ECONOMICS

Sustainability Embodied carbon

Your client's low-energy building has a wind turbine and photovoltaics, the insulation uses sheep's wool and there's no PVC. But just how much carbon has been used in assembling the building – and should we worry? **Simon Rawlinson** and **David Weight** of **Davis Langdon** report on an initiative to rate the embodied carbon of buildings

01 Introduction

Carbon dioxide emissions have for some time assumed centre stage in the fight against global warming. This is because CO_2 is the dominant gas released by our activities that exacerbates global warming.

Most sustainability regulations focus on the reduction of CO_2 emissions, and on the operation, rather than on the formation of the building.

This approach, currently emphasised by Part L of the Building Regulations, adheres to the perception that more energy is consumed by running assets than in constructing them. In contrast, when cost is considered, attention is generally focused on capital, rather than life-cycle, costs.

In the same way that operating and maintenance costs need detailed consideration, it is important that both the day-one carbon impact of a project and the effects of maintenance, refurbishment, and even disposal, should be understood and mitigated. While discounting is a standard technique for calculating future financial burdens and reducing present values, this approach is inappropriate for estimating the environmental liabilities we will leave for future generations.

This means environmental burdens such as future refurbishment should be more significant liabilities in a life-cycle analysis than they are in a whole life cost analysis.

Davis Langdon has developed an approach to measuring embodied carbon in construction. This article sets out the background to the initiative, the importance of embodied carbon and how it is assessed. We illustrate how embodied carbon impacts are calculated and use a case study to demonstrate opportunities to mitigate embodied carbon.

The timber canopy of the Savill building in Windsor Great Park was built using locally sourced wood, making it low in embodied carbon

02 What is embodied carbon and why is it important?

The embodied carbon emissions of a building are from the CO_2 produced during the manufacture of materials, their transport and assembly on site, maintenance and replacement, disassembly and decomposition.

While most CO_2 production is associated with the burning of fossil fuels, a lot comes from the release of fossilised carbon stores, for example in converting limestone to cement. Initial embodied carbon is associated with the original construction, while recurrent embodied carbon relates to that associated with consumables, repairs, maintenance and refurbishment.

Embodied energy has been part of the sustainability debate for many years, but methodological challenges and the focus of regulations on in-use energy and carbon, have kept it low on the sustainability agenda. Davis Langdon's latest initiative, designed as a pragmatic decision support tool, was motivated by the desire to raise the profile of embodied carbon.

A problem associated with carbon mitigation is that carbon is cheap, so financial instruments such as carbon trading do not have much of a deterrent effect. As such, it is important to measure the wider environmental impact to affect behaviour.

White goods labelling is an example of the potential for market transformation – most fridges and washing machines sold in Europe now have an A or A+ rating.

This trend also illustrates the importance of embodied carbon, as accelerated replacement cycles of fridges and so on in pursuit of greater operational efficiency could increase emissions in the short-term.

Considering the impact of manufacture, construction and refurbishment helps put these operational savings in context, hopefully resulting in well considered improvement initiatives with a positive carbon reduction profile.

03 Embodied carbon's relevance to construction

Embodied carbon emissions are worth serious consideration in construction for many reasons, including the following:

- Construction is energy-intensive. The materials sector alone accounts for 5-6% of total UK emissions, so any initiative to reduce them will make a significant contribution to meeting reduction targets.

  Furthermore, research suggests 70% of emissions are associated with manufacture and 15% with transport of materials. This means specifiers can really influence the carbon footprint of buildings.
- Embodied emissions are becoming more significant, as operational emissions of buildings fall in response to regulations. Studies suggest the embodied energy in domestic buildings may be equivalent to 10 times annual operational energy use; for complex commercial buildings, the ratio can be as high as 30:1
- Complex, lightweight building components are often more energy-intensive to make than conventional construction, a factor that is often ignored when "low-carbon" buildings are specified with high-performance components.

  This phenomenon is well-illustrated in recent "dust to dust" assessments of the environmental impact of cars, where a simple, robust, but gas-guzzling Jeep Wrangler scored highly compared with a mechanically complex, but explicitly "green" Toyota Prius
- Savings in embodied carbon emissions achieve significant "year one" reductions that will take many years to achieve through operational savings, for example, via on-site renewables or enhanced insulation. Furthermore, operational reductions are dependent on the performance of the building and could be lost through sub-optimal management or accelerated refurbishment cycles
- Shorter design lives and refurbishment/refit cycles increase lifetime emissions, and only the embodied assessment method reflects this impact
- Embodied carbon assessments take into account the use of low-carbon energy sources such as hydro-electricity and recycled materials such as steel and plasterboard and, so, can be used to support carbon-reduction initiatives by demonstrating the extent of year-one reductions.

