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Embodied Carbon Assessment of a Light Steel Framed Residential Building

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EXECUTIVE SUMMARY

A study was made of the embodied carbon in a 6 storey residential building that was constructed in two light steel framing options compared to a reinforced concrete scheme. The key findings from this study are:

- The gross weight of the light steel framing solution with joisted floors is about one quarter of that of a concrete frame with blockwork walls, excluding foundations.
- The gross weight of the light steel frame and composite floor solution is about a half of that of a concrete frame with blockwork walls, excluding foundations.
- The embodied carbon of the light steel solution with joisted floors is 51% lower than the concrete frame and blockwork solution when expressed per unit floor area.
- The embodied carbon of the light steel and composite floor solution is 37% lower than the concrete frame and blockwork solution when expressed per unit floor area.
- The site waste of the light steel solution is about one third of that of a concrete frame

Further life cycle benefits result from the off-site nature of the construction process and the ability to extend and modify the structure over time and ultimately to re-use or recycle the steel components. The reduced weight of the light steel framing solution is also important when it is supported on a podium structure.

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1 INTRODUCTION

Embodied carbon is the carbon dioxide (CO_2) or, more accurately, the greenhouse gas (GHG) emissions associated with the manufacture and use of a product or service. For construction products, this includes the CO_2 or GHG emissions associated with extraction, manufacturing, transporting, installing, maintaining and disposing of construction materials and products.

There are two types of GHG emissions associated with buildings: the embodied carbon of the products that make up the building and the operational carbon which are the GHG emissions associated with the general day to day use of the building, primarily through water and space heating, lighting, etc. Together they make up the total carbon footprint of the building

As the operational energy efficiency of buildings is improved, the relative importance of the embodied carbon impacts of buildings is increasing. As a consequence, greater attention is being placed on the embodied carbon of buildings and how the embodied carbon (or carbon footprint) of buildings is measured.

Embodied carbon assessment is a subset of a broader discipline called life assessment (LCA) which covers a range of different environmental impacts. As such, many of the principles are equally applicable to both assessment methods.

Light steel framing is widely used in 3 to 10 storey residential buildings, hotels, educational, medical and other applications, including roof-top extensions, where its light weight, robust structural behaviour and off-site construction process are key benefits. The economic argument, in particular, comes from speed of construction, where early completion of the building has a tangible economic return to the client and main contractor.

Early design decisions generally have the greatest impact on both the operational and embodied carbon impact of buildings.

To help inform early decision-making, this Report presents the results of an embodied carbon assessment of a 6 storey residential building constructed using two alternative light steel framing systems, one using a joisted floor and an alternative using a composite steel-concrete floor slab. Results are compared with a more traditional reinforced concrete structure with block-work infill walls.

This report describes:

- LCA and embodied carbon assessments
- the design of the three building options considered in the study
- the scope of the assessment.
- the results and conclusions from the study both in terms of the structure weight and embodied carbon of the three solutions.

Part of the argument for use of steel relates to the imperative of creating a 'circular economy' in which the raw materials are combined with re-cycled materials to reduce environmental burdens by ensuring that resources remain in use and are not 'down-cycled' over time. This process is illustrated in Figure 1.1. Common with other valuable metals, almost all steel is recycled into new production and leads to new products of equivalent or higher quality.

In environmental assessments, credits may be taken now for the eventual reuse or recycling of material in the future, which is included in this study.

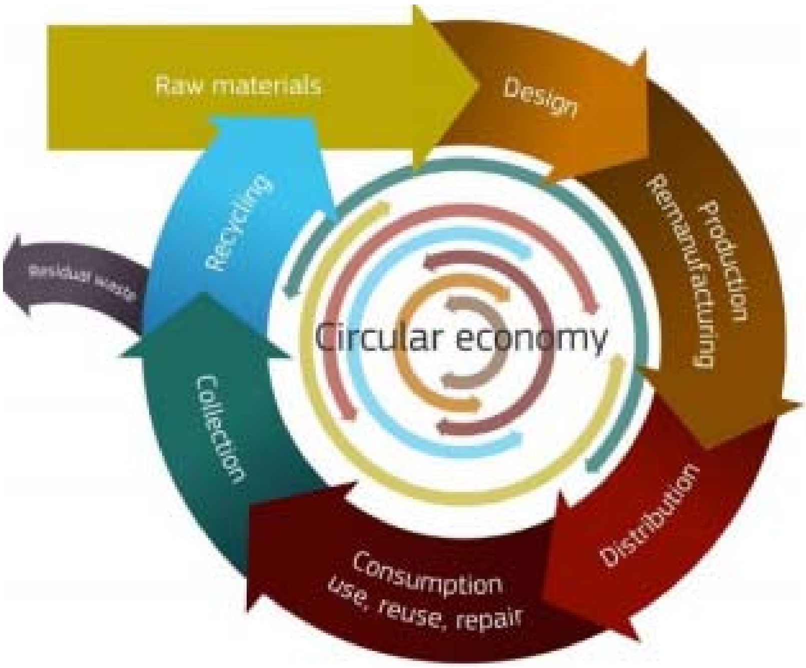

Figure 1.1 Illustration of the circular economy (taken from World Steel Association)

2 BENEFITS OF LIGHT STEEL FRAMING

There are many potential benefits of off-site production of light steel framing as compared with more traditional site-based construction techniques. These include the:

- Ability to achieve rapid reliable construction programmes and reduced exposure to site and procurement risks.
- Simplified (and unified) procurement routes. Suppliers are responsible for design, manufacture and installation of the structural components.
- A wide range of section sizes and steel thicknesses is available for efficient manufacture.
- Integration with the Building Information Modelling (BIM) systems. Light steel framing is leading in this area.
- Light steel framing can be combined with other structural components such as structural steel frames and precast concrete stairs as part of the same ‘package’.
- Its light weight reduces loads on the supporting structure and on foundations. This is important when the light steel framing is supported by a podium structure over a supermarket or railway tunnel for example.
- Reduced waste and damage on site and factory waste is recycled.
- Efficient pre-ordering, delivery and storage of materials in factory conditions.
- Mechanization of the manufacturing process, including over-head lifting, use of sophisticated machine tools, etc.
- High level of quality control, thereby avoiding reworking and delays.
- Dry construction process in the factory and in on-site work.
- Long term movement due to creep and shrinkage is eliminated.
- 90 minutes fire resistance and excellent acoustic insulation is achieved by use of double layers of plasterboards with additional mineral wool insulation. Composite floors achieve excellent fire resistance and acoustic insulation with a single layer of plasterboard.
- Stability is provided by bracing that is built into the walls.
- Long term durability is provided by the galvanized layer and the steel components are in a warm dry environment so that their design life is 200+ years.
- Production rates can be matched to site delivery, which can be timed to suit local conditions.
- Productivity (output per person) is increased in the factory and also in site installation.
- Improved health and safety by reducing risks in a controlled production environment

- Highly skilled and well trained work force in factory production and in site installation with continuity of employment.
- Ability to extend and modify buildings in the future.
- Steel components can be recycled or re-used when the building is demolished or de-mounted.

3 LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is the most widely used tool for quantifying the environmental impacts of products and services. Nevertheless, LCA can be very complex and many, often material-specific, assumptions can significantly influence the results.

LCA is the tool that is used to develop Environmental Product Declarations (EPDs) which are a standardised set of environmental information based on a common set of rules called Product Category Rules (PCRs). EPDs are increasingly used by manufacturers to provide robust, quantified environmental data for construction products.

LCA involves the collection and evaluation of quantitative data on the inputs and outputs of material, energy and waste flows associated with a product over its entire life cycle so that its environmental impacts can be determined. An LCA essentially comprises three steps:

1. Compiling an inventory of relevant energy and material inputs and environmental releases (outputs) associated with a defined system. Releases can be solid wastes or emissions to air or water.
2. Evaluating the potential impacts associated with these inputs and releases.
3. Interpreting the results to help make informed decisions.

