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SESOC Top Tips for Low Carbon Design

SESOC Sustainability Task Force

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SESOC Top Tips for Low Carbon Design

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Disclaimer

The information in this guide is drawn from a wide range of resources as well as the experience of the authorship team, and the research focus groups. Following this guide does not guarantee a level of embodied carbon performance on an individual project. This guidance is intended for informational and educational purposes only, it is not intended to be used as a means of compliance with regulatory requirements or performance-based frameworks for embodied carbon.

It is important to note that this document is issued as guidance and that while it reflects the views of the Structural Engineering Society, it has no official status. However, designers are advised to consider the issues raised and the possible solutions offered when preparing designs, and to exercise their engineering judgement in determining a suitable course of action in this regard.

Where errors or omissions are noted in the document, it is requested that users notify SESOC through exec@sesoc.org.nz.

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Top tips for reducing structural embodied carbon

A guide developed by the SESOC Sustainable Design Task Force

1. Introduction

This guide has been produced to help inform and assist structural engineers in their efforts to decarbonise their designs, specifically for the Aotearoa New Zealand context. Each section of the guide will share a 'Top Tip' either from a design or management perspective. If applied successfully, the tips in this guide should result in ready to implement knowledge to reduce embodied carbon emissions from structures within the design process. Whilst some tips are more focused on buildings, most principles are applicable to all structural projects. Note these are not in any order of importance, they have been arranged based on typical project progression.

In 2023, the Structural Engineering Society of New Zealand (SESOC) obtained funding from BRANZ to undertake a research project with the aim of leveraging off the current state of knowledge and practice of structural engineers in low-carbon construction in Aotearoa New Zealand. A survey to understand the carbon knowledge base and drivers towards low carbon design of practicing structural engineers was issued to SESOC membership in August 2023, following which volunteers participated in focus groups to discuss potential pathways for low-carbon structures. The findings from the focus groups have subsequently been expanded by the SESOC Sustainability Task Force to form the current guide.

For more information around sustainability, carbon, and low-carbon best practice for structural engineers, we recommend checking out the SESOC Low Carbon Design Resource Map available on the SESOC website. This should provide plenty of background reading with both high-level and detailed options available.

What is embodied carbon, and why are we trying to reduce it in our structures?

The term embodied carbon is used to describe the total greenhouse gas (GHG) emissions associated with the lifetime of products or materials. It covers the whole life cycle, including raw material processing, manufacturing, any transportation to and from different locations, maintenance of the product and disposal of the

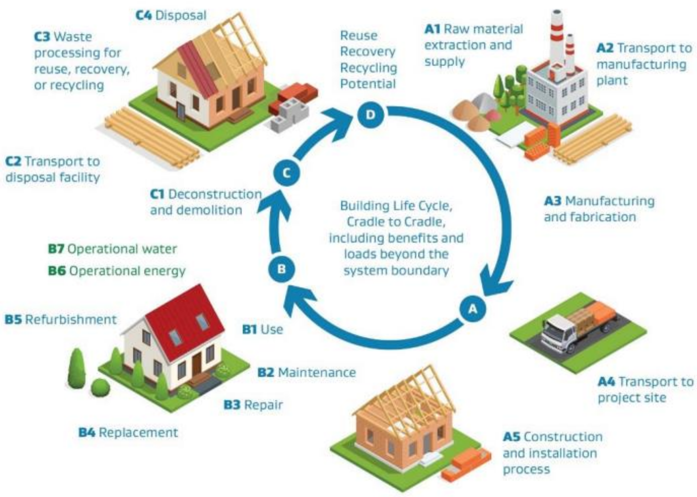

Figure 1 Building life cycle modules[1]

[1] Whole-of-life embodied carbon emissions reductions framework, Ministry of Business, Innovation and Employment, 2020 https://www.mbie.govt.nz/dmsdocument/11794-whole-of-life-embodied-carbon-emissions-reduction-framework

product at the end of its life. These are described as "life cycle modules", with a building example shown in Figure 1. As in many other countries, our construction sector has a growing understanding of the need to reduce annual GHG emissions. In Aotearoa New Zealand, we are responsible for ~15%[2] of annual emissions, increasing by 40% when including imported construction products. MBIE's Building for Climate Change Programme (BfCC) proposed new regulatory requirements[3], published in 2020. Under these requirements, the embodied carbon of a building would need to be calculated, reported and ultimately meet a cap for a building consent to be granted.

By monitoring embodied carbon throughout the design process, it can be used as a factor (alongside cost) to determine a project's success. In early project phases, the structural engineer is well placed to both calculate the embodied carbon and to advise the project team on structurally feasible lower-carbon alternatives. Just like quantity surveyors use approximations to account for uncertainty in assessing cost, structural engineers can do the same to measure and monitor embodied carbon. Global institutions have produced extensive resources[4,5,6] that can be used to upskill in this area. In Aotearoa New Zealand, BRANZ and NZGBC have developed an impressive repository of freely available embodied carbon information, including research reports, databases and tools[7,8].

The diagram below (see Figure 2) illustrates the gap between the embodied carbon of a 'business as usual' design- with no consideration of embodied carbon, and the potential pathway where embodied carbon is reduced throughout the process. In general, the hierarchy of carbon reduction on a project is firstly to reduce the quantity of materials, through re-scoping and efficient material use, and secondly to reduce the carbon intensity of the materials used.

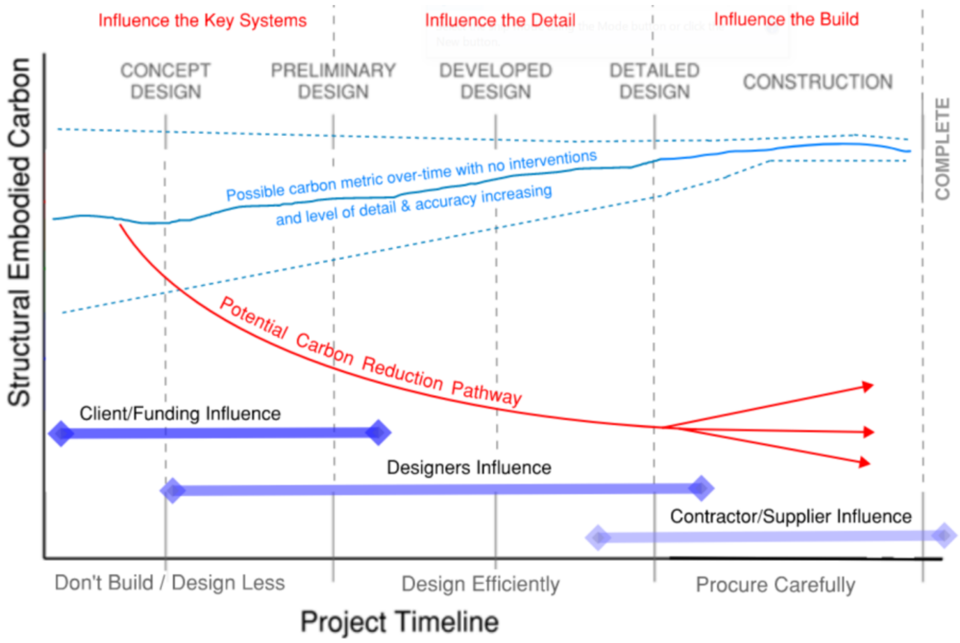

Figure 2 Figure of Carbon influence against design stage (courtesy Nick Carman)

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[2] National Emissions Reduction Plan, Ministry of the Environment, 2022 https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/building-and-construction/

[3] Whole-of-life embodied carbon emissions reductions framework, Ministry of Business, Innovation and Employment, 2020 https://www.mbie.govt.nz/dmsdocument/11794-whole-of-life-embodied-carbon-emissions-reduction-framework

[4] Sustainability Resource map, Institution of Structural Engineers, 2022 https://www.istructe.org/IStructE/media/Public/Resources/IStructE-Sustainability-Resource-Map.pdf

[5] Bringing embodied carbon upfront, World Green Building Council, 2019 https://worldgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2022/09/22123951/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf

[6] Embodied Carbon primer, LETI, 2020. https://www.leti.uk/ecp

[7] Whole-building whole-of-life framework for sustainable building design, BRANZ. https://www.branz.co.nz/environment-zero-carbon-research/framework/

[8] Embodied Carbon Calculator, NZGBC, 2023. https://nzgbc.org.nz/green-star-design-and-as-built#technicalresources

2. Glossary of key terms

Embodied carbon: The greenhouse gas emissions associated with materials and construction processes throughout the whole lifecycle of an asset, including maintenance and replacement. This could be a whole building, or only a building's structure, known as 'structural embodied carbon'.

Upfront carbon: The greenhouse gas emissions associated with the materials and construction processes up to the point of practical completion of a building.

Life Cycle Assessment (LCA): A method used to quantify the greenhouse gas emissions and other environmental impacts of assets or products over their whole lifecycle. An LCA approach is used to calculate embodied carbon (but will also often include calculations of operational carbon).

Global Warming Potential (GWP): The environmental impact of an emission, which could be a combination of different greenhouse gases, expressed as the equivalent amount of carbon dioxide that would create the same amount of global warming, in the units $kgCO_2e$.

For explanations of additional terms specific to low carbon structural design, see the Institution of Structural Engineers 'climate jargon buster'[9].

For more general terms relating to the building sector and climate change in Aotearoa New Zealand, see the Building for Climate Change glossary[10].

[9] Institution of Structural Engineers, 2021 https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/
[10] MBIE Building for Climate Change, 2022 https://www.building.govt.nz/getting-started/building-for-climate-change/resources/glossary/

3. Top tips for reducing structural embodied carbon

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Influence the build

Top Tip #1: Calculate

You can't manage (or influence) what you don't measure. You should attempt to calculate the embodied carbon of your designs in order to meaningfully engage with all the other 'tips' in this guide.

The calculation equation is simply: 'material quantity' X 'carbon intensity' = carbon impact

In units of: kg of material X $kgCO_2e$ / kg of material = $kgCO_2e$

As with other structural calculations, the purpose of the calculation should be clearly stated, along with the scope (explained further in Top Tip #2), and the functional unit (e.g. $kgCO_2e / m^2$). These clarifications ensure consistency throughout iterations of the design and replicability if comparing a final design to a benchmark building.

