

I 3. Lean design

What do we mean by efficiency? A holistic approach to reducing embodied carbon

Ben Gholam describes the development by Price & Myers of a parametric benchmarking tool to allow engineers to produce scheme designs with the lowest embodied carbon.

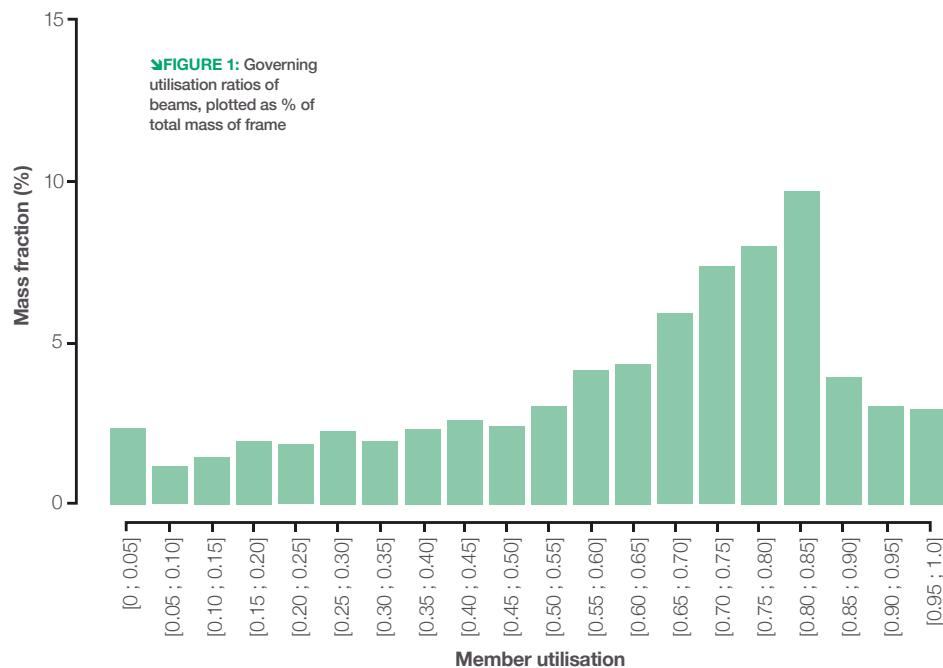
Introduction

Efficiency is something that we all strive to achieve as designers, but it is also something that is very difficult to define. Some define the efficiency of a structure in terms of its cost and programme, while others focus on utilisation of members, or the overall amount of material per m². However, in the face of the global climate emergency, we also need to consider a building's whole-life carbon, which includes its embodied, as well as operational, carbon.

Architects, MEP engineers and sustainability consultants have, in recent years, been very successful in reducing operational carbon. This has been driven by both legislation and the financial savings to the client available from reduced energy bills. These legislative mechanisms do not currently exist for materials, which can also be so cheap in relation to the overall construction cost that there is often little financial incentive to make reductions.

As part of a consortium with the University of Cambridge, the Steel Construction Institute and William Hare Group, Price & Myers recently completed an Innovate UK-funded study into the efficiency of steel-framed buildings in relation to both cost and carbon. The study showed that focusing on the optimisation of individual members is not always the best solution to minimising embodied carbon, and that more focus needs to be placed on optimising high-level factors such as grid spacings, foundation types and flooring types.

This project led us to create a parametric benchmarking tool, aimed at ensuring our engineers can rapidly produce scheme designs that represent the option with the lowest embodied carbon for the clients and architects we work with, while ensuring the relative costs can be assessed. This article summarises the work that led us to this



stage and our findings on the way.

Defining efficiency

Determining the amount of material in a frame is relatively straightforward with modern building information modelling (BIM) tools, but assessing utilisation ratios (URs) requires a bit more work. To do this, the first phase of the study¹ involved the collection of data for over 3500 beams from 30 projects, and the back-calculation of their URs. **Figure 1** shows the governing UR plotted against the fraction of the total mass of the beams (with UR = 1.0 being a 100% efficient member).

The graph indicates that less than 20% of the measured structural mass was mobilised beyond 80% utilisation, and that there is a clear drop-off after 80–85%. While the need to select

the most suitable section from a list of universal sizes means that, in practice, 'full' utilisation is often not achievable, this drop-off indicated that designers were either heavily rationalising sizes for procurement or detailing reasons, or were hesitant to push designs right to the limit, potentially for fear of future changes.

It is worth noting that, overall, this showed a cumulative 40% under-utilisation in terms of material mass. The conclusion here is that there is clearly a lot to be gained in terms of material efficiency by pushing the designs of beams closer to their full capabilities.