An important first step in any LCA is to clearly define the scope of the study, including:

- The functional unit of the product or system to be assessed, e.g. 1m^2 plan area.
- The system boundaries, that defines what is included/excluded in the assessment
- Any specific assumptions and limitations of the study
- The allocation methods used to dthe environmental load of a process when several products or functions share the same process, e.g. blast furnace slag is a valuable by-product of steelmaking and should carry a proportion of the environmental impact from steelmaking to the product in which it is used.
- The environmental impact categories chosen. For example, if only the climate change impact is included, then the assessment is an ‘embodied carbon’ assessment.

The LCA methodology is flexible in terms of the goal and hence scope of assessment. A robust LCA of a construction product (or a building) could include the impacts of:

- Extraction of the relevant raw materials, e.g. quarrying, mining

- Refinement and conversion to process materials, e.g. steel-making or cement production
- Manufacturing and packaging processes, e.g. steelwork fabrication or making precast concrete products
- Transportation and distribution at each stage
- Waste at each stage
- On-site construction impacts, e.g. water and energy use, temporary works, shuttering, worker commuting, etc.
- Operation during the lifetime of the building including maintenance, refurbishment, replacement, etc.
- At the end of its useful life, demolition, transportation, waste treatment and disposal.

Recycling or recovery operations built into the life cycle lead to a proportionate reduction in the adverse environmental impact and should be accounted for. It is important when undertaking LCA and embodied carbon assessments that the system boundaries are clearly defined and, that the data used are consistent in terms of the scope and boundaries defined above. The scope of the embodied carbon assessment is described in Section 5.

3.1 LCA impact categories

The impact of the inventory of flows or outputs from a system is assessed and interpreted by linking them to environmental impact categories through a process known as characterisation. The environmental impact categories generally considered are shown in Table 3.1 and the most common categories assessed are shown in bold.

Environmental Impact Categories	
Climate change	Ecotoxicity to land
Water extraction	Waste disposal
Mineral resource extraction	Fossil fuel depletion
Stratospheric ozone depletion	**Eutrophication**
Human toxicity	**Photochemical ozone creation**
Ecotoxicity to freshwater	**Acidification**
Nuclear waste (high level)	

Table 3.1 LCA environmental impact categories

Environmental impacts in one category can be caused by many different emissions and therefore characterisation factors are used to combine the impact of different substances. A good example is the impact category of climate change, which is caused by a number of different greenhouse gases each which have a varying impact on the climate over time - see data in Table 3.2). Climate change characterisation factors (or global warming potentials (GWP) are used to derive a single metric, in this case CO_2e or carbon dioxide equivalent.

Greenhouse gas	GWP – 100 year timeframe (kgCO_2e)
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	298
Sulphur hexafluoride (SF_6)	22800
Perflourobutane	8860
HFC 134a (tetrafluoroethane)	1430

Table 3.2 Characterisation factors for common greenhouse gases

Having established quantitative measures for each of the impact categories within the scope of the LCA, a further step undertaken in some LCA methodologies is to weight the different impact categories to produce a single value of environmental impact. Although this approach is not endorsed in LCA standards, it can be used to produce a single metric scoring system that is easy to understand for users.

An example of an LCA methodology which uses this approach is BRE's Environmental Profiles methodology [1] which led to the Green Guide to Specification [2] ratings. To produce a single value, two steps are employed:

- Normalisation – the 13 environmental impact category scores are normalised to the annual impact of an average European citizen
- Weighting – the normalised category scores are then combined using weightings of environmental importance, derived from a panel of European experts.

The resulting single value of environmental has the units of Ecopoints where 100 Ecopoints is equivalent to annual impact of an average European citizen.

3.2 LCA codes and standards

The principle standards governing the use of LCA are the ISO 14040 series of standards:

- LCA principles and framework ISO 14040:2006
- LCA requirements and guidelines ISO 14044:2006.

The following additional standards have been withdrawn and are now covered by the above revised versions of ISO 14040 and 14044.

- Goal and scope definition ISO 14041:1998
- Life cycle impact assessment ISO 14042:2000
- Life cycle interpretation ISO 14043:2000

In the context of building and construction LCA, the standards developed by CEN TC 350 are very influential in defining how the environmental impacts of construction products and buildings are assessed and will ensure that they are undertaken on a robust and consistent basis throughout the EU.

European Standards Technical Committee CEN/TC350 and its various working groups, began work in 2005 and a suite of standards has been developed. These include:

- EN 15643-2:2011 - Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework
- EN 15643-2:2011 - Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance
- EN 15804:2012 - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products
- EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

In the UK, the leading environmental assessment methodology for construction materials and products is BRE's Environmental Profiles. BRE's methodology is founded on LCA principles and is used to derive the Green Guide to Specification ratings that are used in BREEAM to assess the embodied environmental impact of construction products.

3.3 Environmental product declarations

Environmental Product Declarations (EPD), are used to provide environmental information from LCA studies in a common format, based on common rules, known as Product Category Rules (PCR). The construction industry has widely adopted EPDs as the means of reporting and communicating environmental information.

Within Europe, PCR for construction products have been developed in the UK, France, the Netherlands, Scandinavia and Germany and EPDs are published by Scheme Operators. For example, in the UK, EPDs (Environmental Profiles) are produced by BRE Global and BBA.

ISO 14025:2006 sets out standards for developing EPDs. This standard also draws on the key LCA standards ISO 14040 and ISO 14044.

To be comparable, EPDs must have been developed using the same PCR, to ensure scope, methodology, data quality and indicators are the same. EPDs can only be compared when the same PCR have been used and all the relevant life cycle stages have been included. This is a frequent limitation or failing of many comparative LCA studies. At present, a manufacturer selling the same product in different European markets may have to produce a separate EPD for each region.

3.4 Embodied carbon assessments

The term 'embodied carbon' refers to the lifecycle greenhouse gas emissions (expressed as carbon dioxide equivalents – CO_2e) 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 term 'embodied carbon' of construction materials and products has become synonymous with the term 'carbon footprint'. An embodied carbon or carbon footprint assessment is a subset of most LCA studies.

The embodied carbon and the in-use carbon emissions from the operation of the building (operational carbon) together make up the complete lifecycle carbon footprint of the building.

Regulations are mainly aimed at reducing the operational carbon emissions from new buildings, for example in Part L of the Building Regulations, and so the relative importance of embodied carbon impacts is increasing.

3.4.1 Embodied carbon codes and standards

As a subset of LCA, embodied carbon assessment (or carbon foot-printing) is subject to many of the same standards.

However, methodologies have begun to emerge to measure a carbon footprint in a standardised way; some of which relate to a company or organisational footprint, others to installations and others to a product. These include:

- The Greenhouse Gas Protocol - provides standards and guidance for companies and other organizations preparing a GHG emissions inventory
- PAS 2050 – specifies requirements for the assessment of the life cycle GHG emissions of goods and services based on key life cycle assessment techniques and principles
- ISO 14064-1:2006, Greenhouse gases – Part 1: specifies principles and requirements at the organization level for quantification and reporting of greenhouse gas (GHG) emissions and removals
- ISO 14064-2:2006, Greenhouse gases – Part 2: specifies principles and requirements and provides guidance at the project level for quantification, monitoring and reporting of activities intended to cause greenhouse gas (GHG) emission reductions or removal enhancements
- ISO 14064-3:2006, Greenhouse gases – Part 3: specifies principles and requirements and provides guidance for those conducting or managing the validation and/or verification of greenhouse gas (GHG) assertions.

3.5 BS EN 15804 Life cycle stages

BS EN 15804 is a key standard in construction LCA and embodied carbon studies. It provides a core set of Product Category Rules (PCRs) for the Europe-wide generation of EPD for construction products. PCRs define the methods for the collection of data, the calculation of environmental impact and how the information should be presented.

The CEN methodology for developing EPDs for construction products and for aggregating product information at the whole building level, is based on a modularity principle. This principle facilitates greater transparency concerning the definition of the scope and boundaries of studies assessing the environmental impacts of buildings.

Figure 3.1 shows how BS EN 15804 defines the various building life cycle stages that can be included within LCAs and EPD. Different life cycle stages are either mandatory or optional for different scope of EPDs. It is noted that only Modules A1 to A3 are mandatory under BS EN 15804, all other phases are optional.

