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AN INTRODUCTION TO EMBODIED CARBON ASSOCIATED WITH BUILDING DESIGN IN AOTEAROA – NEW ZEALAND

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SUMMARY AND INTRODUCTION

Across the construction industry worldwide there is a growing focus on embodied carbon. Whilst by no means a new area of study, with the life cycle assessment (LCA) of construction projects a well-established practice, it is apparent that over the coming years the Aotearoa-New Zealand industry will need to agree a method to calculate, report and improve embodied carbon values for new buildings accurately and fairly across the sector. The charge is being led on the policy side by MBIE, tackling emissions from the construction section through its 'Building for Climate Change' (BfCC) framework. The result is that many professionals in this industry are becoming, or will need to become, more closely acquainted with embodied carbon as a metric of design, along with time, cost, and quality.

Based on some recent experiences and projects quantifying embodied carbon for buildings in Aotearoa-New Zealand, the purpose of this paper is to discuss the fundamentals of LCA for buildings and present some example results from recent studies, from the viewpoint of an engineer entering into the world of LCA. The complexity of embodied carbon should not be a barrier to those looking to measure it, and to a certain extent a good estimate of embodied carbon could be achieved in four columns of a spreadsheet. However, the outturn figures will only be as accurate as the quantities derived, factors used, and consistency of the boundary of the analysis. A few key areas of uncertainty are discussed, such as appropriate steelwork embodied carbon factors (ECFs), comparison between as-designed and as-constructed measures, and whether the use of timber to decarbonise a project is a silver bullet.

Our studies, and others globally, indicate that typically more than half of the total embodied carbon impact of a project is associated with the systems and materials designed and specified by the structural engineer. This is why the structural engineering community must engage with this topic with a similar seriousness as the cost and safety impacts of projects.

BASICS OF EMBODIED CARBON AND LIFE CYCLE ASSESSMENT

Embodied carbon is a generic term to describe the amount of greenhouse gases emitted in the creation of a building, that would otherwise not be reported in energy and water usage during a building's life. Impacts occur at various stages, from the extraction of raw materials, production of building elements, transport and site activity emissions, through to end-of-life costs such as dismantling or demolition. The scope of building elements considered is typically; foundations, superstructure, façade, fitout, and building services. There are many different greenhouse gases with varying potency when released to atmosphere, and so estimated emissions of all gases are normalised into units of carbon dioxide equivalent (kg CO_2-eq.) for fair comparison. Embodied carbon is typically reported as part of a Life Cycle Assessment (LCA), which the Athena Material Institute defines as "*a multi-step procedure to quantify carbon emissions (embodied and operational) and other environmental impacts (such as acidification and eutrophication) through the life stages of a building.*" (Athena Material Institute, 2021) The life cycle stages have been defined for the purposes of building design in *EN 15978:2011 sustainability of construction works* as per *Figure 1*.

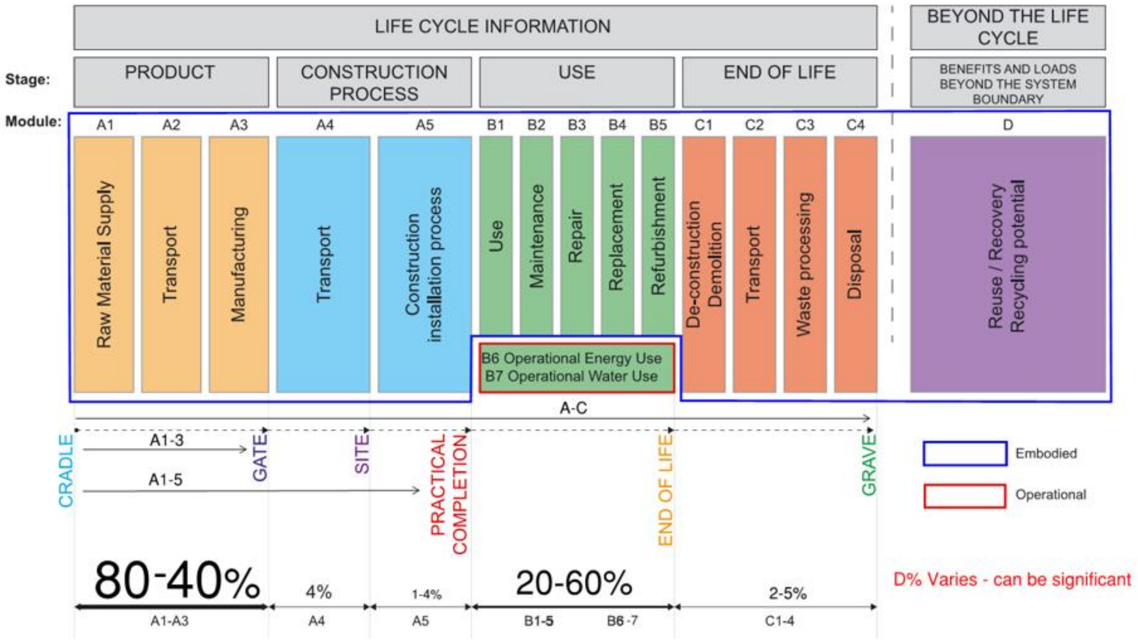

Figure 1 – Life Cycle Assessment for Buildings from guide "How to Calculate Embodied Carbon" adapted from EN 15978, with modified percentage estimates for NZ

