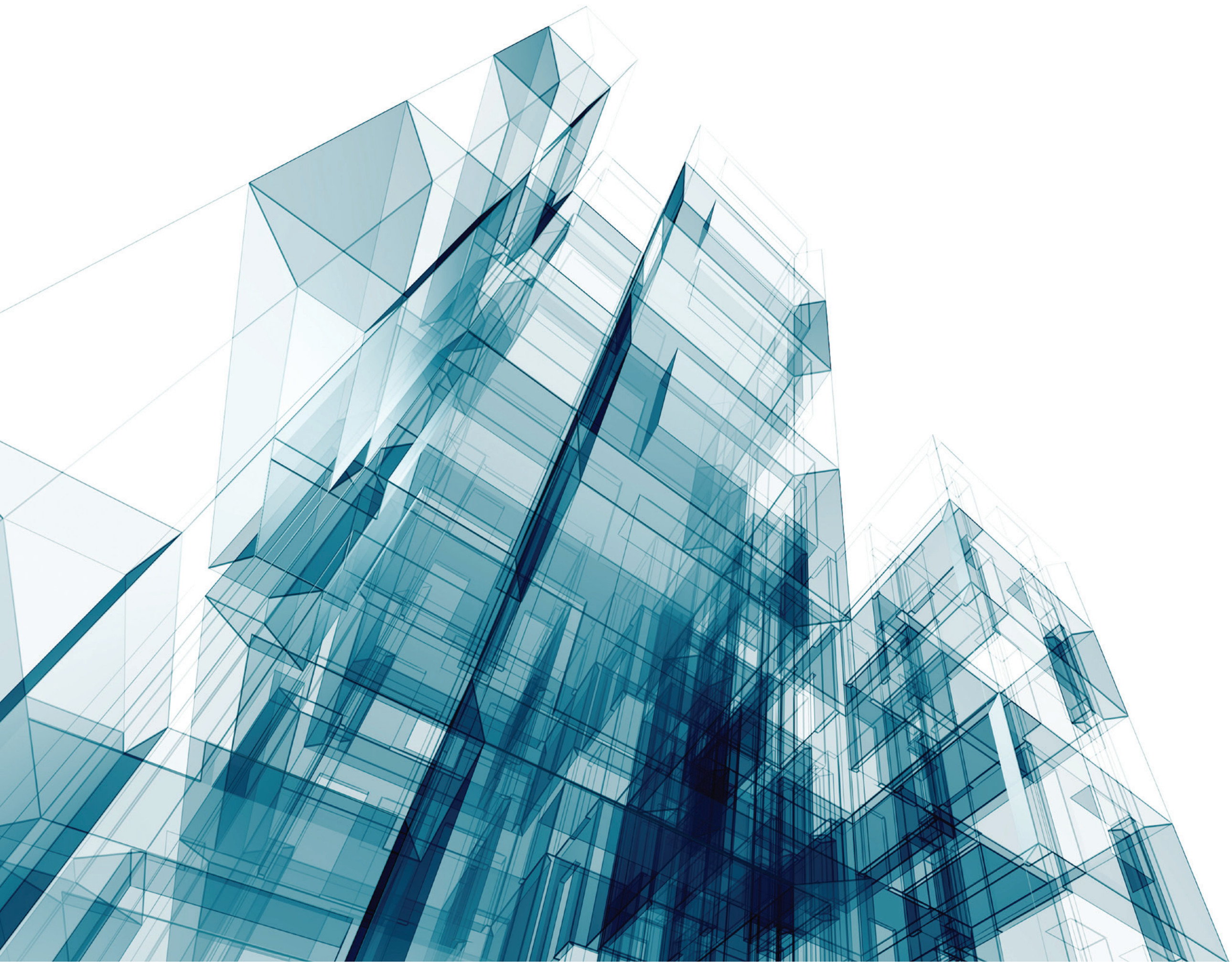
RICS guidance note

RICS Professional Guidance, Global

Methodology to calculate embodied carbon

1st edition



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Acknowledgments

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Contents

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RICS guidance notes

This is a guidance note. Where recommendations are made for specific professional tasks, these are intended to represent 'best practice', i.e. recommendations which in the opinion of RICS meet a high standard of professional competence.

Although members are not required to follow the recommendations contained in the note, they should take into account the following points.

When an allegation of professional negligence is made against a surveyor, a court or tribunal may take account of the contents of any relevant guidance notes published by RICS in deciding whether or not the member had acted with reasonable competence.

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Document status defined

RICS produces a range of standards products. These have been defined in the table below. This document is a guidance note.

Type of document	Definition	Status
Standard		
International standard	An international high-level principle based standard developed in collaboration with other relevant bodies	Mandatory
Practice statement		
RICS practice statement	Document that provides members with mandatory requirements under Rule 4 of the Rules of Conduct for members	Mandatory
Guidance		
RICS code of practice	Document approved by RICS, and endorsed by another professiona body/stakeholder that provides users with recommendations for accepted good practice as followed by conscientious practitioners	Mandatory or recommended good practice (will be confirmed in the document itself)
RICS guidance note (GN)	Document that provides users with recommendations for accepted good practice as followed by competent and conscientious practitioners	Recommended good practice
RICS information paper (IP)	Practice-based information that provides users with the latest information and/or research	Information

Glossary

Carbon emissions/ CO_2e emissions/ CO_2e equivalent/ Greenhouse gas emissions	Shorthand for emissions of any of the basket of greenhouse gases (GHG) that affect climate change. Carbon emissions are usually expressed as CO_2e (i.e. CO_2 equivalent), which is a unit of measurement based on the relative impact of a given gas on global warming (the so-called global warming potential). For example, if methane has a global warming potential of 25, it means that 1 kg of methane has the same impact on climate change as 25 kg of carbon dioxide. Thus, 1 kg of methane would count as 25 kg of CO_2e. The global warming potential of greenhouse gases are presented in the table below:

Greenhouse gas	GWP over 100 years	Typical sources
Carbon dioxide (CO_2)	1	Energy combustion, biochemical reactions
Methane (CH_4)	25	Decomposition
Nitrous oxide (N_2O)	298	Fertilisers, car emissions, manufacturing
Sulfur hexafluoride (SF_6)	22,800	Switch gears, substations
Perfluorocarbon (PFC)	7,390–12,200	Aluminium smelting
Hydrofluorocarbon (HFC)	124–14,800	Refrigerants, industrial gases

Table 1: Global warming potentials (GWP) of greenhouse gases

Modified from *Climate Change 2007: The Physical Science Basis – Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Table 2.14, Cambridge University Press.

Carbon hotspot	The carbon significant aspect of a project that should be targeted for reduction. Carbon hotspots represent not only carbon-intense elements but also ‘quick wins’ where measurement data is more easily available and where carbon reductions are possible.
Construction stage carbon	Carbon emissions associated with construction site energy consumption and transport of construction materials and waste to/from site.
Cradle-to-cradle	The process of making a component or product and then, at the end of its life, converting it into a new component of either the same quality (e.g. recycling of aluminium cans) or a lesser quality (e.g. downcycling of a computer plastic case into a plastic container, which is then turned into a building insulation board, eventually becoming waste).
Cradle-to-grave carbon	Carbon emissions associated with all building life cycle stages: product, construction, use, end of life.
Embodied carbon	Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products. Embodied carbon can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO_2e per kilogram of product or material.
End-of-life stage carbon	Carbon emissions associated with demolition, materials/waste transport, processing and disposal.
Global warming potential (GWP)	A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO_2e which has a GWP of 1 (see Table 1).
Life cycle carbon	Another term for cradle-to-grave carbon emissions.

Operational carbon	Carbon emissions associated with energy consumption (operational energy) while the building is occupied. This includes the so-called regulated load (e.g. heating, cooling, ventilation, lighting) and unregulated/plug load (e.g. ICT equipment, cooking and refrigeration appliances). Operational carbon is sometimes referred to as 'Op Carb'.
Quantity surveyor	Used as a generic term for a variety of construction professionals who undertake measuring and analysing materials in the generation of cost plans or life cycle costing. Professionals such as construction economists, cost consultants and cost engineers are encompassed in this term.
Recycled content	The portion of a product that contains materials that have been recovered or otherwise diverted from the solid waste stream.
Sequestration	Accumulation and storage of atmospheric carbon by some building materials (e.g. timber, concrete).
Use stage carbon	Carbon emissions associated with the operational phase of the building: in-use energy consumption, maintenance, repairs, replacements, refurbishments.
Whole life carbon	Another term for cradle-to-grave carbon emissions.

1 Introduction

Most of the focus on reducing carbon emissions from the built environment to date has been on managing and reducing the energy consumption from building's energy load such as: lighting, heating, ventilation and air conditioning through better design and management in use (regulated and unregulated loads). However, the emissions that occur resulting from the production, installation, maintenance and disposal of a building's materials remain unregulated. As more buildings are constructed to higher energy efficiency standards the proportion of the carbon emissions created shifts from the operational emissions (from gas and electricity and the like) to energy consumed during other life cycle stages of projects. This includes the carbon emissions created in the manufacture of the materials used, their transportation, the construction activities themselves and the eventual demolition and disposal.

Calculations of emissions associated with one of these stages – product manufacture – are based on the quantity of construction materials that make up a building. Research by the UK government (2010) has shown that this stage is the second most significant area of carbon emissions from the entire life cycle of a building (after the operational emissions).

Some municipalities have already included mandatory cradle-to-gate embodied carbon assessments as part of the planning process (Brighton and Hove City Council in the UK, 2011). The latest international version of BREEAM (the Building Research Establishment's Environmental Assessment Method) awards points for calculating and reducing embodied carbon emissions. Also, the US Green Building Council's LEED (Leadership in Energy and Environmental Design) and Green Building Council Australia's Green Star assessment tools recognise embodied carbon measurement and its mitigation as part of minimising building life-cycle impacts.

A number of clients (e.g. developers, utility companies, banks, retailers) are also starting to include embodied carbon quantification and mitigation on their projects. This is done mostly for competitive reasons, as part of their corporate social responsibilities and increasingly as part of planning requirements. As pioneers and early adopters of the carbon calculation, they have started capitalising on the added value gains.

In recent years, it has become a standard practice to employ dedicated sustainability/green consultants to undertake the embodied carbon studies. However, since quantity surveyors are typically involved in measuring and analysing the quantities of materials in the generation of cost plans or life cycle costing studies, they are very well placed professionally to add an embodied carbon dimension to their reports. Linking embodied carbon estimates with cost plans and life cycle costing will not only achieve cost efficiency but, more importantly, it will allow clients to make more informed design decisions.

The aim of this guidance note

In 2012, RICS published the UK-based information paper *Methodology to calculate embodied carbon of materials*, 1st edition. Apart from providing background information on embodied carbon, the focus was explaining how to estimate carbon emissions associated with manufacturing of building materials or cradle-to-gate with a particular emphasis on the construction industry.