In conclusion, embodied carbon accounts for a large proportion of construction's carbon footprint. The principle of "management requires measurement", which enables embodied impacts to be assessed on a like-for-like basis, can encourage greater mitigation efforts and facilitate informed decision-making.

Embodied energy assessments have been used to justify selecting individual components, including frame options, facades and finishes.

However, as embodied emissions are focused on a small number of high-mass or highly-manufactured components, it is important that a building-wide assessment is available so the most readily achievable sources of emissions reductions are targeted.

04 How embodied carbon can be measured

There are many challenges in assessing embodied carbon emissions. Many variables affect the carbon intensity of products, including manufacture, transport, primary energy sources and the extent of waste or recycling. It is sometimes difficult to calculate measures of embodied carbon unless there is a high degree of contextual knowledge, which puts a project team member such as a QS in a good position to make the assessment.

However, as some processes and products are more carbon-intensive than others – cement, aluminium and glass being good examples – it is not necessary to calculate the absolute total carbon footprint of a project, as many components will have a negligible impact and offer limited opportunities for mitigation. We have adopted an approach that focuses on the most carbon-intense and extensively used components, applying the principles of significant item cost estimating to the assessment of carbon, and adding an allowance for the remainder.

In developing Davis Langdon's embodied carbon assessment tool, the principal issues addressed include:

- **Units of comparison. Carbon emissions** C

04 How embodied carbon can be measured (continued)

mostly linked to energy consumption in the extraction and manufacturing processes. This consumption is measured on the basis of product mass. We have converted this mass-based data to more appropriate estimating quantities used in cost plans

- **Data availability. Wider adoption of life-cycle assessment (LCA) means there are multiple sources of embodied emissions data, but this is not necessarily consistent or applicable to construction products. Most data, for example, relates to materials that require further processing or fabrication. We are developing our own library of composite items, including complex systems related to building services and external walling. This will be expanded to take into account the bespoke aspects of our projects**
- **Simplifying complexity. With complex components it is helpful to separate primary components from the processes required to finish them. Many embodied carbon emissions follow mass, so a useful rule of thumb is to focus on the most numerous and heavy components. In curtain wall, for example, we focus on the mass of aluminium and the type, number and thickness of glass sheets, then consider treatments to the aluminium and glass. Other elements with less impact, for example gaskets, can be factored in using adjustments**
- **Manufacturing energy. Measures of energy used in manufacturing complex products are not widely available, and assessments of the carbon footprint of these components needs to account for the energy intensity of all the processes involved and the basic materials**
- **Data consistency and ease of use. Data is variable and there is a steep learning curve. The most reliable sources tend to be subscription-based databases such as SimaPro, which uses the Ecoinvent data resource. Others, such as Athena, are also used. Be careful when using data from open-access sources, as this can be inconsistent.**

05 Case studies: how embodied carbon is calculated and applied

Case study A illustrates how a composite embodied carbon rate is built up for concrete ground slab options, based on ordinary Portland cement (OPC) and 30% pulverised fuel ash (PFA) mix. Calculations are based on a single square metre of slab.

- The original embodied carbon data is based on mass, so conversion to the built quantity is required for all components
- The results are expressed in units that are used in the original cost plan
- There are two or three items which have a significant impact on the total, in this case cement, reinforcement and disposal of excavated material. Other items account for less than 20% of the total. While the calculation must be detailed for carbon-intense items, those with low impact can be dealt with as a percentage adjustment, once the relationship is understood
- Changes to specification can have a dramatic effect on a building's footprint. Use of PFA in this example reduces the embodied carbon by nearly 19% compared with a standard concrete mix. There are many other opportunities to mitigate embodied carbon impacts
- Mitigation may be constrained by availability of substitutes, or the programme and costs. However, the embodied carbon approach helps ensure the issues are considered alongside a project's other success factors.

Case study B extends the assessment to a whole building, in this case a distribution centre. It is an abbreviated BCIS elemental summary and has been derived from the application of cost plan quantities to Davis Langdon's embodied carbon rates database.