Impacts are further split into "modules", which are helpful for the designer to state the scope of their study. There are a few common scopes for a study of embodied carbon:

- A1-A3 Cradle to Gate
- A1-A5 Upfront Carbon, or Cradle to Practical Completion of Works
- A-C Whole-of-Life, or Cradle to Grave
- A-D Whole-of-Life including reuse and recycling, or Cradle to Cradle

The percentages at the bottom of *Figure 1* roughly indicate where the impacts lie for a new building across the LCA modules. Clearly this is highly dependent on many factors, such as the location, type of construction, building function and even the carbon intensity of the electrical grid. Over the last few decades major strides forward in building energy/water efficiency design and technology have and will continue to drop the operational impact of new buildings (modules B6 and B7). This leaves embodied carbon as the increasingly dominant contribution to a building's overall climate change impact, as indicated by the progression shown in *Figure 2*. Similar strides to those made for operational energy efficiency need to be made to reduce the embodied energy of new construction; this is the basic motivation of the study of embodied carbon, aligned with global aims for net-zero 2050 infrastructure and economies.

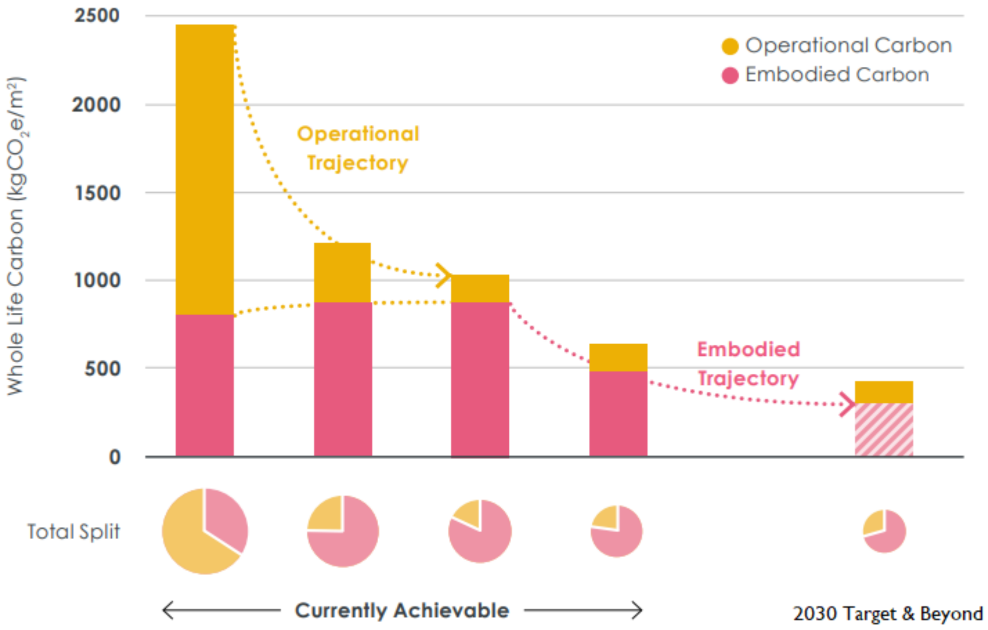

Figure 2 – Possible built environment operational and embodied carbon trajectories, adapted from LETI Embodied Carbon Primer (London Energy Transformation Initiative, 2020)

In the immediate future, achieving net zero embodied carbon will be impossible for the majority of new construction projects. However, there is scope to improve on current standard practice, and show that embodied carbon has been considered during design. To quantify this, many bodies in the UK sector have endeavoured to set targets, which are normalised by gross internal area (GIA) for buildings, an example of which is shown in *Figure 3*. It should be noted that these targets are not New Zealand specific, and that appropriate targets and methodologies are a work-in-progress here as part of the BfCC suggestion of mandatory, anonymised, publicly accessible carbon data for every project seeking a Building Consent (likely to be linked to GFA). Embodied Carbon is also not the only impact that new building projects have on the environment and climate. It is, however, one of the climate impacts that we can measure more directly and accurately, and track on projects (at regional and national levels) until other metrics are developed for other complex issues such as biodiversity.