This guidance note builds on that knowledge and expands the scope to cover emissions during other life cycle stages (i.e. construction, use, end of life). The main aim is to provide a framework of practical guidance for quantity surveyors on how to calculate embodied carbon emissions associated with their projects. Additionally, some good practice carbon reduction solutions have been listed. This presents an opportunity for the QS to offer this advice as part of the standard cost planning service. This guidance should help project teams and clients to make decisions about embodied carbon.

RICS expects BIM (Building Information Modelling) to have a major impact in carbon quantification and mitigation in future, however, there will always be a need for early feasibility studies. This guidance note is not intended to replace any of the existing guides (e.g. the Greenhouse Gas Protocol, ISO 14040:2006, etc.), but to make carbon calculation more accessible to the QS community. It is acknowledged that embodied carbon is a complex and relatively new area of research and therefore a number of assumptions have to be made, which affect the accuracy of the outcome. However, considering that the primary objective of measuring carbon emissions is to improve sustainability performance, it is intended that this guidance will be a valuable resource for the construction industry.

Part of the RICS 'Black Book'

This guidance note is part of the 'Black Book' suite of guidance and professional information that defines technical standards for quantity surveying and construction professionals. These are essential development tools for new professionals working through their APC and useful guides to best practice for more experienced professionals. The 'Black Book' is available online at rics.org/blackbook.

2 What is embodied carbon in the built environment?

Embodied carbon is the carbon impact associated with materials production, transport, assembly, use and disposal. It does not include the carbon emissions associated with the energy used for heating, lighting or cooling in the completed building.

A report produced for the UK government by the Low Carbon Construction Innovation and Growth Team (IGT) (HM Government 2010) concluded that embodied carbon is an important factor that needs to be brought into the systems used for appraisal of projects and hence into the design decisions made in developing projects. This guidance note is a further step in addressing the IGT recommendations (Figure 1).

Recommendation 2.1: That as soon as a sufficiently rigorous assessment system is in place, the Treasury should introduce into the Green Book a requirement to conduct a whole-life (embodied + operational) carbon appraisal and that this is factored into feasibility studies on the basis of a realistic price for carbon.
Recommendation 2.2: That the industry should agree with government a standard method of measuring embodied carbon for use as a design tool and (as Recommendation 2.1 above) for the purposes of scheme appraisal.

Figure 1: Recommendations related to carbon measurement in the built environment

The IGT report notes that CO_2e emissions arise throughout a building's life cycle from the initial design to the refurbishment or eventual demolition. These emissions can be identified and quantified to produce a carbon life cycle footprint for a building, which can then be used to plan an effective reduction strategy. The stages in a building project carbon life cycle emissions as defined in the report are shown in Figure 2.

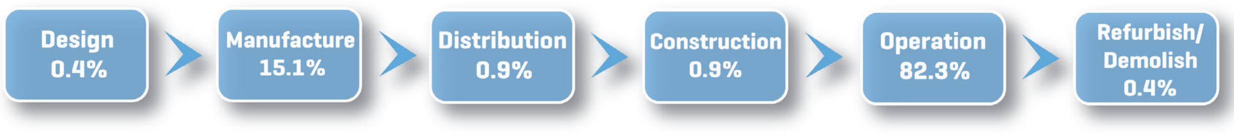
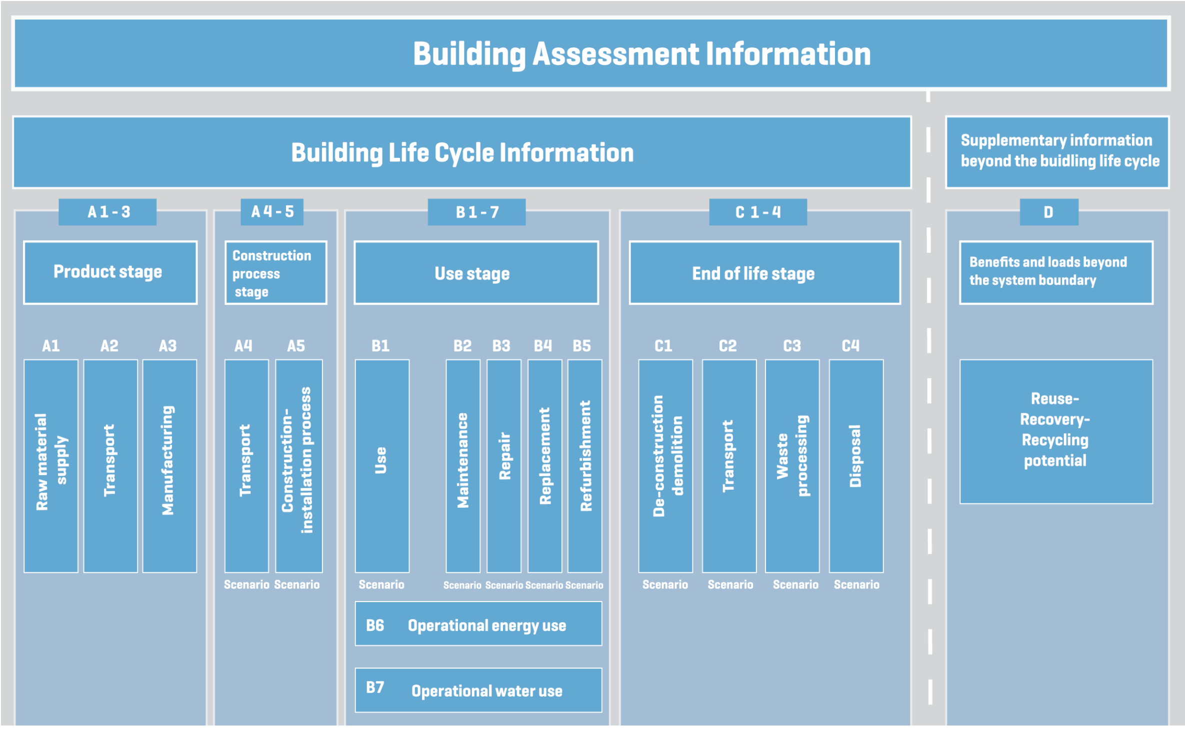


Figure 2: Carbon life cycle phases of a building and their contributions to the overall UK carbon emissions that the construction industry has the ability to influence

A similar process (Figure 3) has been adopted in the BS EN 15978:2011 (BSI 2011) developed by the European Committee for Standardisation (CEN) Technical Committee 350 (TC350).



Included in cradle-to-gate

Materials or product manufacture cradle-to-gate emissions are those associated with the production of construction products/materials. The emissions arise from the energy used in extracting materials, refining them (i.e. primary manufacture), transporting and processing them to produce a finished product (i.e. secondary manufacture). The CO_2e emissions resulting from these processed are often referred to as embodied carbon.

Included in cradle-to-site and cradle-to-end of construction

Emissions from the construction phase include energy and fuel consumption during: transportation of material to site (cradle-to-site), as well as enabling works, remediation, clearance, removal/demolition of existing structures ground improvements, earthworks, assembly (cradle-to-end of construction).

The use carbon emissions from the building include operations emissions resulting from energy consumed for heating, lighting, ventilation, air conditioning, etc. These are typically responsible for around 75 per cent of the life cycle carbon emissions. The actual figure will be heavily influenced by occupier behaviour as well as by the building type. Emissions associated with this phase are usually estimated by mechanical engineers who use software packages designed to calculate operational impacts.

There will also be additional embodied carbon arising from maintenance, repair, replacements and refurbishments of building elements (e.g. fabric or services). Life cycle specialists will be able to advise on predicted lifespans of building elements.

Included in cradle-to-grave

End of life emissions are those associated with energy consumed during building demolition and waste disposal processes. However, unless a planned deconstruction is scheduled it is advised that these impacts are not assessed as part of the project's emissions. Demolition emissions are best assessed at the beginning of the life cycle as part emissions associated with the new building.

Included in cradle-to-cradle

Module D quantifies the carbon impacts beyond the building life cycle emissions. It acknowledges the 'design for reuse and recycling' concept as it allows to demonstrate the benefits resulting from reuse, recycling and energy recovery.

Figure 3: Building life cycle stages (adapted from BS EN 15978:2011)

The BS EN 15978:2011 method is likely to be the dominant calculation method used by the European construction industry (Construction Products Association 2012). Therefore the life cycle classification in this guidance note has been based on BS EN 15978:2011.

As shown in Figure 2, operational emissions contribute the most to the UK building industry carbon footprint. Typically, around 70–80 per cent is associated with the use phase and the rest is associated primarily with the embodied carbon from the materials manufacturing process. However, the ratio between operational and embodied carbon varies according to building type, national building standards and climatic conditions. For example, a low energy-intensive facility such as a warehouse (where no heating or cooling may be required) operating carbon emissions are likely to account for only 20 per cent of the building carbon footprint (over 30 years). The relationship between different types of emissions for different building types is illustrated in Figure 4.

Similarly, the construction standards to be adopted will affect material choice, as will climatic conditions, e.g. countries with high summer temperatures will be constructed to a different standard to those in more temperate zones.

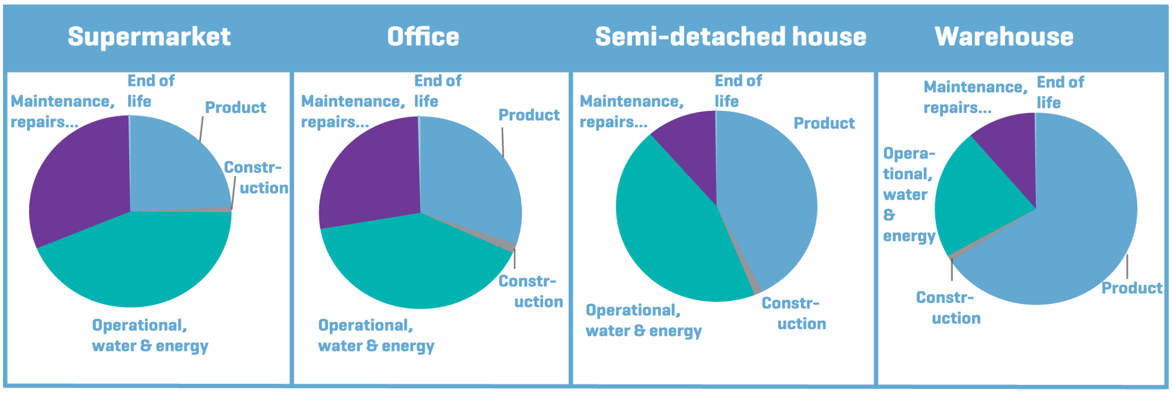


Figure 4: Relative impact of the consequent life cycle stages on the overall carbon footprint for different types of buildings, calculated over 30 years (the energy results have been based on the Building Regulations)

Additionally, the relative contribution of embodied carbon to the overall carbon 'pie' is continuously increasing for the new built projects particularly for many countries where building more energy efficient buildings is a legislative requirement (see Figure 5). This is mainly a direct result of building codes and local planning policies, which require progressively lower operational carbon emissions.

