3. Lean design

How to achieve a SCORS A rating using current materials and technology

Muiris Moynihan takes structural engineers though a series of actions they could take to lower the embodied carbon of projects to a SCORS A rating.

The science is now unequivocal – climate change is happening, and human activities are the main cause; we must act now to mitigate the worst consequences. Structures are responsible for a significant amount of embodied carbon emissions: current practice in buildings results in upfront carbon emissions of 300–600kgCO_2e/m^2 for the structure[1–3]. However, there are significant reductions that can be made using current materials and technology if we:

- design more efficiently
- construct more efficiently.

We can reduce embodied CO_2e by ~75% if we implement all the initiatives outlined below, which would mean a typical building structure contains 123kgCO_2e/m^2. For a 5000m^2 office building, the reduction in carbon emissions is 1 885 000kgCO_2e, equivalent to 940 years' worth of cutting meat, dairy and beer from your diet[4].

This isn't all the way to zero carbon (we still need reuse and new materials to do that), and it might not be possible to realise every saving on a single project – but a very low carbon footprint is possible with the technology and materials we have right now.

Designing efficiently

We have a duty to our clients and to society to apply our skills and abilities to make best use of materials and design efficiently. As a profession, we design conservatively to keep people safe; however, there is evidence that we are over-conservative in places in our assumptions about loading, serviceability requirements and appropriate utilisation.

Target high utilisation (30% saving)

Research suggests that a ~30% reduction in material could be achieved in structural frames by ensuring that utilisation ratios are kept as close to 100% as practicable for every element[5]. Evidence suggests that two factors work against this[6]:

- **rationalisation:** designers routinely reduce variation in beam selection or rebar layouts in order to: i) reduce design/drawing/checking time (hence, fee); and ii) simplify procurement and construction
- **worries about errors ('sleep at night' factors):** designers overdesign structures so that there is excess capacity to ameliorate any mistakes that occur in calculation, draughting, manufacture or installation.

While both behaviours are understandable and stem from good intentions, they add unnecessary carbon emissions.

A more efficient approach would be to design targeting 100% utilisation (using software to do this quickly) and then engage with the contractor to understand if/where it is beneficial to put material back in.

Challenge load allowances (10% saving)

Imposed loads for London offices are still often set at 4+1 = 5kN/m^2, whereas Eurocode recommends 2–3kN/m^2. Research has shown the lower values to be more than sufficient for most scenarios[7] – and using them would reduce carbon by 10%[8].

FIGURE 1: Modern methods of construction (precast columns, facade panels, bathroom pods, etc.) can enhance quality and safety while reducing material use. Cadence building, Kings Cross pictured

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Table 1: Estimated carbon savings as applied to typical building

Change	CO_2e savings estimate	Values for a typical building structure	
		$kgCO_2e/m^2$	%
None (current practice)	–	500	100%
Challenge load allowances	10%	450	90%
Reassess serviceability	25%	337	68%
Target high utilisation	30%	236	47%
Optimise manufacture	30%	165	33%
Reduce material partial factors	20%	132	27%
Reduce waste	2%	130	26%
Use 56-day strengths	5%	123	25%

Engineers can also be overzealous when allowing for future loads: while having long-life structures is also required to minimise future emissions, allowing for adaptability (e.g. enabling future addition of extra members or strengthening) can be a more resource-efficient way of achieving it[9].

Reassess serviceability (25% saving)
Serviceability limits, such as for deflection, often govern structural design, yet too often are excessively conservative. Engagement with clients and the supply chain at appropriate points in the design process can mitigate this by:

- understanding what limit is appropriate for the end user, e.g. could span/360 deflection limits be relaxed to span/250? Is a response factor of 4 absolutely necessary for an office floor or would 6 or 8 suffice?
- adjusting slab-edge deflection limits when the cladding supplier is appointed and can advise the specific capabilities of their system.

Furthermore, given it is a serviceability limit state, stiffness contributions from partition walls or secondary steelwork/concrete could be added into deflection analyses to augment the response of the primary structure. It is estimated that coupling these contributions with relaxing limits by 30–50% could give a 25% carbon reduction.

Constructing efficiently

While many structures are still built in a 1950s, *in situ* manner, modern methods of construction (MMC) are becoming increasingly attractive as a way to enhance quality and safety while also offering the potential to significantly reduce material **(Figure 1)**. Factory environments are more controlled workplaces with the potential to leverage economies of scale, while automated systems offer the ability to more closely tailor manufacturing output to design requirements.

Optimised manufacture (30% saving)
Robots can manufacture complex arrangements efficiently, e.g. changing reinforcement bar diameters, lengths and pitches to closely match steel provision to that required, or fabricating steel beams with variable thicknesses or depths, reducing material by 30% in some examples[10], all while increasing build quality.

Material partial factors (20% saving)
Design codes assume a traditional level of workmanship and inspection in construction; in the Eurocodes these are included in the material partial factor values. Placement tolerances and material properties (e.g. concrete strength) can be more closely controlled off site, resulting in a reliably more accurate construction. Eurocode clauses enable this increased quality to be reflected in a reduction in the material partial factors[11]. Applying this reduction to columns on a UK project resulted in a 20% reduction in embodied carbon.

Reduced waste (2% saving)
Building products for multiple projects on a single production line offers the opportunity to use offcuts from one project on the next and eliminate the need to over-order materials to de-risk construction. On-site construction commonly features abortive work and rework caused by trades working in close proximity or out of sequence; by contrast, factory work typically eliminates such issues. These effects can reduce waste from the 5% typically seen on site[4].

Using 56+ day strengths (5% saving)
Twenty-eight-day concrete strengths are specified; however, particularly for off-site manufacture, the concrete is often more mature than this when it is loaded. Fifty-six-day strengths are 15–20% higher[12], and could therefore enable lower cement mixes to be used, potentially reducing carbon contents by ~5%.

Summation

Obviously, the above savings cannot be arithmetically summed – instead, they compound in the order shown in **Table 1**. The first two columns list the changes described above with an estimate of the savings potential; the latter two columns apply these reductions to a typical 500$kgCO_2e/m^2$ (average of sources 1–3) structure to show the absolute and percentage values.

As can be seen, the net effect is a sizeable 75% reduction, resulting in a typical building structure of just 123$kgCO_2e/m^2$ – less than the 150$kgCO_2e/m^2$ required to achieve a SCORS A rating[1]. SCORS sets this target for 2030, but fortunately we can achieve it immediately.

So, what's stopping us?

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