In the UK, most embodied carbon building comparisons are ‘cradle-to-gate’ studies, i.e. they only include the impacts up until the product leaves the factory gate, i.e. modules A1 to A3. Some studies have included other modules, e.g. A4 (transport to site), A5 (on-site impacts) and B4 (replacement of building elements over time), but there are limited data on these ‘downstream’ impacts and, where robust data are available, it is often difficult to disaggregate this data in a meaningful way. For example, the total fuel/energy consumption for a construction project may have been measured but it is difficult to allocate or apportion these impacts to a specific element of the building.

Also, many of the modules or life cycle stages downstream of production (A4 to C4), are very project specific, e.g. transport to site (A4).

The steel sector has invested heavily over recent years to collect and develop comprehensive LCA data on iron and steel making. In addition, because of the good recycling and recyclability credentials of steel and steel products, the steel sector has generally aggregated these benefits (reported separately as Module D under the new CEN standards) together with the manufacturing impacts (A1 to A3). This approach or scope is called ‘cradle to gate with options’ under the new CEN standards. Module D allows for other benefits, which are outside the building lifecycle scope, to be taken into account. In the context of steel, this includes quantification of the benefits arising from future reuse and recycling. An important change within the new CEN standards, is the requirement that Module D impacts/benefits, which are voluntary, should be reported separately.

Most steel construction products have an intermediate step between the manufacture of the semi-finished steel product, e.g. a steel section or coil, and the final construction product, e.g. the steel beam or the decking. Under the CEN standards, these impacts are a subset of manufacturing Module A3.

The focus of this comparative study is the activities and resulting impacts under Modules A1 to A3 - see Figure 3.1, which concerns the manufacture of construction products.

In addition, for steel construction products included within the scope of this study and some other materials, where data are available, Module D benefits have been calculated and are reported separately – see Section 3.5.1.

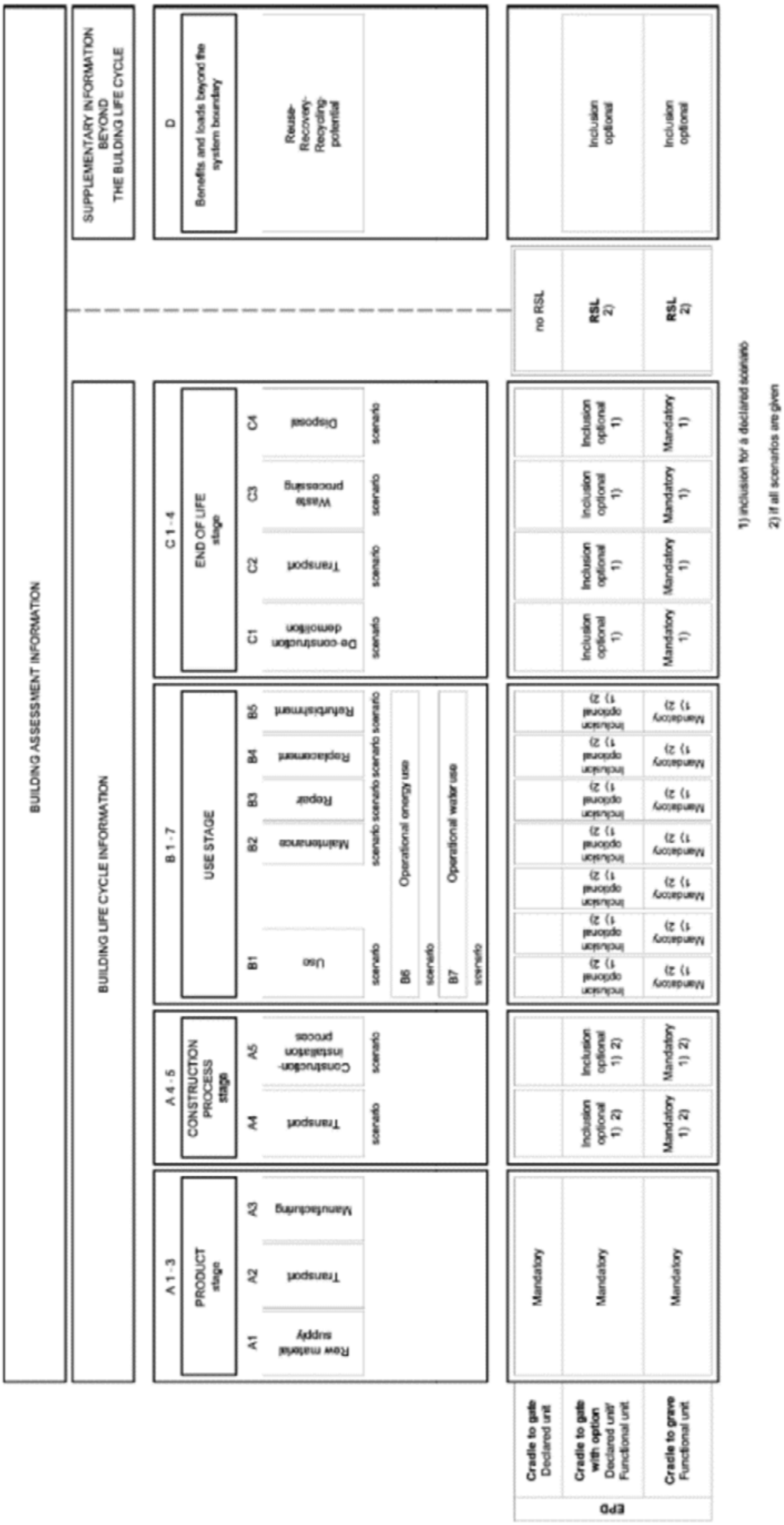

Figure 3.1 Building life cycle stages (modules) used in the CEN TC350 standards

3.5.1 Module D

Within the CEN TC350 standards, there is an additional module (Module D) which can be included in the scope of the assessment. Module D takes account of supplementary information beyond the building life cycle. For construction products, this means the benefits and burdens of arising outside the scope of the building life cycle can be taken into account. The use of Module D is consistent with a 'cradle-to-cradle' approach.

For the metals industries, Module D provides the opportunity to take into account that metals can be recycled almost indefinitely without loss of properties, and also that recycling has the positive effect of displacing production from primary materials.

The use of Module D in BS EN 15804 allows credits to be taken now for the eventual reuse or recycling of material in the future as long as the reuse and recycling scenario is based on current practices (and supported by robust data).

Module D may also take account of the benefits of surplus energy that might be generated by a building. For example, a building that generates renewable PV electricity and exports surplus energy to the grid, can report the carbon emission reduction benefits of generating that additional energy in Module D, since the building also has to report the embodied carbon of the PV installation in Module A.

3.6 Accounting for end-of-life impacts

Materials obtained from demolished buildings can have a significant effect on their whole lifecycle environmental impacts. For example, the end-of-life disposal of bio-based products should include their decomposition in landfill and resulting methane emissions should be taken into account in a whole-life LCA or embodied carbon assessment. In contrast, steel construction products in the UK are 94% recovered and either reused or recycled. Studies that exclude end-of-life impacts, such as 'cradle-to-gate' studies, make no differentiation between these two different scenarios.

Recycling material at end of life provides a benefit, as does using recycled material in the first place. Different approaches of quantifying this benefit are used in LCA and embodied carbon studies.

It is generally recognised that a robust and thorough LCA study should include end-of-life impacts and therefore 'cradle-to-grave' studies are preferred over 'cradle-to-gate' studies. There are several different methods for accounting for recycling within cradle-to-gate studies. Three of the most common generic methods are:

- Recycled content (100:0) approach in which the full benefits of material recycling are allocated to the input side of a product system. This leaves no benefit for end of life recyclability.
- Substitution method (or closed loop system expansion or 0:100 approach) in which the creation of recyclable material is allocated the full

benefit of recycling at end of life (called recyclability). This leaves no benefit for incoming recycled materials, which are effectively neglected.

- Methods in which the impacts and benefits of recycling are shared (or allocated), by some means, between the input and output sides of the product system.

In LCA studies, the type of recycling is significant and can be described as either open or closed loop which reflects the changes in inherent properties of the materials that are recycled.