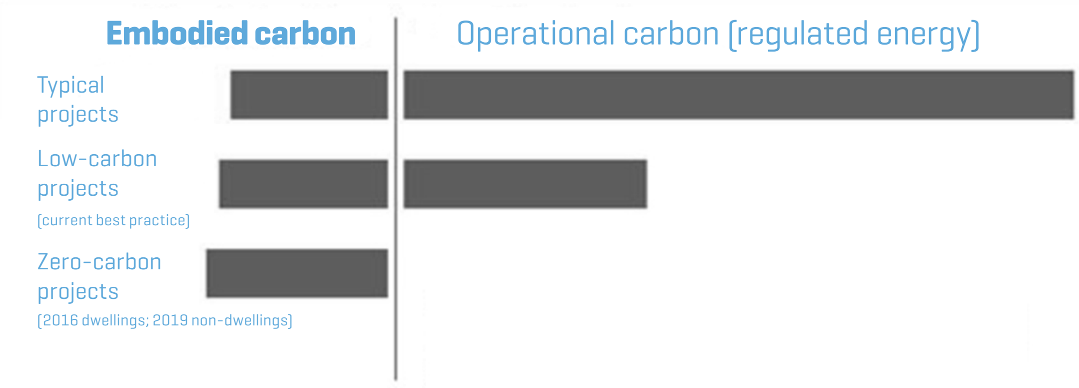


Figure 5: The ratio of embodied to operational carbon increases as Building Regulations are revised

As shown in Figure 3, life cycle carbon impacts encompass not only emissions associated with energy consumption during the product stage. RICS, however, recommends that quantity surveyors start their embodied carbon assessments from this stage. This is due to calculation complexity and limited potential to influence embodied carbon associated with other life cycle stages. Additionally, early in the design process, quantity surveyors are unlikely to have access to the detailed information required to calculate emissions from other stages, causing very high levels of uncertainty and inaccuracy (see Figure 6).

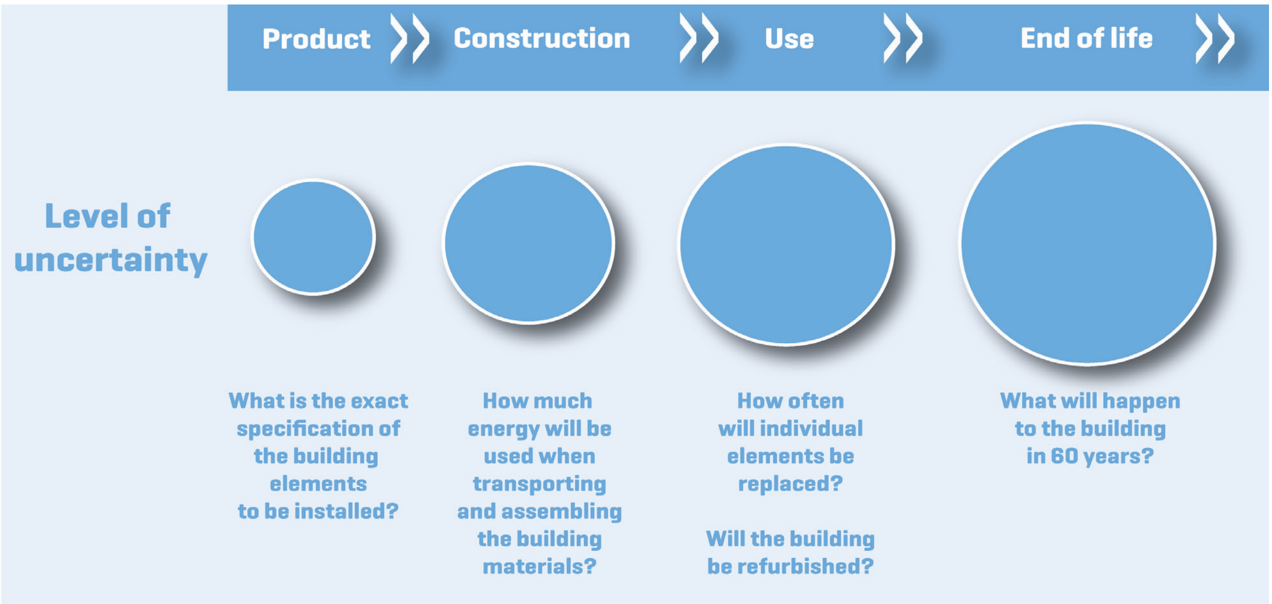


Figure 6: Uncertainty in early stage life cycle embodied carbon assessments

However, if desired, other members of project teams should be able to provide life cycle data associated with the subsequent stages of the project, e.g. construction stage energy demand can be estimated by the contractor; use or end-of-life stage impacts can be analysed by the life cycle specialist. This guidance note explains how quantity surveyors can use data sourced from these specialists to include other life cycle impacts.

3 Measuring life cycle embodied carbon

3.1 Methodologies

Depending on the stage of the project it is recommended to use the methodologies outlined in Table 2.

<table>
<tr><th>Which work stage are you at?</th><th>How to estimate embodied carbon</th></tr>
<tr><td>Preparation
• RIBA Work Stage 1
• NR Grip Stages 1-2
• HA PCF Stage 1-2
• OGC Gateway 1-2</td><td rowspan="2">Multiply the gross internal floor area (GIFA) of the development by the benchmark embodied carbon values (section 3.2).

Embodied carbon benchmarks can be sourced from within your organisation or the public domain (Appendix A).

Concentrate efforts on carbon hotspots (Table 3), e.g. steel vs. concrete frame.</td></tr>
<tr><td>Concept design
• RIBA Work Stage 2
• NR Grip Stages 3
• HA PCF Stage 3
• OGC Gateway 3A</td></tr>
<tr><td>Developed design
• RIBA Work Stage 3
• NR Grip Stages 4
• HA PCF Stage 4
• OGC Gateway 3B</td><td rowspan="5">Start by establishing the project specific product stage embodied carbon by calculating quantities of construction materials/products and multiplying the results by the relevant embodied carbon factors, which can be sourced, for example, from the ICE (Hammond and Jones 2011) or others such as Ecoinvent (Ecoinvent Centre 2010) databases. Other data sources are mentioned in References and information sources.

If more specific factors (e.g. from the manufacturer) become available, then they can replace the generic factors from the generic databases.

Calculate carbon impacts associated with other life cycle stages (i.e. construction process, use, end of life) when the relevant information becomes available (sections 3.3 –3.5).</td></tr>
<tr><td>Technical design
• RIBA Work Stage 4
• NR Grip Stages 5
• OGC Gateway 3C</td></tr>
<tr><td>Specialist design
• RIBA Work Stage 5</td></tr>
<tr><td>Construction (offsite and onsite)
• RIBA Work Stage 6
• NR Grip Stages 6-7
• HA PCF Stage 5-6
• OGC Gateway 4</td></tr>
<tr><td>Use and aftercare
• RIBA Work Stage 7
• NR Grip Stages 8
• HA PCF Stage 7
• OGC Gateway 5</td></tr>
</table>

Table 2: Embodied carbon methodology depending on the project stage

Monitoring the embodied carbon emissions of different types of buildings is a relatively new field of research and therefore there are limited regulatory standards or academic studies to provide comprehensive peer-reviewed benchmark values for use at the initial work stages of projects. Some early studies can, however, be used at the concept design stage to provide a predicted embodied carbon impact. Initial efforts should mainly be concentrated on the designs of carbon hotspots (Table 3), which often cannot be modified at the later stages of the project. Even if the initial results are high-level estimates only, it is recommended to start embodied carbon assessments very early because the carbon reduction ability is highest at the beginning of the design process (Figure 7).

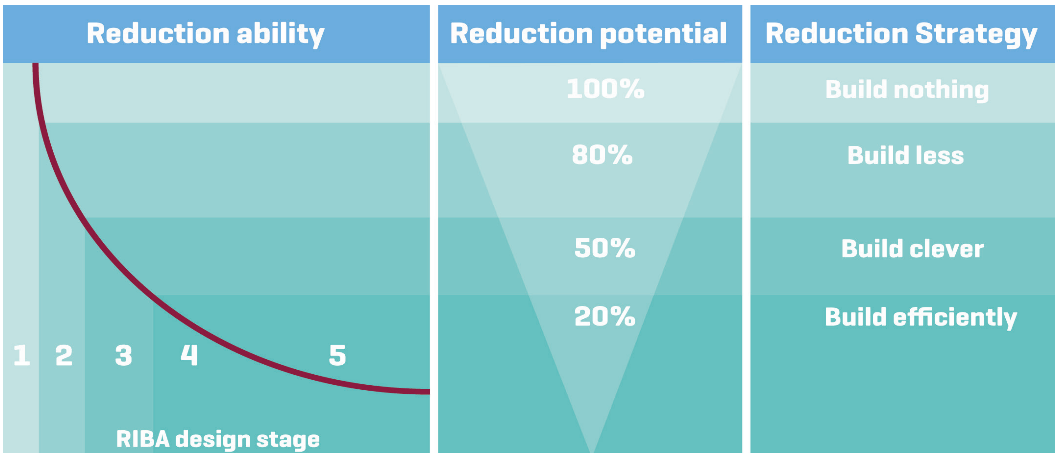


Figure 7: Embodied carbon reduction ability is highest early in the design process (original figure courtesy of Mott MacDonald)

As the design progresses it should be possible to calculate project-specific embodied carbon emissions based on the actual quantities of materials. If the relevant information is available, efforts should be made to estimate embodied carbon impacts associated with the remaining life cycle stages, i.e. construction process, use, end of life.

3.2 Product stage

During the early stages of the project (i.e. preparation, concept design), the detailed information about the types and quantities of the actual construction materials is unlikely to be available. The values in Figure 8 have been established to fill this information gap and provide some high level benchmarks that can be used by quantity surveyors when providing a preliminary estimate of product stage embodied carbon emissions.

It should be noted that there is a large range and potentially a high level of inaccuracy in the numbers shown in Figure 8. This is due to a small data set and assessment boundaries not always being captured (i.e. there is uncertainty whether some studies included basements, external works, furniture, etc.). Also, the figure includes only the product stage emissions as defined in the BS EN 15978:2011. The emissions associated with other life cycle stages (construction process, use, end of life) are not covered.

A more comprehensive database is to be launched by WRAP in the UK. The online Embodied Carbon Database will provide embodied carbon information for a range of building types in an aggregated form. Data across life cycle stages will be provided depending on the data availability for each specific project. This will give indicative values that could then be adapted to suit a particular country or location.