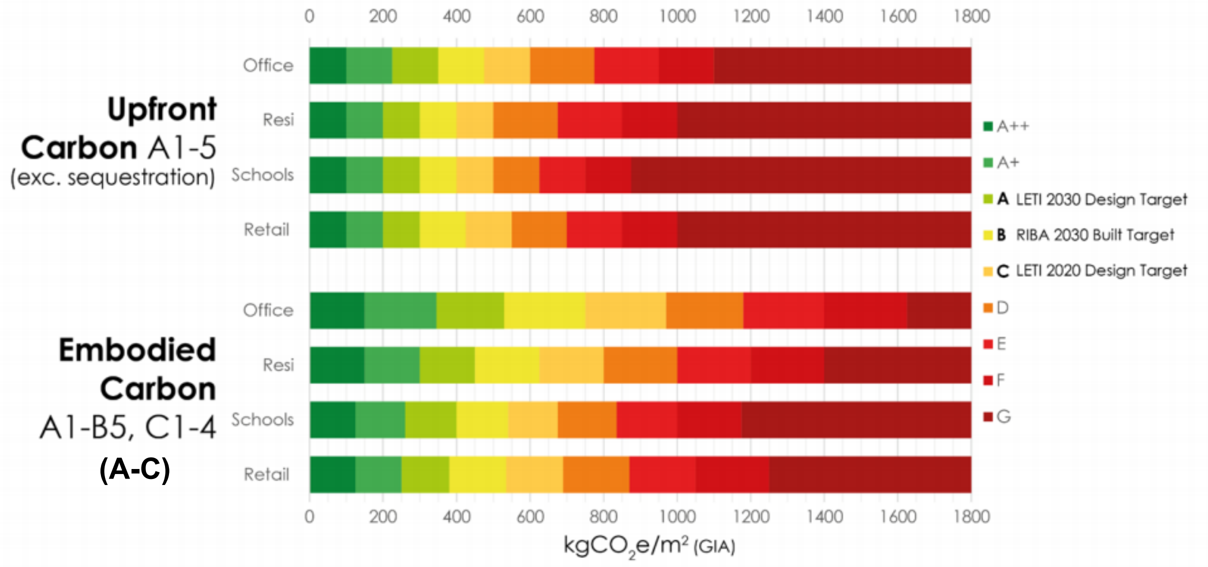

Figure 3 – A letter banding system with targets set by LETI and RIBA, LETI Embodied Carbon Target Alignment (London Energy Transformation Initiative, 2021)

In order to measure embodied carbon, it is key to have appropriate Embodied Carbon Factors (ECFs) for the materials used in the project. A selection of typical building materials are presented in *Table* 1, with their carbon impacts across the LCA modules, estimated for construction within Aotearoa-New Zealand. The data source for this is LCA Quick, a free tool developed by BRANZ to help quantify the carbon footprint of new buildings in New Zealand. The tool contains data collected from various sources (e.g. EcoInvent, EPD Australasia) plus NZ-specific factors calculated in-house for modules such as A4-A5 Transport and Construction Processes. The table is provided as an illustration of material impacts, and it is recommended that appropriate tools and data sources are used when developing a project LCA.

Table 1 *– Typical, non-project specifc ECFs (kg CO_2-eq. / kg) for New Zealand based construction materials, for typical LCA modules*

Material	A1-A3	A4-A5	B	C	D
In-situ concrete, 40MPa (OPC), 100kg/m^3 reinf.	0.33	0.02	0.00	0.02	-0.02
Structural steel sections	2.85	0.06	0.00	0.09	-1.14
Laminated glass	1.36	0.11	0.00	0.01	0.00
Softwood timber framing (from sustainable forestry practices)	-1.15	0.12	0.00	0.61	-0.29
Aluminium curtain wall framing (anodised)	11.40	0.18	0.00	0.26	-6.61

Once the right data-source is agreed, a project-level embodied carbon value can then simply be built-up by deriving the quantities of each major material from the Revit or analytical model, drawings, or early-phase sketches, and multiplying these by the relevant ECFs for each LCA stage/module of interest. Many different tools exist to assist the designer with this process, such as the BRANZ LCA-Quick tool mentioned above or the simplified CO_2NSTRUCT dataset.

SELECTED BUILDING ARCHETYPES

Table 2 below shows the overall embodied carbon for a number of selected projects within Aotearoa-New Zealand, measured using NZ-specific data.

Table 2 – Typical total embodied carbon (kg CO_2-eq./m^2 GFA) for building archetypes

Boundary	**Upfront**		**Whole-of-Life**		**Material reuse and recovery**
LCA Modules	**A1-A5**		**A-C**		**D**
Industrial[1]	200-250	**A**	275-325	**A**	− 25-50
Commercial/Office mid-rise (excl. services)	425-475	**B/C**	475-525	**A/B**	− 75-125
Residential mid-rise (steel frame and Comflor)	625-675[2]	**D**	925-975	**D**	− 200-250
Residential mid-rise (CLT floors and LVL gravity structure, timber stud)	425-475	**C**	750-800	**C**	− 200-250

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[1] There is no letter banding specified for industrial structures, but for the purposes of this paper the Office archetype has been used.

[2] By way of relating 625 kgCO_2 eq, this is almost the same impact as 1 seat on a return flight SYD-AKL, but it is for every m^2.

- Scope includes building structure, foundations, façade/envelope, base-build fitout and services allowance, U.N.O., as given in the RICS guidelines.
- Letter banding shown is in accordance with the LETI system in *Figure 3*, which is a UK-based target system, not necessarily appropriate for New Zealand, using GFA instead of GIA.
- Material reuse and recovery is reported as a separate column.
- Some commentary about building archetypes, why impacts per GFA are different and where the hotspots lie are given in the following sections.
- Some example reduction strategies are presented for the Residential and Office archetypes.

