle to cradle etc) and that LCA has been assessed using all the lifecycle stages in BS EN 15804 if it is not explicitly stated and apparent within the literature.

Finally, (as with cost models) a standard material comparison on a kgCO₂e/kg of material basis should be avoided as different materials are not used in the same quantities within a building to deliver equivalent performance. As a minimum a kgCO₂e/m² assessment should be used for different options to consider the effects of material intensity in the ‘as built’ condition.

**Environmental Product Declarations (EPD)**

The construction industry has widely adopted EPD as the means of reporting and communicating environmental information.

They are used to provide environmental information in a common format.

To be comparable, EPD must have been developed with the same scope, methodology, data quality and indicators and designers should ensure that all the relevant life cycle stages have also been included.
The Significance of End of Life Impacts

Strength:
- Data is widely available for most construction products

Weaknesses:
- Covers impacts from use of a construction material or product only over part of its lifecycle
- Using cradle to gate data excludes what happens at end of life and therefore assumes that all materials are the same
- It considers recycling, reuse, landfill, incineration and downcycling to have the same impacts. This is simply not the case

Strengths:
- It provides an accurate assessment of embodied carbon impacts throughout the lifecycle of a construction material or product
- It ensures that comparisons of lifetime impacts of a construction material are correct
- Using cradle to cradle data accurately considers the end of life impacts

Weakness:
- The previous lack of data on end of life outcomes. This issue has now been addressed by the PE INTERNATIONAL dataset

What happens to a building’s structural frame once it is demolished?

3 The recycling process when the resultant material is of a lower quality than the original source; for example, using crushed concrete as hardcore. This avoids landfilling but does not substitute concrete production.
Case Study – Different End of Life Scenarios for Different Materials

Lackenby Open Hearth Steel Plant

Built in 1953, the Lackenby open hearth steel plant was a huge building. Over 330m long, 39m high and with a width of 70m and incorporating over 20,000 tonnes of structural steelwork, it dominated the Tata Steel site at Teesside. Opened in 1956 by HM Queen Elizabeth II it remained in production for over 20 years. After that time, the huge volumes and large column-free spaces made it ideal for conversion to a material storage facility. But by 2004, the building had come to the end of its useful life and it was marked for demolition.

Once demolished, the building materials were recovered from the site. 100% of the steel was recovered from the site and 100% was recycled. This included the rebar in the floor slab.

The concrete from the floor slab could only be downcycled and was crushed for low-grade fill material for hardstanding areas.

The steel from the building was recycled and supplied to hundreds of customers for a wide variety of end uses including:

1. Structural sections used in Heathrow Terminal 5
2. Structural sections used in the new stand at the Oval cricket ground
3. Plates used in the Paddington Station redevelopment
4. Plates fabricated into large girders for the A249 bridge to the Isle of Sheppey
5. Galvanized strip steel to make light steel framed houses
6. Strip steel supplied to the Royal Mint to make copper plated 1p and 2p coins
7. Strip steel for automotive parts
8. Plates made into bulb flats used in the construction of ships
End of Life Dataset by PE INTERNATIONAL

In order to enable designers to effectively compare embodied carbon data for commonly used framing materials on a cradle to cradle basis, PE INTERNATIONAL has produced an end of life dataset.

This dataset covers the demolition and recycling impacts (modules C and D to BS EN 15804) for common construction materials.

It enables designers to add end of life impacts to manufacturer’s data and establish a robust means to compare different options for a project.

Below is an extract from PE INTERNATIONAL’s dataset. A full list of all products can be viewed in the construction product information article online.