Over time, as an increasing volume of buildings data is collected and methodologies such as those proposed in this guidance note are followed, it is expected that there will be a greater degree of benchmarking accuracy.

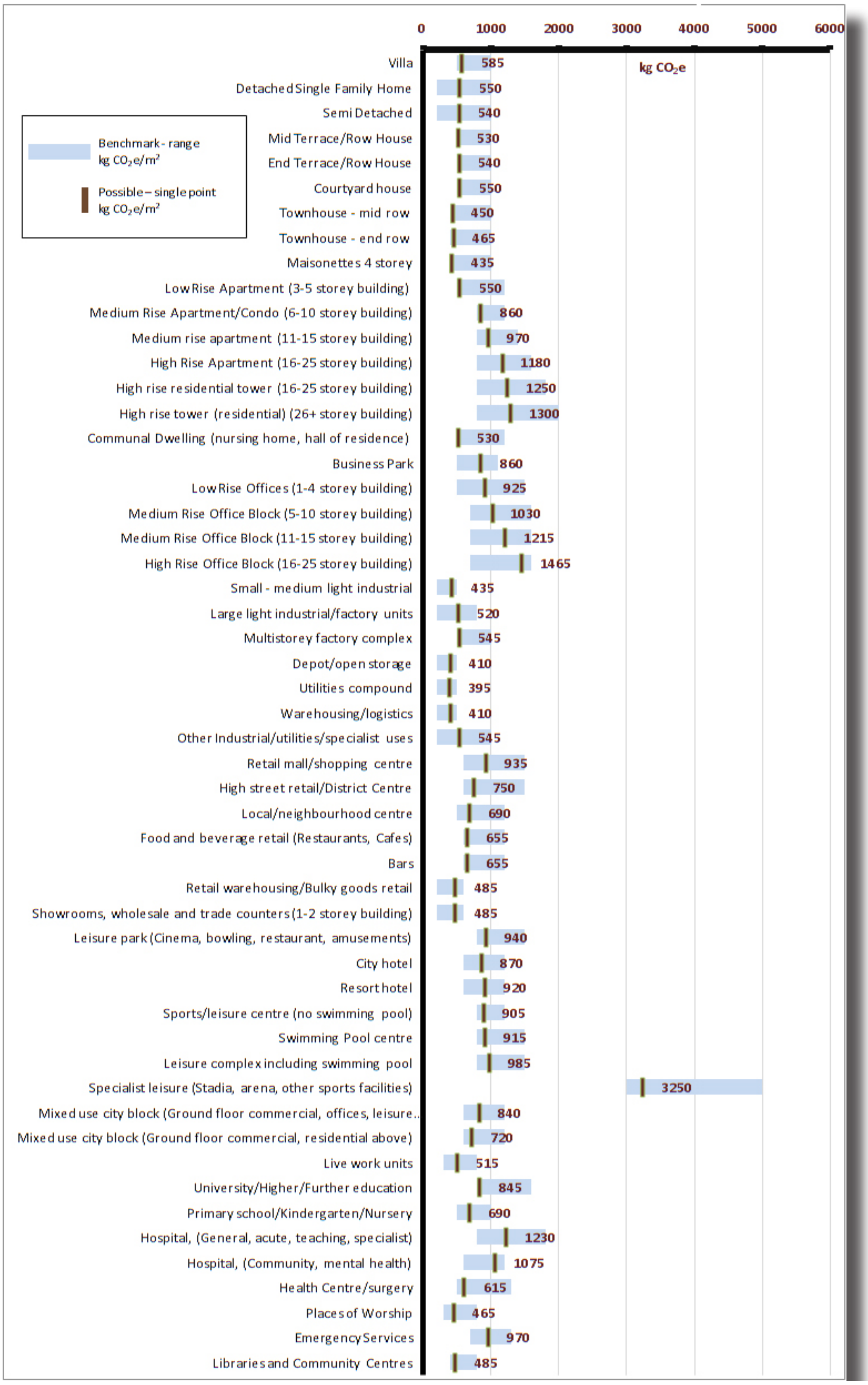


Figure 8: Product stage embodied carbon benchmarks (data courtesy of Atkins)

During the detailed design phase when the types and quantities of materials have already been established, it is possible to deliver a project-specific product stage embodied carbon estimate. The calculation process is explained in Figure 9.

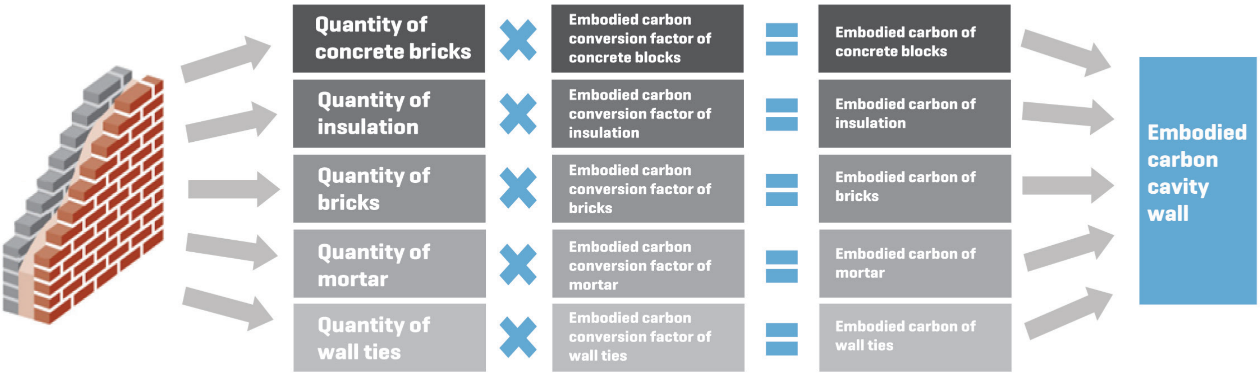


Figure 9: Approach to cradle-to-gate carbon calculations – a cavity wall is broken down to its components (original figure courtesy of Davis Langdon)

The calculation requires a given building element to be broken down into its components for which embodied carbon factors need to be sourced. Factors representing the embodied carbon for construction materials are being researched and published, usually in the following format: kg CO_2e per kg of material/product. Some of the manufacturers have already responded to the market demand and have included embodied carbon factors on product datasheets or in EU Environmental Product Declarations (EPDs) as defined in BS EN 15804:2012 (BSI 2012). There is also a range of publications where average factors have been compiled into one database. The most well-known is the Inventory of Carbon and Energy (ICE), which is a generic database produced by the University of Bath and published in hard copy format by BSRIA (Hammond and Jones 2011). ICE provides average values for materials taken from a range of studies and assessments. These factors usually refer to cradle-to-gate emissions.

Users should be aware that the embodied carbon of a product from a specific manufacturer could vary highly from the averages found in the generic databases.

The initial assessment will, however, identify construction elements contributing most to the overall embodied carbon footprint. These can then become the focus of further investigation to refine the carbon factors used. Manufacturers can be helpful in this process if they can provide product-specific figures. These should include the effects of waste produced, and energy used, during the manufacturing process. The services of a life cycle assessment (LCA) expert may also be called on for more detailed studies.

As some widely used building materials typically contribute more to the overall carbon footprint of buildings (concrete, aluminium and steel being good examples), it is advisable not to calculate the total carbon footprint of a project, because many components will have a negligible impact and offer very limited opportunities for mitigation.

The initial efforts should be focused on high-impact elements (‘carbon hotspots’), which allow for relatively uncomplicated carbon calculations and which, in total, typically contribute to the majority of the overall embodied carbon footprint. Table 3 lists the building components, as defined by NRM 1 (RICS 2012), which RICS recommends are included in initial embodied carbon studies delivered by quantity surveyors. The selection has been based on analysing a number of projects and represents not only the carbon critical elements but also ‘quick wins’ where data is more easily available and where carbon reductions are possible.

Table 3: Carbon hotspots – carbon critical elements that RICS recommends are included as a minimum in embodied carbon calculations delivered by quantity surveyors

	Building components		Carbon critical elements (shaded in dark grey) that RICS recommends are included in embodied carbon calculations delivered by quantity surveyors*
1	Substructure		Foundations
			Basement retaining walls
			Ground floor construction
2	Superstructure		Frame
			Upper floors
			Roof
			Stairs and ramps
			External walls
			Windows and external doors
			Internal walls and partitions
3	Internal finishes		Wall finishes
			Floor finishes
			Ceiling finishes
4	Fittings, furnishings and equipment		
5	Services**		
6	Completed buildings and building units		
7	Works to existing buildings		
8	External works		Roads, paths and pavings
			External drainage
			External services
9	Facilitating works		

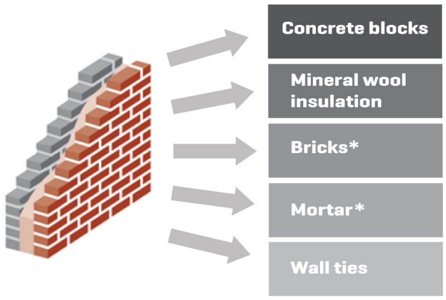
* The selected carbon hotspots should be measured net where applicable (e.g. external walls should be measured deducting openings for windows and external doors).

**Although detailed studies have shown that services can contribute up to 25 per cent of the overall embodied carbon footprint, they are complex to assess at early design stages and the mitigation potential may be limited.

Figure 10 presents an illustrative example of product stage embodied carbon calculation methodology. This can be used as general guidance on the approach to be taken to calculate embodied impacts of other carbon hotspots.