Building Archetype: Industrial Buildings

Industrial buildings are usually repetitive with exposed structure and minimal fitout requirements. For instance, portal frame sheds typically have a very efficient design, with long span steel members restrained by roof purlins and fly-braces. Design is often balanced between generous deflection limits and the ultimate strength of the section, without the need for the increased stiffness to support a floor slab or for tall steel frame construction. For a study of a new-build industrial building in the Auckland region, typical of warehouse construction, an efficient design lead to a low embodied carbon per square metre for the plan area, of around 200-250kg CO_2-eq/m^2 for the upfront construction.

The façade design is different from other urban buildings, with little use of high-impact materials such as glass. However, there is typically a larger ratio of external-envelope-area to floor-area due to the low-rise nature of this typology, and much of it is covered in metal cladding or precast concrete; so façade formed around 25% of the total building impact in this particular case. Typically, fitout within active areas was minimal, and the value of embodied carbon for the small proportion of ancillary office and convenience spaces was a reasonably small proportion of the overall total. Similarly, building services installation is not considered to be a high proportion of the overall building impact.

The embodied carbon associated with earthworks, ground improvement (e.g. stabilising soils prone to settlement and installing resilient foundations) and landscaping have a larger effect on these larger sites when compared to inner city projects. For this particular case, hardscaping outside of the building footprint included large quantities of fibre-reinforced concrete, granular fill (GAP 40/65) and a surface layer of asphalt. These elements represented about 20% of the total impact of the project over modules A1-A5. Foundations, ground improvement, and hardfill under the building formed around 40% of the entire project carbon, including the carbon sequestering impact of using H5 timber piles for the ground stabilisation.

Building Archetype: Commercial/Office Buildings

Commercial buildings in city locations typically are mid or high rise and tend to have large structural grids for open “clear-span” spaces for tenant organisations to inhabit without major inhibition from the primary structure. Often, they lend themselves well to steel-framed structures with numerous options for floor slabs depending on the constraints and desired performance. Taller construction introduces a more complex interaction of wind, seismic and gravity loading, which drives larger framing members and more material per square metre. In the last few decades, curtain walling with large extents of glazing have become common place on multi-storey inner-city commercial buildings, from which the glass and aluminium represents a large contribution to the façade and overall embodied carbon.

For this example Wellington-based commercial office project, the structural embodied carbon was primarily from composite floors (~20%), the foundations, comprising piling and reinforced concrete elements with heavier reinforcing ratios of 150kg/m^3 and above (25-30%), and the primary steel frame and floor-support structural steel members (~20%). The façade embodied carbon for the building was primarily from the curtain wall glazing (~45%), the precast concrete panels (~17%), and the curtain wall aluminium (~15%). The net base-build fitout impact was found to be small, as it had a limited scope, and the timber studs offset much of the GIB linings.

Table 3 shows the relative proportions for primary structure and façade when compared to operational energy usage. For the analysis of this particular project, which is of typical construction for a commercial building, the predicted operational consumption over a 50-60 year design life is almost equivalent to the embodied carbon of the building.

Table 3 *– Embodied and operational impacts of an example NZ commerical development*

	Embodied Carbon Intensity		**Operational Carbon**	**Total**
	Primary Structure	**Façade**		
Absolute [A–C] (t CO_2e)	11,000	3,000	14,500	28,000–29,000
Normalised (kg CO_2e/m^2 GFA)	375-425	100 (approx.)	450-500	950-1,000

Building Archetype: Multi-storey Residential Buildings

Mid-rise inner-city residential buildings can have many different types of construction. With less need for open spaces, walls are often used as primary structure in concrete shear-wall construction and concrete floor plates have good vibration characteristics that lend themselves to achieve inter-occupancy dividing walls and floors.

This particular study was of a mid-rise apartment block in Auckland employing a steel-frame and concrete deck construction similar to that described in the Office archetype. A difference between these two is the relative proportions of impact, with larger impacts in fitout. *Figure 4* shows the total relative split in embodied carbon for the residential building elements over Modules A-C between the structure & foundations (45%), building envelope (25%), fitout (20%) and building services equipment estimate (5-10%).