Step 1: Define your scope

The scope of what should be included within an embodied carbon assessment can be based on the MBIE Technical Methodology (see earlier reference). For structural engineers, you can focus your physical scope on all the elements which you design or specify.

An assessment of upfront carbon will typically capture 80-90% of the whole-of-life embodied carbon of the structural impacts (i.e. not including operational energy impacts).

Step 2: Choose your methodology

Calculation methodologies based on relevant ISO/EN standards have been produced by MBIE[11] and the NZGBC[12] in Aotearoa New Zealand, as well as a number of organisations around the world, including the Royal Institution of Chartered Surveyors (RICS)[13]. Free spreadsheet-based tools produced by BRANZ and NZGBC are available to assist in your calculations. Using a tool that defaults to using Aotearoa New Zealand-relevant data means your primary task will be to estimate the structural material quantities for your design, input them into the tool, and assign a carbon intensity or emissions factor, based on the material specification.

Step 3: Calculate material quantities

Early in the design process, estimates should be made for elements that are undesigned: for instance, secondary steelwork and reinforcement rates. Later in the design process, these estimates can be updated. Don't wait until information is perfect to calculate the carbon - iterate through increasing levels of certainty.

Early-stage carbon estimates, when key system decisions are still to be made, will always have the most potential for finding the biggest and most cost-effective solutions to reduce carbon emissions (refer to tips in the "Influence the System" section and the diagram in the introduction).

Given that our structural models (analytical, or BIM) are never a 100% accurate representation of what will be physically built, a degree of judgement will be needed when quantifying amounts of structural materials.

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[11] Whole-of-Life Embodied Carbon Assessment: Technical Methodology, MBIE 2022, https://www.building.govt.nz/assets/Uploads/getting-started/building-for-climate-change/whole-of-life-embodied-carbon-assessment-technical-methodology.pdf

[12] Green Star NZ Embodied Carbon methodology, NZGBC 2023 https://23159811.fs1.hubspotusercontent-na1.net/hubfs/23159811/Green%20Star%20technical%20resources/Design%20and%20As%20Built%20v1.1/19%20Embodied%20Carbon%20Methodology.pdf

[13] Whole life carbon assessment for the built environment, RICS 2023 https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/whole-life-carbon-assessment

Step 4: Select carbon factors

Starting point: the table below provides conservative NZ-specific upfront carbon intensities for the following key materials:

Structural steel	Reinforcing steel	Concrete (30MPa)	Timber (excl. Glulam)
3 $kgCO_2e$ / kg	4 $kgCO_2e$ / kg	300 $kgCO_2e$ / m^3	100 $kgCO_2e$ / m^3

Note the values above are highly variable depending on supplier, but should provide a starting point to enable calculation. More emissions factors can be found in databases such as BRANZ CO2NSTRUCT.

Step 5: Calculate and iterate

You should estimate the embodied carbon of the structure in each project stage to find carbon 'hotspots', and to review options for carbon reduction. You should then communicate your results to other project parties (see Top Tip #2).

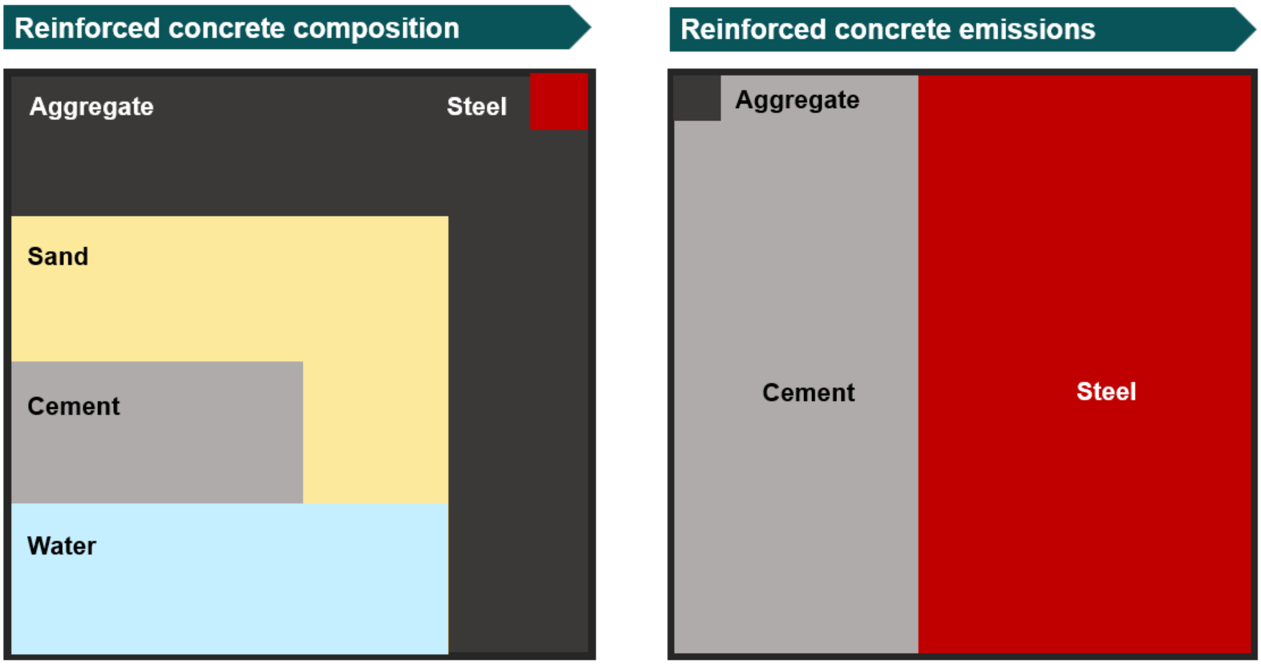

Figure 3 Indicative proportions of reinforced concrete, by composition and associated emissions

Top Tip #2: Communicate the impacts

Calculating the carbon in your structure is a great first step to making emissions reductions. As the design process is a team effort, you need to communicate the information clearly, so everyone involved can see where they can have an impact.

If you're part of a larger structural team, make sure the other structural engineers are aware of their own impact and specific areas of influence. As the person most often in the client's ear, and with the greatest sway over key building features, the architect is a key ally in the quest for a low-carbon design – you should keep them up to date on the carbon impacts of their decisions. If you are relying on specification of low carbon materials, make sure to work with the quantity surveyor to make sure they can take account of any costing implications. And of course, the client should understand the emissions associated with their project. For any project, it's important all parties have agreement with the embodied carbon objectives from the outset.

Often embodied carbon reductions may not be realised in the first project for which you calculate carbon, but if you can communicate the carbon impacts clearly, everyone can learn the lessons to apply in future projects. Focus on making the outputs understandable and accessible.

The embodied carbon of a structure can be broken down in a number of different ways:

- By life cycle stage: present and future emissions, or by life cycle "module" (A, B, C, D – see image in introduction)
- By structural 'system': e.g. for a building, this is typically substructure, superstructure, envelope, non-structural internal elements and building services, and all their constituent elements,
- By structural material: steel, concrete, timber, aluminium, glass, plastics, each of which may be in more than one system,
- By project coverage: e.g. for buildings, separating out the main building from ancillary or external areas like garages or decks, or for bridges, separating out surrounding civil infrastructure.

Showing the breakdown, preferably in a visual way (e.g. pie or bar chart) communicates the 'hotspots' and shows the reader quickly where the biggest opportunities for carbon reduction are. There are two examples shown below.

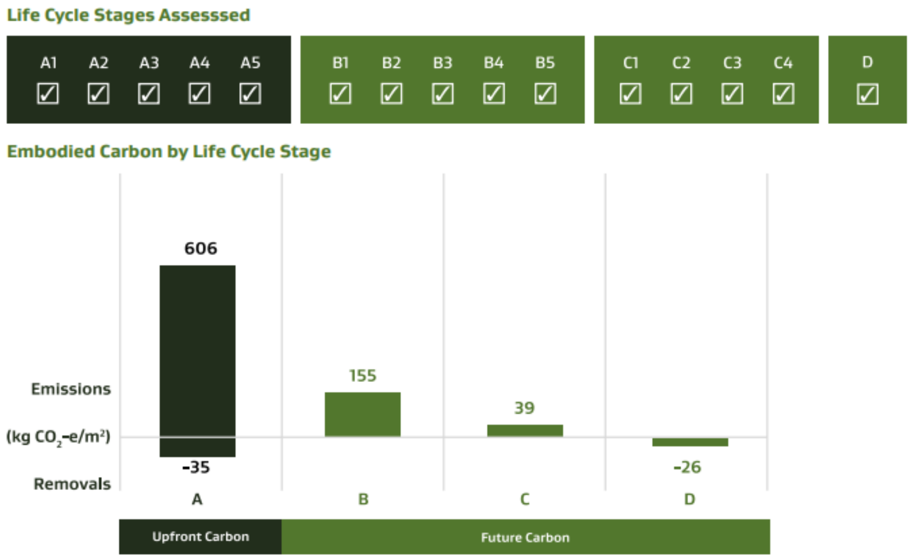

Figure 4: Graph showing embodied carbon hotspots by life cycle stage (excl. operational energy and refrigerants)[14]

[14] Embodied carbon assessment examples, MBIE 2023 https://www.building.govt.nz/getting-started/building-for-climate-change/emissions-reduction/embodied-carbon-assessment-examples

