2.Low carbon

Making low-carbon material choices

Will Arnold, Jenny Burridge, David Moore, Keerthi Ranasinghe and Sean Wilkins argue that engineers should always look to specify the most suitable material for a particular project, and offer advice on how to use materials efficiently once a choice is made.

In August 2020, the Institution released a guide, *How to calculate embodied carbon*[1], outlining a consistent approach for structural engineers to use in tracking embodied carbon on their projects. The guide enables engineers to calculate both the upfront carbon (modules A1–A5), whole-life carbon (modules A–C) and potential future benefits (module D).

Embodied carbon is a fantastic metric to compare efficiency across different material types, and while it is only part of the wider sustainability picture, it is a current topic of choice due to the need to dramatically decrease carbon emissions around the world[2]. In this article, we look at the four most-used materials in structural engineering – masonry, reinforced concrete, steel and timber – and discuss how to make low-carbon choices for each.

Which material is lowest carbon?

All four materials, when detailed correctly, can last far longer than the typical design life of a building, and each has sustainability advantages and disadvantages. Historically, there has been much debate as to which material is 'lowest carbon' or 'most sustainable', but of course the answer is not as simple as that. As with all things in engineering, it depends on the situation – with different materials most suitable for different scenarios.

This statement is not ground-breaking. Research in 2012 by Arup and The Concrete Centre[3] showed little difference between the carbon emissions of different concrete and steel options for commercial, hospital and school designs. The study found that *'there was little difference between the embodied CO_2 of the different types of structural frames'*. More recently, Buro Happold's 'Embodied carbon sensitivity study'[4] showed similar results, demonstrating that efficiently designed timber, steel or concrete frames could lead to a similar carbon footprint per m².

In both papers, greater carbon differences are demonstrated through decisions about column grids and imposed loads, for example, rather than through material choice alone.

We can do our own 'back of an envelope' study by estimating the amount of carbon in three different beams of similar capacity. **Table 1** shows three structural elements with similar strengths and similar carbon footprints as an example.

Of course, different carbon factors would give different numbers again, but the general principle remains – there is currently no single structural material that can be considered 'lowest carbon' as a rule of thumb across projects.

Therefore, we cannot ask, *'which material is lowest carbon?'*, as if this will ensure that we have no more work to do to reduce our structure's carbon footprint. Instead, we must understand which structural system is lowest carbon, driven by a combination of options such as materials, grid, construction type, etc; and varying based on project drivers such as ground conditions, building height, climatic conditions, floor loading, etc.

As such, in this article, we propose asking instead, *'which material is better for this situation?'*, closely followed by *'and how do I use that material as efficiently as possible?'* – with embodied carbon used as the key metric for both.

> **"WHICH MATERIAL IS BETTER FOR THIS SITUATION AND HOW DO I USE THAT MATERIAL AS EFFICIENTLY AS POSSIBLE?**

Which material is better for this situation?

All these studies reinforce the need to work with materials that can be sized appropriately for the spans and loads that they will support.

So, while long-span, high-load and high-rise structures might be most efficient when built in steel or concrete, timber may often be the better option for small/medium-scale or cellular buildings. Roof structures, with self-weight dominating, often lend themselves to steel or timber. Masonry facades and partitions should be used structurally in many circumstances. And clearly elements in contact with the ground need to be made from a material durable enough to be permanently wet.

Of course, the only way to definitively choose the lowest-carbon option is to quantify the carbon in each option as accurately as possible. These calculations should form a vital part of our work, and they make a persuasive argument with which we can direct the material choices of a project. This is particularly so during the concept and scheme design stage when we have the greatest opportunity to influence the design direction.

The reader is reminded to refer to the Institution guide, *How to calculate embodied carbon*, to calculate the upfront and whole-life impact of each option. The article, *A brief guide to calculating embodied carbon*[5], also contains an example hand-calculation outlining the approach, and we highlight again that an Institution Carbon Tool is forthcoming this year.

Once material choices have been made, we must continue to maximise our efforts to use these as efficiently as possible.

TABLE 1: Embodied carbon estimates (modules A1–A3 only) across three different structural options

Element	Cross-sectional area [m^2]	9m long beam weight [kg]	Upfront carbon, modules A1–A3 [$kgCO_2e/kg$]	Embodied carbon [$kgCO_2e$]	*Assumptions*	*Reference from* How to calculate embodied carbon, *Table 2.3*
Glulam beam, 750d, 480w	0.360	1620	0.512	~830	*European FSC glulam*	*Glulam, 100% FSC/PEFC*
Concrete beam, 600d, 400w	0.240	5184	0.12	~830	*UK-produced typical concrete and rebar*	*Unreinforced concrete, C32/40, 25% GGBS*
1.6% reinforcement	0.004	271	0.76			*UK: UK CARES sector average EPD*
Steel beam, UKB 610×178×82	0.010	738	1.13	~830	*Average European steel*	*European steel: Bauforumstahl average EPD*

And how do I use that material as efficiently as possible?

Due to the differences between structural materials, the approach to minimising the impact of one's design also varies. The Climate Emergency Task Group has commissioned several articles that will consider the sustainable specification of different materials, and others[6] that discuss efficiencies regardless of material, such as minimising construction, reusing site-won materials, keeping spans short, avoiding the use of finishes, and targeting high utilisations (all available at www.istructe.org/climate-emergency).

Other design resources, such as LETI's *Embodied Carbon Primer*[7], contain guidance on using different materials efficiently. Here are a few of the most impactful:

Masonry

Key reference: Brick Development Association *Sustainability Report 2019* (https://brick.org.uk/admin/resources/2019-bsr.pdf).