Figure 10: Product stage (cradle-to-gate) methodology example

1 Establish constituent materials



2 Calculate weights** of constituent materials per m^2 of cavity wall

Concrete blocks: Area (m^2) x Mass (kg) = Mass per m^2 (kg)	1.05 m^2 x 60 kg = 63 kg
Wool insulation: Area (m^2) x Mass (kg) = Mass per m^2 (kg)	1.03 m^2 x 7 kg = 7.21 kg
Bricks: Quantity of bricks (nr) x Mass of a single brick (kg) = Mass per m^2 (kg)	60 nr x 2.3 kg = 138 kg
Mortar: Volume (m^3) x Density (kg/m^3) = Mass per m^2 (kg)	0.033 m^3 x 1650 kg/m^3 = 54.45 kg
Wall ties: Quantity (nr) x Mass of a single unit (kg) = Mass per m^2 (kg)	5 nr x 0.04409 kg = 0.22045 kg

** Quantities of some materials not always have to be converted to weights as their embodied carbon factors are often provided in the same unit as used by quantity surveyors (e.g. paint, roof tiles, carpets, ceramic floor tiles, concrete paving blocks, windows)

3 Apply embodied carbon factors***

Concrete blocks: Mass (kg) x Embodied carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	63 kg x 0.133 kg CO_2e / kg = 8.379 kg CO_2e
Mineral insulation : Mass (kg) x Embodied carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	7.21 kg x 1.28 kg CO_2e / kg = 9.229 kg CO_2e
Bricks: Mass (kg) x Embodied carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	138 kg x 0.5512 kg CO_2e / kg = 76.066 kg CO_2e
Mortar: Mass (kg) x Embodied carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	54.45 kg x 0.174 kg CO_2e / kg = 9.474 kg CO_2e
Wall ties: Mass (kg) x Embodied carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	0.22045 kg x 6.519 kg CO_2e / kg = 1.437 kg CO_2e

***This example uses factors from the ICE database (Hammond and Jones 2011)

4 Add embodied carbon of constituent materials to establish the overall embodied carbon

Embodied carbon of concrete blocks 8.379 kg CO_2e

\+

Embodied carbon of mineral insulation 9.229 kg CO_2e

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Embodied carbon of bricks 76.066 kg CO_2e

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Embodied carbon of mortar 9.474 kg CO_2e

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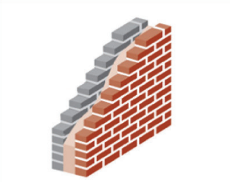
Embodied carbon of wall ties 1.437 kg CO_2e



104.585 kg CO_2e per m^2

It should be noted that the relatively straightforward example in Figure 10 assumes that the embodied carbon factors can be sourced from an existing database or manufacturers' literature. However, when this is not available a full life cycle assessment may be required to establish the amount of carbon emissions per unit of a given construction material. The detailed methodology to establish a bespoke product stage embodied carbon factor is summarised in Figure 11.

Figure 11: Summary of the process of establishing cradle-to-gate embodied carbon factor

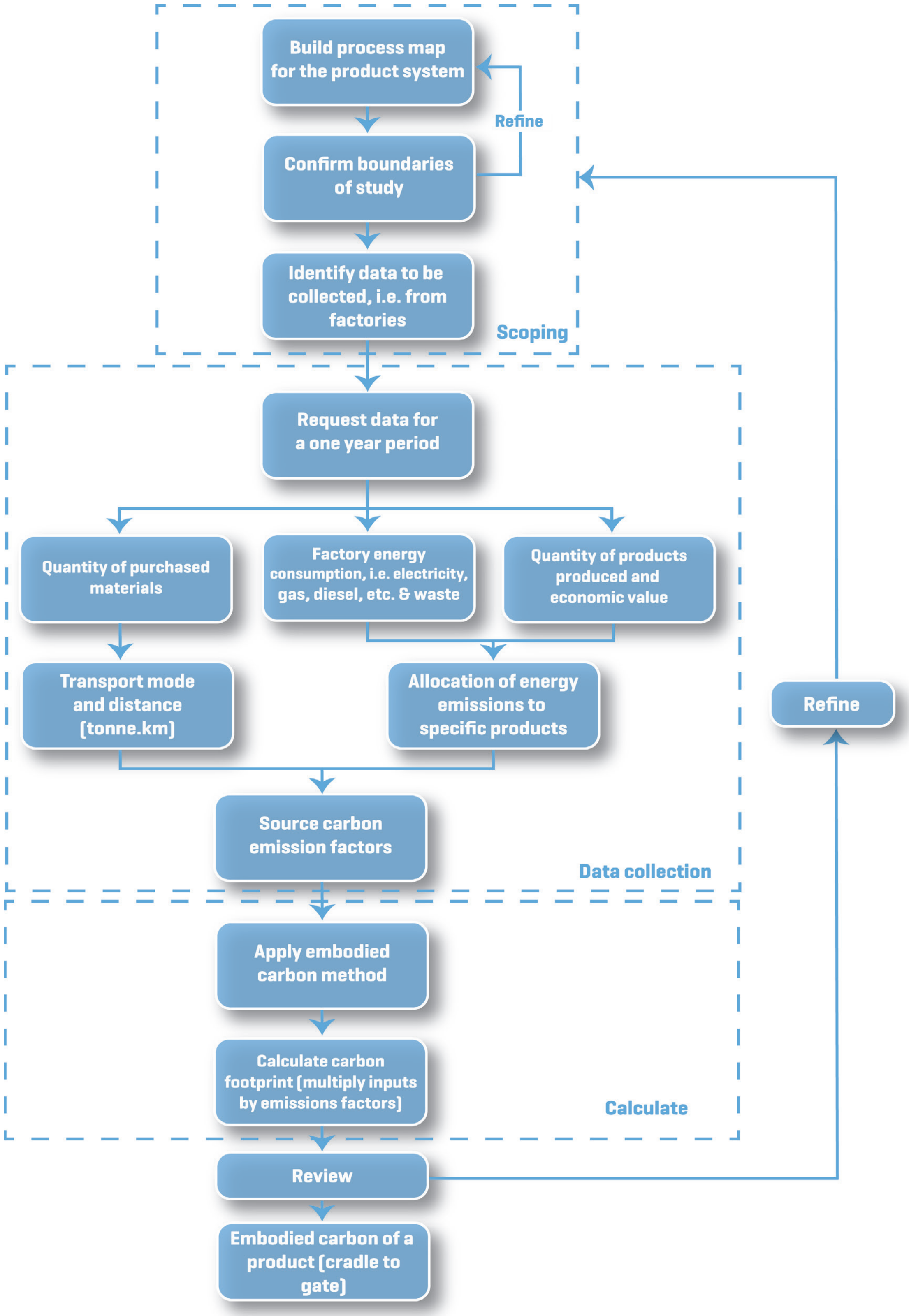


Table 4: How to reduce the embodied carbon impacts of the product stage

Product stage carbon mitigation
More efficient building design (e.g. compact building form).
Change the specification for building elements (e.g. lower-weight roof design).
Select materials with lower carbon intensities (e.g. cement substitutes such as PFA, sustainably-sourced timber, prefabricated elements).
Select reused or higher recycled content products and materials (e.g. reuse of demolition debris, reclaimed bricks, higher recycled content blocks, locally recycled aggregates) offering lower carbon intensities.
Engage with suppliers to avoid excessive packaging.

3.3 Construction process stage

Emissions during the construction process phase include energy and fuel consumption during the site activities such as: enabling works, remediation, clearance, removal/demolition of existing structures ground improvements, earthworks, assembly, piling, asphalt laying. Also included are transport of materials to/ from construction site, lighting, temporary works and site offices. These are summarised in Table 5.

Table 5: Construction process stage embodied carbon sources

Construction process stage	**A4** **Transport**	• A4 Transportation from the production gate to the construction site. • A4-A5 Storage of products, including the provision of heating, cooling, humidity control, etc. • A4-A5 Wastage of construction products (additional production processes to compensate for the loss of wastage of products). • A4-A5 Waste processing of the waste from product packaging and product wastage during the construction processes up to the end-of-waste state or disposal of final residues. • A5 Installation of the product into the building including manufacture and transportation of ancillary materials and any energy or water required for installation or operation of the construction site. It also includes on-site operations to the product.
	A5 **Construction-installation process**	

The embodied carbon calculations will mainly rely on the actual or estimated energy consumption during the processes associated with the construction phase of a project. Although early embodied carbon research efforts have mainly been focused on emissions during the product stage of a project, many leading contractors have now started to collect carbon data associated with construction site activities.

Example: Embodied carbon emissions caused by construction site lighting

1 Estimate / measure electricity consumption

4,500 kWh of electricity has been consumed for lighting during the construction stage of the project.

2 Source carbon conversion factor

Carbon conversion for electricity* = 0.6 kgCO_2e/kWh

(*The list of conversion factors databases can be found in Appendix A.)

3 Carry out the calculation

4,500 kWh of electricity x 0.6 kgCO_2e/kWh = 2,700 kgCO_2e

Good practice guidelines for including construction process emissions in the embodied carbon assessment include:

Onsite fuel and electricity should be metered and recorded so that emissions factors can be applied to calculate the related emissions.

Transport mode and mileage from the final manufacture should also be recorded. This should at least cover major building elements (i.e. external walls, roof, upper floor slabs, internal walls, windows, floor finishes/coverings), ground works and landscaping materials, transport of construction waste from the construction gate to waste disposal/processing/ recovery centre gate.

Table 6: How to reduce embodied carbon impacts of the construction stage

Construction stage carbon mitigation
Design out waste – design for less waste on site (e.g. designing buildings and infrastructure that can be constructed efficiently; specifying work procedures and methods that avoid waste and allow use of waste arising).
Select materials with lower transport-related carbon emissions (e.g. locally-sourced aggregates).
Use a concrete batching plant rather than ordering liquid concrete delivered by lorry.
Use a consolidation site to minimise half full deliveries.
Specify a delivery vehicle that suits load sizes so the smallest possible vehicle is used.
Consider implementing just-in-time (JIT) delivery to minimise over-ordering and reduce the risk of damage or loss of materials stored on-site.
Analyse whether deconstruction can be used instead of demolition. Deconstruction will facilitate re-use of components.
Make sure that the construction programme does not prevent the use of low carbon materials. For example, different cement substitutes require different curing times.
Avoid arranging deliveries during peak traffic times.
Ensure regular vehicle maintenance (vehicles that are well maintained, tuned, serviced and running correct tyre pressures use less fuel).
Provide adequate protection to fragile materials to minimise damage during the construction process.
Avoid waste caused by excessive customisation and fitting on site.
Planning work sequences to minimise waste and re-work.
Ensure that tools, equipment and construction plant used on-site are well maintained and kept in a good working order.
Use energy-efficient site offices.
When not required, always turn off lights and any other energy-consuming equipment.
Supply the construction site with renewable energy.
Work with suppliers to implement ‘take-back’ schemes for material surpluses and offcuts.

3.4 Use stage

During the lifetime of a building, materials will be required to be maintained, repaired, replaced and refurbished as aspects wear out or a use changes. Embodied carbon emissions will be caused by making and transporting these materials and the emissions will vary depending on the intensity of these processes.