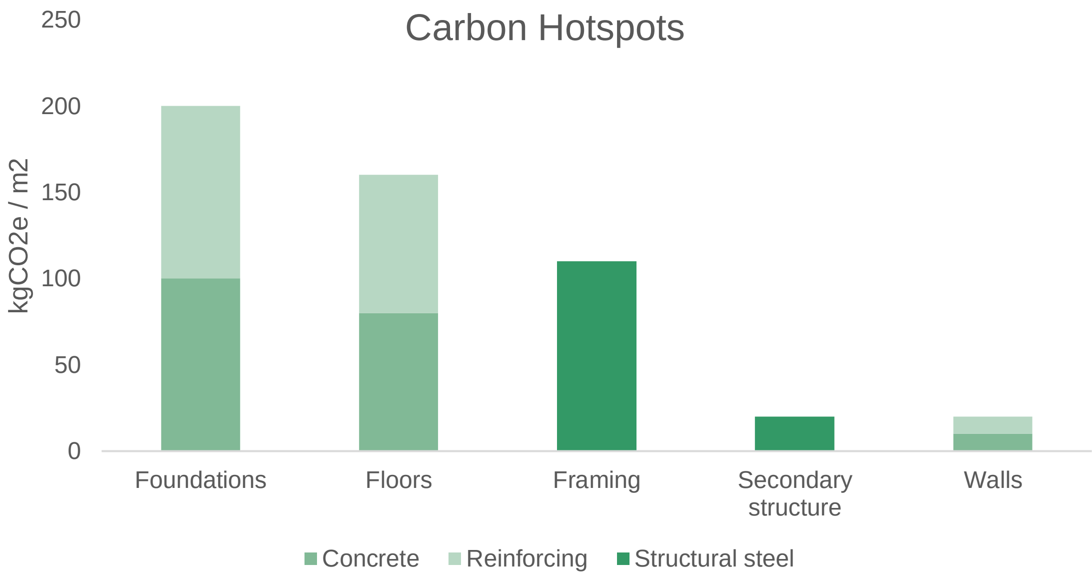

Figure 5 Graph showing indicative hotspots by structural system and material

Report the scope of your assessment alongside the result: what building elements and life cycle stages have you included? The more you count, the bigger your total will be, so for consistency it's important to be transparent about this. Ideally, the scope of the assessment will align with MBIE's Whole-of-Life Embodied Carbon Technical Methodology, or an established industry framework such as the Upfront Carbon Methodology published by the NZGBC[15].

Report emissions separately to removals: this ensures any climate benefits are recognised but aren't masking emissions (e.g. separate out stored biogenic carbon from upfront carbon). They might not necessarily happen at the same time.

When reporting embodied carbon quantitatively, **ensure you are using an appropriate degree of accuracy**. If the values are based on factors with a large degree of uncertainty (e.g. early in design), quantify that with a % error margin if possible, and don't use too many significant figures. If you can't estimate an error margin, it may be best to simply highlight the relative performance of options as opposed to making claims that could be misrepresentative.

Knowing what 'good' looks like for the embodied carbon of your project is currently challenging when there is a lack of comparable data available, particularly for non-building structures. There are a number of benchmarks and targets that have been developed for buildings as well as building structures specifically, for example:

- LETI embodied carbon targets (section 7 of the Embodied carbon primer)
- IStructE's Structural Carbon Rating Scheme (SCORS)[16],
- Built Environment Carbon Database (BECD) asset database[17]
- SE2050 database[18].

[15] Embodied Carbon Methodology, NZGBC, 2023. https://nzgbc.org.nz/green-star-design-and-as-built#technicalresources
[16] Setting carbon targets: an introduction to the proposed SCORS rating scheme, IStructE, 2020 https://www.istructe.org/IStructE/media/Public/TSE-Archive/2020/Setting-carbon-targets-an-introduction-to-the-proposed-SCORS-rating-scheme.pdf
[17] Built Environment Carbon Database (BECD), BCIS 2023 https://becd.co.uk/
[18] SE2050 database, SEI 2023 https://se2050.org/se-2050-database/

Remember to consider the scope when comparing your embodied carbon assessment result against a benchmark or target: if different building elements or life cycle stages have been included you won't be comparing 'apples with apples'.

Consider how reporting is standardised to allow for comparisons: It is common to report the embodied carbon of a building in $kgCO_2e$ / m^2 , to allow buildings of different sizes to be compared. Note that this unit won't account for the benefit of 'building less': a small building that provides the same function as a larger one with the same $kgCO_2e$ / m^2 embodied carbon will have lower total emissions. This should be considered and communicated alongside the results.

Reporting Requirements: Reporting embodied carbon for specific purposes, such as rating schemes like Green Star, Homestar and ISCA, or to determine a quantity of emissions to offset under a certified offsetting scheme will likely have separate reporting requirements, which should be followed. Potential regulatory requirements in Aotearoa New Zealand are still being developed, however an outline of expected reporting requirements is included in MBIE's Whole-of-life Embodied Carbon Technical Methodology.

Example:

Since 2022, the Ministry of Education has required a whole-of-life embodied carbon assessment to be carried out for all new build property projects with a capital value over $8M, and a target of 500 $kgCO_2e$ / m^2 for the whole-of-life embodied carbon has been set for these new buildings[19].

[19] Whole-of-life carbon assessment for new build projects at schools, Ministry of Education 2022, https://www.education.govt.nz/school/property-and-transport/projects-and-design/design/design-standards/whole-of-life-carbon-assessment-for-new-build-projects-at-schools/

Top Tip #3: Coordinate

There are several reasons why early, collaborative coordination with other project team members is important when considering embodied carbon and achieving low-carbon outcomes. The steps below outline how to integrate these considerations.

Step 1: Agree carbon targets and outcomes for the project

Consensus agreement with other project team members is needed to both agree on carbon targets and outcomes for the project, and to enact most embodied carbon reduction strategies (see tips in the *Influence the System* section). When structural engineers are both aware of, and can communicate these strategies, we will be able to advocate and negotiate towards low-carbon solutions in early conceptual design team meetings.

Example:

You should be able to use carbon reduction (as well as structural efficiency) as an argument for adding points or lines of support to long span beams when initial building layouts are being defined.

Step 2: Ensure adequate early coordination

Collaborative coordination through the design, particularly in early design stages, reduces the likelihood of ad-hoc structural elements being added or changed late in the piece. These elements are likely to be inefficient, or could otherwise have been avoided altogether, had thorough early coordination taken place.

Example:

If a penetration through a concrete floor is missed in design (or through construction), on-site remediation will likely require partial demolition and waste of some materials, as well as more additional remedial structure than if it had been designed and constructed intentionally.

Step 3: Consider flow-on implications for others

All design decisions (whether taken to reduce embodied carbon or not) are likely to impact carbon, cost or programme outcomes for other disciplines or the project as a whole. Generally the primary structure is the most significant source of a building's embodied carbon, in comparison to other building systems such as the cladding/roofing/envelope, non-structural elements, finishes and building services. However structural design decisions triggering significant alterations in design strategies for other disciplines should be considered holistically from a carbon perspective.

Examples:

- ***Fire and acoustic design may require additional protective layers needed from moving to a lightweight ground or raised floor.***
- ***Adding photovoltaic panels to a building is likely to require an uplift of embodied carbon in the support structure, framing and the panels themselves - site specific solar studies will be needed to ensure whole-life carbon (embodied + operational) is still overall reduced.***
- ***A large amount of structure in external walls may impact thermal performance of the envelope insulation – thus reducing energy efficiency.***
- ***Consider buildability – designing to minimise temporary structure (refer Top Tip #4).***

Top Tip #4: Engage with contractors

Engaging with a contractor/builder/site manager/site engineer during the design process provides opportunity for the construction methodology and logistics to be considered and incorporated into the design. With regards to embodied carbon, this can give a range of benefits such as reductions in waste, temporary works and construction duration, or the use of alternate solutions provided by the market.

On larger projects, this is typically achieved through Early Contractor Involvement (ECI), a formal process in which a contractor reviews and provides input as the design progresses. For smaller projects there is not usually a formal process, but often the client will have a preferred contractor who may be willing to provide input.

Clients can often be unaware of the benefit ECI can bring, particularly on complex or challenging projects so if you think there is a good opportunity to utilise it, make the suggestion. Generally the earlier in the design process the better, to maximise flexibility to changes.

Some examples of contractor led initiatives which may influence embodied carbon include:

- Supply chain visibility: Advise on the availability, costing and supply chain sustainability of building products or materials, including any potential stock or lead time issues.
- Diversion of waste: Reusing or recycling construction waste and demolition salvage to avoid landfill. Utilizing product stewardship schemes.
- Design optimisation: Working with the supply chain to optimise material dimensions for cost, transport, buildability, and waste reduction from onsite work,
- Prefabrication: Using prefabricated elements and systems to reduce waste and the duration of construction,
- Construction sequencing: Design modifications to suit the intended construction sequencing and methodology, as well as possible future deconstruction / demountability,
- Operational considerations: Offer design improvements relating to durability, maintenance or serviceability to improve the performance and longevity of the building,
- Market solutions: Liaise with the market and suggest alternative solutions or low-carbon products,
- Buildability: Assist with assessing the feasibility of innovative ideas or solutions.

Example:

Work with the contractor to understand their build methodology, sequence, and approach to temporary works. Temporary works are necessary for most structures, however the goal should be to minimise bespoke and single use temporary works which may be required by the design. In the case of complex structures and geometry, this can lead to additional carbon which won't typically be picked up in carbon assessments. This can be mitigated by designing with re-usable temporary works systems in mind (e.g. Acrow Props, Superslim soldiers, etc), using recycled materials for temporary works (e.g. using parts of a demolished building - beams/columns and concrete for ballast) and where possible integrating the temporary works requirements within the design of permanent works.

Top Tip #5: Evaluate opportunities for adaptive reuse

Most of the buildings that will exist in 2050, when Aotearoa New Zealand is aiming to be net zero, have been built already. Therefore if we only concentrate on reducing emissions of new buildings, it will take a long time to achieve the significant emissions reductions from the building stock as a whole. Improving the utilisation and operational efficiency of our existing building stock is one of the top ways we can reduce emissions attributed to the building sector. You might have heard people say the lowest carbon building is the one you already have. Adaptive reuse means making use of buildings that already exist, so that you don't need to build, or at least you build less. It not only avoids emissions that would have been associated with a new building, but also the emissions and waste created when the existing building is demolished.

Example:

The B201 Building at the University of Auckland was able to save more than 30% upfront carbon compared to an equivalent new building (almost 3,000 tonnes of carbon[20]) through the adaptive reuse and strengthening of the existing structural frame and foundations.