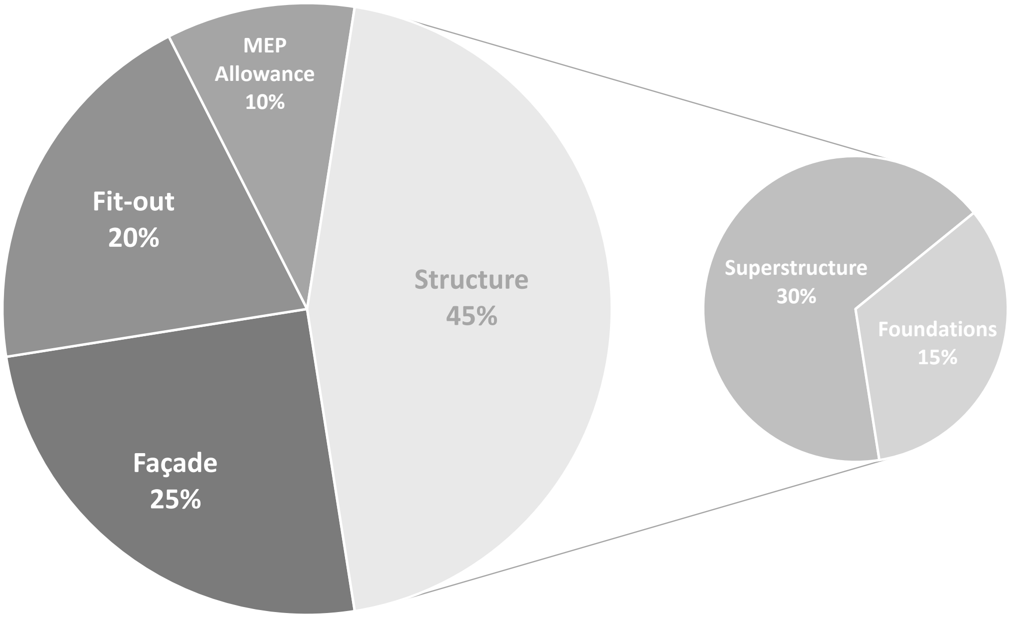

Figure 4 – Lifetime embodied carbon (modules A-C) by building discipline

Quantification of Reduction Strategies

There are many ways to reduce the embodied carbon of a new building, across all disciplines. These are likely to be project-dependent, but some example strategies are:

- Optimise design and refine rationalisation of structural system (do not over rationalise).
- Swapping internal floors from composite or concrete slabs to CLT, where appropriate.
- Reduce concrete strength specifications by 5MPa by relying on 56-100 day strengths instead, with delayed loading if necessary.
- Use of substitute cementitious materials (SCMs): specify 25% GGBS for all concrete in place of standard ordinary Portland cement (OPC).
- Swap precast façade panels for a lightweight panelised façade/rainscreen system.
- If present in the scheme, delete the basement.
- Reducing / optimising the amount of glazing and detailing to extend their usable design-life beyond that of normal to avoid the ‘Stage B’ replacement carbon penalty.

As an example, for the multi-storey residential archetype described above, some reduction strategies were quantified:

1. The use of CLT decks is an effective way to include a carbon sequestering product in the place of concrete. In this particular scenario, it was considered that CLT would not be able to span the same distance as the composite deck. Spacings of gravity only beams were reduced and swapped from steel sections to 600x100 hySPAN LVL (laminated veneer lumber) members. These two changes represent a 35% reduction in the whole-of-life embodied carbon for the entire structure, as shown in *Figure 5*.

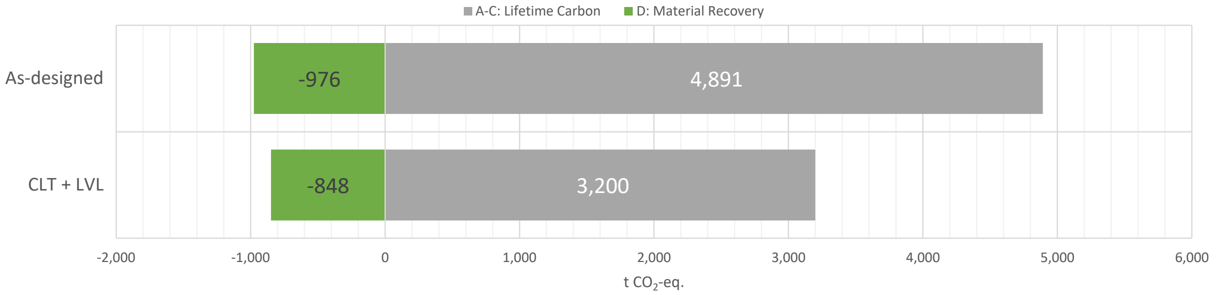

Figure 5 – Replacement of gravity structure elements with CLT and LVL

2. A significant portion of the embodied carbon of the interior fitout is often associated with ongoing maintenance or replacement of internal finishes such as carpet, elevators and coatings. For this particular study, amongst the highest carbon materials in the internal fitout are the standard GIB wall linings and the light gauge steel studs. These are two areas where simple material swaps could significantly reduce the embodied carbon of this component of the fitout. *Figure 6* demonstrates the global warming potential of the GIB wall lining on steel studwork, compared with a potential substitute system, 10mm plywood on timber studs, for the entire internal partition wall area for the example project.