Utilisation vs geometry

This data related to individual beams, but logic dictates that there should be a direct relationship between the

overall utilisation of a floorplate and the embodied carbon. To demonstrate that this is not necessarily the case, consider two options for a simple three-storey ~4000m² commercial building. Option A (**Figure 2**) has a typical span of 15m, with all beams designed at maximum UR (say 99.9%). Option B has the more typical value of 80–85% (**Figure 3**) but has extra rows of columns decreasing the grids to 7.5m in each direction.

A crude embodied carbon estimate (for the steelwork only) gives 100kgCO₂e/m² for Option A, but only 40kgCO₂e/m² for Option B. In this example, the building that has been optimised still has an embodied carbon 2.5 times higher than the one that hasn't. (If we decide to optimise Option B and reduce steel by 15% as above, this value increases to almost three times higher.) The grid has a much more significant impact on the material use and the carbon figure than the optimisation.

The ability to influence this outcome changes as a project progresses. Optimising the members in Option B could be done right up to the fabrication process with little impact on the overall design (a 'local' factor), whereas changing the grid would have a wide-ranging impact and would need to be done as early as possible (a 'global' factor).

Decision-making

We started listing all decisions that could influence efficiency of both individual beams and overall floorplates, at all project stages, and separated them into two distinct categories (**Figure 4**).

A different set of drivers influences the outcome of each of these, and as structural engineers, we find many of these are often outside our control once the design has passed a certain point – with cost, programme and procurement taking precedence and usually dictating


THE GRID HAS A MUCH MORE SIGNIFICANT IMPACT ON THE MATERIAL USE AND THE CARBON FIGURE THAN THE OPTIMISATION

the global factors.

Coupled with the pressures of design fee and programme, the outcome is often a design that fulfils the brief but sacrifices structural efficiency – with the engineer limited to being able to adjust the local factors towards the end of the design process (**Figure 5**). This is a reactive process which – as we've shown – has the potential to make reasonable savings but may not allow the engineer to unlock the optimum design.

Interaction

Altering some of these global factors will typically lead to direct savings – such as lower imposed loads. However, some global factors are far more interconnected. Possible examples include:

- a reduction of dead loads resulting in lower foundation and column loads, but increased problems with vibration performance or uplift from wind
- an increase in structural zones and subsequent building height leading to lighter floor beams, but increased wind loads on the stability systems and cladding quantities
- a decrease in column grid reducing materials in the floors, but increasing overall materials (or costs) due to the increased numbers of columns and foundations required.

Therefore, a holistic approach that considers the relative impacts and interactions of all possible decisions relating to the global factors listed above needs to be taken. If done at a sufficiently early stage, this can influence the design brief, allowing the maximum potential for savings in materials/embodied carbon throughout the design process (**Figure 6**).

There is likely to be a single or limited range of options that provide the optimal balance between a project's cost and embodied carbon, and we needed a means for determining these.

One option would be to compare against benchmarked data for similar completed buildings. This is possible, but to ensure sufficient data to cover all

FIGURE 2: Option A for typical office building, with all beams designed to full utilisation

