3.Lean design

Lean design: 10 things to do now

Natasha Watson **explains how structural engineers can produce designs that make efficient use of material to reduce their environmental impact.**

The June issue of *The Structural Engineer* introduced six themes for climate guidance. One of these was 'Lean design', calling on structural engineers to strive for designs that minimise the demand for new material wherever viable.

This article gives pragmatic advice on reducing the impact of your buildings on the environment today, in order of magnitude of savings.

1. Don't build!

It might seem counterintuitive, but a structural engineer's job is to ensure that the underlying objectives behind creating a space are met, and not necessarily to design and create new structure to achieve that. See Ibell *et al*[1] in the June issue.

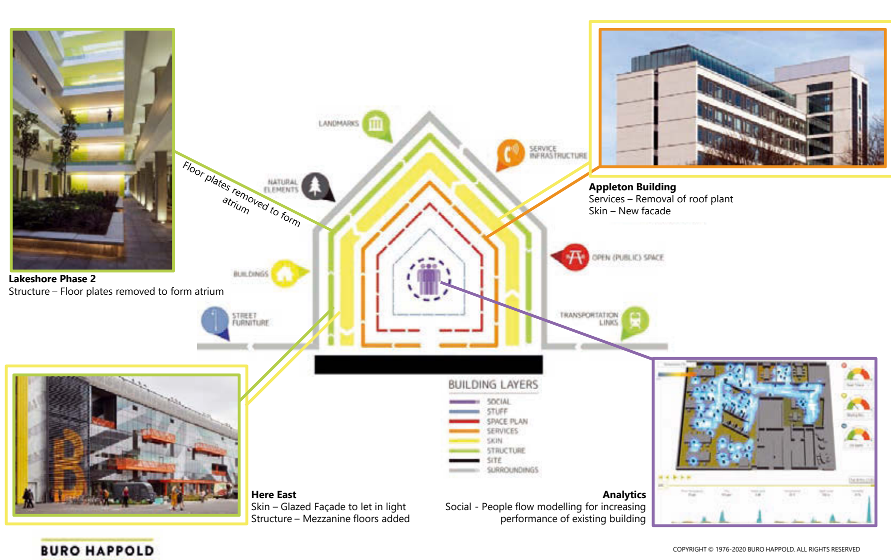
2. Upgrade existing buildings wherever viable

There are many ways of upgrading existing buildings, from space planning to significant structural interventions. Even if the superstructure is demolished, the foundations may be suitable for reuse[2].

Using the Brand model[3], which considers a building as a series of layers with varying longevity, these different layers of intervention can be systematically explored **(Figure 1)**[3,4].

Alternatively, if it is not viable to reuse an existing building, new buildings can be designed with circular principles in mind, such as design for disassembly or proportionate repair.

FIGURE 1: Building layers[3,4]



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3. Maximise utilisation

Results from the MEICON 2018 survey[5] indicate that ease of construction, a perceived risk of construction errors, and a lack of significant penalties for overdesign all have an adverse impact on the final utilisation ratios of our structural elements. Moynihan and Allwood[6] found average utilisation ratios to be below 50% for typical steel buildings.

Buro Happold has produced guidance for its structural engineers that focuses on increasing minimum utilisations to acceptable levels, which change as a project progresses **(Figure 2)**. Working to lower utilisation ratios gives designers leeway for late design changes and flexibility, and so working to higher minimum utilisations requires appropriate quality controls, such as:

- contractual obligations for design refinement
- colour-coding utilisation ratios within BIM models
- recommendations that project managers allow a certain time/cost in bids or budgets for optimisation.

It is important to communicate to the project team the value of the time and fees spent on design development and refinement, with the potential material savings leading to cost and carbon reductions.

4. Interrogate serviceability criteria

If the limiting utilisation of a structural member is for a serviceability criterion (e.g. a deflection limit), then it is worth pursuing the relaxation of those criteria in consultation with the client and wider project team.

- **Facades –** are the facade contractor's limits realistic and based on the actual conditions or generic and can be challenged? Can you perceive a span/360 deflection with the naked eye?
- **Internal partitions –** can larger deflection heads and vertical joints be used as standard? Deflection heads can have detrimental impacts on acoustic performance; can the acoustic criteria be relaxed?
- **Long-span beams and slab deflections –** can you pre-camber? Can you use a lower-strength element or material as SLS is governing? Can you assume additional stiffness by assuming that connections are somewhere between pinned and fixed?
- **Dynamic criteria –** are the limits set appropriate for the intended use; could some localised exceedance be accepted?
- **Crack width requirements –** crack widths should only govern if water-tightness is necessary.

5. Refine loading criteria

Conservative loading assumptions can be appropriate at early design stages where the brief is fluid and there are many unknowns.

For permanent and semi-permanent loads, the different layers of the building are typically finalised as the design progresses, and so refinement is more straightforward. Imposed loads **(Figure 3)**, though more difficult to refine, can be adapted in several ways.