<table>
<thead>
<tr>
<th>Product</th>
<th>BS EN 15804 Modules</th>
<th>Total C1-C4 and D (kgCO₂e/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1-C4 (kgCO₂e/kg)</td>
<td>D (kgCO₂e/kg)</td>
</tr>
<tr>
<td>Brickwork</td>
<td>0.01</td>
<td>-0.0207</td>
</tr>
<tr>
<td>Concrete blockwork</td>
<td>0.0103</td>
<td>-0.0053</td>
</tr>
<tr>
<td>C40 concrete</td>
<td>0.0043</td>
<td>-0.0053</td>
</tr>
<tr>
<td>C50 concrete</td>
<td>0.0037</td>
<td>-0.0053</td>
</tr>
<tr>
<td>Lightweight C40 concrete</td>
<td>0.0111</td>
<td>-0.0053</td>
</tr>
<tr>
<td>Hollowcore slab</td>
<td>0.0006</td>
<td>-0.0103</td>
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<tr>
<td>Hot rolled plate and structural sections</td>
<td>0.06</td>
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</tr>
<tr>
<td>Hot formed structural hollow sections</td>
<td>0.06</td>
<td>-1.38</td>
</tr>
<tr>
<td>Reinforcing deck</td>
<td>0.061</td>
<td>-0.426</td>
</tr>
<tr>
<td>Steel deck</td>
<td>0.06</td>
<td>-1.45</td>
</tr>
</tbody>
</table>

PE INTERNATIONAL is the international market leader in strategic consultancy, software solutions and extensive services in the field of sustainability. It has developed and maintained the GaBi software for product sustainability.

Development of this end of life dataset was overseen by Jane Anderson, co-author of BRE’s original Environmental Profiles Methodology for life cycle assessment of construction products and lead author of BRE’s Green Guides to Specification.
Whole Life Embodied Carbon Data for Common Framing Materials

In order to assist designers, robust data has been sourced for the extraction and manufacture lifecycle stages and combined with the end of life dataset from PE INTERNATIONAL. The result is a robust and comprehensive dataset of embodied carbon impacts for materials commonly used as framing materials in construction.

Below is an extract from the full dataset. Data for all the materials included can be viewed online, along with sources for the cradle to gate (A1-A3) data used.

As previously stated, a standard material comparison on a kgCO₂e/kg of material basis should be avoided as different materials are not used in the same quantities within a building to deliver equivalent performance. As a minimum a kgCO₂e/m² assessment should be used for different options to consider the effects of material intensity in the ‘as built’ condition.

Designers using this dataset can have confidence in its transparency, robustness and consistency, enabling comparison between different frame options to accurately and effectively carry out on any project.

<table>
<thead>
<tr>
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<th>BS EN 15804 Modules</th>
<th>Total (kgCO₂e/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1-A3 (kgCO₂e/kg)</td>
<td>C1-C4 (kgCO₂e/kg)</td>
</tr>
<tr>
<td>Brickwork</td>
<td>0.16</td>
<td>0.01</td>
</tr>
<tr>
<td>Concrete blockwork</td>
<td>0.09</td>
<td>0.0103</td>
</tr>
<tr>
<td>C40 concrete</td>
<td>0.13</td>
<td>0.0043</td>
</tr>
<tr>
<td>C50 concrete</td>
<td>0.17</td>
<td>0.0037</td>
</tr>
<tr>
<td>Lightweight C40 concrete</td>
<td>0.17</td>
<td>0.0111</td>
</tr>
<tr>
<td>Hollowcore slab</td>
<td>0.2</td>
<td>0.0006</td>
</tr>
<tr>
<td>Hot rolled plate and structural sections</td>
<td>1.735</td>
<td>0.06</td>
</tr>
<tr>
<td>Hot formed structural hollow sections</td>
<td>2.49</td>
<td>0.06</td>
</tr>
<tr>
<td>Reinforcing steel</td>
<td>1.27</td>
<td>0.061</td>
</tr>
<tr>
<td>Steel deck</td>
<td>2.52</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Fabrication (bending, cutting and welding for rebar) impacts have not been included.
Carbon Footprint Tool for Buildings

A simple web tool that enables designers of multi-storey buildings to easily estimate the embodied carbon footprint of the superstructure has been developed and published online.