- Open loop recycling involves the conversion of material from one product life cycle into another product life cycle. This usually involves a change in the inherent properties of the material itself (often a degradation in quality). For example, recycling plastic bottles into plastic drainage pipes. Often this is called down-cycling or reprocessing.
- Closed loop recycling describes the recycling of a product into an identical product, for example recycling a steel beam into another steel beam.

In LCA terms, steel products are described as flowing in 'open loop' recycling systems, e.g. a steel beam can be recycled into another steel beam or a car. However, since there is no change in the inherent material properties, recycling steel can be considered as 'closed loop' and allocation avoided by expanding the system to include both primary and secondary production. This 'closed-loop' approach forms the basis of the recycling methodology adopted by the global Metals Industry and the World Steel Association.

3.7 Accounting for the recycling of steel

BS EN ISO 14044 states that "a closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

Accounting for recycling in LCA and embodied carbon studies is important for highly recycled materials like steel.

Following the guidance of BS EN ISO 14044, the steel industry advocates using a closed-loop system expansion method to account for steel recycling.

The method developed by the World Steel Association is the closed-loop recycling method. In this approach, the principle for calculating the benefits of steel recycling is based on BS EN ISO 14044 guidance and uses the principle of avoided impacts. Put simply, a benefit equal to the avoided primary production is credited to the system.

This future 'avoided impact' can be separately reported, under the CEN TC350 standards, under Module D.

4 BUILDING PARAMETERS USED FOR THE STUDY

The building form considered in this study is suitable for efficient design in light steel framing and also reinforced concrete with blockwork walls. The comparison of weights of materials and embodied carbon is made per unit floor area so that the study results can be extrapolated to similar sized buildings.

Figure 4.1 Typical architect's representation of a 6 storey residential building used in this study

4.1 Physical dimensions of the building

The building form is taken as a typical 6 storey, residential apartment building or hotel with a central corridor. The depth of the apartment is 6 m and the corridor is 1.5 m wide, which leads to an overall building depth of 13.5 m. The width of an apartment is taken as 7.5m so that it occupies 45m^2 of floor area which would meet planning requirements for a two person, single bedroom apartment. The length of the building is nominally 30 m and it consists of 8 apartments per floor accessed from a central lobby.

The floor to floor height is 3 m, which allows for an acoustically resilient floor and for a plasterboard ceiling with 100 mm deep ducts above. The main room is taken as 4m wide and the bedroom is 3.5m wide. The building is designed to modern standards for thermal and acoustic performance. The building is designed for 90 minutes fire resistance, and the 6 storey structure does not require a concrete or braced core for stability.

4.2 Light steel framing design

The light steel structure is designed with load-bearing cross walls and corridor walls using 100mm deep C sections in the walls and 200mm deep C sections in the floors - see Figure 4.2. The front and back façade walls do not provide a load-bearing function but resist wind loads and support the weight of the cladding. The wall panels are X-braced in the factory.

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Figure 4.2 Light steel cross-walls and floor joists

The light steel framing and other material quantities are based on the following design of a 6 storey building:

Cross-walls - Lower 2 floors	100 mm x 1.6 mm C sections at 600 mm cs. in pairs
Cross-walls - Middle 2 floors, façade and corridor walls	100 mm x 1.6 mm C sections at 600 mm cs
Cross-walls - Upper 2 floors	100 mm x 1.2 mm C sections at 600 mm cs
Floor joists	200 mm x 1.2 mm C sections at 400 mm cs
Plasterboard	2 x 15 mm fire resistant boards on all walls and ceiling
Insulation	Mineral wool between the Cs on all separating and façade walls.
Façade	Additional 100mm PUR on external face with sheathing board to support insulated render
Floors	OSB to floor and plywood to roof.

4.3 Light steel framing supporting composite floors

In an alternative light steel system, the light steel walls are designed to support a composite floor slab of 150 to 180mm depth depending on its span. The composite floor consists of steel decking of 0.9 or 1.2mm thickness depending on whether the decking is able to span between the walls in the construction stage or whether it is propped until the concrete has gained its design strength. For spans of 4m, a 160mm deep slab using a 80mm deep decking is used -see Figure 4.3.

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Figure 4.3 Light steel cross-walls and composite decking before concreting

For the composite floor solution, the light steel framing quantities are increased because of the higher loads supported by the walls, but the joists are eliminated in this solution. The design is based on the following data for a 6 storey building:

Cross-walls -Lower 2 floors	100 mm x 2.4 mm C sections at 600 mm cs. in pairs.
Cross-walls -Middle 2 floors	100 mm x 1.6 mm C sections at 600 mm cs in pairs.
Cross-walls -Upper 2 floors, façade and corridor walls	100 mm x 1.6 mm C sections at 600 mm cs .
Plasterboard	2 x 15 mm fire resistant boards on all walls and one 12.5mm board suspended below the floor slab.
Insulation	Mineral wool between the Cs on all separating and façade walls.
Façade	Additional 100mm of PUR on external face with sheathing board to support insulated render
Floors	OSB to floor and plywood to roof.

4.4 Reinforced concrete structure

The reinforced concrete structure is based on 7.5m/6 m and 7.5 m spans in which the columns are off-set on one side of the corridor. In the long direction of the building, the columns are placed at 7.5 m spacing.

The concrete flat slab is 275 mm deep with shallow column shear heads. The columns are 400 mm square internally and 300mm square externally although they could also be designed as blade columns to fit in the separating walls.

The walls that provide a separating function use medium-density concrete blocks. These blockwork walls also are used along the corridors. The walls on the facades use lightweight concrete blocks for thermal reasons.

The design of the in-situ concrete building with a maximum span of 7.5m x 7.5m is taken as follows for residential loading:

Flat slab:	275 mm depth flat slab
	1 m square x 100 mm deep shear heads
Concrete columns:	400 mm square internally
	300 mm square on periphery of the building
Reinforcement:	Equivalent to 0.5% of slab area in both directions
	Equivalent to 2% of column area
Internal supporting walls:	Double leaf 100 mm heavy duty blockwork with 50 mm cavity and single layer of plasterboard
External walls:	Single leaf 140 mm lightweight blockwork with 80 mm PUR insulation and single layer of plasterboard
Other internal walls:	Single leaf 100 mm heavy duty blockwork with single layer of plasterboard on both sides
Finishes:	Heavy duty mineral wool on floor boards

4.5 Common building data used in the analyses

The following data is used in the building design for both the light steel framed and concrete forms of construction:

- Floor to floor height 3 m
- Internal room height 2.5 m
- Window in façade 2 windows each of 1.5m x 1.5m per apartment
- Imposed loading on floors 2.0 kN/m^2
- Wind loading on façade 1.0 kN/m^2
- Thermal insulation of façade 0.2 W/m^2 K

- Fire resistance 90 minutes
- Acoustic insulation $D_{n,T,d}$ =45 dB (inc. C_{tr})

The self-weight of the structure is calculated from the material quantities presented above.

5 SCOPE OF THE EMBODIED CARBON ASSESSMENT

5.1 Goal and scope of the study

The goal and scope of the study was to undertake a comparative embodied carbon assessment of the impacts of the materials used to construct the superstructure of a 6-storey, apartment building typical of the form used as a city centre hotel or for student accommodation.

Three structural forms are compared:

- Option 1 – Light steel framing
- Option 2 – Light steel framing with steel composite floor decking for the upper floors
- Option 3 - Reinforced in-situ concrete with blockwork infill walls.

These structural forms are described in detail in Section 4.

5.1.1 Functional unit and scope of the study

The functional unit for the comparative assessment is the construction of a 6 storey, city centre apartment building.

The scope of the study includes only the manufacture of the construction products and materials required to construct the following elements of the building:

- Sub-structure (ground floor slab and foundations)
- Primary structure including upper floors
- Roof structure (but not roof coverings)
- Internal and external walls but excluding windows, doors, etc.
- External cladding (insulated render).
- Plasterboards and other boards, insulation etc.

Some floor finishes are included in to make all three options compatible with respect to acoustic performance. The scope excludes the doors and windows, the roof covering, services and finishes. All three building options are clad with the same insulated render system.