Imposed load reduction

According to BS EN 1991[7], imposed loads can be reduced if loaded areas are greater than 10m² (α_A) and if the structure is three storeys or greater (α_n).

$$\alpha_A = \frac{5}{7}\psi_0 + \frac{A_0}{A} \le 1.0$$

with the restriction for categories C and D:
$\alpha_A \ge 0.6$

where:
ψ_0 is the factor according to EN 1990, Annex A1 Table A1.1
$A_0 = 10.0\text{m}^2$

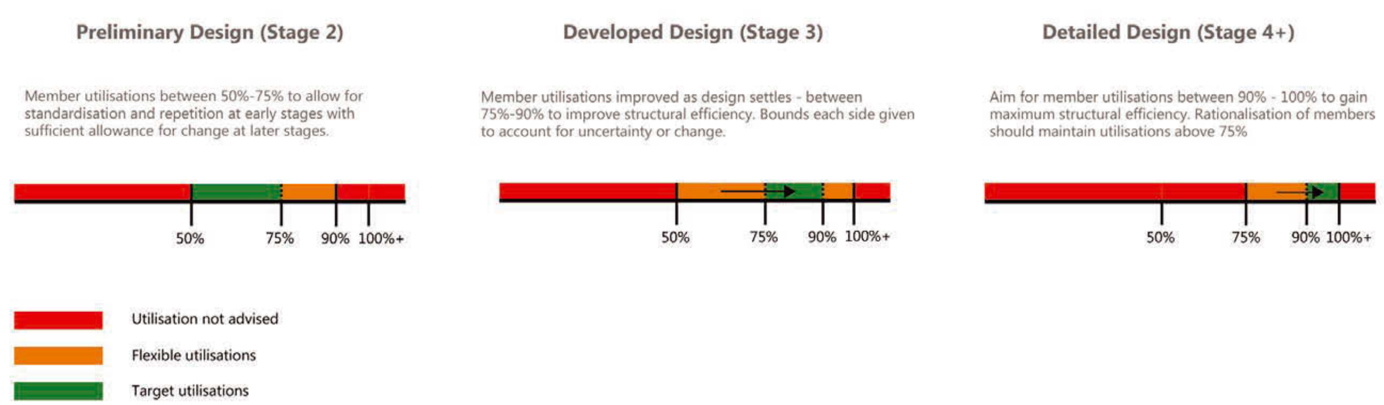

FIGURE 2: Target utilisation rates for each design stage

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A is the loaded area.

$$\alpha_n = \frac{2+(n-2)\psi_0}{n}$$

where:
n is the number of storeys (>2) above the loaded structural elements from the same category
ψ_0 is in accordance with EN 1990, Annex A1 Table A1.1.

Minimum appropriate imposed loading
BS EN 1991 gives loading categories to cover most building uses, and the minimum appropriate value should be used (e.g. refining a plant room loading of 7.5kN/m^2 for the weight of actual plant proposed for the space). Furthermore, the appropriate partial factors should be applied when more than one load value is present.

Clear brief
When preparing options at concept stage, create an option with the minimum appropriate loading available, and the subsequent cost and carbon savings. These should be discussed with the client so that they understand the importance of clarifying the uses of the spaces.

6. Design for use now, and strengthen if use changes

The urgency of climate breakdown means that we must prioritise today's emissions[8]. We should not be designing buildings with initial redundancies which may never be needed, but instead designing for the current use of a building, with a strategy for how strengthening of the building could be achieved in the future.

Buro Happold conducted a study on a simple concrete frame with initial redundancy versus a design without redundancy in the floor slabs only. The latter had 12% less material compared with the design with initial redundancy, and strengthening only added 3% of this back in **(Figure 4)**.

7. Concentrate on reducing grids and floor slabs

Various studies indicate that floors typically account for 40–50% of the embodied carbon of a building. Structural sensitivity studies[9] show that an infallible way of reducing the material required for floors is to reduce the size of the structural grid **(Figure 5)**[10].

If time and/or the fee is tight on a project, concentrating your efforts on refining the floor slabs of the structures can make significant embodied carbon savings.

8. Don't forget substructure

Substructure typically forms 20% of the total embodied carbon that a structural engineer has direct control over **(Fig. 5)**. Below are a few substructure-specific considerations:

- **Avoid basements and suspended floor slabs** where possible.
- **Use the superstructure and the site to minimise foundations.** To minimise foundation sizes, the proposed superstructure must work with the ground that it sits on. If the ground is poor, the superstructure should be light or designed to accept greater movements.
- **If designing driven steel piles, use reclaimed steel tubing** from the oil and gas industry where possible.
- **Specify a low-cement-content concrete** with the lowest strength appropriate, especially if a GEO load case is limiting.
- **Design for 56-day strength.** Typically, foundations will not be subject to their full design load until later in the construction programme.
- **Refine settlement criteria.** Settlement criteria for foundations are often chosen as a