- Maximise lifespan through correct detailing (movement joints, overhangs) and specification of the masonry and mortar.
- An unfired brick system with much lower embodied carbon may be suitable for internal non-loadbearing walls and can also help with humidity regulation.
- For concrete blocks, specify the use of cement replacements whenever possible. Many manufacturing plants can provide low-cement units with properties similar to normal units for little or no increase in price.
- For a circular approach, it is advised to use a mortar which is suitable for the exposure category, but no harder than necessary. Hard concrete mortars are less easily removed from brickwork at the end of life.
- Where possible, designing unreinforced masonry removes the need for both the rebar as well as the grout (a cement-rich flowable concrete). If reinforcement is required, use partially grouted masonry rather than fully grouted. Unreinforced brickwork is also easily adapted to allow for changing use, thereby minimising the requirement for demolition.
- Ensure that wall and opening geometries fit to the standard brick or block module to minimise wastage on site.

Reinforced concrete

Key reference: *Specifying Sustainable Concrete* by the Concrete Centre (www.concretecentre.com/Publications-Software/Publications/Specifying-Sustainable-Concrete.aspx).

- Consider the embodied carbon of the whole reinforced section to find the right combination of slab or beam depth, reinforcement rate and concrete strength for the overall lowest-carbon solution. For example, voided, post-tensioned, ribbed or waffled slabs will result in lower material and carbon quantities than flat flabs. Post-tensioned systems may offer further savings through optimised tendon layout[8] (note that PT may require increased cement content to reduce creep).
- Utilise as much concrete curing time as the schedule makes possible, as this will allow for more cement to be removed or replaced in the mix. Work with the contractor to try and enable a concrete based on a 56- or 72-day strength rather than the typical 28.
- Utilise cement replacements where available, as Portland cement content is the main driver behind a mix's emissions. Ground granulated blast furnace slag (GGBS; from iron production) and fly ash (from burning coal) are two of the most common, but others include silica fume, limestone powder, pozzolanas (volcanic rock) and other waste ashes – though these may require increased pre-construction testing. A combination of several replacements may be of benefit. Aggregate replacements can also be used.
- Calculate whether piles or shallow foundations are more efficient and avoid over-standardising foundation sizes across the site. Consider high cement replacement percentages for foundations (up to 80% GGBS may be possible).
- Use admixtures where they can reduce the amount of cement required (e.g. by increasing workability and thus reducing the water content).
- Investigate the use of novel lower-carbon concrete technologies coming onto the market.

Steel

Key reference: Steel Construction *Sustainability* webpage (www.steelconstruction.info/Sustainability).

- Understand the range of possible carbon factors between the electric arc furnace (EAF) and basic oxygen (BOS) steelmaking routes. This is important when comparing steel options with other materials. Current guidance advises the use of carbon factors based on average regional consumption mixes, but understanding the range will allow you to estimate how much higher- or lower-carbon the final procured steel could be compared with your initial figures.
- Composite design, possibly with lightweight concrete and braced frames, will lead to a lighter structure. Note that welded studs reduce end-of-life reusability potential – refer to SCI guide P428[9] for guidance on

demountable composite construction systems, although the steel can still be recycled.

- Long-span deck systems to eliminate intermediate framing often result in a lower total carbon footprint when slabs and beams are summed.
- High utilisations can be targeted for each individual beam rather than keeping all elements similarly sized. Fabricating beams (uniform, tapered or cellular) can minimise material usage, but these may be more expensive and may need more energy to produce than standard rolled sections.
- An early decision should be made between end-of-life reuse versus lowest carbon today. Where circular economy and reuse is prioritised, maximise this through the use of non-composite connections, and ensure that an accurate asset library is created for the project. See further references published by the IStructE and UKGBC on the circular economy[10,11], and refer to SCI guide P427[12] for guidance on reclaiming steel sections for use today.

Timber

Key reference: TRADA *Sustainability* webpage (www.trada.co.uk/ad-hoc/sustainability/introduction).

- Always use FSC or PEFC-certified plantation-grown timber (with chain of custody), replacing harvested wood with new saplings and ensuring that future carbon sequestration takes place[13].
- Consider the full range of timber options to minimise the volume of wood. Engineered wood systems (CLT, glulam) are popular for their speed, but lightweight timber studwork and prefabricated cassette panels could bring material efficiencies, lower embodied carbon factors, or lower transport distances.
- Transport emissions can make up a relatively high proportion of the embodied carbon of timber structures. Research whether there are any suitable local timber sources that could be used for your project.
- Detail timber carefully to protect it from moisture and rot. Design to keep the timber sheltered and off the ground, avoid standing water, and pay special attention to roofing details with multiple waterproof layers.
- Use reversible fixings (bolts and dowels) instead of permanent ones (glues) to allow for end-of-life dismantling where possible. Note also that some treatments and finishes could complicate end-of-life options.
- Where possible, prioritise timber sourced from biodiverse forests, offering additional benefits to our ecosystem beyond carbon sequestration.

Other

Key references: IStructE blogs on *Nine recommended reads on earth and straw* (www.istructe.org/resources/blog/nine-recommended-reads-earth-straw/) and *11 recommended reads on using timber and bamboo* (www.istructe.org/resources/blog/11-recommended-reads-timber-bamboo/).

- Lower-carbon alternatives – such as cob or compressed earth bricks, sand bedding, rubble stone footings and bamboo – all have their place alongside 'the big four' construction materials discussed in this article. Where there is a potential appetite from the client to exploit one of these, run the carbon calculations early on and agree a carbon target aligned with this material, and then maximise the efficiency of it!

HAVE YOUR SAY

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