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CHALLENGES AND POSSIBLE SOLUTIONS FOR STRUCTURAL ENGINEERS SEEKING TO MAKE A POSITIVE CONTRIBUTION TO THE CLIMATE EMERGENCY

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ABSTRACT

As the construction industry, and the society within which we operate, seeks mitigations to our present climate emergency, structural engineers are seeking ways to transform from part of the problem, to part of the solution. In this paper, the Author examines the barriers that face practicing engineers in the meaningful implementation of low-carbon structures, and how those barriers might be hurdled, either by individual design teams, or by the industry at large.

This paper will first consider industry or society wide issues. This will include: New Zealand's minimal regulatory environment and lack of green property market drivers in comparison to other countries; and the relative lack of readily available carbon calculation information for the New Zealand supply chain's carbon impact.

It will then consider common project level challenges, including: Client and industry perceptions on cost; the dominance of operation carbon impact on building sustainability decision making and the impact of their inapplicability to embodied carbon impacts; and the dearth of reliable, local, benchmark data available to design teams.

Finally, it will consider some of what are, in the author's opinion, the biggest technical challenges. This will include the current environmental impact of New Zealand concrete based construction, and some simple improvements that any project could adopt; and enormous improvements in embodied carbon available via timber construction, alongside some of the ways that the timber industry is making it difficult to make timber structures feasible in New Zealand.

For each of these challenges, some of the solutions available to practicing engineers will be discussed. Both established solutions available internationally, and nascent New Zealand solutions.

BACKGROUND - ISTRUCTE CLIMATE EMERGENCY

When considering structural engineering practice in New Zealand, one touchstone that can be useful is a comparison with practice in the United Kingdom. In this comparison, New Zealand engineering practice has several strengths. Not just in the obvious arena of earthquake engineering. New Zealand engineers have an extremely deep understanding of engineering fundamentals, with a first-principles-based design philosophy, and the ability to consider

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buildings holistically as complex, three-dimensional structures. They also have an eye for practical, robust, real-world solutions.

We do, unfortunately, have a glaring deficiency. By comparison to British and Irish engineers, we are sorely lacking in our application of environmentally sustainable practices in our projects. The UK has had sustainable building accreditation since 1990, with regular increases in both regulatory requirements and market driven adoption. In 2019, IStructE, along with many UK structural engineering companies followed the UK government's lead, declared a Climate Emergency, and committed to addressing it. This commitment now has 211 signatories and is an established part of engineering practice in the UK.

By contrast, sustainable structural design in New Zealand remains very much the exception. A nice-to-have that gets ignored by most busy practitioners spinning multiple plates and gets squeezed out of projects by value-engineering processes that give no weighting to environmental considerations.

Through the course of a range of projects that have attempted to hurdle the real-world pressures of implementing structural sustainability, the author has formed a view of the barriers presented to structural engineers and presents some possible solutions.

THE PROBLEM - SOCIETAL AND MARKET ISSUES

Regulation

New Zealand, like many other western democracies, has embraced free trade and deregulation. Somewhat unusually, and in sharp contrast to the likes of the UK, Singapore, and even the US, New Zealand has chosen to extend this deregulation to the built environment. Whether it be our current home insulation ratings being approximately half of what was required in the UK twenty years ago, our industry's continuing dalliance with self-regulation, or the symphony of regulatory dial-downs that lead to the leaky buildings crisis, our regulatory environment has consistently managed to hold the bar low.

Given our history, it seems unlikely that central government will impose impactful sustainability regulation in the near future. However, there are some potential regulatory currents down which the nation's waka might drift to seek out greener pastures.

The Building for Climate Change Programme offers one such route. While it is not clear how much this might result in meaningful regulatory change, it does seem likely that it will at least influence government procurement and funding. Importantly for structural engineers, the framework proposed by this programme places just as much emphasis on whole-of-life embodied carbon as it does on its more bolshy cousin, operational efficiency.

While there may not yet be regulatory teeth in either the Building for Climate Change Programme, or the broader Climate Change Commission advice, they do signal governmental direction.
As such, they may allow practicing engineers to work with sympathetic clients to promote sustainable practices on projects. When boards, councils, or trustees are benchmarking against best practice (rather than minimum practice) these central government documents can provide that mandate. The author would recommend that practicing engineers engaged with client side decision makers familiarise themselves with the content and direction of these documents.