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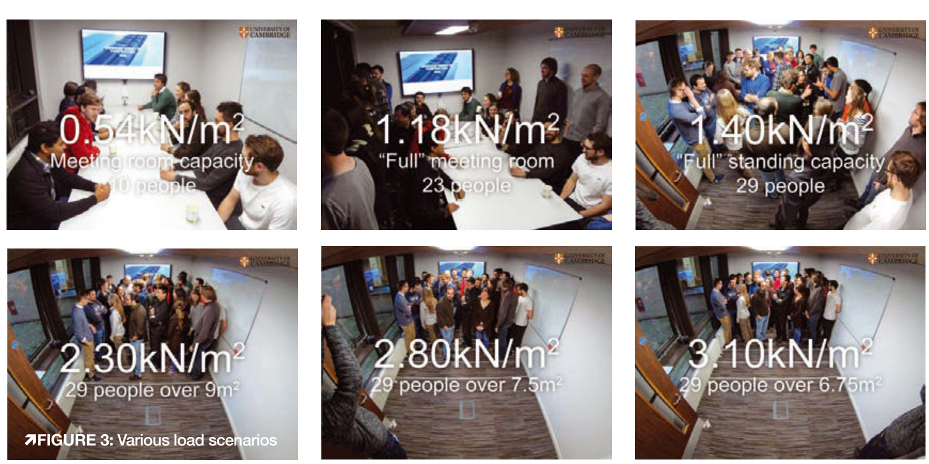

FIGURE 3: Various load scenarios

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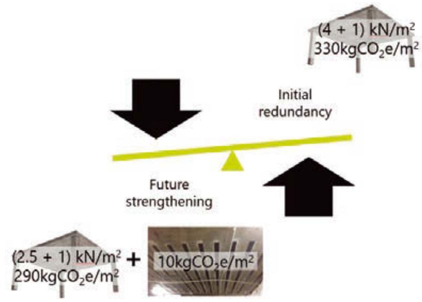

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FIGURE 4: Comparison of material use in two alternative designs

'typical' differential settlement and maximum settlement value, rather than as a value that is appropriate to the individual structure. This 'one-size-fits-all' approach can lead to an increased quantity of foundations and substructure.

- **Ensure a timely and appropriately detailed investigation.** Appropriate ground and site investigations can increase confidence in the soil assumptions used for substructure design, minimising the chance of having a conservative design born from uncertainty.

9. Avoid CEM 1 designations

The embodied carbon of concrete is dominated by the production of Portland cement, and the designation of CEM 1 mixes should therefore be avoided wherever possible. As a minimum, use 20% cement replacement within the superstructure, substructure and blinding.

During the construction of a project, subcontractors may request a change of mix to CEM 1 in order to have higher early-day strengths to make up for lost programme. However, by working with the subcontractor, you can determine the required strengths at the required times and compare these against the typical strength gain curves for your initial design mix; mitigating the need for a CEM 1 mix.

10. Keep learning, talking and sharing

We need to work together and share our knowledge so that we can learn from our mistakes and progress faster to mitigate climate change and lead ourselves into a more sustainable future.

USEFUL RESOURCES

LETI
www.leti.london/
A number of useful guides on low-carbon design.

RICS BUILDING CARBON DATABASE
https://wlcarbon.rics.org/Default.aspx
The recommended place to share embodied carbon calculations in the UK.

ISTRUCTE CLIMATE EMERGENCY HUB
www.istructe.org/climate-emergency
Resources to help structural engineers respond to the climate emergency.

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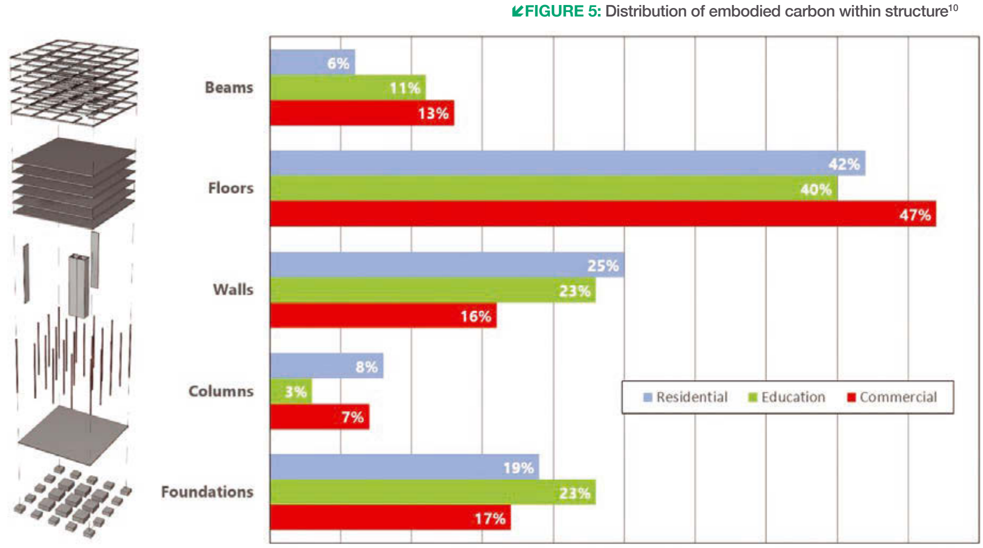
FIGURE 5: Distribution of embodied carbon within structure[10]



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FURTHER READING

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