The sizes of the foundations are estimated for the light steel framing and concrete schemes which both include a ground-bearing floor slab. The assumed maximum bearing pressure is 100 kN/m^2. The light steel framing options uses strip footings under the load-bearing walls and the concrete scheme uses deep pad footings integrated into the floor slab.

The generation of site waste is taken into account using the wastage rates for materials shown in Table 5.2.

In terms of life-cycle information (see Figure 3.1), the study includes all raw material and manufacturing impacts (Modules A1 to A3 only) for the building elements defined above. However, it excludes the following:

- Transport from factory to construction site (Module A4) Transport impacts are highly dependent upon the location of the manufacturing facility and the construction site, which are clearly project-specific and therefore have been excluded from the scope of assessment. A similar previous study conducted by SCI [3] found that the transport (A4) impact only accounted for around 6% of the Module A1-A3 impact for a similar steel-framed building.
- On-site construction impacts (Module A5). Insufficient data on the construction impacts of the three different buildings are available to include this module within the scope. A previous SCI study [4] showed that the construction impacts (A5) only account for around 2% of the Module A1-A3 impact for a similar steel-framed building.
- Building use stage (Modules B1 to B5) – it is assumed that the energy use in operation (B1) would be broadly similar based on the common building form/layout and the external wall U-values assumed. Maintenance, repair and refurbishment impacts are not included.
- End-of-life stage (Modules C1 to C4) – insufficient data are available on the end-of-life stages of buildings to robustly assess these impacts and, in general, Module C impacts are relatively small.

Where available, Module D impacts (benefits) of materials are included in the embodied carbon comparisons.

5.2 Embodied carbon data

5.2.1 Embodied carbon data for steel

For light steel C sections and steel decking, the data in Table 5.1 have been used.

Process	Module	Embodied carbon kgCO2e/kg	Source
Coil production	A1	2.49	WorldSteel global average for hot dipped galvanised strip steel [5]
Transport of coil (mill to roll-former)	A2	0.015	270km, 2 x 7.5t coils per vehicle, ave. artic. lorry 50% laden, Defra GHG factors [6], zero empty return trips
Slitting, cold-rolling, cutting and punching	A3	0.009	Slitting and roll-forming from, Defra GHG carbon factors [6]
Recycling potential	D	-1.45	Calculated by PE International [7]

Table 5.1 Embodied carbon data for galvanised steel

The end-of-life recycling rate for galvanised strip was taken as 89% or 0.89 kg of scrap/kg and the average input of scrap into hot dip galvanised products is

0.103 kg of scrap/kg of product, resulting in a net scrap of 0.787 kg/kg of galvanised strip. The credit uses the WorldSteel value of scrap, based on the difference between the LCI of EAF steel and a 100% primary BF route; WorldSteel 2011. This is the methodology used to derive the Module D impacts (benefits)

The end of life recycling rate for reinforcing bars was 91% or 0.91 kg of scrap/kg of steel and the average input of scrap required to manufacture rebar 0.698 kg of scrap/kg of steel, resulting in a net scrap of 0.212 kg/kg of reinforcing steel.

5.2.2 Embodied carbon data for other materials

The embodied carbon coefficients (for Module A1-A3) used for all materials in the study are shown in Table 5.2.

Material	Density		Factory wastage rate	Site wastage rate	A1 to A3	D	Source of EC data
			%	%	kgCO2e/kg		
Steel C sections and decking	7800	kg/m^3	2	2	2.49	-1.45	Worldsteel and PE [5,7]
Plasterboard	8-11.7	kg/m^2	10	15	0.26		British Gypsum EPD [8]
Mineral wool	45	kg/m^3	5	5	0.81	-0.09	Knauf EPD [9]
Polyurethane insulation, PUR	3.27 (100mm)	kg/m^2		5	3.49		PE Europe factsheet 13/1 [10]
OSB sheathing board	640	kg/m^3	5	5	0.99		ICE [11]
In-situ concrete	2307	kg/m^3		3.3	0.13	-0.0053	Concrete Centre datasheet [12]]
Reinforcing bars and mesh	7800	kg/m^3		5	1.27	-0.426	Worldsteel and PE [5,7]
Lightweight AAC concrete blocks	630	kg/m^3		10	0.28		BRE EPD for Hanson [13]
Concrete blocks	1450	kg/m^3		10	0.1		Aggregate Industries EPD [14]
Plywood	680	kg/m^3		12.8	0.90		ICE [11]
Ballast	1400	kg/m^3			0.0052		ICE [11]
Materials in Insulated Render Cladding							
Acrylic modified render	4.5	kg/m^2		5	0.35		ICE [11]
Polypropylene mesh	0.16	kg/m^2		5	1.54		ICE [11]
Water resistant plasterboard	16	kg/m^2		5	0.35		ICE [11]

Table 5.2 Embodied carbon data and typical wastage rates for other materials used in the study

6 COMPARISON AND ANALYSIS OF THE EMBODIED CARBON RESULTS

This section compares the results of the comparative assessment of the light steel framed and reinforced concrete framed buildings. Two options for the light steel framed structure are considered: joisted floor on light steel walls, or composite floor slab supported on light steel walls

6.1 Weights of materials

The schedule of the (gross) weights of the light steel framed building is shown in Table 6.1. The total normalised weight of the materials used to construct the building is 245 kg/m^2 gross floor area and the foundations weigh an additional 113 kg/m^2 (or 46%).

Element	Weight (kg/m^2)	Percentage (%)
Light steel framing	25	7
Plasterboards	63	18
Other boards and insulation	44	12
Façade & cladding	12	3
Roof structure	1	0.4
Ground floor	100	28
Building fabric (total)	*245 kg/m^2*	*68*
Foundations	84	24
Sub-base/ballast	29	8
Total / GFA	*358 kg/m^2*	

Table 6.1 Breakdown of gross weight by element for the light steel framing option

Figure 3.1 gives the elemental breakdown of the weight of materials in the light steel framed building. The light steel weight is 7% and the plasterboards are 18% of the total weight. This is consistent with a general observation that the total area of plasterboard is 6 to 7 times the floor area in a light steel framed building.

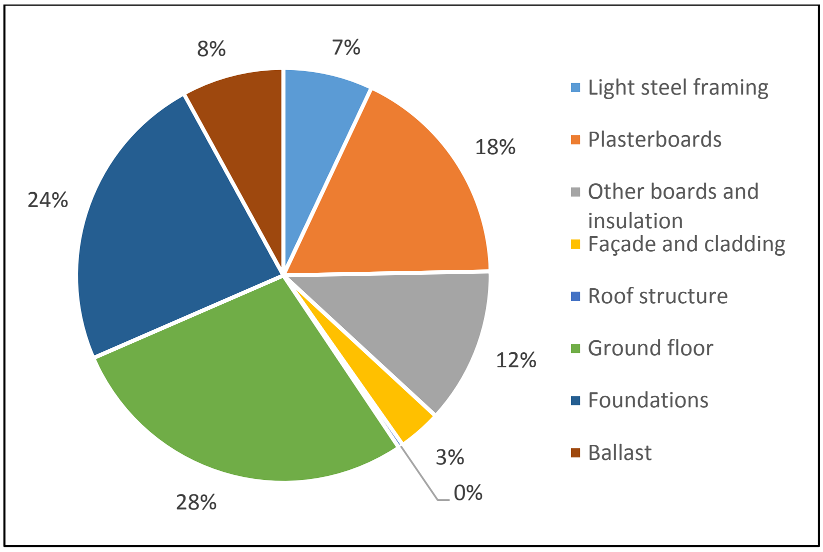

Figure 6.1 Breakdown of gross weight by element for the light steel framing option

The schedule of the (gross) weights of the light steel framed building with composite floors is shown in Table 6.2. The light steel frame and decking weight is 30 kg/m^2, which is an increase of 5 kg/m^2 on the joisted system. The total normalised weight of materials in the building is 458 kg/m^2 floor area and the foundations weigh an additional 142 kg/m^2 (or 31%).