Market Drivers and Certification

Along with generally low regulatory standards, New Zealand has typically also had low penetration of market driven certification. Perhaps it is simply that the size of our market has not permitted the likes of GreenStar to gain traction. The only building system that seems to have penetrated public perception is %NBS, which was most certainly not intended as a market-driving certification system, though its gleeful adoption by the real estate industry provides a lesson in the benefits of simplicity to certification providers!

For the New Zealand Building Industry, the most effective market certification approach is surely alignment with established international systems such as GreenStar, which would allow international clients a known benchmark. It does however seem that certification in New Zealand will likely remain a badge of honor, rather than means of driving widespread change.

Whilst current certification seems unlikely to influence the market, it does provide a means for engineers to influence individual projects. In particular, Net Zero carbon accreditation has a focus on whole-of-life carbon reduction, which generally necessitates a need to implement a low carbon structure. This is emergent accreditation managed by the NZGBC (New Zealand Green Building Council), which sits alongside their existing NABERSNZ and GreenStar accreditation, but with a much heavier focus on carbon. Currently, NZGBC are running a pilot carboNZero certification for building operational carbon, with an equivalent embodied carbon certification soon to come. Certification will be in line with their NetZero Carbon Roadmap for Aotearoa, and is expected to release in time for buildings achieving practical completion after 1 January 2022.

THE PROBLEM - PROJECT AND INDUSTRY ISSUES

The following are issues that exist at an industry level. They are challenges that are best addressed by industry groups. The author's view is that SESOC can play a major role in overcoming these issues.

Carbon Calculation

Ultimately, most project decisions are driven by hard numbers, be they construction cost, structural capacity, or net lettable area. To allow sustainable aspirations or green goals to be realised on a project, there is a need to quantify carbon benefits so that meaningful decisions can be made.

Historically, this has been difficult for design teams to achieve, however a number of tools now exist that were not available a few short years ago.

At the heart of most current carbon calculation is IStructE's *"How to Calculate Embodied Carbon" (2020)*, which consolidates much of the latest research into a practical calculation process. Whilst this guide was developed in the UK, it is rapidly gaining international adoption as the baseline approach for embodied carbon calculations.

BRANZ have been developing a New Zealand specific dataset of embodied carbon values that is appropriate to our particular material carbon-costs. This is available via BRANZ CO_2NSTRUCT and covers life cycle modules A1-A3 i.e. up-front carbon emissions. Full life cycle assessment of buildings or structures is also possible through its free online tool, BRANZ LCAQuick, which also includes transportation and construction data most appropriate to New Zealand: https://www.branz.co.nz/environment-zero-carbon-research/framework/branz-co2nstruct/

To speed the process of embodied carbon calculations, many organisations have developed their own tools to facilitate the calculation, several of which have now been publicly released. These include:

IStructE: The structural Carbon Tool:
https://www.istructe.org/resources/guidance/the-structural-carbon-tool/

BRANZ: LCAQuick:
https://www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick/

Naylor Love: Naylor Love Building Carbon Calculator:
https://www.naylorlove.co.nz/carbon/

Supply Chain

Like any change in a design paradigm, the expectation is that over time the mix of products and materials used in our buildings will change. This will create supply chain challenges, some of which are already becoming evident in New Zealand.

Most obvious is the engineered timber supply, which in New Zealand is both narrow and shallow. Though we have a well-established forestry industry, this has not yet translated away from primary industry into a robust manufactured product supply chain. Not just the timber itself but associated structural fixing and architectural finishing solutions. An improvement in this supply chain is likely to need suppliers, specifiers, contractors, clients, and government all working together.

Similar issues exist in other low carbon alternatives. There are few options for fly ash supply, limited alternative foundation options, limited locally manufactured low-damage solutions. There are no quick solutions to this, but neither need it be an overly challenging problem if it is acknowledged and steadily improved.

Standard Solutions

Similar to the supply chain challenge, the transition to different forms of construction means those alternative forms lack standardisation.

A key part of this is standardisation of materials, particularly for timber. Whilst concrete and steel, as well as general framing timber, have established material standards, engineered timber does not. As with any product, the lack of standardisation makes it harder to specify and implement, reduces completion, and generally makes that product less desirable to use.

Similarly, standard products and details greatly enhance the likelihood of adoption. The SCNZ connections significantly reduce the design time for steel and have done an enormous amount to ease its widespread adoption. Such standard solutions are not available in heavy engineering applications for timber, and it would surely be to the advantage of the timber industry to develop similar solutions.