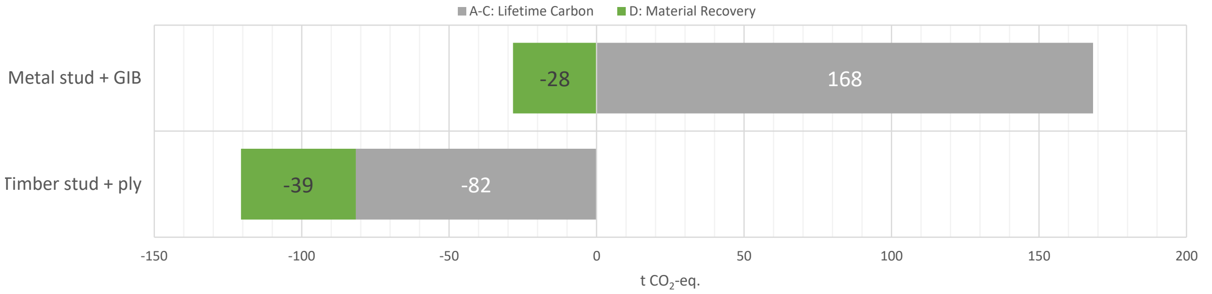

Figure 6 – Alternative stud wall system

DISCUSSION

Structural Timber and Carbon Sequestration

Trees are net-absorbers of carbon (until they reach maturity) and by incorporating timber products into buildings and regrowing forest plantations it is suggested that carbon is being "sequestered" i.e. stored in solid state, in a similar fashion to how crude oil is sequestered carbon that is being released by human activity. Fundamentally, timber needs to be sourced from sustainably managed plantations, for instance certified to the Forest Stewardship Council (FSC) management standards, otherwise no sequestration can be assumed.

Carbon sequestration presents as a negative ECF for timber products. This can paint a misleading picture, suggesting that 'inefficient' use of timber can have project benefits for reducing embodied carbon. This is a complex question: the initial A1-A5 impact of making timber products is a positive spike in emissions well in advance of any sequestration benefit that would occur during the next plantation cycle. Using a dynamic climate model (Will Hawkins, 2021) highlights the fact that carbon emitted in the present has a cumulative temperature change associated with it; looking at it another way, 1kg CO_2 emitted in the present and removed 20 years in the future is not the same as no carbon dioxide emitted, in terms of global warming. In this sense, inefficient use of timber should not be seen a silver-bullet for reducing embodied carbon.

Furthermore, end-of-life scenarios are important when it comes to long-term sequestration. Incineration for energy recovery will release all sequestered carbon back to atmosphere. Landfill is the most common end-of-life route for wood products in Australia (Wood Solutions, FWPA, 2020) and NZ, the chemistry of which is complex. In general terms, wood in landfill will biodegrade to a certain extent over long periods of time and release both carbon dioxide and methane. The amount of these gases is dependent on the degradable organic carbon fraction (DOCf) of the wood, and further to this some methane is captured at landfill sites, which will then be flared or used in energy recovery. The remainder of carbon will remain in a solid-state, as sequestered carbon. Some landfills sites have recorded DOCf values for softwoods (e.g. *pinus radiata*) of 0.1% indicating that degradation is extremely slow in this environment.

The underlying data-set for results quoted in this paper assumes 75% of timber at end-of-life goes to landfill, 7.5% goes to energy recovery and 17.5% is reused or recycled. This high rate (92.5%) of timber remaining solid in the NZ system means that in the module C calculation only a modest amount of stored carbon is returned to the project. Other studies, in other global regions, suggest much higher rates of end-of-life incineration, which releases more of the carbon to the atmosphere (IStructE, 2020), but in NZ incineration rates are unlikely to climb due to the complexity in burning our heavily chemically treated structural wood products.

These complications around sequestration can be partially addressed through the way embodied carbon figures are reported. Current guidance from the IStructE suggests that timber sequestration should always be included for timber products from sustainably managed forests when reporting Modules A-C (as any end-of-life re-emissions or loss of sequestration is included in Stage C). This inclusion should be acknowledged when presenting results, as shown in *Figure 7*.[3] It also suggested that if reporting upfront carbon only (A1-A5 modules), that the carbon sequestered should be reported alongside the upfront figure. Reporting benefits separately to emissions is likely to be part of the BfCC Technical Methodology.

Further detailed commentary and analysis on this topic in the NZ context can be found online in Chapter 2.1 of the WPMA study *"Timber, Carbon and the Environment"* (Wood Processors & Manufacturers Association NZ, 2020).

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[3] *Table 7 – Example table to report embodied carbon results* has further suggestions on reporting sequestration.

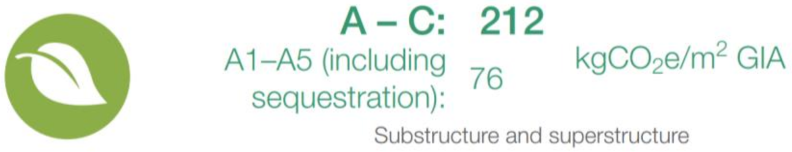

Figure 7 – Example presentation of sequestration for A-C embodied carbon (IStructE, 2020).

Appropriate ECFs for Steel

Concrete and steel are likely to be the two largest contributions to the embodied carbon under the influence of the structural engineer. The embodied carbon of concrete is more straightforward and is accurately reported in Aotearoa-New Zealand by ready-mix producers like Firth and Allied. Concrete is produced locally and there is less mixing of the product in global markets. There is complication around use of SCMs and with end-of-life recycling where crushing concrete can replace the use of virgin aggregate, although these can be quantified.