Element	Weight (kg/m^2)	Percentage (%)
Light steel framing	16	3
Plasterboards	55	9
Other boards and insulation	27	5
Façade & cladding	12	2
Roof structure	1	0.2
Ground floor	100	17
Upper floors (excl decking)	233	39
Steel decking	14	2
Building fabric (total)	*458 kg/m^2*	*76*
Foundations	113	19
Sub-base/ballast	29	5
Total / GFA	*600 kg/m^2*	

Table 6.2 Breakdown of gross weight for the light steel framing and composite floors option

Figure 6.2 gives the elemental breakdown of the weight of materials in the light steel framed building with composite floors. Compared to the joisted floor option, the self-weight of the super-structure is increased by 87% but the light steel and steel decking weight is reduced to 5% of the total.

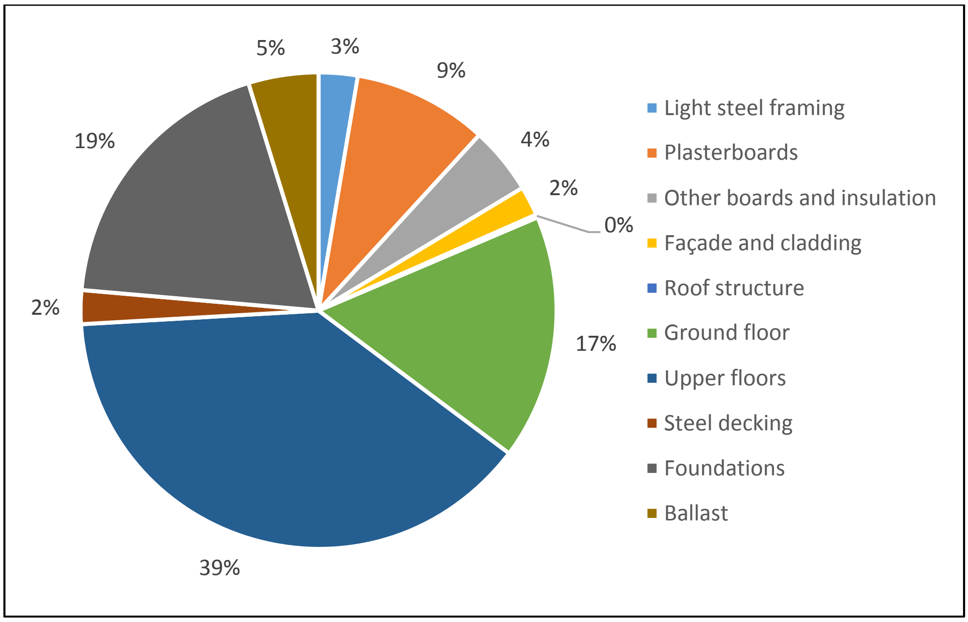

Figure 6.2 Breakdown of gross weight for the light steel framing and composite floors option

The schedule of the weights of the reinforced concrete building is shown in Table 6.3. The total normalised weight of materials in the building is 1,008 kg/m^2 floor area, which is over four times that of the light steel framing option.

Element	Weight (kg/m^2)	Percentage (%)
Columns	37	3
Upper floors incl finishes	574	46
Internal walls	221	18
Roof structure	3	0.3
External walls & cladding	73	6
Ground floor	100	8
Building fabric (total)	*1,008 kg/m^2*	81
Foundations	202	17
Sub-base/ballast	29	2
Total / GFA	*1,238 kg/m^2*	

Table 6.3 Breakdown of gross weight by element for the reinforced concrete option

Figure 6.3 gives the elemental breakdown of the weight of materials within the concrete framed building. The upper floors and internal walls account for 68% of the total weight.

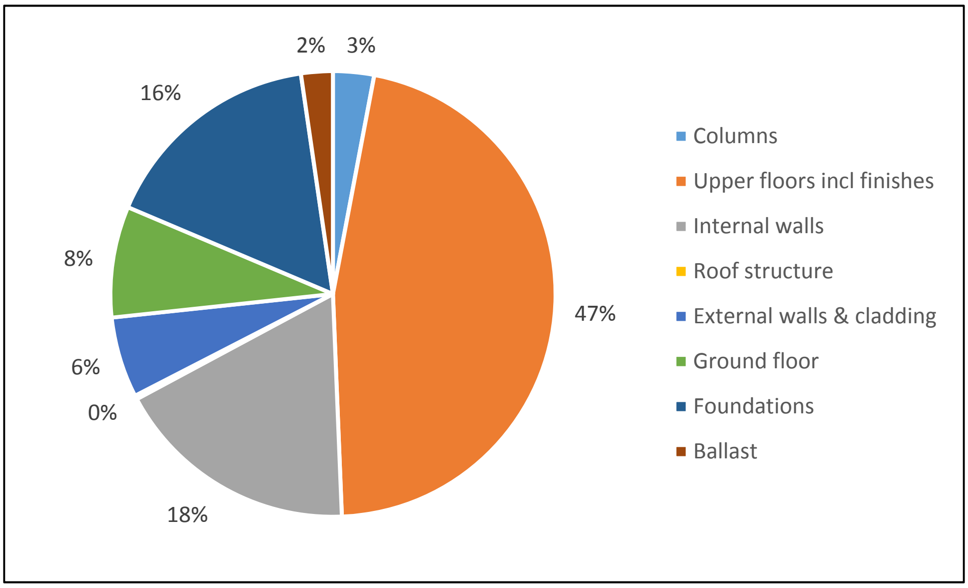

Figure 6.3 Breakdown of gross weight by element for the reinforced concrete option

Figure 6.4 shows the comparison of the gross weight (i.e. including any site waste) of the materials and products used to construct the three building types considered. The ground floors are the same in each building types

Comparing the superstructure weights, the concrete superstructure is over four times the weight of the light steel frame with a joisted floor and 2.2 times the weight of the light steel frame with a composite floor.

The foundation sizes reflect the weight of the superstructures. Relative to the light steel frame with a joisted floor, the foundations for the light steel frame with a composite floor are 34% heavier and the foundations for the concrete option 140% heavier.

In terms of the total weight of materials, including foundations, the light steel frame with a composite floor is 68% heavier and the concrete building is 246% heavier than the light steel frame with a joisted floor.

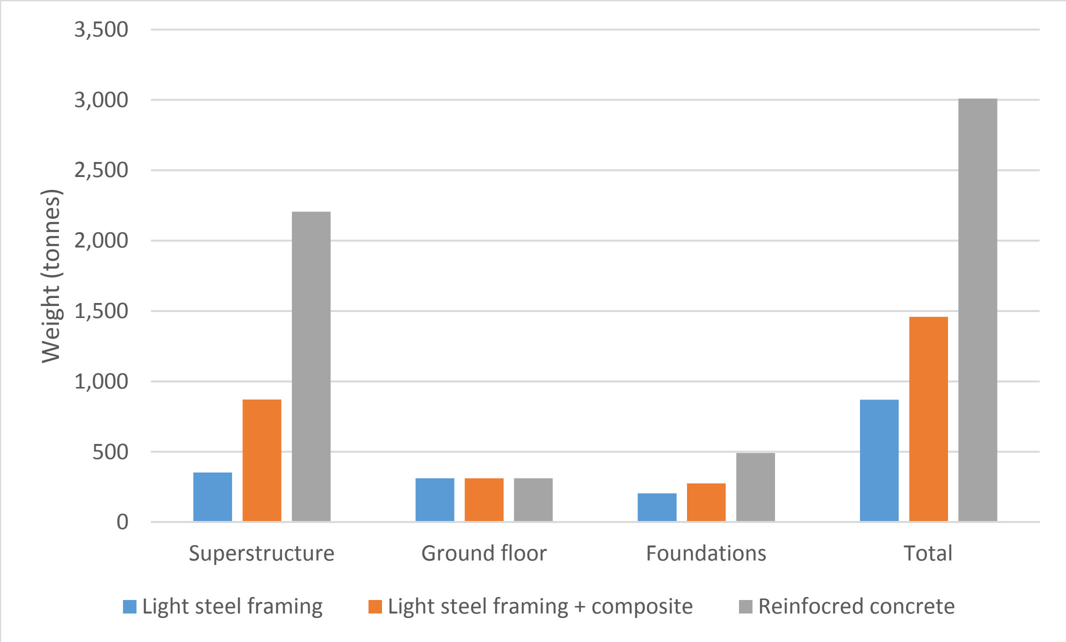

Figure 6.4 Comparison of gross weight of the materials used in the construction of the three building types

6.2 Embodied carbon results

The breakdown of embodied carbon impacts associated with the materials and products used to construct the three forms of construction are presented below.