Misguided Green

Often projects may have a client or sponsor who is interested in improving the sustainability of the project but may not have knowledge of the best way to do so. This can lead to misguided, or suboptimal outcomes. Thus, we see projects prioritising solar panels in regions where the grid supply is 85% renewable, or rainwater harvesting in our drier regions, rather than the much more substantial improvements that are often available via the structure.

Structural engineers have an important educational role to play in adoption of a more thoughtful and impactful application of sustainable design. Part of the reason that Green-bling, like solar panels, are often adopted is that other sectors of our industry are more active in addressing and promoting sustainable design.

The solar panel industry is actively marketing the benefits of their systems, hence its visibility in the public imagination. Services engineers see sustainable design as a core part of their daily operation, and thus have a plethora of options ready to present to clients at project inception. This has over time trained project managers and clients to expect and anticipate sustainability initiatives relating to building operation. Embodied carbon is still not on many design team's radars.

It is the author's belief that structural engineers should consider embodied carbon as a core part of structural performance. Just as cost, robustness and constructability are measures of a good structural design - and form part of the ingredients a structural engineer mixes into the melting pot of concept design, so too should embodied carbon be added to the broth.

To do so, the burden is on individual engineers to understand embodied carbon measures, as well as methods to design it out.

As a simple example of the impact of structural substitutions on embodied carbon, the new classroom blocks at Waimea College were constructed out of timber rather than concrete and steel. This move to timber means Waimea College's new teaching block superstructure has approximately 82 tonnes of CO2e sequestered from the atmosphere into sustainably forested timber, and a further 190 tonnes CO2e of emissions avoided by removing the concrete and steel from the superstructure. 270 tonnes of CO2e all up.
What does 270 tonnes CO2e look like? To give a sense of scale, that represents around 110,000 school drop-offs worth of carbon savings (assuming a 15km round trip).

Figure 1 – Waimea College

Figure 2 – Waimea College

The Fear of Uncertainty

"Taking a new step, uttering a new word, is what people fear most."
— Fyodor Dostoevsky, *Crime and Punishment*

Moving from a design paradigm that does not consider carbon, to one that places it alongside cost, function and safety as a critical driver inevitably means change.

With change comes risk. Structural engineers and their cost estimating colleagues are a risk averse bunch, and whilst it is natural and appropriate to consider and allow for risk associated with sustainable alternatives, if the industry is to progress, it is necessary that the risk allowance be appropriate. Currently a lack of individual experience, especially within the cost estimating community, can tend to artificially inflate estimates for sustainable alternatives.

For example, in the author's experience, significantly higher rates are typically placed on timber by QS's inexperienced in its construction than by those QS's who have undertaken numerous timber projects. This has a tendency to limit timber buildings to those being costed by a sympathetic QS and stunt its use in the wider industry.

A similar dynamic to that witnessed with QS's plays out amongst structural engineers, project managers, contractors, architects, and clients.

What this often means on projects is that a majority of members on a project team need to be inclined towards sustainability in order for it to be implemented on a project. Often individual engineers can make or break a sustainable approach on a project by shifting from an ambivalent position, to a pro-active position on sustainability.

To allow sustainable approaches to spread beyond niche consultancies and become common practice, the various industries need to actively share information until a sufficient professional body of knowledge can be established.

Timber and Fire

The relationship of timber and fire is one of particular complexity. In New Zealand, both the engineering timber industry and the fire engineering industry are still relatively immature. This is leading to some peculiarities, which is not helped by some representatives of other industries adopting scaremongering tactics.

Fire engineering in New Zealand, by comparison to structural engineering, is in a phase of relative immaturity, and as such is both extremely risk-averse, and heavily compliance focused. Whilst structural engineering has adopted a generally accepted acknowledgement of risk (via our limit states) and accepts the adoption of engineering judgement to determine the appropriate bar (sometimes with peer review), fire engineers take a different approach.

In practice, most fire engineers start with a 'zero-risk' assumption, and then overlay a highly compliance focused methodology. This typically relies on acceptance by a designer, peer reviewer, territorial authority, FENZ, *and* insurance certifiers. It also typically relies on prior physical testing rather than engineering judgement.