Structural engineers are key to a successful adaptive reuse project.

We can assess the existing capacity of a structure and highlight where there are opportunities to add floor space at different levels, or open up existing spaces by removing structural elements. We can develop strengthening schemes for existing buildings to improve their structural performance, resilience and prolong their life. Working with existing structures can be challenging - there is more uncertainty compared to designing a new building, but the key role of the structural engineer in reuse projects makes them rewarding to be involved with.

[20] A Practical Guide to Upfront Carbon, NZGBC 2023. https://nzgbc.org.nz/research-and-reports

Top Tip #6: Interrogate user requirements and refine assumptions

Spend time early on with other project team members (client, architect, services engineer etc) to understand what the key 'drivers' are behind each of their design requirements. Then, when you are considering various structural systems to meet the brief and budget, determine which of these requirements are driving the structural solution - and whether that is impacting on the efficiency of the design. Ask interrogative questions and be curious.

Example questions:

- ***Is the architectural column grid layout limiting floor system selection options?***
- ***Are the sizing of structural elements driven by strength, deflection, vibration, or other?***
- ***Are there any significant effects where specified performance criteria exceeds Building Code requirements/ standard practice? E.g. Is future-proofing of floor plates for future flexibility of use / loading adding significant structure and cost to the design?***
- ***What conservative assumptions are we relying on that we can reduce the level of uncertainty / become more informed about? (geotechnical parameters, existing building condition, seismic spectra etc)***

Using carbon as a metric to show the implications of different design performance requirements - For each structural design variable (e.g. deflection criteria, geotechnical parameters) estimate an approximate embodied carbon range associated with the lower and upper bound possibilities. Use this to discuss the impacts of the different options, and advocate for the options with lower embodied carbon. See the figure in Tip #7 below for an example of how the impact of different beam, floor, grid, and loading options can be presented.

Doing this work may lead to constructive conversations with the client and project team to determine if some flexibility in requirements or assumptions could offer the project significant embodied carbon savings.

Example:

A strengthening design is being undertaken for a 2-storey building with URM external walls. Conservative assumptions around the out-of-plane face loading capacity of the walls can result in a highly intensive and extensive strengthening solution.

Site testing of actual capacities was subsequently undertaken and resulted in significantly higher capacities than had been estimated. The quantity of material required for strengthening to meet requirements was therefore reduced.

Top Tip #7: Define optimal geometries

The shorter the span, the smaller the beam.

Engineers have long prided themselves on delivering clear, column free spaces in a cost-effective manner. Unfortunately, those spaces carry a carbon premium that can be eliminated by an honest discussion about the need for long spans.

Structurally efficient grid layouts should always be considered as a primary option for reducing embodied carbon (and for good engineering). Excessively long spans often cause disproportionate increases in beam weight (and thus embodied carbon) driven by serviceability requirements. Adding additional support can result in significant material quantity reductions. Communicating the amount of carbon saved by these decisions is often critical in influencing decision making by architects and clients.

Similarly, regular, simple buildings and layouts are the most efficient from a carbon (and cost!) perspective. Introducing complexity nearly always results in more material, and thus increases the embodied carbon. In particular, transfer structures and cantilevers should be avoided where practicable.

Inputs into building form are often architecturally driven, and structural engineers aren't always part of the conversation early enough to influence geometry. One of the most important opportunities for engineers delivering low carbon buildings is to get in front of key decision makers early, armed with convincing and credible data and evidence about carbon savings to promote simple, regular, efficient layouts.

Remember, in order to achieve this, being able to quantify carbon benefits at an early stage is critical - refer to Top Tip #1: 'Calculate'.

Example:

Buro Happold's "Embodied Carbon Routes to Reduction"[21] sensitivity study provides a great example of the impact of moving to a more structurally efficient grid (note it is a UK example, but although some dimensions are likely to be different in Aotearoa New Zealand, the same principles would apply).

Moving from a 9m grid with steel framing and composite steel deck floors (considered the baseline) to a 7.5m grid with the same system resulted in a >20% reduction in structural upfront carbon for the whole building.

See figure on the next page.

[21] Buro Happold Embodied Carbon Routes to Reduction, 2020 https://www.istructe.org/IStructE/media/Public/Resources/case-study-embodied-carbon-routes-to-reduction-20200406.pdf

SESOC Top Tips: Influence the System

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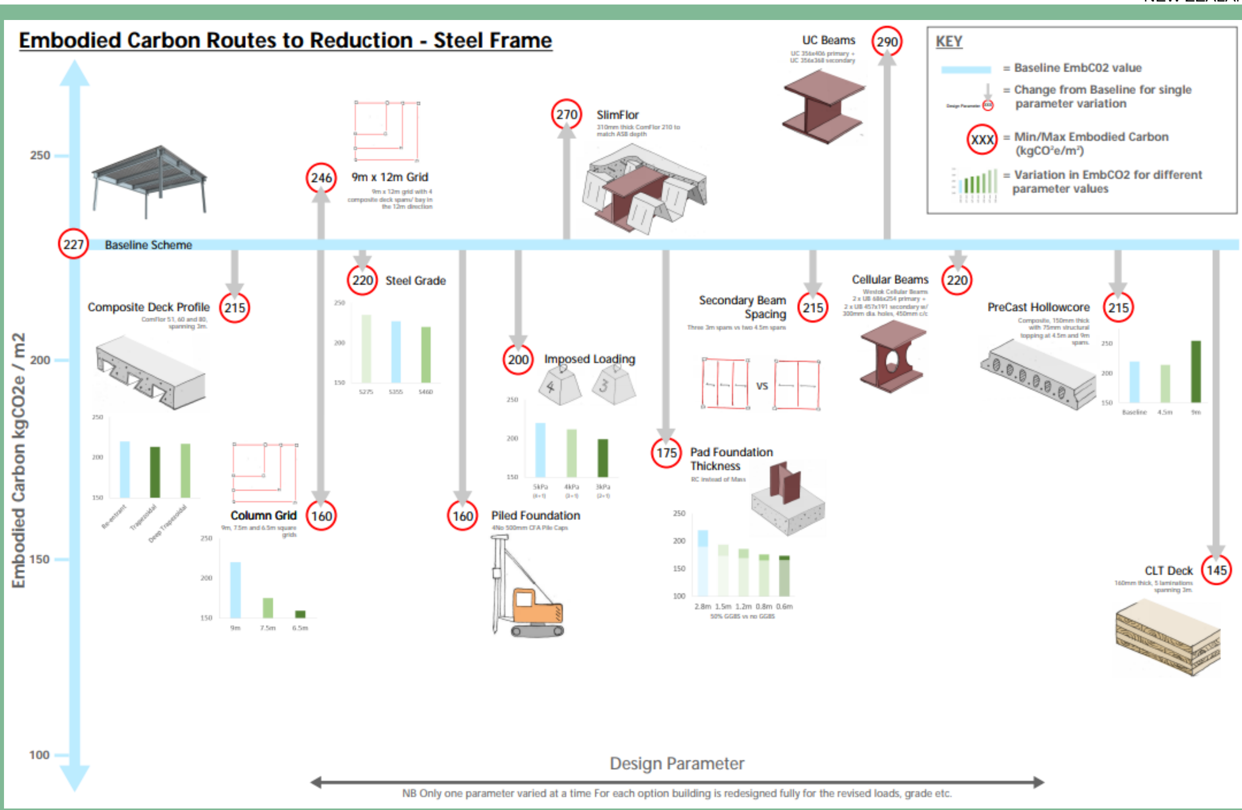


Figure 6 Embodied Carbon routes to reduction for a steel frame [21]

Top Tip #8: Sensibly maximise the life of the structure

As discussed in Top Tip #5, extending the life of existing structures should always be the first consideration when considering upgrades or renewals. Although the MBIE Technical Methodology is based off 50 years, BRANZ modelling is often 90 years, and dynamic LCA modelling can be up to 200 years. For structural engineers, avoiding the use of new materials is the most powerful tool we have to reduce the embodied carbon of structures. This applies just as much if not more so to civil engineering structures such as bridges, tunnels, dams and other infrastructure, as it does to building structures, on account of the longer design life typically associated with civil engineering structures. Assessing the condition of existing structures, and ensuring the long lasting durability of new structures is key to extending their lives.

Existing structures

The use of advanced analysis techniques, materials testing, and structural health monitoring are all options in the engineering toolkit which can be utilised to provide increased confidence in the performance of existing structures and extending their life.

Innovative structural products and materials are increasingly being used where remediation or strengthening is required to extend the design life of bridges and other civil structures, as an alternative to full replacement, or more extensive repairs using greater material quantities. These include:

- Advanced analysis techniques (e.g., non-linear modelling and performance-based analyses), which test the inherent conservatism in design and simplified assessment techniques,
- Testing of in situ material properties to verify critical assumptions,
- Instrumentation and monitoring to calibrate analytically-derived response and performance,
- Prefabricated repair modules for bridge deck replacements,
- Fibre reinforced polymer plates for seismic strengthening of existing piers and bridges,
- Specialist epoxy grouts and reinforcement coatings for deteriorated concrete elements (e.g. cracking, spalling, carbonation, chloride attack).

New structures

It is important to consider the expected life of structural components in the design of new structures, particularly when those components are exposed to weathering elements such as salt, moisture, extreme temperatures, or industrial environments. Nearly all civil structures fall within this category, as do any exposed building structural elements.

Structural engineers should endeavour to ensure that the structural materials used have a good chance of lasting for an extended period of time with minimal intervention or replacement. This doesn’t mean over-designing the structure, by providing excessive concrete cover for example. Instead, structural engineers should focus on a few key principles to sensibly maximise the life of structures:

- Avoid the need for protection altogether - if there is another structural option which reduces exposure, opt for that where practicable,
- Avoid the need for secondary protection or frequent maintenance - e.g. opt for weathering steel beams rather than painted steel beams in external environments,
- Ensure structural elements in high risk areas are readily visible so regular maintenance can be performed before deterioration goes too far,

- Develop an inspection and maintenance programme for the structure which includes consideration of access for maintenance and the use of locally available materials for maintenance and replacement,
- Allow for potential future modification (e.g. widening of bridges) where possible through the use of standardised components and detailing,
- Consider the potential for deconstruction, re-use and/or recycling of the structure in the design to contribute to the circular economy.