Table 7: Use stage sources of embodied carbon

Use stage	**B2** **Maintenance**	• All processes for maintaining the functional and technical performance of the building fabric and building integrated technical systems, as well as aesthetic qualities of the building's interior and exterior components. • All cleaning processes of the interior and exterior of the building. • The production and transportation of the components and ancillary products used for maintenance. Examples: Painting work on window frames, doors, etc. and the annual inspection and maintenance of the (oil or gas) boiler, replacement of filters in the heat recovery or air conditioner.
	B3 **Repair**	• The production of the repaired part of component and ancillary products. • The transportation of the repaired part of component and ancillary products, including production impacts and aspects of any losses of materials during transportation. • The repair process of the repaired part of component and ancillary products. • Waste management of the removed part of the component and of ancillary products. • The end-of-life stage of the removed part of the component and of ancillary products. Example: For a window with a broken pane, this includes waste generated by the pane, production, transportation of a new pane and all impacts due to the repair process (rubber seal, etc.).
	B4 **Replacement**	• The production of the replaced component and ancillary products. • The transportation of the replaced component and ancillary products, including production impacts and aspects of any losses of materials during transportation. • The replacement process of the replaced components and ancillary products. • Waste management of the removed component and of ancillary products. • The end-of-life stage of the removed component and of ancillary products. Examples: Replacement of a partition wall, a complete covering of an existing roofing felt, or a complete renewal including removal of the existing roofing felt, replacement of a heating system or boiler, replacement of a window (frame, glass), etc.
	B5 **Refurbishment**	• The production of the new building components. • Transportation of the new building components (including production of any materials lost during transportation). • Construction as part of the refurbishment process (including production of any material lost during refurbishment). • The waste management of the refurbishment process. • The end-of-life stage of replaced building components. Examples: A major change of the internal layout (partitioning) and/or the building envelope, change of the technical systems related to heating, cooling or air conditioning, modifications for the purposes of a planned or expected change of use.

It is however very difficult to predict the maintenance requirements or the exact year of the replacements in advance. The design lives quoted by the manufacturers or installers provide only an indication and do not guarantee that a given element will not have to be replaced earlier.

Therefore, the embodied carbon of the use phase can only be estimated based on the likelihood of a given item's replacement. Typical lifespans of building components can be estimated using data sources such as the BCIS life expectancy data (BCIS 2006). Resource intensity of the maintenance and repair strategy can be estimated with the help of a facilities management adviser.

Example: Embodied carbon of replacing office carpet tiles

1 Calculate the quantity of material to be replaced

1,400 m^2 of office carpet tiles

2 Estimate service life

100 per cent of the carpet tiles will need replacing every eight years. Therefore there will be seven replacements during the 60 years of an asset lifespan.

3. Source the embodied carbon factor

Carbon conversion factor for carpet tiles* = 13.7 $kgCO_2e$ per m^2

*The list of conversion factors databases can be found in Appendix A.

4. Carry out the calculation

7 carpet tile replacements x 1,400 m^2 of carpet x 13.7 $kgCO_2e/m^2$ = 134,260 $kgCO_2e$

Table 8: How to reduce embodied carbon impacts of the use stage

Use stage carbon mitigation
Select materials with high levels of durability and low through-life maintenance (e.g. facades and fixing components that last as long as the building frame).
Ensure high quality finishing of the building components to avoid premature failure.
Design to allow easy reconfiguration/remodelling of the building to meet changing needs.
Design that allows the easy replacement of aspects (e.g. replace a few carpet tiles in high traffic areas).
Develop a proactive maintenance, servicing and repair strategy.

3.5 End-of-life stage

End-of-life emissions include carbon impacts associated with demolition, transportation, waste processing and disposal. This is another poorly understood part of the building life cycle carbon footprint. The calculation is relatively straightforward if it is carried out at the time of the actual building decommissioning. However, it is nearly impossible to undertake it 60 years in advance because of the uncertainty surrounding its use.

Table 9: End-of-life stage embodied carbon sources

Use stage	**C1** **De-construction, demolition**	On-site operations and operations undertaken in temporary works located off-site as necessary for the deconstruction processes after decommissioning up to and including on-site deconstruction, dismantling and/or demolition. Example: Dismantling or demolition of the building, including initial on-site sorting of the materials.
	C2 **Transport**	Transport to and from possible intermediate storage/processing locations. Example: Transportation of the discarded materials to a recycling site and transportation of waste.
	C3 **Waste processing**	Collection of waste fractions from the deconstruction and waste processing of material flows intended for reuse, recycling and energy recovery.
	C4 **Disposal**	Neutralisation, incineration with or without utilisation of energy, landfilling with or without utilisation of landfill gases, etc.

A demolition contractor may be best positioned to estimate energy demand for the future demolition process. It is very unlikely, however, that one will know the resource intensity of the end-of-life stage which may occur in 60 years or later. Therefore, an assumption may have to be made, e.g. based on an estimate that the demolition will last a quarter of the time required for the construction activities.

Unless a planned demolition is scheduled, it may be advisable to exclude end-of-life impacts from the project's emissions. Demolition emissions could be assessed at the beginning of the subsequent life cycle as part of construction emissions associated with a new project.

Example: Embodied carbon of demolition plant

1. Estimate / measure electricity consumption

The 360-degree excavator will require 30 litres of diesel per hour over 200 hours. Therefore the total diesel consumption has been estimated at 6,000 litres.

2. Source the carbon factor

Carbon conversion factor for diesel fuel* = 2.68 kgCO_2e per litre

*The list of conversion factors databases can be found in Appendix A.

3. Carry out the calculation

6,000 litres of diesel fuel x 2.68 kgCO_2e/litre = 16,080 kgCO_2e

Table 10: How to reduce embodied carbon impacts of the end-of-life stage

End of life stage carbon mitigation
Design for reuse (e.g. increase reuse of materials from demolition and earthworks).
Design a building for deconstruction at the end of its life.
Divert waste materials from landfills.
Find uses for the demolition materials.
Use efficient demolition equipment.

4 Practical issues

4.1 Carbon sequestration

Sequestration is an often-claimed benefit of using biogenic products in construction. During growth, materials such as timber, straw or hemp use sunlight to convert CO_2, water and nutrients into carbohydrates. This absorbs carbon and the accumulation of stored carbon is known as carbon sequestration. At the same time, processing and transportation of bio-based materials requires energy, which causes carbon emissions.

In this regard, biogenic products are unique as the carbon they 'consume' during their growth can often outweigh the carbon generated during the processing. Therefore, by specifying bio-renewable materials the case can be made that this is helping to remove carbon from the atmosphere.

Claiming this benefit is contingent on many assumptions; for example, that at the end of service life the materials will not be buried in landfill, breaking down into greenhouse gases (carbon dioxide and methane). Due to this uncertainty, some practitioners choose not to include sequestration in their embodied carbon reports.

This guidance note does not promote or reject including the benefits of carbon sequestration. RICS encourages practitioners to source relevant life cycle information from the project teams or peer-reviewed datasets in order to present the overall impacts of their projects.

Example: Carbon sequestration

1 Estimate the quantity of timber

75 m^3 of timber used. The density of timber = 550 kg per m^3. Therefore 41,250 kg of timber has been used.

2 Source the carbon factor

Carbon conversion factor for the timber used on the project = -1.5 $kgCO_2e$ per kg

(Sustainably sourced timber has been specified. The contract confirms that the timber will not be landfilled or burnt without energy recovery at the end of service life).

3 Carry out the calculation

41,250 kg of timber x -1.5 $kgCO_2e$ per kg = -61,875 $kgCO_2e$

Good practice carbon sequestration includes:

- All timber should be sourced in accordance with the UK government's Timber Procurement Policy. This ensures that timber comes from sustainably managed forests, certified by the FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification).
- At the end of service life, timber should not be landfilled or incinerated without energy recovery.

4.2 Steel recycling

Manufacture of steel from virgin materials involves a series of energy-intensive processes. However, at the same time most of the scrap steel is recovered from end-of-life buildings and used to make new products. Exclusion of this information may misinform some of the embodied carbon comparisons.

Highly recycled materials, such as metals, can be penalised by limiting the analysis to cradle-to-gate processes only, whereas materials that are more often disposed of as waste (e.g. timber) or downcycled (e.g. concrete) can be advantaged. The benefit of cradle-to-gate analysis is that it covers processes that are fairly well defined and do not change significantly. The cradle-to-grave analysis in turn requires a series of assumptions on what happens once the project leaves the factory gate. However, because one of the roles of measuring embodied carbon is to find the biggest mitigation opportunities, it is recommended that all stages of building life cycle are analysed. Some further information can be found in the *The carbon footprint of steel* report (British Constructional Steelwork Association 2010).

4.3 Thermal mass of concrete

'Thermal mass' is a common shorthand term to describe a property that enables building materials to absorb, store and later release significant amounts of heat. This is more accurately called 'effective thermal capacity'. Concrete and other materials can absorb energy slowly and hold it for much longer periods of time than lightweight materials. This means that adding large thermal mass materials may increase product stage embodied carbon, or it may reduce cooling/heating loads, thus lowering the use stage carbon emissions. For this reason, the impacts of design decisions should be considered on embodied and operational carbon together rather than separately. Careful design can maximise the thermal capacity effect available from a given mass of material, resulting in lower embodied carbon levels than by simply adding mass.

5 Analysing the results

To verify the results and also to indicatively measure the performance of a project it would be useful to compare the final result (i.e. tonnes of CO_2e per m^2 of a building) with the industry benchmarks in the same way mechanical engineers compare the results of their operational carbon calculations with well-established datasets (e.g. CIBSE Energy Benchmarks TM46) or even energy consumption monitoring of actual buildings.

Unfortunately, embodied carbon is a relatively new and still unregulated indicator in the building industry and there are no comprehensive and peer reviewed datasets covering embodied carbon emissions associated with different building types. There are, however, some early databases emerging:

The WRAP Embodied Carbon Database will allow practitioners to understand results achieved for a number of similar projects. The industry data has been compiled in a comprehensive manner and facilitates input across all life cycle stages as defined in BS EN 15978:2011. Additionally, practitioners will be able to contribute to developing the database by sharing their results.

Atkins Masterplanning Tool (Atkins 2010) includes a range of cradle-to-gate embodied carbon benchmarks. As opposed to the ICE database, the figures have not been compiled in a statistical way and have not been peer-reviewed.

It is suggested that in the absence of any other source, these datasets can provide a useful benchmarking opportunity for the practitioner.

It should also be stressed that the ultimate goal of carbon footprinting is to reduce environmental impacts rather than deliberating on the level of accuracy of the results. Therefore, the embodied carbon figures obtained should be used to inform the decision-making process. It is recommended that quick wins for high-impact building elements are researched and implemented.

Figure 12 shows an example of embodied carbon results along with an indication of the carbon mitigation potential.

Examples of how embodied carbon can be reduced during the individual life cycle stages have been presented throughout this guidance note. It should, however, be noted that when trying to improve carbon performance of a project, individual life cycle stages should not be analysed on their own. For example, a product with very low cradle-to-gate embodied carbon produced overseas may actually have much higher overall life cycle carbon footprint than a locally sourced alternative due to emissions associated with transportation. In this case, to allow for a fair comparison, calculations should include the distance and carbon intensity of the shipping modes used (Figure 13).