Designers can use the tool in two ways. In ‘auto-generate’ mode, the basic building geometry, structural grid and chosen floor system are used to estimate structural material quantities using algorithms developed by the Steel Construction Institute (SCI) for common structural steel solutions. Alternatively, a user may use the ‘manual input’ mode to enter the actual material quantities for the building.

To compare the impact of a steel framed building with a concrete framed building, quantities should be manually input into the tool for each option.

For both auto-generated or manually input data, appropriate carbon emission factors are then applied to the material quantities to estimate the overall carbon footprint of the building. The results are presented as a single CO₂e figure for the building, a CO₂e figure per m² of floor area, and a bar chart illustrating the contributions to the total made by the various elements of the building, i.e. frame, concrete cores, floors, roof, fire protection and void walls.

Alternatively, the carbon emissions rates used in the tool can be incorporated into a designer’s own spreadsheet.

Article of interest: • CARBON FOOTPRINT TOOL FOR BUILDINGS
STEEL CONSTRUCTION

Embodied Carbon Case Studies
Building 1 –
A Typical Business Park Office Building

Building 1 is an independently developed case study by Gardiner & Theobald (G&T), Peter Brett Associates (PBA) and Mace that has been published in the Steel Insight series in Building and in more detail in Steel Construction: Cost.

It demonstrates the cost and programme performance of comparable structural designs for a three-storey business park office. The same models developed by G&T for each structural option have been used to calculate their embodied carbon impacts by applying the carbon rates from the simple design tool to the quantities for each material.

PBA established the structural grid at 7.5m x 9m, based on an optimum grid for a typical business park office not dictated by site constraints. Four frame types were considered:

1. Steel composite beams and composite slab
2. Steel frame and precast concrete slabs
3. Reinforced concrete flat slab
4. Insitu concrete frame with post-tensioned slab

For all options the foundations were designed as unreinforced mass concrete pads. The core construction is steelwork cross-braced framing with a medium density blockwork infill for the steel options and concrete shear walls for the concrete options.

For both steel options, the 30 minute fire resistance is provided by intumescent coating to beams and bracing members and boarding to columns. For the concrete options, the internal columns are plastered and painted for aesthetic purposes.

All options include a part-open and part-enclosed roof plant area and lift motor room. The two steel framed options have a lightweight steel deck roof, while the concrete options continue the concrete slab construction of the lower floors.
Building 1 – Embodied Carbon Impacts

The embodied carbon impacts for each option have been considered on a cradle to cradle basis. Only the structural aspects of each option have been assessed, using the dataset from the SCI’s simple design tool.

For frame and floors, the embodied carbon impact of the steel composite option is significantly lower than all the other options at 97kgCO₂e/m², with the post-tensioned flat slab 58% higher at 153kgCO₂e/m², the concrete flat slab 92% higher at 187kgCO₂e/m² and the steel precast 106% higher at 200kgCO₂e/m².

The lighter superstructure for the steel options results in smaller foundations than those of the concrete options. Consequently, the impacts from the substructure are different for each option. The foundations for the steel composite option have an embodied carbon impact of 24kgCO₂e/m². This compares with 30kgCO₂e/m² for the steel precast option, 42kgCO₂e/m² for the post-tensioned flat slab concrete option and 50kgCO₂e/m² for the concrete flat slab option.

For the total structure, which includes frame and upper floors, foundations and roof construction, it can be seen that the steel composite has the lowest embodied carbon impact at 180kgCO₂e/m². Interestingly, steel precast and post-tensioned flat slab have similar total impacts at 268kgCO₂e/m² and 267kgCO₂e/m², respectively, with concrete flat slab at 328kgCO₂e/m².

It can therefore be seen that the steel composite option has significantly lower embodied carbon impacts than any of the other options. Whilst the steel precast and post-tensioned flat slab concrete options have similar embodied carbon impacts, the steel precast has significantly lower cost and a quicker construction programme.
Building 1 – Cost and Programme

Cost
The impact of the construction programme for each option has been considered in the total building costs – the steel options benefit from lower preliminaries costs because of their shorter construction programmes.