BRANZ has looked at the relationship between durability and embodied carbon in a number of studies[22], with the goal of helping the building industry make more informed material choices to deliver buildings that are both durable and sustainable from a carbon perspective.

Figure 7 Renewed Waioeka bridge with structural strengthening (courtesy DC Structures Studio)

[22] How durability influences embodied carbon, BRANZ 2023 https://www.buildmagazine.org.nz/articles/show/how-material-durability-influences-embodied-carbon

Top Tip #9: Build up not down

Structural engineers can work with the design team to encourage reduction or elimination of basements and below-ground structures. The embodied carbon associated with site works on or above the ground is generally small compared to below ground excavations. Basements require a large amount of reinforced concrete, but in addition their construction requires a lot of on-site plant which is typically diesel-powered. The emissions associated with excavation equipment, and transportation of spoil are often significant. Additionally, carbon is released from disrupting the soil during excavation, creating further emissions.

Examples:

Comparisons between a 4-storey building with a 2-storey basement, and an equivalent 6-storey building on the same site, found that the embodied carbon was ~10% higher for the building with a basement. The additional embodied carbon was from the basement walls and requirements of additional structure for excavation such as secant pile walls.

Another investigation on a recent 8-level building in Auckland evaluated the potential saving that could have been achieved from reducing the two-levels of basement to a single level only basement as approximately 15% of the total structural embodied carbon.

Top Tip #10: Choose lowest volume foundations

Structural foundations are most commonly constructed out of reinforced concrete, in the form of shallow pad foundations, raft slabs, piles (and the list goes on). The choice of foundation type is typically determined by the ground conditions and geotechnical design and recommendations, however, it is not all out of the structural engineer's control.

Choosing the lowest volume foundation that meets the performance criteria of the structure, can have a big impact on carbon emissions. Upfront carbon calculations undertaken by the authors of new non-residential buildings have found that emissions associated with the foundations are typically between 20-40% of the total structural embodied carbon.

To minimise material in foundations, consider the following three approaches:

Explore some options

It can be too easy sometimes (at the earlier design stages) to sketch up a highly conservative foundation and only revisit in future design stages to prove that it works.

As structural engineers in a seismically active country, we are well practised at quantifying the building's superstructure to determine the seismic mass. However, we can often forget to quantify the foundations. It is a quick exercise to calculate the volume of concrete of a raft slab, pad foundations or piles. Comparing approximate kgs of reinforcement and m^3 of concrete can be the first step in reducing the material in foundations.

Loads and load paths

By reducing the weight of materials in the superstructure and challenging imposed loads such as superimposed dead loads (refer Top Tip #6: Interrogate User Requirements), the loads on the foundations may be reduced. This is particularly important when the foundations are on the cusp of a less voluminous typology.

Don't over-design reinforcement

The typical reinforcement supplied in Aotearoa New Zealand is roughly 37 times more carbon intensive than ready mix concrete by weight, and 2-3 times more carbon intensive than the global average for reinforcement bar[23][24][25] (refer Top Tip #21 – Specify steel well for more information). Being careful to not overdesign the quantity of reinforcement in the foundations is important for embodied carbon for two reasons:

Firstly, the more reinforcement – the more associated carbon emissions. Simple.

Example:

Take a 1m wide x 1m long x 0.6m deep pad footing constructed from 30 MPa ready-mix concrete. Reinforcement in this pad could be in the range of 150 kg/m³ (medium- high reinforced).

Based on the above, the concrete would contribute ~170 kgCO₂e whilst the reinforcement would contribute ~390 kgCO₂e which is 2x the carbon emissions of the concrete itself.

Secondly, the more reinforcement means the harder it is for it to pass adequately through joints or to achieve laps or hooks, which can force the designer to increase the foundation size so that it is easier to construct.

[23] Pacific Steel Reinforcement EPD, 2018 (expired 2023 – yet to be renewed). https://www.pacificsteel.co.nz/assets/Uploads/EPD-Pacific-Steel-SEISMIC-reinforcing-bar-coil-rod-and-wire-Copy.pdf
[24] ICE Database v3.0, Rebar Steel -world average. https://circularecology.com/embodied-carbon-footprint-database.html
[25] IfraBuild EPD – Reinforcing Bar and Mesh, 2022. https://www.infrabuild.com/resources/epd/reinforcing-bar-and-mesh-epd-infrabuild-constructi/

Top Tip #11: Start with low strength concrete

Since higher strength concrete uses more cement, a first practical step in lowering the upfront carbon of your concrete could be choosing a lower concrete strength by default, if appropriate. Simply reducing foundation concrete strength from 30 MPa to 25 MPa could offer an 8% reduction in embodied carbon. Often this change will come with very few design consequences other than slightly greater reinforcing cover.

Other possible options to reduce the carbon associated with concrete in buildings could include:

- Replacing site concrete with compacted hardfill,
- Specifying a maximum strength for site concrete (e.g. 10 MPa) rather than using a higher strength product,
- Only including requirements such as a minimum cement content or water to cement ratio when there are technical reasons to,
- Using surface hardeners, if required, instead of increasing the strength of the whole concrete volume,
- Avoid members with congested reinforcement if possible. Congestion can require self-compacting concrete which uses far more cement.

Concrete strength decisions are not often scrutinised by designers as the cost impacts of using slightly higher concrete strengths are typically minimal and often seen as being outweighed by durability and strength advantages. However, when viewed through a carbon lens, the determination of concrete strength is a significant contributor to the building's overall embodied carbon. Making good decisions on what concrete strength to use in a structure should lie well within the capabilities of most structural engineers.

Example:

This table[26] can be used to roughly quantify the embodied carbon of standard concrete mixes. Note some suppliers can have higher (or lower) emissions factors for their mixes, including specific low-carbon mixes - see Top Tip #20 for more information on how to specify concrete and other materials for improved carbon performance.

Concrete Strength Grade (MPa)	North Island Averages GWP impact (kgCO_2e/m^3) (A1-A3)	South Island Averages GWP impact (kgCO_2e/m^3) (A1-A3)
20	223	209
25	248	230
30	263	250
40	307	286
50	365	354

[26] https://www.firth.co.nz/sustainability/) & https://epd-australasia.com/wp-content/uploads/2020/09/Firth-EPD-Ready-mixed-concrete-Sep-20-WEB.pdf

Top Tip #12: Optimise don't rationalise

Rationalisation is a common design process where structural members with similar design conditions (geometry, spans, sizes, connection types, etc) are grouped together. This has many advantages, including simplified design, coordination and construction process, reducing the risk of error, and providing a buffer for accommodating future design changes and errors on site.

This process is adopted on most building designs, despite the fact it increases material quantities, as the increase in material costs are small in comparison to design and labour costs, even before the potential programme benefits are considered. This presents a challenge unique to the construction industry: to reduce material use without the financial incentive to do so.

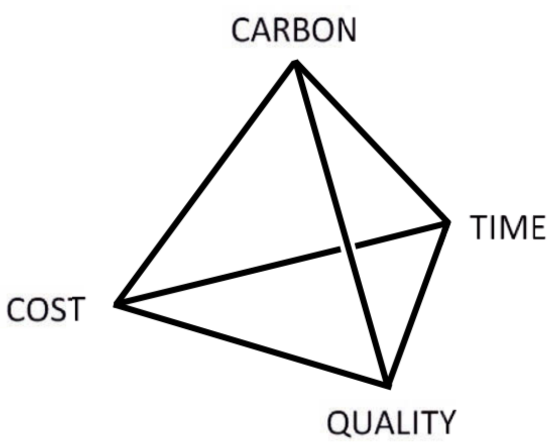


Figure 8 Amended project management triangle for climate emergency[27]

The underutilisation of members within completed structures is well known, and studies published by the Structural Engineering Institute (SEI) and the Institution of Structural Engineers (IStructE)[27] report **average utilisations within buildings of around 60%,** meaning large amounts of additional material are being added within the design process. Approximately half of this additional material, up to 20% of the structural material within an average building, is thought to be from rationalisation alone (the remainder is a result of target utilisation ratios being in the range of 80-100%).

In order to increase material efficiency, optimisation must be at the heart of the design process, and the perceived benefits of rationalisation need to be challenged.

Optimisation must always begin with geometry and challenging the brief (i.e. at a global level - see Top Tips #6 & #7) before focussing on member utilisations (local level), to avoid highly utilised but otherwise inefficient structures.

At a local level, **expanding the number of design groupings to cover more unique situations**, or removing these entirely, has a large impact on material volume. It is recommended that the designer has a clear picture of the peak and average member utilisations, and this can be easily done with modern software packages. Modelling software can also be used to create helpful colour-coded 3D views of member utilisation. To provide some buffer during the design process, one option is to track and increase the average utilisation at each design stage.

Many of the traditional arguments for rationalisation noted above can be addressed using the powerful design and modelling tools now available to many designers and contractors. However there will be a point in a

[27] Rationalisation versus optimisation – getting the balance right in changing times, Institution of Structural Engineers 2020 https://www.istructe.org/IStructE/media/Public/TSE-Archive/2020/Rationalisation-versus-optimisation-getting-the-balance-right-in-changing-times.pdf

building design where sufficient optimisation has occurred to reduce material volumes, but it is not safe or practical to go further, and early discussions with the contractor would help establish this.

Example:

In the project summarised below (from the IStructE article[27]), the tonnage of a large steel building with long span trusses was reduced by approximately 30% through switching focus from rationalisation to optimisation, with no perceived impact on construction program.