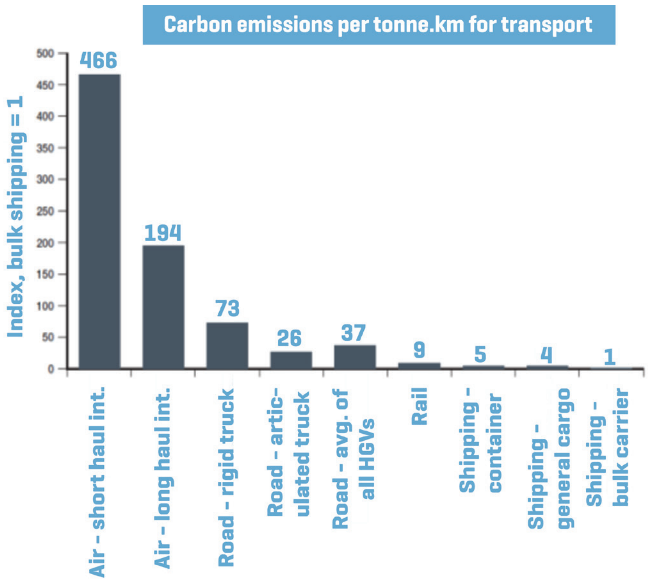
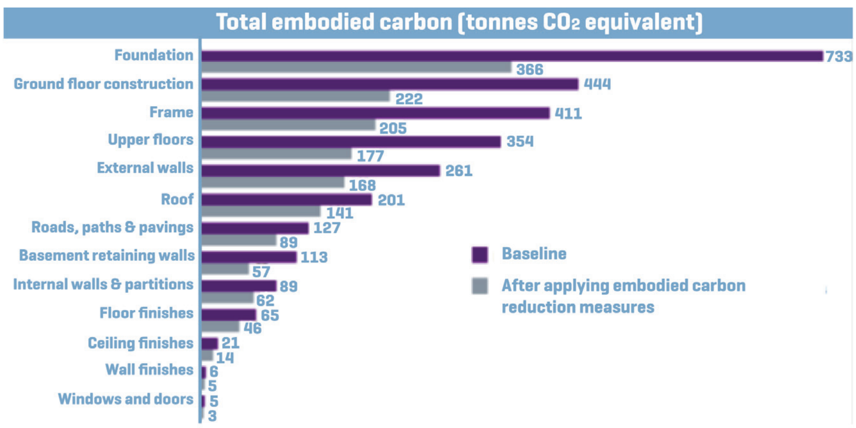


Figure 13: The relative carbon intensity of different modes of transport

Figure 12: An example of how carbon reduction measures can affect the embodied carbon of a project



6 Conclusions

In recent years, building-related standards and regulations have concentrated mainly on reducing operational energy loads without much consideration of embodied emissions. As a result, buildings are becoming more and more efficient in terms of their operational carbon performance. The interest now, however, is in shifting towards embodied carbon where the reduction potential has not been investigated to the same extent.

Unfortunately, there is still no consensus on exactly how embodied carbon should be defined and calculated. Different assumptions and boundary conditions are used, which leads to widely differing results. There is therefore a growing need for the standardisation of embodied carbon data and assessment methods. Undertaking embodied carbon assessments is not as straightforward as it may seem and without a standard methodology, agreed rules, data and data structures, clients have not been assured of consistent and evidenced results.

This publication is the next step in creating rules and life cycle embodied carbon benchmarks for buildings. It is primarily aimed at quantity surveyors and the decision makers in the design team. Quantity surveyors have a good understanding of the quantities and specifications, so they are ideally placed to quantify embodied carbon emissions. Measuring embodied carbon will allow owners and occupiers to easily understand and compare the carbon value of different buildings. Operational and embodied carbon work hand in hand. Acquiring a complete understanding of both allows design teams and consultants to create the best possible specifications for a low-carbon building.

7 Case studies

Case study 1: Life cycle carbon assessment of Marks & Spencer, Cheshire Oaks (UK)

About the project

Cheshire Oaks is one of the biggest M&S stores with a floor area of over 20,000 m². It was designed with an architectural and design strategy that addresses several areas of sustainability at once. The site is located on Longlooms Road, Cheshire Oaks, UK. The development generated much local interest as the site is located in close proximity to 600 homes and a range of businesses. It is also M&S' third Sustainable Learning Store, which aims as part of the Plan A commitment to build a strong bank of knowledge and experience in sustainable building practices.

One of the key aims of the project was to create a positive store environment that improves the health and well-being of staff, customers and the local community. The store received the *Carbon Champion of the Year Award* at the prestigious Building Performance Awards, organised in 2014 by the Chartered Institution of Building Services Engineers.

The designers were given a target of reducing the operational energy use by 30 per cent and carbon emissions by 35 per cent compared to a peer store. These figures were decided on by assessing the success of energy saving measures implemented at other M&S stores. A number of sustainability features were investigated before the final design was produced. Some of the features considered, and ultimately rejected, included the installation of a wind turbine and the provision of a green roof.

In order to ensure that sustainability was considered throughout the construction process, a unique project team structure was adopted. In a traditional construction team the environmental manager and environmental champion report to the project manager; however, in this team they reported directly to the project director. This meant that sustainability was part of every decision made, and the principles set out by M&S were implemented throughout the construction process. This organisational structure allowed the environmental team to influence the project in ways that would have been difficult were they reporting directly to the project manager.

In order to minimise the embodied carbon impact of the store a series of mitigation measures were implemented. The store's design team achieved 30 per cent recycled content by value including a100 per cent recycled aluminium roof (for more detail see the points made under building fabric selection overleaf). Meanwhile, concrete mix designs were adapted to include recycled content while recycled insulation was used in the roof lining. There were also several carbon sequestration benefits from the timber frame and the Hempcrete panels.

Other sustainblity features and considerations included:

- A number of sub-contractors were helped through the FSC certification process ensuring that all timber products delivered to site were accompanied by full chain of custody.
- Over 60 per cent of aggregates used in the ground works were from locally recycled sources, with virgin aggregates and gabion infill natural stone also locally sourced.
- During the construction phase, none of the construction waste was sent to landfill with as much as possible being recycled. The cheapest way to dispose of waste is to use a 40-yard mixed waste skip so as to minimise the number of skip movements. This, however, increases the risk of entire waste consignments going directly to landfill. To reduce this risk the waste needs to be segregated. Waste segregation requires a larger number of skip types, which in turn increases the costs associated with waste disposal as the number of skip movements increases. The waste budget was doubled due to the extensive onsite segregation, which was around 90 per cent on completion of the building.
- 54,000 tonnes of quality soils and clay from the initial bulk excavation works were used in projects such as capping a contaminated quarry and developing a local Moto-X park.
- Although FSC certified glulam is increasingly being used in the construction of buildings, there were only a limited number of contractors available to meet the quantity and specification required. Also, there is little understanding in industry of how to use glulam as a structural element. As a result, a significant amount of steel bolt reinforcements were added to the frame in the ceiling in order to satisfy the building insurers that it was structurally sound. This had an impact on the programme, which would not have been incurred with a traditional steel frame building. It was also found that the glulam deflected to a greater extent than the designers predicted, resulting in the first floor screed cracking and a more flexible grout being required. This deflection was not related to the number of steel bolts in the ceiling.
- Heat reclaim technology from a refrigeration plant is used for building heating. The refrigeration plant itself uses CO_2 as the working refrigerant.
- Rainwater harvesting is used for the toilets and

irrigation. In order to facilitate this, an 80,000 litre underground storage tank was included.

- A 300 m² living wall runs along the side of the car park structure and contains 30 different plant species. The watering is provided automatically through the rainwater harvesting systems.
- The store has extensive sub-metering allowing most of the energy-using systems to be monitored in real time. A monitoring and targeting system is in place to provide feedback on performance and to track improvements to the systems.

Building fabric was also carefully selected to reduce energy consumption and environmental impact:

- 1,400m³ of 100 per cent FSC-certified glulam timber was used in the roof and first-floor structural decking.
- Timber used has sequestrated approximately 2000 tonnes of CO_2 or 100 kgCO_2/m² of floor area.
- FSC project certification with 99.5 per cent of the timber provided from FSC-certified sources (TT-PRO-003615).
- 2600 m² of Hemclad® panels were used in the external walls to give a U-value of 0.12W/m².K saving around 360 tonnes of CO_2 emissions.
- Features a 100 per cent recycled aluminium roof, fermacell dry lining board and 40 per cent recycled floor tiles.

Scope of the assessment: Cradle-to-grave.

Results

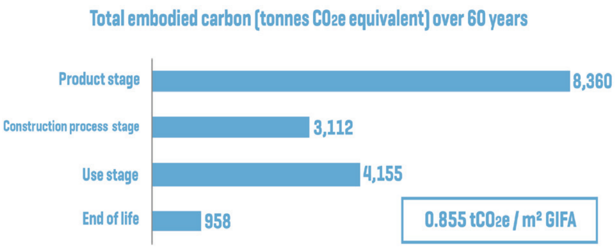


Figure 14: Results of Cheshire Oaks life cycle carbon assessment

Case study 2: Ten Oaks Farm (UK)

About the project

Ten Oaks Farm is a proposed five-bedroom dwelling with a one-bedroom annex to be built within the Hertfordshire Green Belt. One of the main aims of the development is to create a dwelling that has a positive impact on the local environment compared to the existing rundown bungalow and outbuildings on the site. At the time of publication the project was at the planning stage.

This innovative house will use local and traditional materials and will be built by adapting and developing conventional trade skills. The new dwelling is intended to be an exemplar of sustainable living, with low energy and water use and a net zero carbon footprint. On-site renewables will provide enough energy to meet the site needs over the lifetime of the development. The project will demonstrate how low carbon buildings can be constructed using and adapting conventional and local trades, materials, skills and techniques.

The site proposals include bringing the agricultural land at the site back into productive use. Planting an orchard and other new trees on part of the agricultural land, together with renewable energy sources on site, will over time offset the carbon embodied in the construction of the building.

A life cycle carbon methodology was used to make informed decisions on the design of the development, materials chosen for construction and the suppliers of the specified products. The project team calculated carbon emissions for the product stage, construction process stage, use stage, with less defined figures for the end-of-life stage. Based on the predicted duration of the deconstruction works, the end-of-life stage emissions were estimated at a fifth of the emissions associated with the construction process.

Scope of the assessment: Cradle-to-grave.

7.2.2 Results

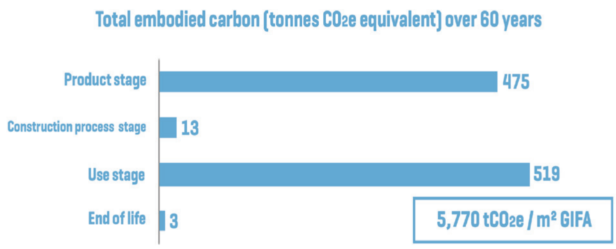


Figure 15: Results of Ten Oaks Farm life cycle carbon assessment

Case study 3: Skanska House (Finland)

About the project

Skanska House is the head office of Skanska Finland and is situated in the Manskun Rasti quarter of Helsinki, 3 km northwest of the city centre. It has a total leasable area of 9,100 m^2, and includes eight above ground floors centered around a glazed atrium and three basement garage levels.