This has created some very unusual and onerous design outcomes, including:

- The new Timber Fire standard requiring steel connectors to be protected to a limiting temperature of 300 degrees Celsius (or 120 degrees Celsius depending on the connector). A level much more onerous than the functionally equivalent requirement in the steel standard, and a level not achievable by any available applied fire protection system!
- Onerous requirements for surface spread of fire.
- Negligible differentiation between high risk situations (hotels, apartments etc.) and low risk situations (offices etc.)

It is the author's opinion that the examples above, and other idiosyncrasies of timber fire design, pose an obstructive barrier to timber low carbon solutions, and one that is inappropriately out of alignment with other building risks (such as earthquake or flooding) for the majority of buildings. The exception to this view being multi-story sleeping accommodation where the risks of timber in fire are considerably higher and should be very carefully considered.

SOLUTION?

Practical Easy Wins for Structural Engineers

There are several systemic, societal or industry changes that are required to make sustainable structural design stick in New Zealand. There are individuals and organisations seeking to make these changes, but much of that may occur beyond the reach, or the perhaps interest, or the typical structural engineer.

There are however many practical things that a structural engineer can do immediately. The author's opinion on some of the most simple and impactful of these are below.

Acknowledge embodied carbon

The single most impactful thing that a project can do is to simply acknowledge embodied carbon as an issue (of roughly equal stature as operational carbon), and put it on the table as a design driver. If it is discussed and considered properly, then designs will change.
The diagram below is a powerful tool that resonates with many project stakeholders. It allows them to see at a glance the relative impact of embodied carbon. When a client asks about solar panels, show them this instead!

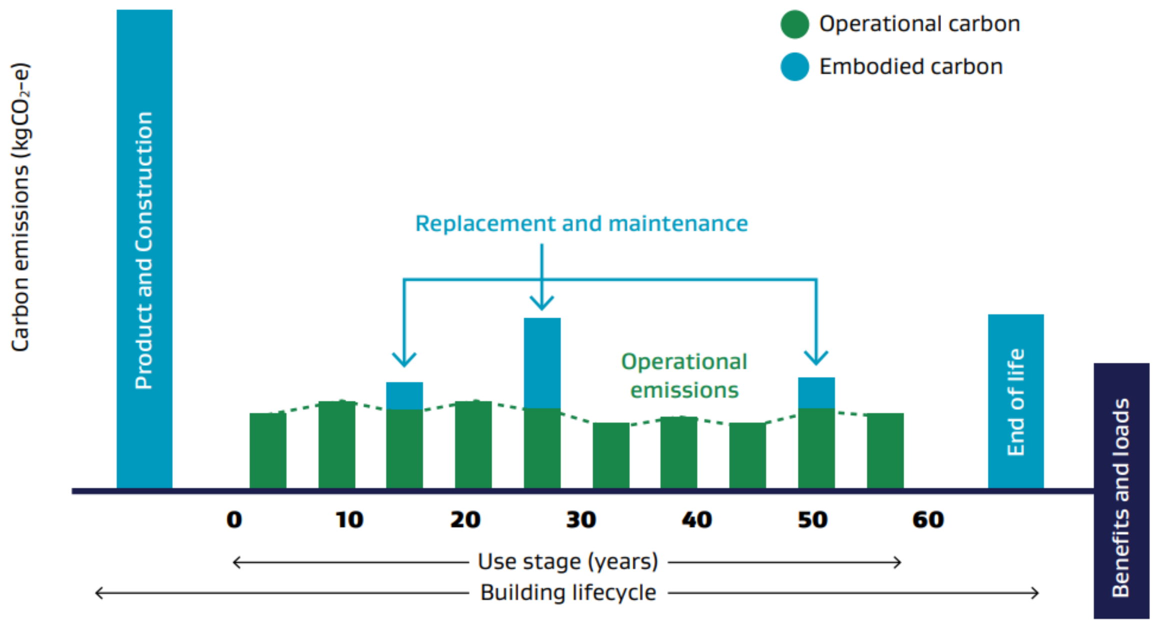

Figure 3 - MBIE, Whole-of-Life Embodied Carbon Emissions Reduction Framework (Aug 2020) https://www.mbie.govt.nz/dmsdocument/11794-whole-of-life-embodied-carbon-emissions-reduction-framework

Quantify Embodied Carbon

If quantities are available from a PQS, then it is a relatively straightforward exercise to quantify the carbon using the tools presented earlier in this paper. Putting hard numbers to the issue can focus some minds. Many clients might not want to pay a premium for a general sense of greenness. But if you asked them how many dollars they would be willing to pay to eliminate the carbon equivalent to 110,000 school drop-offs, most could probably allocate a dollar value to that benefit and make a decision.