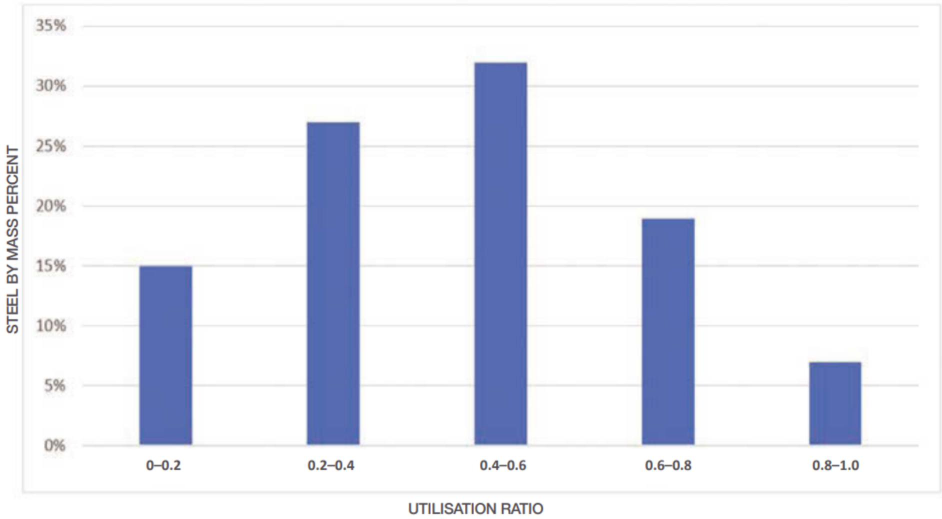


FIGURE 5: Rationalised member utilisation

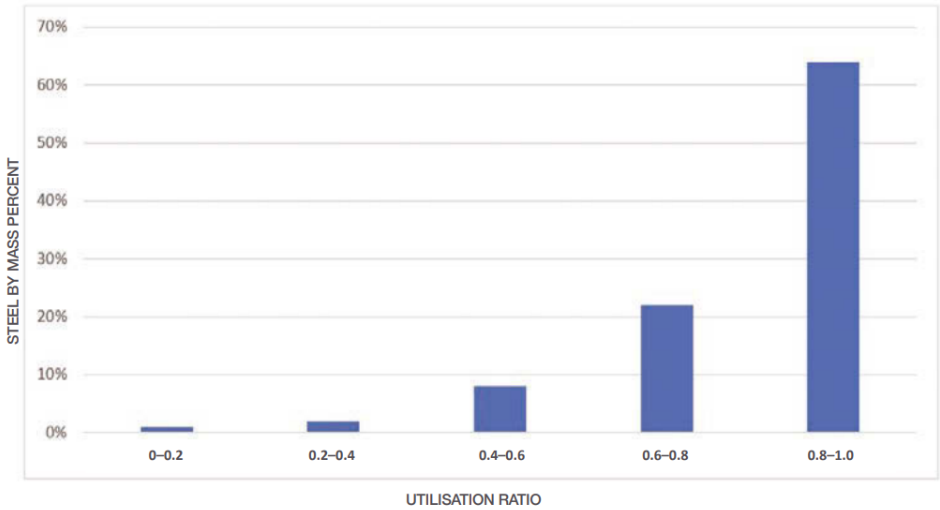


FIGURE 6: Optimised member utilisation

Top Tip #13: Consider seismic resilience and material efficiency

Improved seismic resilience, or damage reduction is one of the key current challenges for structural engineers, and this now sits parallel with the very real and pressing need to actively reduce the embodied carbon in the structures being designed. Seismic resilience has links with sustainable design when looked at from both the upfront carbon of the structure, and also from the potential damage and repair or likelihood of demolition and rebuild across the structure's life as a result of performance during a seismic event.

Applying probabilistic modelling, ongoing research by Toma and Stephens at the University of Auckland has shown that the carbon emissions from damage induced by earthquakes is dominated by the risk that the structure is not repairable after an event. In this situation, the entire building would be demolished, potentially before the end of its useful life, resulting in emissions from the demolition and also from the construction of a replacement building in future. Minimising the potential for a structure to be considered unrepairable can therefore reduce the building's life cycle seismic carbon risk.

Second to the probability of an unrepairable outcome, damage to the non-structural elements, including facades, MEP services, fitout and stairs and elevators has been shown to contribute significantly to the lifecycle seismic carbon risk. The damage profiles of these elements can be drift or acceleration controlled. Detailing which allows for this movement, limiting potential damage to the elements and connections.

More research to understand the relationship between design characteristics and seismic carbon risk across a range of building forms, structural systems, and hazard zones is still in development.

In striving for improved resilience, we should be careful to not create excessively carbon intensive buildings, but rather look to balance improved resilience and therefore lower potential seismic carbon risk, against lower upfront carbon. Equally, in looking to reduce upfront embodied carbon, we should not be creating buildings prone to unusually high damage.

Example:

Buildings with a higher potential to be deemed unrepairable include:

- ***Highly ductile structures with limited self-centering, or extensive damage profiles that extend throughout the building,***
- ***Buildings with expected high levels of drift at the ULS, as they will result in extensive damage to the non-structural and fitout elements, including facades and services.***

Top Tip #14: Compare embodied carbon of floor types

For residential and other lightweight single-storey buildings, a concrete slab on grade comprises a large proportion of the whole building upfront carbon. Compare carbon outcomes to a lightweight raised floor, or refer Top Tips #9, #11 and #20 for how to reduce the embodied carbon of the slab.

A substantial share of the embodied carbon in medium to high-rise buildings can be directly linked to the horizontal floor structure, typically accounting for 40-60% of the structural upfront carbon. Recognising this, the selected floor system should be interrogated as a focus of embodied carbon reduction. It's already commonplace to compare multiple floor systems and grid arrangements in concept design and evaluate options based on cost, depth, vibration performance, buildability, fire etc. It is a simple exercise to overlay a carbon lens and include embodied carbon estimates as a parameter to be factored into decision-making.

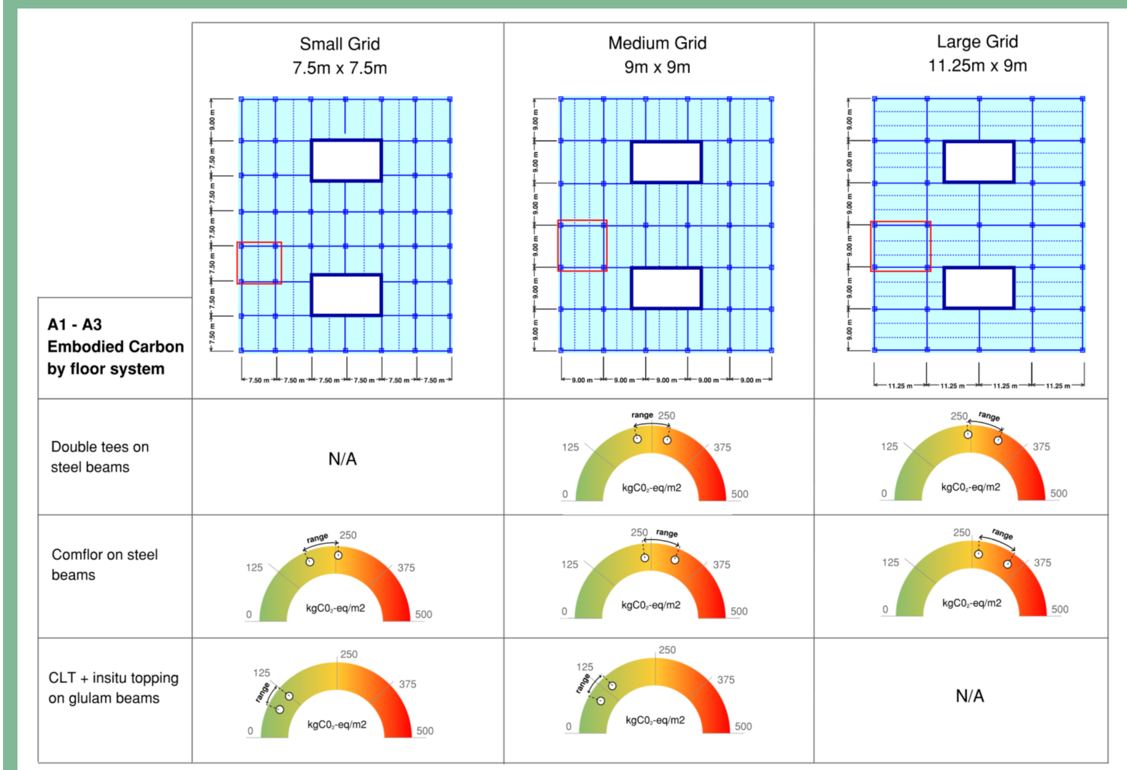
Start with the grid – include options for small to larger arrangements which may be appropriate for the building. Then consider which structural typologies would be compatible with each grid size alongside the other project drivers. Some typologies, such as mass timber, may not be suitable for a large grid and others, such as double tees, may not make sense for a smaller grid. Ensure the holistic performance of the system is considered with any additional material or build-ups needed for acoustics, fire or vibration performance accounted for. This will influence the overall depth, weight, and cost of a system as well as its carbon intensity.

Have an open discussion with the architects and client about the results of comparative studies – smaller grids are typically more efficient, and the team may be willing to accept additional vertical structure if it means increased clear heights and reduced carbon (and cost). Refer also to Top Tips #3 & #7.

A smaller grid corresponds to an increased number of columns; however, assuming similar stress demands, the embodied carbon of more small columns is typically comparable to fewer large columns.

Example:

The figure below provides an example of how the carbon intensity of different floor systems and grid arrangements could be compared at an early design stage. It also demonstrates the upfront carbon efficiency of a smaller grid arrangement across multiple typologies.



Top Tip #15: Know how to make lightweight flooring systems work well

In a multistorey building, much of the embodied carbon is in the floors (refer Top Tip #14). Designing lightweight floor systems such as timber can offer significant carbon savings.

While typical for smaller scale residential buildings, timber floors have not been the traditional floor of choice for larger commercial or apartment buildings due to the many advantages of a concrete floor (strong diaphragms, excellent fire, acoustic, and vibration performance). Designing timber or other lightweight floors well requires considerations noted below, as well as early engagement and coordination - refer Top Tip #3. Also refer Top Tip #19 - not all timber can be considered low carbon!