The steel composite beam and slab option has both the lowest frame and upper floors cost and lowest total building cost. This option also has the lowest substructure costs of all frame options due to the lighter frame weight and the lowest roof cost due to the lightweight steel roof deck.

The steel composite beam and slab option remains the most competitive for Building 1, with both the lowest frame and upper floors cost, lowest total building cost and shortest programme.

The reinforced concrete flat slab option has both the highest frame and upper floors cost and highest overall building cost. The frame and floors cost is 7% higher than the steel composite and the total building cost is around 6% higher. This option has the highest substructure costs because of the heavier frame weight, the highest roof costs and the highest preliminaries costs due to the longest programme.

A review of the steel and precast concrete slab and post-tensioned flat slab concrete options also highlights the importance of considering total building cost when selecting the structural frame material during design. The post-tensioned option has a marginally lower frame and floor cost than the steel and precast option (£154/m² compared to £155/m²), but on a total building basis, the steel and precast slab option has a lower cost (£1,590/m² compared to £1,640/m²). This is due to a lower roof cost and lower preliminaries resulting from the shorter programme.

Programme
Both steel options have very similar programme periods for both the frame and overall construction. The steel composite option, though, provides the quickest frame and overall duration by one week, due to the speed of laying and distributing the steel decks. The programmes for the frame and upper floor construction are also similar for both concrete options, as the processes involved in constructing the structure are the same.

Of all four options, the steel composite frame provides the fastest method of frame construction and overall programme for Building 1.
Building 2 –
A Typical City Centre Office Building

Building: An eight-storey L-shaped city centre office
Gross internal area: 16,500m²
Floor-to-ceiling height: 3.0m

Building 2 is also an independently developed case study by Gardiner & Theobald, Peter Brett Associates (PBA) and Mace that has been published in the Steel Insight series in Building and in more detail in Steel Construction: Cost.

In addition to demonstrating the cost and programme performance of comparable structural designs, PBA also carried out a cradle to cradle embodied carbon assessment, which was published too.

PBA established the structural grid at 7.5m x 15m based on experience of similar city centre schemes, and this was used for both of the following frame options:
  1. Cellular composite beams and composite slab
  2. Post-tensioned band beams and slab, in situ columns.

Both options use CFA piles, with three to four piles per column pile cap. The core construction is steel cross-braced framing with a medium density blockwork infill for the steel option and concrete shear walls for the concrete option.

Buildings of this type normally include a basement, but the options in the study are assumed to start from ground floor as impacts from any basement would be common to all options.

The 60 minute fire resistance is provided to the steel framed option through intumescent coating to beams and bracing members and boarding to columns, while the internal columns of the concrete option are plastered and painted for aesthetic reasons.

The roof plant area is a fabricated steelwork portal frame with composite metal panel cladding and the roof decks for both options continue the floor construction of the lower floors.
PBA's study has been carried out on a cradle to cradle basis. It considers the whole building, although the emissions from the structural elements represent the main carbon differences between the options.

PBA assessed the options as buildings in line with the cost study designs, which used only Portland cement for the concrete mix.

For the frame and floors, the post-tensioned concrete flat slab had an embodied carbon impact 26% higher than the steel composite option. The heavier superstructure for the concrete option also resulted in an embodied carbon impact for the substructure that was 22% higher than for the steel composite option.

When considering the total building, embodied carbon impact for the steel composite option was 205kgCO₂e/m² compared to 253kgCO₂e/m² for the concrete option, which was 23% higher.

However, as cement replacement is often used to reduce sustainability impacts, the embodied carbon impact on both options from a 30% cement replacement with fly ash and ground granulated blast furnace slag was also assessed. This level of cement replacement is considered to be reasonable without having a significantly adverse impact on the construction programme because of increased curing time.