Table 6.4 shows the elemental breakdown of the embodied carbon in the light steel framed option. Results are normalised to total gross floor area and presented excluding and including Module D impacts – see Section 3.5.1

The total normalised embodied carbon impact (excluding Module D) of the building is 149 $kgCO_2e/m^2$ increasing to 162 $kgCO_2e/m^2$ when the foundations are included. The embodied carbon impacts reduce to 108 $kgCO_2e/m^2$ and 120 $kgCO_2e/m^2$ respectively when Module D is included.

Figure 6.5 gives the breakdown of embodied carbon in the light steel-framed building (excluding Module D). The largest contribution to the embodied carbon is the light steel framing but when Module D benefits are included, this reduces to 22% of the total.

Element	Excluding Module D		Including Module D	
	Embodied carbon ($kgCO_2e/m^2$)	(%)	Embodied carbon ($kgCO_2e/m^2$)	(%)
Light steel framing	63	39	27	22
Plasterboards	16	10	16	14
Other boards and insulation	46	28	45	37
Façade & cladding	4	3	4	4
Roof structure	3	2	1	1
Ground floor	16	10	14	12
Building fabric (total)	*149*	92	*108*	90
Foundations	13	8	12	11
Sub-base/ballast	0.1	0.1	0.1	0.12
Total / GFA	*162*	-	*120*	---

Table 6.4 Breakdown of embodied carbon associated with the materials used in the light steel framed building

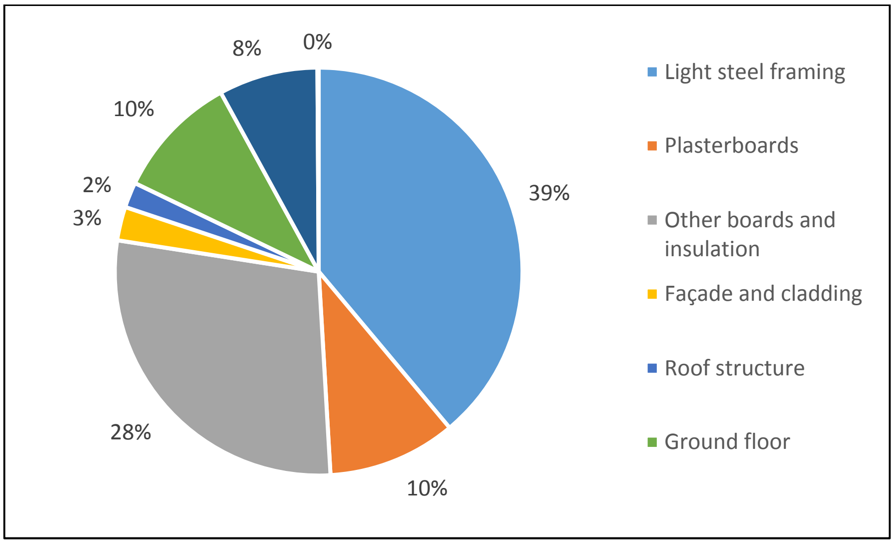

Figure 6.5 Embodied carbon breakdown by element for the light steel framed building (excluding Module D)

Table 6.5 shows the embodied carbon impacts of the light steel frame with composite floors (excluding Module D).

Element	Excluding Module D		Including Module D	
	Embodied carbon ($kgCO_2e/m^2$)	(%)	Embodied carbon ($kgCO_2e/m^2$)	(%)
Light steel framing	54	26	23	15
Plasterboards	14	7	14	9
Other boards and insulation	31	15	30	20
Façade & cladding	4	2	4	3
Roof structure	3	2	1	1
Ground floor	16	8	14	10
Upper floors excluding decking	34	16	33	22
Steel decking	35	17	15	10
Building fabric (total)	*192*	*92*	*136*	*89*
Foundations	17	8	16	11
Sub-base/ballast	0.15	0.07	0.15	0.11
Total / GFA	*209*	-	*152*	-

Table 6.5 Breakdown of embodied carbon associated with the materials used to construct for the light steel framed building with composite floors

Figure 6.6 gives the elemental breakdown of the embodied carbon n the light steel framed building with composite floors (excluding Module D). In this case, the largest impacts are the steel framing and decking but when Module D is included, this reduces to 25% of the total.

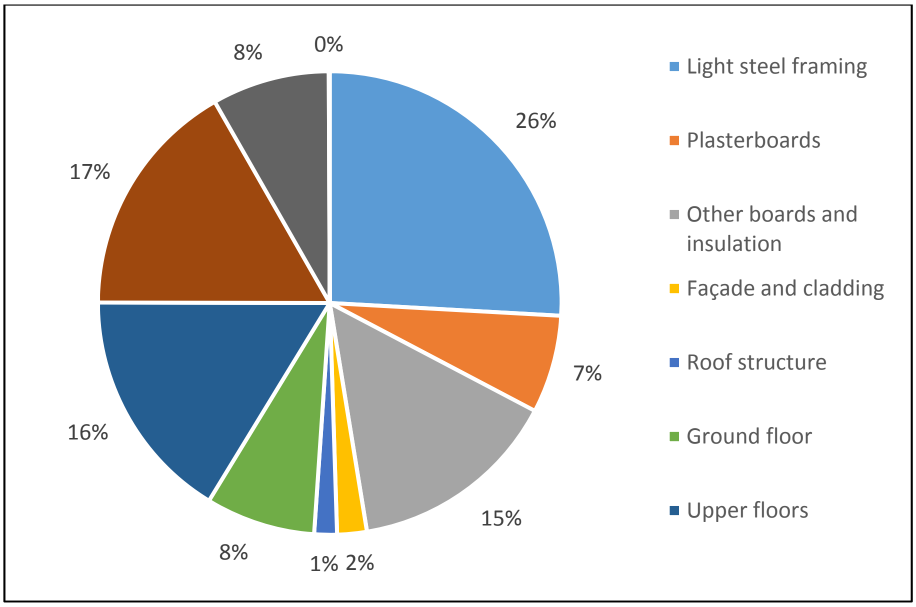

Figure 6.6 Embodied carbon breakdown by element for the light steel framed building with composite floors (excluding Module D)

Table 6.6 shows the embodied carbon in the concrete framed building. In this case, the embodied carbon is dominated by the upper floors and the internal block walls.

Element	Excluding Module D		Including Module D	
	Embodied carbon ($kgCO_2e/m^2$)	(%)	Embodied carbon ($kgCO_2e/m^2$)	(%)
Columns	8	3	7	3
Upper concrete floors and finishes	103	40	98	40
Internal blockwork walls	61	24	61	25
Roof structure	8	3	4	1
External walls & cladding	26	10	26	11
Ground floor	16	6	15	6
Building fabric (total)	*223*	*86*	*211*	*87*
Foundations	35	13	32	13
Sub-base/ballast	0.15	0.06	0.15	0.06
Total / GFA	*258*	-	*243*	-

Table 6.6 Breakdown of embodied carbon associated with the materials used to construct for the reinforced concrete framed building

Figure 6.7 shows the elemental breakdown of the embodied carbon within the reinforced concrete building. Including Module D has only a 6% effect for a concrete building.