Diaphragms:

Timber diaphragms are *much* weaker than concrete diaphragms and the design is likely to be governed by the capacity of fixings. It may only be practical to make timber diaphragms work with **distributed lateral systems**, which likely means moment frames, or wall-intensive systems. Assume that timber diaphragms can span horizontally over only a bay or two.

Consider the seismic performance of CLT planks, as these can be prone to many of the displacement compatibility concerns historically associated with hollowcore planks. Similar solutions can therefore be adopted.

Figure 9 Distributed lateral systems on display at Bealey Lodge (courtesy of EngCo)

Acoustics:

It is common to require special acoustic treatments for timber floors, often in the form of floating 'batten and cradle' systems (refer image over page).

Fire:

Many fire protection systems have not been tested with timber products, and it can therefore be difficult to demonstrate compliance.

The fire engineer should be involved very early in the design, and a Fire Engineering Brief should be agreed early, which specifically addresses the changes with using timber floors for fire separation. Consolidating multiple floors into a single fire cell can enable designers to eliminate many of the most complex fire compliance requirements. This should be done in conjunction with the project fire engineer as it is only suitable for some types and sizes of building [reference guidance document for fire engineering for timber buildings].

Designers should be prepared for any large areas of timber soffits to require covering with fire-proof materials such as plasterboard, and for the fire engineering requirements to govern both the structural and architectural design of the floor.

Vibration:

Systems like batten and cradle floors can reduce vibration, but effort will still be required to prepare occupants for increased vibration. If possible, designers should try to provide their clients the opportunity to visit a timber floor building so they can understand the likely performance.

It is likely that certain building performing functions that cannot accept higher vibration floors won't be appropriate for timber floors.

Example:

Figure 10 Batten and cradle system from Ecoply pictured above [28]

[28] Ecoply - *https://futurebuild.co.nz/assets/Uploads/CHHPlywoodLVLBattenAndCradleLiteratureCurrent.pdf*

Top Tip #16: Evaluate the embodied carbon of residential and partition wall framing

Residential building construction in Aotearoa New Zealand is predominantly light timber framed, holding over 90% of the market share[29]. The other material choice for framing, light gauge steel, has risen in popularity due to timber supply issues, as well as the steel's durability, potential for reuse, and high degree of dimensional accuracy.

Comparing the two products through a carbon lens has been thoroughly investigated as part of a Masters' thesis at the University of Auckland[30], including the consideration of thermal efficiency in creating thermal breaks when using light gauge steel (i.e. operational and embodied together).

The study found that for a typical 180 m^2 stand-alone house in Auckland, across the cradle-to-gate boundary (A1-A3 modules), the timber framed solution designed to NZS3604:2011 had 25% less embodied carbon emissions than the light gauge steel option. This does not include the stored biogenic carbon, which separately accounted for a further 9% emissions benefit. Another study in 2022 had similar findings - timber-framed external and internal walls had lower upfront and whole-life embodied carbon than equivalent steel-framed walls. [31]

Across the whole-of-life embodied carbon scope, accounting for demolition and potential re-use, the timber framed house had 6.9% less embodied carbon than the steel framed house, excluding stored biogenic carbon, which separately accounted for a 6.4% emissions benefit. These numbers look at the house in its entirety, inclusive of foundations, cladding, framing, roofing, and internal linings. Looking at the distribution of carbon across the elements, the foundation and steel roof comprise over 25% of the total upfront embodied carbon.

Comparing the embodied carbon intensity across just the two framing materials considering modules A1-A3, C3/C4 and D, the carbon intensity profiles show that timber framing has approximately ⅓ of the embodied carbon of the steel stud, using current Aotearoa New Zealand supply chains.

Table 1 Embodied Carbon profile for timber and steel stud framing

A1 to A3 + C3/C4 + D impacts	Embodied Carbon kgCO_2e / m length	Biogenic carbon stored kgCO_2e / m length
90 x 45 timber framing	0.38	-3.15
89 x 0.75 steel stud	1.07	0

29 https://www.branz.co.nz/investing-research/research-portfolio/contact-us/11-materials-and-characteristics-survey-2020-21/
30 ShahMohammadi, A. (2022). Low-carbon design for future-build houses in timber and light-gauge steel framing: A comprehensive whole life cycle assessment for housing construction in Aotearoa, New Zealand. University of Auckland.
31 https://www.thinkstep-anz.com/assets/Whitepapers-Reports/Cost-neutral-low-carbon-residential-construction.pdf].

Top Tip #17: Include architectural elements when comparing options for walls, ceilings, floors

In general, building elements (particularly in residential and commercial industrial construction) which are measured on a per m2 basis (walls, ceilings, floors, facades) will have a significant contribution from non-structural elements. Therefore, when the choice of structural material or system involves a different approach to non-structural element buildups, it is recommended to review the carbon from a larger scope than just structural elements.

Example:

A 90mm insulated timber framed wall (400 c/c stud spacing) lined both sides and painted might expect to have an upfront carbon impact in the realm of ~7 $kgCO_2e / m^2$ (not including the bio-genic carbon stored in the timber). Of this, more than half is from the impact of the plasterboard and insulation.

If this wall is required to have a higher Sound Transmission Class (STC) rating (for acoustic / privacy reasons), there are several options. These are summarised below along with approximate upfront embodied carbon impacts (note the actual acoustic performance improvement is not quantified, and is likely to differ between options):

- ***Change to steel studs: increases by ~25% (also refer Top Tip #16)***
- ***Add additional layers of plasterboard lining: increases by ~40% - may also require stud size increase***
- ***Increase stud size to 140 and increase stud spacing to 600mm c/c: increases by ~5%***

As always, these impacts will vary depending on project specific context and requirements.

Another important aspect to consider with non-structural elements is the replacement cycles. Typically replaced at a much higher frequency than structural elements, initial upfront carbon impacts of these elements are likely to occur every 10-15 years (or more frequently in some cases). Therefore, it is important to choose structural systems to minimise architectural finishes and linings where possible.

Top Tip #18: Request Environmental Product Declarations (EPDs)

To make informed decisions about the impact of the materials we specify, we need reliable information about the environmental impact of these materials. Environmental Product Declarations (EPDs) are independently verified documents that communicate the life-cycle environmental impact of a material or product in a consistent way. BRANZ has an informative Bulletin Paper – BU603 Environmental product declarations for more information on the types and standards of EPD's .

In Tip #1, we talked about 'carbon intensity', the measure of Global Warming Potential for one unit of a material or product. EPDs are a good place to find the carbon intensity for a specific product, and are widely regarded as a reliable source of this information. For instance, the large concrete suppliers have EPDs for all their standard concrete mix designs including down to which batching plant the concrete will be sourced from.

As specifiers, if we can compare the EPDs of two similar products for environmental data such as the Global Warming Potential to produce 1 kg of that material, we can then make an informed decision on which to recommend (for instance, steel reinforcement produced by different suppliers can have vastly different carbon intensities).

You may not know which supplier you are going to use during design, and therefore may use a more generic industry average carbon intensity than one from a specific EPD. These industry average values are normally derived using the EPDs of individual suppliers.

The more products that have EPDs, the more reliable we can make our carbon assessments and the bigger impact we can have.

However, not all material suppliers have EPDs for their products. There is a cost for suppliers to produce EPDs and keep them up to date. By requesting EPDs, we are showing there is market demand for this information and encouraging suppliers to understand their own impact (which may result in them finding ways to minimise it).

Example specification request [generic]:

The following additional information shall be submitted at tender:

Current supplier EPD Type III environmental declarations according to ISO 14025:2006 and compliant with EN 15804; or

A Carbon Footprint of Product declaration with third-party verification

It's important to remember that material quantities are just as important as carbon intensity when assessing embodied carbon. Carbon intensities from EPDs should only be taken with the same degree of accuracy as the material quantities. Changes at the construction stage that impact material specifications may affect both carbon intensities and material quantities and should be monitored.

Top Tip #19: Specify timber well

This tip focuses on how to help you use and specify timber on your project in a way which minimises current and future carbon emissions.

Firstly, the same principle of resource stewardship applies equally to timber as for other structural materials. Don't use more than you need - using unnecessary additional timber in a building does not result in a better carbon outcome.

Example:

Typically, producing 1 m³ of construction timber from raw logs results in about 100 kgCO₂e of emissions. Manufacturing 2 m³ will emit 200 kgCO₂e. More material = more emissions.

Secondly, carbon emissions from the processing of timber products is significant. In particular, kiln drying and gauging consumes a lot of energy. It is not always intuitive to know which timber products are higher carbon as this will depend on the different manufacturing processes used. Always refer to an EPD if available.

Example:

1 m^3 of LVL is typically lower carbon than 1 m^3 of sawn gauged timber. The veneers dry faster in the kiln and no gauging is required. So as well as LVL sections typically being smaller than their equivalent sawn timber counterpart, their carbon intensity is lower for the same volume.

Thirdly, the location of manufacture is significant. Timber processing plants are highly dependent on the local electricity grid to supply energy. Where timber is produced can have a large impact on the carbon intensity of the product.

Example:

CLT manufactured in Australia can have a carbon intensity as high as reinforced concrete (on a volumetric basis). Because the grid electricity in Australia is often produced from burning coal, it has a higher carbon footprint than grid electricity in Aotearoa New Zealand. Designing in mass timber is no guarantee of low carbon outcomes.

Much is made of the biogenic carbon that is sequestered by trees as they grow, and subsequently stored in timber products made from them. This amounts to ~1,000 $kgCO_2e$ / m^3, and can be considered a climate benefit, as long as the carbon remains in the product, and the timber has come from a sustainable forest.

The supply chain has to be transparent enough to be confident that the timber is from a renewable source, i.e. a sustainably managed forest, maintained with a replant rate that matches the harvest rate. FSC or PEFC certifications (Forest Stewardship Certification, Programme for the Endorsement of Forest Certification[32]) is one way to manage this risk. If the timber has been harvested from forestry practices that result in permanent land-use change (i.e. deforestation), the climate benefit of the carbon stored in the timber cannot be considered.