Engineers are, however, busy people, and many are unlikely to want to undertake detailed carbon estimation for the sheer enjoyment of the exercise. To assist those engineers, some (very crude) estimates are provided in Table 1 below of how the most common materials would appear if their commonly estimated costs were paid in carbon rather than dollars.

Table 1 – Carbon Estimation

Material	Nominal supply and install cost	$CO2e/m^3$ (A1-A3)	$CO2e/m^3$ (A1-A3), presented as dollars normalized to steel cost
Concrete (Firth 30MPa)	$\$450/m^3$	$0.26t/m^3$	$\$730/m^3$
Steel (Bluescope)	($8/kg) $\$63,000/m^3$	$22.3t/m^3$	($8/kg) $\$63,000/m^3$
Timber (Glulam NZ)	$\$2,500/m^3$	$-0.33t/m^3$	*$-\$930/m^3$*

All data values in the table above are based on the up-front embodied carbon, i.e. life cycle stages A1-A3 only. The carbon data value for concrete is based on the recent Firth EPD for average North Island 30MPa concrete. The data value for steel has been taken from the Bluescope EPD for welded beams and columns. The dollar value is a simple scaling to nominal steel costs for indicative purposes. It does *not* represent the current New Zealand Emissions Trading Scheme (ETS) prices (of ~$25/T)

Clearly the costs and carbon-costs above are gross simplifications, and the real project impacts would require specific assessment, but the differences in materials should be obvious from a glance. If the indicative carbon-cost above were real dollars, it requires very little imagination to foresee changes to structural forms that would occur. Meter thick concrete rafts would not be a popular design choice.

<u>Don't Build it, Fix it.</u>

The lowest carbon building is the one that isn't built.

This almost flippant statement becomes a complex technical challenge for the New Zealand structural engineer grappling with the joint challenges of seismic assessment and the climate emergency.

Our current seismic assessment process intends to strike a balance between resilience and cost. As such, we strengthen some buildings, and demolish and replace others.

When a carbon overlay is applied to this, it makes it much more likely that we would want to keep and strengthen buildings. Whilst strengthening can often be costly, due to construction complexity or the use of more expensive materials or devices, it usually comes as a low carbon-cost. And usually at a trivially low carbon cost by comparison to a new build.

Detailed calculations for exact comparative carbon studies for strengthening versus replacement is likely to be relatively complicated. But to qualitatively acknowledge the carbon impact of a new build as orders of magnitude more than most strengthening schemes is quite straight-forward, yet rarely done.

<u>A Silver Bullet?</u>

Is timber a silver bullet? Well, in some ways, yes. From an embodied carbon standpoint, timber is exceptionally good. Concrete (and the cement in it), on the other hand, is particularly bad.

However, there is more to building design that only embodied carbon, and other factors must obviously be considered. Concrete is a cheap, durable material. It makes an excellent material choice for foundations of larger buildings. Steel has excellent strength and ductility.

The goal for a structural engineer is to find the best material for the job. It is very unlikely that timber will ever serve all purposes, even on projects that place a very heavy emphasis on embodied carbon. The aim for designers seeking to reduce as much embodied carbon as practical should be to focus on those areas where it makes most sense to minimise concrete volumes and substitute with timber.

<u>Low Hanging Fruit</u>

With the goal of minimising embodied carbon for as little impact on cost, constructability, resilience or utility, there are some areas that can readily be substituted with minimum effort. The following provide some brief guidance on good areas to look to substitute in timber:

Simple substitutions

- Construct lightweight areas such as mezzanines from timber studs walls and lightweight timber floors, using residential house type systems.

- Replace precast concrete stairs with prefabricated CLT stairs.
- Replace lift shafts with CLT panel shafts.
- Use timber and ply systems for roof cladding.
- Adopt timber stud rather than steel stud for fitouts.

Moderately complex substitutions

- In general, primary gravity systems can be substituted on medium rise structure.
- This can include LVL or glulam beams and columns.
- Floor systems can be substituted out for CLT or Potius systems, however timber diaphragms are much more difficult to substitute.