With the replacement mix, the embodied carbon reduced to 184kgCO₂e/m² for the steel option and to 204kgCO₂e/m² for the post-tensioned flat slab concrete option. Though the difference between the steel and concrete options was reduced, it was still significant with the composite steel frame having 11% less embodied carbon than the post-tensioned concrete frame.
Building 2 – Cost and Programme

Cost

The cellular steel composite option has both a lower frame and floor cost and lower total building cost than the post-tensioned concrete band beam option.

On a total building basis, the steel option benefits from lower substructure costs due to the lighter frame weight and a lower roof cost due to the cost of the steel deck compared to the post-tensioned slab.

The steel option has a lower floor-to-floor height (4.18m compared to 4.375m) which results in around a 5% lower external envelope cost due to the smaller area of cladding and also has lower preliminaries costs due to its shorter programme. This contributes to its lowest overall total building cost. Overall, the frame and floor cost of the steel option is over 8% lower than the concrete option and over 3% lower on a whole building basis.

The study also highlights the importance of considering total building cost, not just structural frame cost, because the structural frame material and configuration impacts on many other elements, including the substructure, roof and external cladding.

The total building costs for the steel options are over 3% lower than the concrete options due to the frame and upper floor costs, as well as smaller foundations, lightweight roofs, lower storey heights reducing cladding costs and reduced preliminaries costs. Furthermore, the construction durations of the steel framed solutions are shorter than the concrete framed buildings at 11% for Building 2.

Programme

While the substructure and ground slab construction have the same programme period - 20 weeks - for each option, the steel frame has a significantly shorter frame and floor construction (16 weeks compared to 28 weeks for the concrete option), so the internal fit-out can start earlier.

This means the cellular steel option provides a significantly shorter frame construction and overall programme for Building 2 compared to the post-tensioned concrete option, with a saving of 12 weeks for the frame and eight weeks across the programme.
One Kingdom Street, London

Building: A 10-storey city centre office
Gross internal area: 33,018m²
Floor-to-ceiling height: 2.8m

One Kingdom Street is a Grade A office building completed in 2008 and used as the office in the Target Zero research project by AECOM, Sweett Group and the SCI.

This 40m high building is rectilinear with approximate dimensions of 81m x 45m. It accommodates 24,490m² of open plan office space on 10 floors and, on the eastern half of the building, two basement levels providing car parking and storage. The gross internal floor area is 33,018m². A typical office floor plate provides approximately 2,500m² of highly flexible space on a 1.5m planning grid.

One Kingdom Street has three cores and is designed around two central atria on its southern elevation, which house six scenic wall chamber lifts. The western half of the building is partly constructed on a podium transfer structure enclosing future works access for Crossrail.

One Kingdom Street has a steel frame, on a typical 12m x 10.5m grid, comprising fabricated cellular steel beams supporting a lightweight concrete slab on a profiled steel deck. The larger span is dictated by the location of beams within the Crossrail podium deck on which they are supported.

The foundations comprise 750mm diameter bored-piled foundations with insitu concrete pilecaps. Ground beams provide lateral restraint to the pilecaps. The piles are the same size as those used to support the existing Crossrail podium in order to reduce potential differential settlement arising from the use of different pile diameters.
One Kingdom Street – Embodied Carbon Impacts

The embodied carbon impacts for both options on One Kingdom Street have been considered on a cradle to cradle basis.

For frame and floors, the steel composite option has an embodied carbon impact of 152kgCO₂e/m² compared with 190kgCO₂e/m² for the post-tensioned concrete option. The impact of the concrete option is therefore 24% greater than that of the steel option.

The lighter superstructure for the steel option also results in smaller foundations compared to the concrete option. Consequently, the impacts from the substructure are different for each option. The foundations for the composite steel option have an embodied carbon impact of 59kgCO₂e/m². This compares with 74kgCO₂e/m² for the post-tensioned concrete option, an increase of 26%.