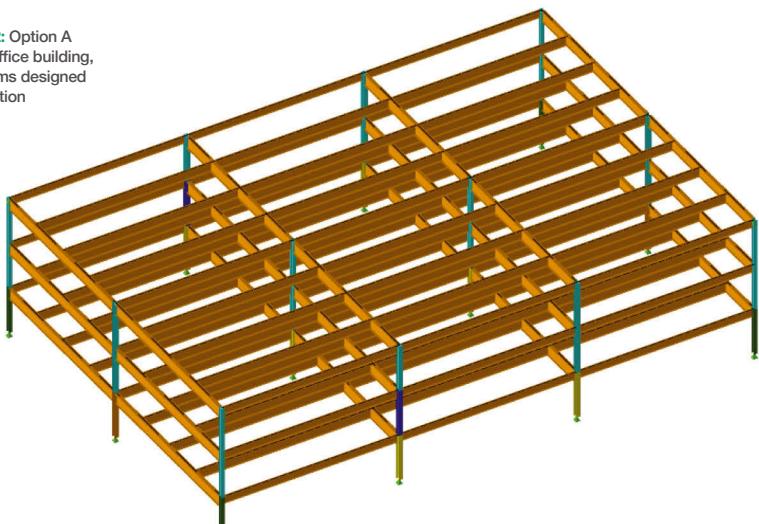
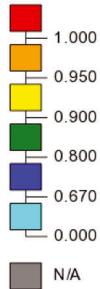
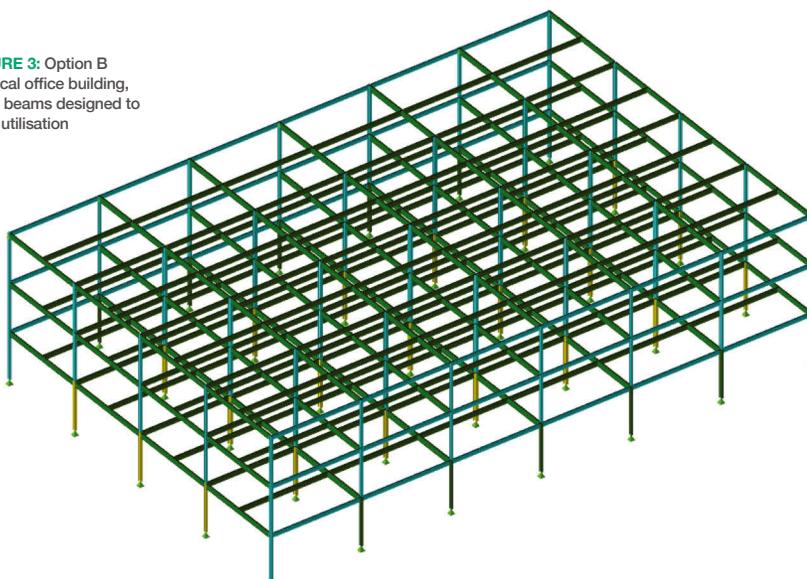
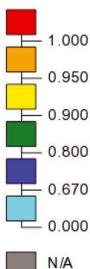
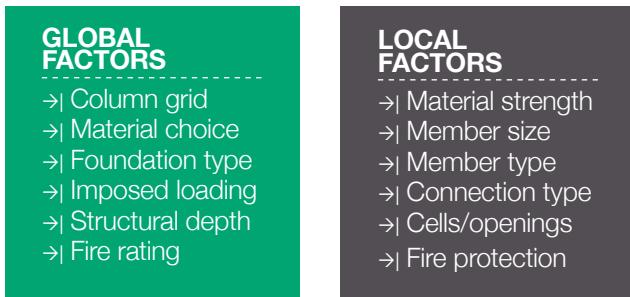
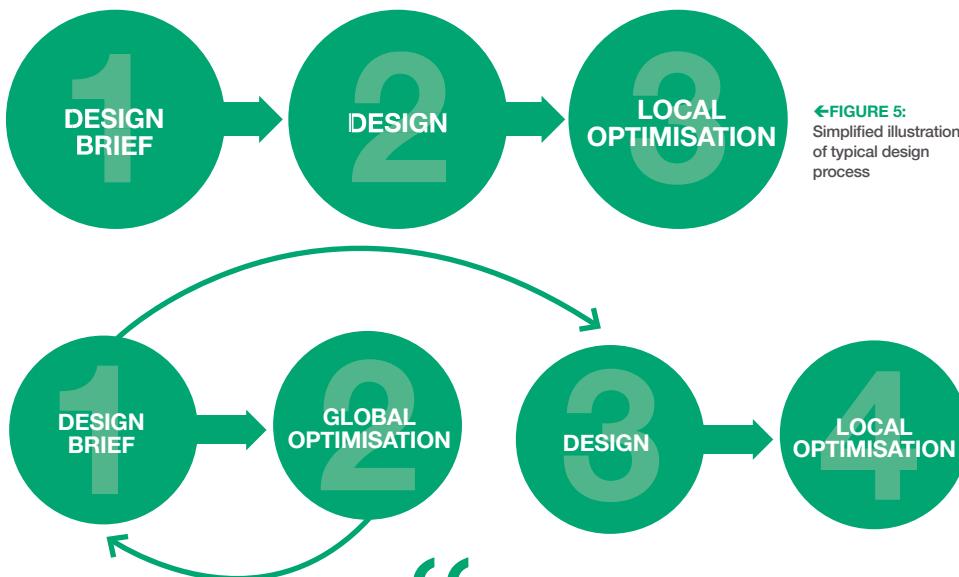


FIGURE 3: Option B for typical office building, with all beams designed to typical utilisation





◀FIGURE 4:
Breakdown of
design decisions
into those
considered
'global' and 'local'



◀FIGURE 5:
Simplified illustration
of typical design
process

◀FIGURE 6: Revised design process, showing how early-stage optimisation could affect design brief

scenarios, thousands of detailed cases would be required. A previous article in *The Structural Engineer* discussed the challenges of assembling a dataset of 80 benchmarked projects² – and this work would have to be repeated many times over to achieve sufficient numbers of examples.