[32] https://www.pefc.org/

Transportation emissions for timber can be a significant proportion of upfront impact. Trucking is much more carbon intensive than shipping, so projects should estimate the likely route of transportation to give a holistic understanding of carbon when selecting different products.

Example: Shipping 1 m^3 of timber from Europe to Aotearoa New Zealand on a bulk carrier is likely to cause the same amount of carbon emissions as trucking it for ~250 km (approximately Auckland to Tauranga).

Treatment types can have a big impact on the carbon emissions associated with timber products. H1.2 treatment is negligible from a carbon perspective, but H3 and above can add ~50 $kgCO_2e$ / m^3 (up to 50% additional).

The carbon impact of connections in timber-framed buildings, particularly mass timber buildings can be particularly significant. These should be included in your calculations of carbon for the system or structure as a whole.

Finally, facilitating future re-use of timber products (through designing for disassembly and maintaining clear documentation) will increase the likelihood that the carbon benefit stored in timber can remain 'locked up' away from the atmosphere for longer.

Top Tip #20: Specify low carbon concrete

SESOC published a journal article in 2023 with detailed information and guidance on specifying low-carbon concrete[33]. Key points have been duplicated here.

Reduction in global warming potential of concrete mixes is generally achieved through reducing the amount of cement. In practice, reducing cement usage can be accomplished by specifying the carbon performance of concrete through a limit on upfront carbon.

Specifying the carbon performance has the following advantages:

- it allows the ready-mix supplier to use the 'best tools in their tool belt' to achieve the end product, for example, using whatever Supplementary Cementitious Materials (SCMs) are available,
- emissions from all ready-mix production activities are taken into account including raw material production and transport,
- the particular cement source and associated up-front carbon is included,
- different geographical constraints can be taken into account, for example, the locally available aggregate may increase or decrease the cement demand.

This specification should be in alignment with that for 'Special Concrete' under NZS3104, meaning that the performance requirement and means of meeting it need to be given.

Example specification text:

Global Warming Potential Limited Concrete

The required maximum Global Warming Potential (GWP) for the concrete mix is [X] $CO2_2e$ /m^3. The bounds of the measurement are to be modules A1-A3 as defined in ISO 14044.

The following additional information shall be submitted in support of GWP limited concrete:

- ***Current supplier Environmental Product Declaration according to ISO 14025:2006 and EN 15804***
- ***The mix GWP with a supporting calculation showing a breakdown of components, and third-party verification where available***

There are EPDs for Aotearoa New Zealand ready-mix concrete which give GWP values for standard concrete mixes across the country. BRANZ have collated these values into the CO_2NSTRUCT database[34], also refer to Top Tip #11 for some generic factors. In general, cement manufactured in Aotearoa New Zealand will be lower-carbon than imported cement.

Engineers will need to determine an appropriate GWP limit for their project. This should be benchmarked against what is standard locally. In general, a 10% reduction is likely to be easily achievable while a reduction of over 30% may require a specific mix design and introduce other complexities to be managed.

Often a lower carbon concrete will result in a supplier wanting to use SCMs. Cement replacements of up to 70% by SCM's are technically possible, however these can sometimes interfere with another performance requirement of the concrete. For example, the inclusion of SCMs can slow strength gain which may be inconvenient for precast elements. For this reason, the specifier needs to have a basic knowledge of the influence of SCMs on concrete properties, and needs to be able to communicate impacts to other project stakeholders.

[33] Specifying concrete with low upfront carbon, SESOC 2023 https://www.sesoc.org.nz/download/9-specifying-concrete-with-lower-up-front-carbon-sesoc-journal-vol-36-no1-apr-2023-pdf

[34] CO2NSTRUCT database, BRANZ 2023 https://www.branz.co.nz/environment-zero-carbon-research/framework/branz-co2nstruct/

Top Tip #21: Specify steel well

Specify less steel:

Most of the carbon emissions from steelmaking is in the transformation of virgin material (iron ore, or iron sands in Aotearoa New Zealand) to steel. Through recycling steel scrap, we can avoid many of these emissions. Unfortunately, steel scrap is a limited resource, and the quantities available are only ~20% of the annual global demand[35]. With the supply of scrap steel at nearly full utilization, **any steel that you specify is triggering demand for virgin steel production**, irrespective of where that steel is coming from, and irrespective of what the verified carbon intensity is for the material that arrives on site. Therefore the first and most important step is to design in a way that allows you to specify less steel – in particular, prioritising its use where its strengths can be maximised for structural performance (refer *Influence the System* and *Influence the Detail* sections).

In industrial buildings, the use of large-format light-gauge steel framing for portal frame members is sometimes considered. When compared against more traditional I-section hot-rolled-steel portal frames, these frames can have lower total steel tonnage (and embodied carbon). Note that specific Aotearoa New Zealand-study information on this is currently lacking, so your own study will be required to evaluate this for a particular project.

Specify low carbon steel sources:

As noted in the introduction, reducing the carbon intensity of the material is secondary to reducing the material quantity. The specification and sourcing of low carbon materials is one of the ways consumer power and emissions targets are used to drive improvements in global steel production practices.

Specifiers should review the steel sourcing options, opting for the least carbon-intensive product. EPDs will be the most straightforward way to compare the carbon outcomes of different steels (refer Top Tip #18). Unfortunately, most steel suppliers don't yet have an EPD for their products. HERA has good resources for assumptions on the carbon intensity of steel from different sources[36]. Typically, mills which operate an Electric Arc Furnace (EAF) will produce steel with a lower carbon intensity than other methods of production, particularly in countries with a low-carbon electricity grid. Working with contractors and their steel distributors to understand supply chain options for various steel section types will increase the likelihood of achieving lower-carbon outcomes on projects (refer Top Tip #4). Incorporate into material specifications either by direct specification of source, or by specifying maximum GWP for each section type and grade.

Aotearoa New Zealand Steel is underway with replacing their current furnace with an EAF, which is expected to be operational in 2026. However, this manufacturer only supplies some structural steel products (reinforcing, cold formed steel framing, some welded sections and some plate sections)[37]. Most other structural steel products used in Aotearoa New Zealand (hot rolled sections, hollow sections) are imported and so their embodied carbon will not be affected by the Aotearoa New Zealand Steel EAF.

Enable reusability:

Structural steel is one of the most stable and reusable structural materials we have available to design and build with, therefore lends itself well to reuse opportunities over long periods of time. There are different levels of reusability, with differing levels of carbon benefit:

1. Continue to use existing steelwork.
2. Repurpose deconstructed steelwork.

35 Scrap use in the steel industry. Worldsteel, 2021. https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf
36 Steel Sector Carbon Offset Programme. Thinkstep and HERA, 2021. https://www.hera.org.nz/wp-content/uploads/Steel-Sector-Carbon-Offset-Programme-Instructions-v1.pdf
37 New Zealand Steel, 2024 https://www.nzsteel.co.nz/products/

3. Recycle steel for scrap.

Option 3) above is business as usual, and is not further covered here.

Options 1) and 2) above can be considered from two perspectives: that of reusing an existing building, and of setting up new buildings to enable reuse in the future. Both of these strategies call under the "use less material" strategy, as this will avoid the need for new production of material.

Key considerations for enhancing existing steel reusability are summarised as follows:

Design for disassembly (new buildings): Specifiers should design steel structures with bolted connections to allow easy disassembly (and then reuse) at any point.

Steel passports (new and existing buildings): specifiers are encouraged to collate an easily accessible and enduring record of the steels' source, grade and properties, to allow future easy identification and remove a barrier to re-use. Work with a certified Steel Fabricator to emphasise quality assurance and risk reduction.

Steel identification and testing (existing buildings): In cases of unidentified steel, such as in older buildings or imported products of uncertain provenance, specifiers should employ efficient methodologies such as non-destructive testing (NDT), to estimate the mechanical properties and chemical composition of structural steel elements. This will minimise conservative assumptions used in design and assessment, and therefore minimise material.

Example (steel identification and testing):

The CAB building in Auckland Central was a 1950s designed steel framed building. Its recent redevelopment comprised retention of the existing basement and superstructure steel frame, and replaced the floors and facade. The reuse of the steel frame saved >6,000 tCO_2e through avoided emissions[38].

Summary:

- Early non-destructive testing of a representative sample of the steelwork enabled structural engineers to prove a level of performance and make the most of the existing frame, rather than accepting conservative treatment of unidentified steel.

- This example demonstrates the value in material passports for the future, and comprehensive as-built records which minimise future barriers.

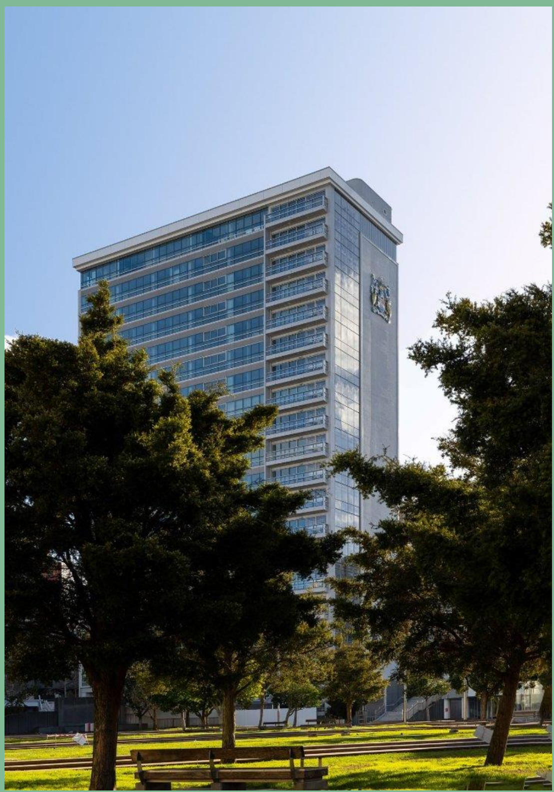


Figure 11 CAB Building (courtesy of Beca)

[38] https://www.beca.com/what-we-do/projects/buildings/the-cab-former-civic-administration-building and https://www.hera.org.nz/stp-ep101-reuse-the-past-the-quest-for-net-zero-construction/

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