When considering the both options for the building as a whole, the steel composite option has an embodied carbon impact of 452kgCO₂e/m², which equates to a total of 14,937tCO₂e. This compares to the post-tensioned concrete option with an embodied carbon impact of 506kgCO₂e/m², which equates to a total of 16,716tCO₂e.

The total building impact for the post-tensioned option is 12% greater than the steel composite option.
One Kingdom Street – Cost

The steel option comprises composite cellular steel beams supporting a lightweight concrete slab cast onto profiled metal decking.

The concrete option comprises 350mm thick post-tensioned flat slab construction.

For the frame and floor costs alone, the steel composite option is £316/m² compared to £377/m² for the post-tensioned concrete alternative. The concrete option is therefore 19% more expensive.

When considering the total building costs, the steel composite option is £1869/m² or £61.7m compared to £1941/m² or £64.1m for the post-tensioned concrete option. The concrete alternative is therefore 4% more expensive than the steel option.
**MediaCityUK, Salford**

*Building:* The 17-storey mixed-use Holiday Inn tower  
*Gross internal area:* 18,625m²  
*Floor-to-ceiling height:* 3.0m in hotel, 4.0m in offices

Inspired by the success of other media clusters in cities such as Dubai and Singapore, Phase 1 of MediaCityUK started in 2007 and was completed in 2011. It is the new home for parts of the BBC relocated from London, ITV, Coronation Street and the University of Salford.

The mixed-use Holiday Inn tower at MediaCityUK in Salford was used in the Target Zero research project by AECOM, Sweett Group and the SCI.

The 17-storey Holiday Inn tower is attached to the main studio building at ground, mezzanine and first floor levels. An atrium connects the office floors of the tower block to the studio block (floors 2 to 6). Two concrete cores, one at each extremity of the building, provide the stability of the tower as well as housing the risers and lifts. The foundations are 750mm diameter CFA concrete piles.

The building accommodates 7,153m² of open plan office space on five floors (floors 2 to 6) and 9,265m² of hotel space on eight floors (floors 8 to 15). The ground and mezzanine floors accommodate the hotel reception and a restaurant. Floor 7 houses plant for the office floors and floor 16 houses plant serving the hotel. The first floor accommodates dressing rooms and make-up areas. The gross internal floor area of the building is 18,625m². The 67m high building is rectilinear with approximate dimensions of 74m x 15.3m.

Project constraints meant that unusually this building was constructed in Slimdek. For the purposes of this case study, only the more common structural options of composite cellular steel frame construction and concrete flat slab construction are included.
MediaCityUK – Embodied Carbon Impacts

The embodied carbon impacts for both standard construction options on the Holiday Inn tower at MediaCityUK have been considered on a cradle to cradle basis.

For frame and floors, the steel composite option has an embodied carbon impact of 218kgCO$_2$e/m$^2$ compared with 259kgCO$_2$e/m$^2$ for the concrete flat slab option. The impact of the concrete option is therefore 19% greater than that of the steel option.

The lighter superstructure for the steel option also results in smaller foundations compared to the concrete option. Consequently, the impacts from the foundations are different for each option. The foundations and ground floor slab for the steel composite option have an embodied carbon impact of 42kgCO$_2$e/m$^2$. This compares with 75kgCO$_2$e/m$^2$ for the concrete flat slab option, an increase of 77%.

When considering both options for the building as a whole, the steel composite option has an embodied carbon impact of 395kgCO$_2$e/m$^2$, which equates to a total of 7,352tCO$_2$e. This compares to the concrete flat slab option with an embodied carbon impact of 467kgCO$_2$e/m$^2$, which equates to a total of 8,692tCO$_2$e.

The total building impact for the concrete flat slab option is 18% greater than the steel composite option.

The embodied carbon impacts for each option have also been broken down to show the contributions from the office and hotel parts of the building. It can be seen that the embodied carbon impacts are lower for the steel composite construction in both instances than for the concrete flat slab construction alternative.
The steel option comprises composite cellular steel beams supporting a lightweight concrete slab cast onto profiled metal decking. In the hotel part of the building, the floor beams are UKC sections to deliver the shallower floor construction required.