We considered creating a large database of hypothetical structures, acting as a quick reference guide to the optimal grid under certain conditions. However, the grid is not the only consideration, and when other key global decisions such as material choice and foundation type are factored in, the number of potential scenarios needing to be assessed quickly becomes commercially unmanageable – which is where the benefits of parametric analysis come in.

PANDA tool

Our solution was to create a parametric benchmarking tool, enabling rapid assessment of all potential options for any given situation. Within a few months of starting development, we had

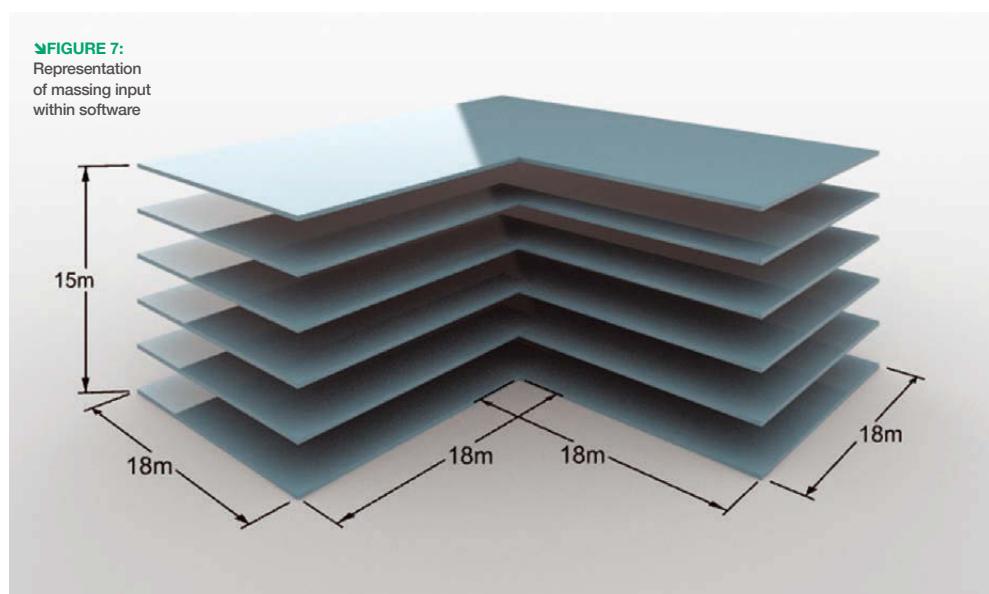
a functional prototype, able to output rapid comparisons for steel-framed superstructure options. It became known as PANDA (Parametric Analysis & Numerical Design Assessment). After realising its potential, we decided to apply for additional Innovate UK funding to continue the work into a second phase.