The results of the assessment illustrate the impact of a few components on a building's carbon footprint. The ground slab is the most important element, accounting for 42% of emissions, but in cost terms it equates to only 17% of total cost.

The, frame, roof and external walls, account for the most value in shell construction – about 32% of both the carbon footprint and capital cost. While this shows carbon often "follows mass", the quantity of external envelope relative to floor area means walls and roofs also present an opportunity to reduce the carbon footprint.

The assessment also encourages proportionality. In this case, the results show mitigation efforts focused on finishes and services (equating to 10% of embodied carbon and capital cost) yield less cost-effective outcomes. For services, focusing on reducing in-use energy consumption would probably yield best outcomes.

A Material assessment: ground slab

Total embodied carbon emissions/m² of slab area 103.2

Concrete mix based on 30% PFA substitution of OPC

	Kg embodied carbon/unit	Kg embodied carbon/m² gifa
Excavation (m³)/ PFA mix	11.1	6.66
Disposal (m³)	16.7	10.02
Blinding, 75mm thick (m³)	9.0	0.72
Concrete, 200 thick, OPC cement (m³)	309.1	61.82
Reinforcement, A252 mesh (kg)	0.44	1.72
Movement joints (m)	8.7	0.44
Damp proof membrane (m²)	0.7	0.7
Insulation board (m²)	1.7	1.7
Total embodied carbon emissions/m² of slab area		83.8

Exclusions: demolition and disposal of slab construction at end of life

B Building assessment: distribution centre

	£/m² gifa	%	Kg embodied carbon/m² gifa	%
Substructure	59.00	17.4	146.5	42.3
Frame, upper floors and stairs	60.70	17.9	68.4	19.7
Roof	48.50	14.3	41.6	12.0
External walls, windows and doors	14.70	4.3	13.3	3.8
Internal walls and doors	0.80	0.2	2.3	0.7
Internal finishes	4.40	1.3	5.6	1.6
Building services installation, including dock levellers	31.80	9.4	30.2	8.7
External works and services	81.40	24.0	38.6	11.1
Preliminaries	37.50	11.1		
Total construction cost/m² gifa	338.80	100		
Total embodied carbon emissions/m²			346.5	100.0

Exclusions: site preparation, site abnormals, distribution centre and administration area fit-out, operating equipment, professional fees

The concrete structure of the Innovate Green Office in Thorpe Park business park, Leeds, gives it a high thermal mass, which helps cut energy bills. The high embodied energy was reduced by using recycled materials for the concrete and reinforcement

06 Making use of the assessment: reporting and mitigation

By reporting on clients' embodied carbon footprint, project teams will be able to provide, along with existing operational carbon measures, a more rounded view of the impact of their developments.

As data improves, advisers will be able to band buildings by their embodied carbon rating and clients will gain a greater appreciation of their and their project teams' roles in addressing carbon impact through:

- Intelligent specification, based on impact as well as ease of implementation
- Creating demand for products with low-carbon processes
- Encouraging demand to create market transformations in carbon-intensive sectors of the supply chain
- Fostering an appreciation of the impact of strategies such as renewable energy technologies
- Encouraging the use of recycled and recyclable products
- Designing for deconstruction.

The drive to consider end of life issues has been a surprising outcome of an initiative focused initially on "year one" carbon emissions. However, it is likely some materials may incur disproportionate future liabilities.

The most famous historical precedent is asbestos. While we hope no equivalent liability will emerge in the future, issues such as the disposal of CFC and HCFC-based foam insulation products, now classified as hazardous waste, illustrate the need for continual vigilance.

Conversely, some materials may have latent benefits. The recycling of metals such as steel or copper reduces energy use compared with manufacture from primary materials.

Even basic materials like bricks can be reused if the design and mortar specification are correct, and there are plenty of opportunities to reuse steel and aluminium sheeting.

Awareness of the carbon footprint of refurbishment may also help encourage loose-fit, long-life fit-outs to be commissioned, countering the trend towards short or refurbishment cycles.

07 Conclusion

Davis Langdon's work on embodied carbon has a long pedigree but only now is being applied to mainstream projects.

It is an evolving approach and our databases will become richer and more diverse as our project coverage increases. Project teams need to develop understanding of the processes which give rise to high levels of embodied carbon in the first instance and encourage the industry to achieve the degree of market transformation that has occurred in white goods and other sectors.