The project team used pioneering 4D Building Information Modeling (BIM) to plan the construction of the project with a delivery timeline. The BIM model incorporated construction scheduling, safety and site logistics information, existing underground utility lines and the site's terrain, which was laser-scanned prior to the project. The BIM model helped to improve productivity, reduce waste, enhance safety and reduce disturbance during construction. The project was awarded *Best Project* at the 2011 Tekla Global BIM competition and *Work Site of the Year 2011* by the *Rakennuslehti* construction magazine, also for its pioneering use of BIM.

Skanska House was part of Skanska's Green Initiative and the project was designed to achieve LEED Core & Shell Platinum certification, the highest level possible under the certification process.

One of the main sustainability objectives of the project was to establish an embodied carbon benchmark, which could then be used to make reductions in embodied carbon during the design phase of future developments. The carbon analysis was integrated into the BIM model of the building.

During the BIM design analysis, Skanska compared various steel and concrete combinations to identify the most energy and carbon efficient arrangement. Materials with recycled content included steel bars (99% recycled content), gypsum boards (90%) and insulation (70%). The project's ready mixed concrete also contained pulverised fly ash, which is a byproduct of coal-fired powerstations that can reduce embodied carbon by up to 30 per cent compared with conventional concrete mixtures.

Ninety-nine per cent of the construction waste materials was diverted from landfill. Approximately 85 per cent of the waste was sorted on site into fractions, including wood, insulation, gypsum, plastic, steel, stone and waste for incineration at a local power plant. The remaining 15 per cent of the waste was then sorted at a specialist facility off-site with an efficiency of 95 per cent. The waste insulation accumulated on site was collected by the insulation supplier, which recycled the material back into the production process.

Around 75 per cent of the workforce was based within the Helsinki area. A significant proportion of the construction materials were sourced from within 800 km of the site. Regional construction materials included the insulation and gypsum boards. The hollow concrete slabs were sourced from within the Helsinki area.

Scope of the assessment: Cradle-to-gate.

Results

The embodied carbon emissions from the extraction, manufacture, processing of construction materials was calculated to be 7,481 tCO_2e or 274 $kgCO_2e/m^2$ GIFA.

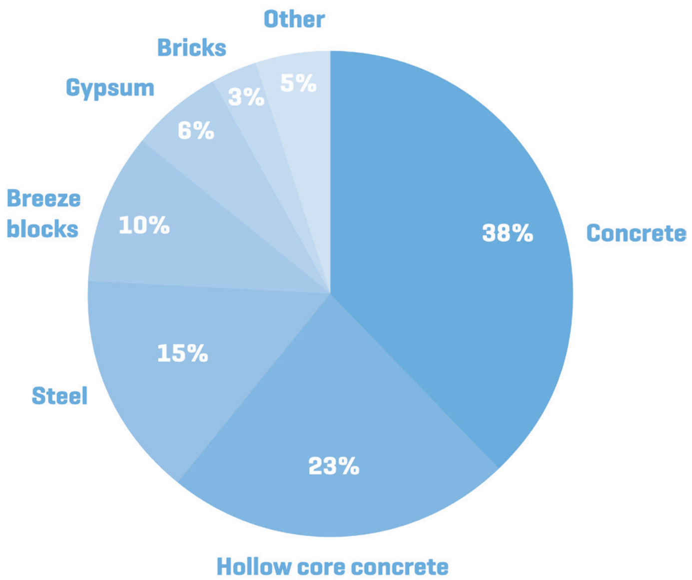


Figure 16: Results of the Skanska House carbon assessment

Case study 4: Red Cross Flanders Building (Belgium)

About the project

The Belgian Red Cross Blood Service is currently spread over a number of hospitals in various regions. The main purpose of the new building will be to centralise the service on the 5,884 m² site in Ragheno Park, Mechelen. The development will provide office spaces, laboratories, a cafeteria, warehouse, library and outdoor space.

Bopro was commissioned to deliver this project, which will include implementing an extensive soil remediation strategy and incorporating a number of innovative technologies – energy piles, heat pumps and a geothermal heat exchanger. Energy saving measures will reduce the use phase carbon emissions by over 60 per cent compared to the baseline. The project aims at achieving the BREEAM Outstanding certification, the highest possible BREEAM award.

Throughout the construction phase, the on-site construction energy, transport, water and waste consumption was monitored and compared against the set targets on a monthly basis. Efforts were made to reduce the CO_2e emissions arising from transport by giving preference to locally sourced materials.

Furthermore, the design team have been tasked with quantifying the embodied carbon impacts of the building. The product stage or cradle-to-gate embodied carbon assessment included the main construction materials, but excluded building services. Carbon factors were sourced from the ADEME Bilan Carbone database. The quantities of materials were established using the bill of quantities.

Scope of the assessment: Cradle-to-gate.

Results

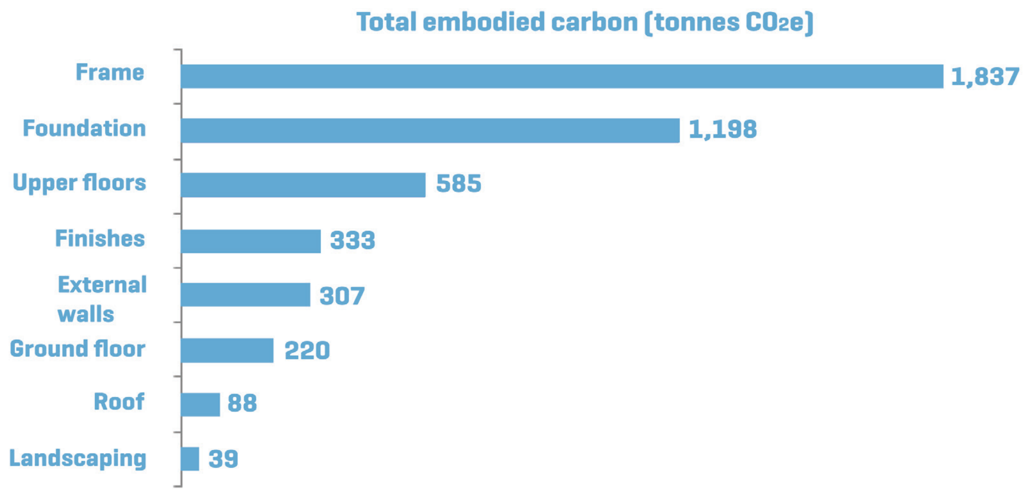


Figure 17: Results of the Red Cross Flanders building carbon assessment

Appendix A: Life cycle embodied carbon summary

	Product stage	Construction stage	Use stage	End-of-life stage
Project stage	A1: Raw materials supply A2: Transport A3: Manufacturing	A4: Transport A5: Construction-installation process	B2: Maintenance B3: Repair B4: Replacement B5: Refurbishment	C1: De-construction demolition C2: Transport C3: Waste processing C4: Disposal
Popular terms	**CapCarb, cradle-to-gate**	**gate-to-site**	**use carbon**	**grave**
Scope	• A1: Extracting and refining raw materials (i.e. primary manufacture) • A2:Transport of materials to the manufacturer • A3: Processing to produce a finished product (i.e. secondary manufacture)	• A4: Transport of materials and waste to and from construction site • A5: Energy consumption during construction process	• B2: Cleaning, inspections, minor replacements • B2-B5: Production and transport of materials used in the maintenance, repair, replacement, refurbishment	• C1: Energy consumption during demolition • C2: Transport of discarded materials • C3-C4: Energy consumption for processing and disposal of waste materials
Infor-mation required	• A1-A3: Quantities (m^3, tonnes) of construction materials and products	• A4: Transport mode and mileage from the final manufacture to construction site • A5: Energy and fuel consumption during construction	• B2: Energy used for cleaning, inspections • B2-B5: Service lives (years) • B2:B5: Quantities of materials for maintenance, repair, replacement, refurbishment • B2:B5: Transport mode and mileage from the final manufacture to site	• C1: Energy and fuel consumption during demolition • C2: Transport mode and mileage from site to waste processing facility • C3-C4: Energy consumption for processing and disposal of waste materials
Data sources/ tools	Emissions factors for different materials: • Inventory of Carbon and Energy (UK) (Hammond and Jones 2011) • SimaPro (International) • GaBi (International) • INIES Database (France) • Nederlands Instituut voor Bouwbiologie en Ecologie (Netherlands)	Emissions factors for different transport modes, energy sources and fuels: • DEFRA Greenhouse Gas Conversion Factor Repository (UK) • GHG Protocol calculation tools (International) • National Greenhouse Accounts Factors (Australia)	Emissions factors for different transport modes, energy sources and fuels (as Construction stage) Service lives of building components: • BCIS Life Expectancy Of Building Components (BCIS 2006) Emissions factors for different materials (as Product stage)	Emissions factors for different transport modes, energy sources and fuels (as Construction stage)
Example: curtain walling	A1-A3 Product stage **Glass:** Mass (kg) x Carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e) **Aluminium:** Mass (kg) x Carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e) **Gaskets:** Mass (kg) x Carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e) **Sealant:** Mass (kg) x Carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e)	A4 Transport Distance from manufacturer to construction site (km) x Fuel consumption (litre/km) x Carbon conversion factor of the fuel used (kg CO_2e/litre) = Embodied carbon (kg CO_2e) A5 Construction-installation process Fuel consumption during construction-installation process (litre) x Carbon conversion factor of the fuel used = Embodied carbon (kg CO_2e)	B2 Maintenance Electricity consumed for maintenance (kWh) x Carbon conversion factor of electricity (kg CO_2e/kWh) B2-B5 Maintenance, repair, replacement, refurbishment Number of replacements during 60-year period (no.) x Mass of new material(kg) x Carbon factor (kg CO_2e / kg) = Embodied carbon (kg CO_2e) Distance from manufacturer to site (km) x Fuel consumption (litre/km) x Carbon conversion factor of the fuel used (kg CO_2e/litre) = Embodied carbon (kg CO_2e)	C1 De-construction / demolition Fuel consumption during de-construction/demolition process (litre) x Carbon conversion factor of the fuel used = Embodied carbon (kg CO_2e) C2 Transport Distance from site to waste processing facility (km) x Fuel consumption (litre/km) x Carbon conversion factor of the fuel used (kg CO_2e/litre) = Embodied carbon (kg CO_2e) C3-C4 Waste processing, disposal Fuel consumption during waste processing and disposal processes (litre) x Carbon conversion factor of the fuel used = Embodied carbon (kg CO_2e)

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