The carbon associated with structural steel is slightly more nuanced and harder to quantify exactly. There is large variance in the embodied carbon factors (ECFs) for structural steelwork depending on the geographical location of the steel production, emissions factor of the electricity grid feeding the plant, the type of steel-making process, percentage scrap input and assumed recycling rate. Some examples are shown in *Table 4*. As this factor is likely to have a large effect on the upfront carbon for a steel frame, it is important that the number is interrogated to determine its reliability and relevance when reporting an embodied carbon value.

Table 4 – Embodied carbon factors for steel sections

EPD Source	**A1-A3 (Cradle to Gate) t CO_2-eq. / t**	**D (End-of-Life recycling) t CO_2-eq. / t**
BlueScope EPD – Welded beams and columns (2020)	2.81	-1.19
InfraBuild EPD – Hot-rolled structural section (2020)	3.72	-2.26
British Steel EPD – Steel rails and sections (2020)	2.45	-1.60
Bauforumstahl EPD – European average (2018)	1.13	-0.41
BCSA UK average (3-yr average, 2017-2019)[4]	1.74	-0.92
World Steel average - Asia	1.70	-0.68
World Steel average - Global	1.60	-0.34

New Zealand is a not a large steel-producing nation, and structural steelwork for construction is typically sourced from the Asian and Australian markets. A commonly used ECF for steel in NZ is the BlueScope EPD, which covers steelmaking from raw materials (iron ore, coal, fluxes, scrap) at the Port Kembla steelworks in New South Wales, using a Blast Furnace/Basic Oxygen Furnace (BF-BOF) 'integrated steelmaking' method (BlueScope, 2020). The basic oxygen furnace method can accommodate scrap steel as an input; the recycled content declared for the current EPD is a 17.4% average value. The raw steel plate is then manufactured into structural sections in the range 350 WC to 1200 WB at the nearby Welded Products Plant in Unanderra.

Whilst this is a high-quality, reliable data source for the particular product, it is not necessarily representative of the steelwork used on all Aotearoa-New Zealand products. Large amounts of steel product are bought from the Asian market, with China, Japan and South Korea dominating steel production in the region and globally. *Table 5* lists the steel mills from which raw material was bought for a particular project in NZ, with further fabrication done off-shore

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[4] Source: (British Constructional Steelwork Association (BCSA), 2020)

and locally. For projects measuring embodied carbon, data should be requested as to the source of the steel, and a specific EPD may be published by the steel mill. If a particular EPD cannot be obtained, World Steel regional averages can be used, and in the complete absence of knowledge of the procurement routes, the designer may deem the BlueScope EPD as the most appropriate to adopt with a possible variation to the A4 module for shipping/transport.

Table 5 – Example steel mills used in procurement for an Aotearoa-New Zealand project and their output tonnages to indicate mill size (World Steel Association, 2018)

Steel Mill	Country / Region	2018 Output (million tonnes)
BlueScope	Australia	5.9
Hyundai	South Korea	21.9
Posco	South Korea	42.9
Siam Yamato	Thailand	1.1
NZ Steel	NZ	0.7
Nippon Steel	Japan	49.2
JFE	Japan	29.2
Liberty Steel	UK/USA/Europe/India	18.0

Module D accounts for material reuse and recovery beyond the system boundary – i.e. not within the lifetime of the current building. This is reported separately, as it should be seen more as an indicator of how well the building can feed into the circular economy, than a credit to be included in an assessment. Steel's inherent recyclability (around 85% for the construction industry globally, (World Steel Association, 2018)) means that a large *potential* credit is assigned in the D module; this is largest for BF-BOF steel which has a low recycled content and a majority of the product will feed into steel's closed-loop of recycling.

Current targets for embodied carbon do not include the D module. The D credit assumes that recycling steel from the building at the end-of-life can offset the production of virgin steel. Whilst this is true, this process would occur decades in the future, and is not a good measure of the GWP of emissions from a construction project that takes place in the present. The targets presented by LETI and RIBA reflect the pressing need to reduce emissions immediately.

On the face of it, the specification of recycled steel produced through the electric arc furnace (EAF) process would appear to be a quick way to de-carbonise a project by avoiding the carbon-intensive BF-BOF production. EAF steel will have high scrap content, meaning a lower A1-A3 burden as scrap is carbon-cheap, but a correspondingly small D credit as no credit is awarded for recycling steel already within the closed-loop. This may be true on a project level, but on a macro-scale it will make little difference as there is insufficient scrap within the closed-loop to satisfy current global demand. More steel is required to enter the system through BF-BOF process plants (and mining), and a focus should be placed on developing less carbon-intensive ways to produce virgin steel, such as through the use of developing technologies like hydrogen direct reduced iron. For the designer, focussing on using steel efficiently or re-using existing steel products from de-construction is *currently* likely to have more of a tangible impact than mandating a particular source of product.

As-Designed or As-Constructed?