The concrete option comprises 260mm thick flat slab construction for the offices and 250mm thick flat slab construction for the hotel.

For the frame, floor and foundation costs alone, the steel composite option is £318/m² compared to £355/m² for the concrete flat slab alternative. The concrete option is therefore 12% more expensive.

When considering the total building costs, the steel composite option is £1868/m² or £34.8m compared to £1845/m² or £35.3m for the post-tensioned concrete option. The concrete alternative is therefore 1% more expensive than the steel option.
When considering embodied carbon, designers should always check and ensure any data that they use for any construction material or product is creditable and robust. Within construction, this is usually achieved with a LCA that follows all of the lifecycle stages set out in BS EN 15804.

Where comparisons are being made between materials, it is important to ensure that the data used is similar in scope.

Some manufacturers present data for their products based on some but not all of the lifecycle stages to BS EN 15804. Most frequently this will be ‘cradle to gate’ data that consider only the impacts from extraction and manufacture processes.

Other manufacturers will present data for their products considering all of the lifecycle stages to BS EN 15804, this is ‘cradle to cradle’ data.

Designers must also ensure that they are assessing different options using consistent data. The most common issue is the basis of any embodied carbon number presented as it is not always obvious whether it is cradle to gate or cradle to cradle.

As end of life impacts vary significantly between different materials, cradle to cradle assessment should always be used when considering alternative structural options. The dataset independently produced by PE INTERNATIONAL enables designers to add the end of life impacts to cradle to gate data to create a robust assessment. The end of life dataset has been incorporated into a whole life embodied carbon dataset for common framing materials that has been published.
The case studies included demonstrate that standard steel framed buildings outperform standard concrete framed buildings on the three key metrics of embodied carbon impacts, cost and speed of construction. These case studies have all been produced independently by Gardiner & Theobald, Peter Brett Associates and Mace or AECOM, Sweett Group and the SCI.

As cement replacement is often used to reduce sustainability impacts, PBA's study of Building 2 included the embodied carbon impact on both structural options from using a 30% cement replacement with fly ash and ground granulated blast furnace slag.

With the replacement mix, the embodied carbon reduced from 205kgCO₂e/m² to 184kgCO₂e/m² for the steel option and from 253kgCO₂e/m² to 204kgCO₂e/m² for the post-tensioned concrete option. Though the difference between the steel and concrete options was reduced, it was still significant with the steel composite frame having around 11% less embodied carbon than the post-tensioned concrete frame.

Results for each aspect of the case studied considered are summarised in the table.

<table>
<thead>
<tr>
<th>Building</th>
<th>Embodied carbon (kgCO₂e/m²)</th>
<th>Cost (£/m²)</th>
<th>Programme (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Embodied carbon (kgCO₂e/m²)</td>
<td>Cost (£/m²)</td>
<td>Programme (weeks)</td>
</tr>
<tr>
<td></td>
<td>Frame &amp; floor</td>
<td>Substructure</td>
<td>Total building</td>
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<tr>
<td>Building 1</td>
<td>Steel composite</td>
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<td>Steel precast</td>
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<td></td>
<td>Concrete flat slab</td>
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<tr>
<td></td>
<td>Post-tensioned flat slab</td>
<td>153</td>
<td>42</td>
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<tr>
<td>Building 2</td>
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<tr>
<td></td>
<td>Post-tensioned flat sab</td>
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<tr>
<td></td>
<td>Steel composite (replacement mix)</td>
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<tr>
<td></td>
<td>Post-tensioned flat slab (replacement mix)</td>
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<td>Post-tensioned flat slab</td>
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<tr>
<td>Media CityUK</td>
<td>Steel composite</td>
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<td>42</td>
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<tr>
<td></td>
<td>Post-tensioned flat slab</td>
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<td>75</td>
</tr>
</tbody>
</table>
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September 2014