Difficult Substitutions

- Lateral seismic systems are very difficult to deliver in timber without significant cost or complexity. Or via a significant reduction in floorplate flexibility of the type usually only appropriate for apartments or hotels.

There is very little reason that the simple substitutions couldn't be adopted on almost every project. Although the resulting buildings may not have the architectural impact of some of the more showcase timber buildings, the resulting carbon reduction if accomplished on many buildings would be substantial.

Concrete Material Reduction

Concrete is a material that is going to be used in buildings for the foreseeable future. Its low cost, high strength, and exceptional durability will mean it remains in use even as we transition away from carbon.

One of the most significant actions that any structural engineer can undertake, and one that usually aligns with cost drivers, is to reduce the volume of concrete via more efficient concrete placement.

Currently, many engineers focusing solely on cost minimisation will be using larger than necessary concrete volumes. For example, Christchurch saw a proliferation of thick raft foundations as part of its rebuild, in order to avoid piling and reduce reinforcing quantities.

There are numerous areas where engineers can reduce concrete volumes with minimal, or even positive, cost impacts. These include:

- Adopting rib-raft or ground beam solutions rather than solid rafts.
- Adopting piled solutions, rather than shallow mass footings. This may include wider adoption of screw piling or timber piling.
- Reducing concrete thicknesses, with an increase in reinforcing if necessary.
- Reducing solid concrete thicknesses for walls or floors by using closer spacing of linear supporting elements such as beams, portals, or buttresses.

Cement Substitution and Reduction

It is extremely simple for engineers to substitute out a portion of their cement with fly ash. 15% substitution can be readily achieved, and there are means to substitute out higher amounts, perhaps up to 50% substitution. For low levels of substitution (up to 15%), the impact on direct supply cost is negligible, as fly ash is no more expensive than Portland cement to procure. However, increasing percentages of fly ash substitution typically necessitate inclusion of additives to offset its side effects, which drives up cost of supply.

The primary adverse impact of this is longer curing times. It therefore may impose challenges for precast concrete, or for concrete with visual finish requirements, but for the majority of concrete this is a viable substitution, with minimal cost impacts. Anecdotally, indications are between 0.5-1 hour increase in set time for a 10% fly ash substitution, depending on the class (i.e. quality) of fly ash used. It has the additional advantage of being able to be tendered as an option without fundamentally impacting the design, allowing clients and engineers to defer the decision until tender, thus minimising project risk.

There is relatively limited supply of suitable fly ash in New Zealand, and the challenge for the New Zealand concrete industry is to secure reliable supply and make it easier for engineers to specify lower cement mixes. Fly ash is not the only SCM to lower the embodied carbon impact of concrete – slag is commonly used in overseas markets to increase cement replacement to 50% total substitution (for example in Australia). As with fly ash, slag is a low-value by-product, so the majority of the supply cost comes from transportation. Its lack of availability locally is reflected in its scarcity of use in the NZ market.

Another very simple method for reducing cement content, and thus carbon, is to specify lower strength concrete. Many engineers will default to higher strength concrete when it is not necessary or accept supplier substitutions of higher strength concrete when it is not needed. These practices make sense until carbon is added as a design driver, at which point they become an extremely simple means for engineers to reduce carbon with almost no adverse project impact.

In the past few years, the average annual ready-mix concrete production volume has been in the order of 4.1 million cubic metres. For the purposes of this paper, let us assume it all contains enough cement content to achieve 40MPa strength at 28 days. If just 50% of this concrete reduced the cement content to achieve strengths of 25MPa at 28 days, this would equate to 492,000 tonnes of CO_2e emissions saved on an annual basis (using data from BRANZ CO_2NSTRUCT for unreinforced concrete, no SCMs).

CONCLUSION

The most significant challenge we are likely to face over the next few generations will be how we either mitigate the climate emergency, or failing that, how we address the much more difficult challenges of living with its consequences.

Structural engineers have a very important role to play if we are to successfully mitigate it. Whilst there will surely be signature projects pushing the boundaries of sustainable structural design, our collective success or failure will be measured by the aggregate embodied carbon invested in structures over the next generation.

Thus, what matters most is what all structural engineers do, from the tallest tower, all the way to the simplest ground bearing slab. For our industry to succeed, we need everyone, from the newest graduate, to Fellows of the Society, to do their bit for those parts of our built environment that are within their control.

The author hopes to provide in this paper some examples where individuals may recognise areas that they can make a direct difference, and encourages them to make it happen.