Embodied carbon is usually calculated by designers, as they will have ability to control the design. Therefore, measures will be of the "As-Designed" building, derived from design information such as Revit models, drawings and specifications. Clearly, this is not necessarily exactly the same as the "As-Constructed" building and its embodied carbon. In most cases it can be expected that the latter will be higher.

Best practice LCA calculations do make provision for the extra carbon associated with construction activities within Module A5 *Construction Process Stage*. Module A5 emissions are broken down into A5w for material wastage on site and A5a for emissions due to general construction activities. Waste rate data (*Table* 6) is embedded within the LCA-Quick based on data from various sources, from NZ Contractor estimates to WRAP Net Waste Tool rates. The latter is typically average values for the consumption of electricity and fuel on-site through the provision of site welfare facilities, use of cranage and machinery etc.

Table 6 – *Example Module A5 waste data for selected materials* (BRANZ, 2016)

Material	Construction Site Wastage
Structural steelwork	1%
In-situ concrete	4%
Glazing	0%
Timber stud	10%

However, where construction requires the manufacture and use of ‘temporary works’ products, these production impacts are not included automatically within Module A5 and need to be added separately into Modules A1-A3. This data is not typically available to the designer and is best sourced from site information (or rules of thumb). Sources of extra site-based embodied carbon not already accounted for could come from:

- Single-use materials e.g. timber formwork, polystyrene blocking;
- Non-designed construction e.g. blinding layers, bespoke steel for temporary propping;
- Any significant excavation or earthworks for unforeseen conditions encountered on-site.

In addition, any material substitutions made in procurement and construction (e.g. alternative steel or concrete supply) will affect the resulting embodied carbon of the project. At this point in time no public database exists on the comparison between as-designed and as-constructed materials for projects, but indications are that it could easily account for another 10% of emissions over-and-above the as-designed values for some projects. *[The authors would welcome input and data from the Contractor and QS community to better establish this.]*

Tools for Measuring and Communicating Results

BRANZ is a good source of New Zealand specific information; the CO_2NSTRUCT database with A1-A3 emissions factors and their in-house LCA Quick (at v3.4.4 at the time of writing) which is a spreadsheet-based LCA calculation tool. Many web-based software platforms are also available for doing in depth life cycle analyses, with varying quality and/or transparency of New Zealand specific material data. EPD Australasia is a trans-Tasman framework, which has a good register of EPDs published from the region.

There are lots of helpful resources on how to present embodied carbon results in reports, drawings or email communication. In August 2020, the IStructE published a guide ‘*How to calculate embodied carbon’* and has further guidance of reporting and targets in its SCORS rating scheme. The London Energy Transformation Initiative (LETI) has been particularly active in this field, and their *Embodied Carbon Primer* also has a multitude of resources for presenting results. Presenting embodied carbon in absolute and normalised data can be as simple as *Table 7*, from which multiple graphs can also be created.

Table 7 – Example table to report embodied carbon results

Life Cycle Stage	Embodied Carbon Emissions (tons CO_2 eq.)	% of Total Structure Embodied Carbon (A-C)	Normalized/GFA Embodied Carbon (kg CO_2 eq./m^2)
A1-A3: Product stage	5,000	56%	500
A4-A5: Construction process stage	500	6%	50
B2: Maintenance & B4: Replacement	3,000	33%	300
C1-C4: End of life	500	6%	50
A-C: Lifetime Carbon	**9,000**	**100%**	**900**
D: Materials	-2,500	-28%	-250
A-D: Full Life Cycle Assessment	**6,500**	**72%**	**650**

Note: The above net emissions values encompass the effects of materials with carbon storage properties in each Stage to the values of: A1-3: XX tonsCO$_2$e, B2+4: YY tonsCO$_2$e, C1-4: ZZ tonsCO$_2$e, and net A-C: ## tonsCO$_2$e. If these CO$_2$ storing materials are kept in-use/solid beyond the life of the project this benefit will remain until they are destroyed or burnt.

CONCLUSION AND MOVING FORWARD

Embodied carbon is going to become an increasing important metric of design. Quantifying and reducing carbon on a project doesn't mean an overriding preference for a certain structural material, or a complete rethink of current methods of design. It means measuring the impact of a design, identifying hot-spots, and making efficiencies and improvements where possible and appropriate. Things you can do in this field, starting tomorrow, include:

- Starting to measure your own projects: use A1-3 reporting at Concept Design, and move into LCA at Preliminary Design. Add a section to design reports or on drawing notes. It is best to 'front-foot' this before your client perhaps highlights the significant contribution of the structural embodied carbon on the total project impact and asks "what are you doing about it?.."
- Suggest that the rest of the design team calculates the embodied carbon of their designs: e.g. architects 'do their bit' on fit-out and facade, and MEP engineers follow the latest CIBSE TM65 guidance on the embodied carbon in services equipment.
- Focus on relative percentage differences between options, rather than 'precise' absolute values.
- When speaking to product suppliers ask for EPDs; this will help plug data gaps for everyone.
- Quantify and challenge areas of a project brief that are found to be significantly influencing carbon and where compliant alternatives exist (but perhaps are just not common).
- Discover that this is an interesting and rewarding aspect of structural engineering – get involved!

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