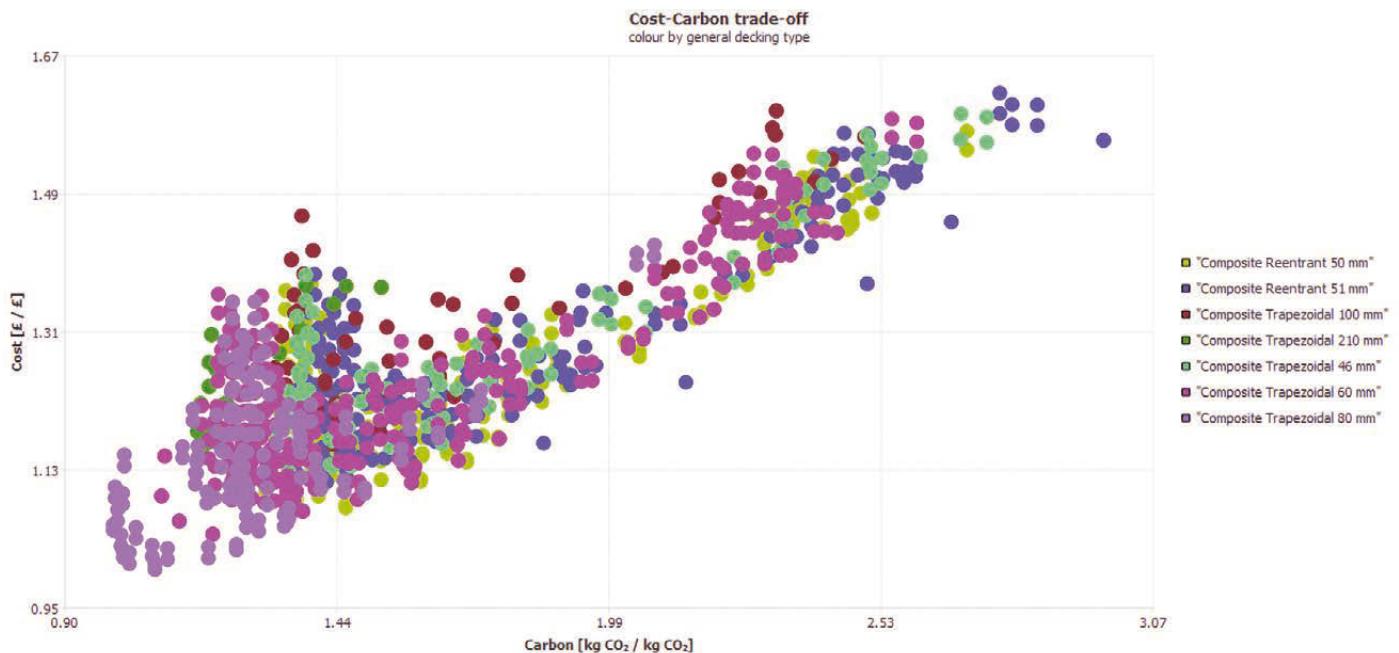
The tool has two parts: a design algorithm, and data comparison. In the design algorithm, the user inputs a simplified, orthogonal representation of the structure (Figure 7), and then sets parameters which cover a broad range of both global and local factors, including maximum/minimum grid spacings, loadings, material types and geotechnical data. The algorithm then assesses all possible combinations of all the various factors and carries out a full structural design for each.

Each valid design results in a detailed material and task list which is then run through a bespoke data model to assess the cost and embodied carbon of each option. The carbon data is based on the current (v3.0) ICE database³, with some adaptations made by the Cambridge team.

The cost model is being overseen by one of the UK's leading quantity surveying companies to ensure relevance to the current market. All data within the tool is fully customisable to ensure it can be adapted as the needs of the industry alter over time.

The software compares all these results in a graphical output (Figure 8), clearly showing the variation between the relative cost and embodied carbon for each option. The results can be viewed in terms of a wide range of variables





(decking type, grid spacing, etc.) and can be filtered as necessary to remove unwanted results.

The tool has been developed to enable comparison of steel, concrete and timber frames over a variety of different foundation types and is due to be launched across our practice later this year.

Our engineers will use this tool at early conceptual stages. Using basic information on massing, loading and ground conditions, an output report for a simplified version of the building can be produced within minutes. The effects of varying individual or multiple factors can then be rapidly assessed and quantified. The aim is that the fundamentals of the initial scheme design – the global factors which play such a key role in the eventual carbon figure – will be set at the best possible values, ensuring that our engineers are working to a design that is as efficient as it can be under the parameters of the design.

While this is not intended to be a full design tool and doesn't cover the intricate geometries often found on real projects, the level of detail provided will be sufficient to enable the generation of benchmarking values for cost and carbon. Any changes or developments to the scheme can be assessed against this initial benchmark, ensuring that the design team is confident about the impact of all decisions.

Impact and next steps

Achieving true net-zero will require a huge step change in construction methods

and materials, featuring both existing and new technologies. However, for the foreseeable future, high-carbon materials such as steel and concrete will remain an essential part of the mix. We therefore need tools such as PANDA to ensure we design as carbon-efficiently as possible, while still meeting fee, programme and cost constraints.

We will also need to liaise with clients, contractors and the rest of the design team to challenge decisions that result in things being done 'the way we always do them', and persuade others to pursue lower-carbon grids, loading and materials.

The greatest potential we have for influencing the final outcome is by ensuring the correct decisions are made in the critical early stages. We must therefore also ensure we are given the opportunity to feed into the design brief to enable this⁴. Optimising for cost and optimising for carbon are not mutually exclusive, and with better ways of quantifying and assessing the impact of the decisions made in designing a structure, we will be much better placed to advise the rest of the team and ensure our buildings can be as efficient as possible.

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For further information about the PANDA tool, visit www.pricemyers.com/news/parametric-cost-carbon-benchmarking-for-structural-frames

FIGURE 8: Graphical output from prototype parametric tool, showing cost vs embodied carbon for typical building in Fig. 7 and highlighting deck type variable

[benchmarking-tool-for-embodied-carbon-efficiency--24](mailto:bgholam@pricemyers.com) or contact Ben at bgholam@pricemyers.com.

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