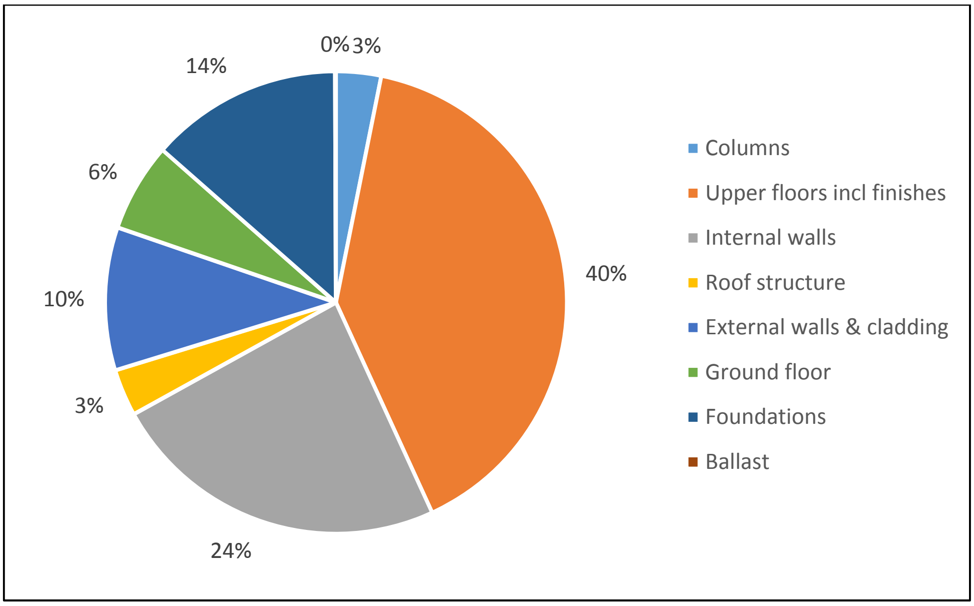

Figure 6.7 Embodied carbon breakdown by element for the reinforced concrete building (excluding Module D)

The following figures compare the embodied carbon impact of the three forms of construction. Figure 6.8 shows the comparison excluding Module D impacts and Figure 6.9 includes the impacts of Module D.

This shows that including Module D, the total embodied carbon of the light steel frame option is 49% of that of a the concrete scheme and the embodied carbon of the light steel frame with composite floor option is 63% of that of the concrete scheme.

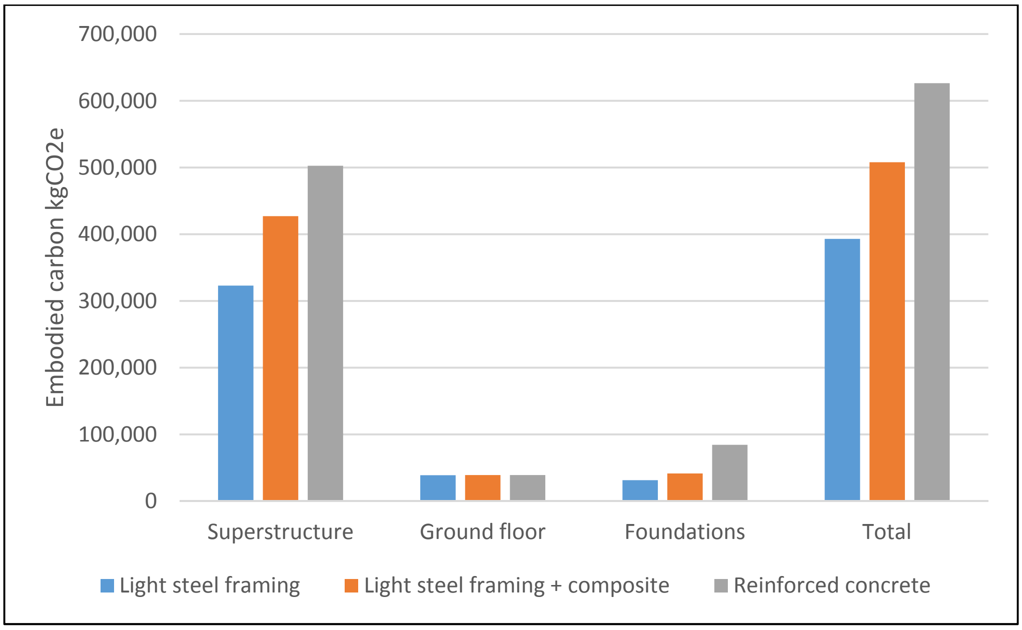

Figure 6.8 Comparison of the embodied carbon of the three forms of construction (excluding Module D)

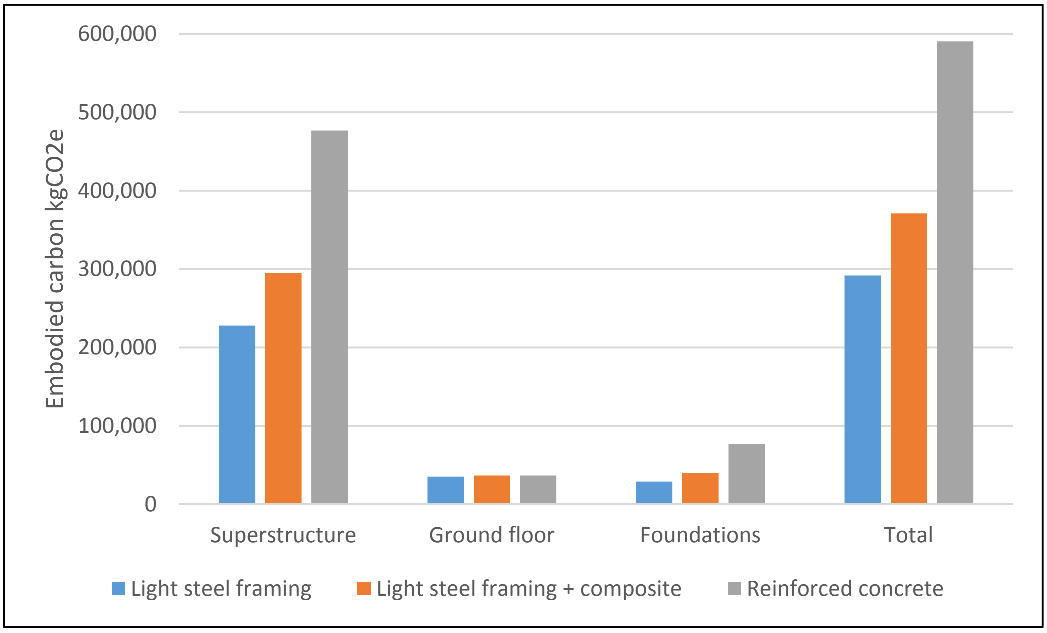

Figure 6.9 Comparison of the embodied carbon of the three forms of construction (including Module D)

7 SUMMARY OF ESTIMATED MATERIAL USE AND EMBODIED CARBON

From this embodied carbon assessment of a 6 storey residential building using three comparable forms of construction, it is concluded that:

- The self-weight of the light steel framing solution is 245 kg/m^2 floor area including the façade and that of the concrete and blockwork scheme is 1008 kg/m^2. The weight of the light steel framing solution is therefore only 25% of that of the concrete scheme.

- The self-weight of the light steel framing and composite floor solution is 458 kg/m^2 floor area including the façade and is 45% of the weight on the concrete scheme.

- The embodied carbon of the light steel framing solution and its foundations is 162 kgCO_2/m^{2}e and that of the concrete scheme is 258 kgCO_2/m^{2}e. This shows that the light steel framing solution has 37% less embodied carbon per unit floor area.

- When the future recycling of steel is included (the Module D approach), the embodied carbon of the light steel structure reduces to 120 kgCO_2/m^{2}e, which is only 49% of that of the reinforced concrete scheme.

- A major factor in the difference in the embodied carbon between the light steel framing and concrete schemes is related to the heavier foundations in the concrete scheme, which adds 23 kgCO_2/m^{2}e.

- The embodied carbon of the light steel framing and composite floor solution and its foundations is 209 kgCO_2/m^{2}e, reducing to 152 kgCO_2/m^{2}e when module D is included. This shows that the light steel framing and composite floor solution has 37% less embodied carbon per unit floor area than the concrete scheme (including Module D).

- The embodied carbon associated with panel manufacture, transport and construction of light steel framing scheme is estimated as 8% of the embodied carbon in the materials.

- The site waste in the light steel framing scheme is only 30% by weight of that of the concrete scheme. Light steel components lead to negligible site waste and all steel waste in the factory is recycled.

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