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THE EMBODIED CARBON OF BUILDINGS IN NEW ZEALAND: PROPOSALS FOR FUTURE REGULATION, AND THE ROLE OF INCREASED SEISMIC RESILIENCE

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SUMMARY

Structural engineers make design decisions with the objectives of making buildings materially efficient, seismically resilient, and now increasingly, low carbon. This paper discusses the importance of embodied carbon of buildings in the context of New Zealand's emissions reduction targets, and outlines MBIE's Building for Climate Change (BfCC) programme proposals to drive transformational change in the sector to reduce these emissions. It explores the role that greater seismic resilience could play in achieving reductions in embodied carbon of New Zealand buildings, including which elements of a building contribute significantly to embodied emissions, and how these emissions can be minimised. Further research work is required to determine the existence of the perceived trade-off between resilience and material efficiency in structural design.

CLIMATE CHANGE AND BUILDINGS

Carbon emissions as an environmental impact of buildings

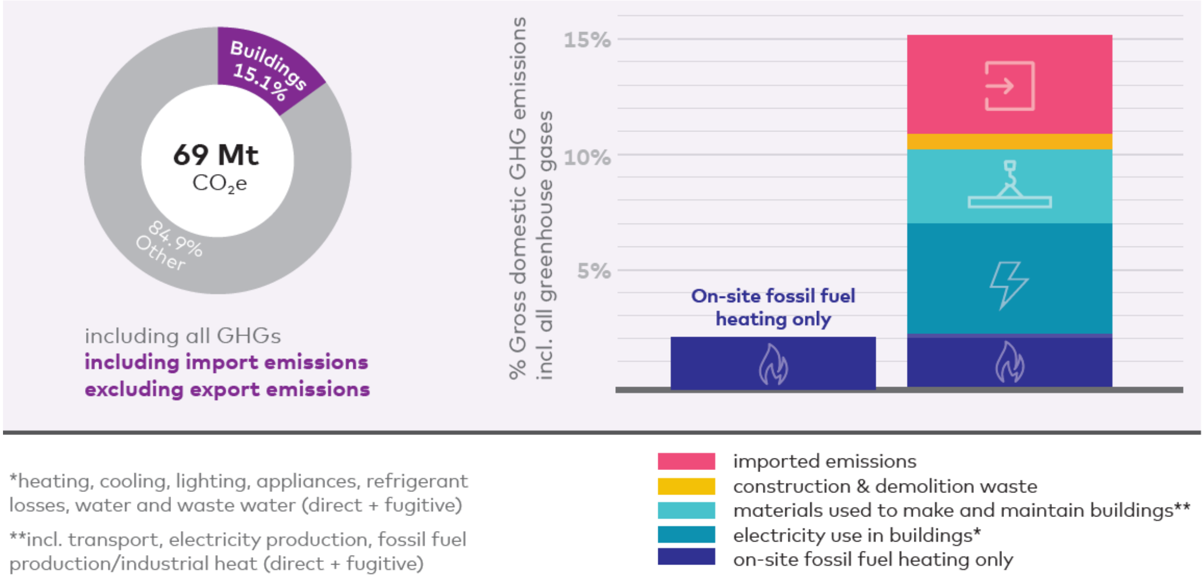
Embodied carbon, operational carbon and whole of life carbon are not terms that most structural engineers in practice today were familiar with at the start of their careers. Engineers however are likely to be aware of our changing climate, the threats it poses to future generations, and the direct link between the effects of climate change and global emissions of greenhouse gasses (GHG).

Note that the terms 'emissions', 'carbon emissions' and 'carbon' are used throughout this paper as shorthand for all GHG emissions: this includes Carbon Dioxide (CO_2), but also all gasses that have a warming effect on the climate. Quantities are measured in units of Carbon Dioxide equivalent, or kg CO_2-e.

Carbon emissions are not the only environmental impact of buildings. Others environmental impacts that can be measured include energy and depletable resource consumption, acidification, eutrophication and ozone depletion, among others. Despite the diverse nature of these environmental impacts, it has been shown (Simonen et al 2018) that for earthquake damage repair work to buildings, there is a close correlation between embodied carbon and most other environmental impacts. Therefore there is a strong argument that the results of embodied carbon assessments can be considered a proxy for the assessment of overall environmental impact for most building work.

Carbon emissions of buildings in New Zealand

Although New Zealand's carbon emissions are dominated by the agriculture and transport sectors, the emissions from buildings and construction are not insignificant. Modelling carried out as part of MBIE's Building for Climate Change (BfCC) programme shown in figure 1 indicates the sector accounts for around 15% of national annual GHG emissions.



*heating, cooling, lighting, appliances, refrigerant losses, water and waste water (direct + fugitive)

**incl. transport, electricity production, fossil fuel production/industrial heat (direct + fugitive)

Figure 1: Breakdown of New Zealand's annual GHG emissions from buildings

While direct GHG emissions from buildings themselves are relatively low (limited to the combustion of fossil fuels in buildings, around 2% of the national total), buildings drive a significant amount of emissions in other sectors.

Embodied and operational carbon emissions

Operational carbon emissions are those directly (from on-site fossil fuel use) and indirectly (from electricity use) attributable to the operation of buildings: for heating, cooling, hot water, lighting, ventilation, appliances etc. From figure 1, these account for approximately 7% of New Zealand's GHG emissions per year.

Embodied carbon emissions are those attributable to the building itself, i.e. the construction materials and products that come together to form the physical entity of the building. Whole-of-life embodied carbon includes emissions across the full supply chain of construction materials and products, construction processes (and the waste arising), repair and maintenance, and processes at the end-of-life of a building. Where construction products are imported into the country, to be used in New Zealand buildings, the emissions occur overseas. From figure 1, these account for approximately 8% of New Zealand's GHG emissions per year.

Life cycle assessment of buildings

Most assessments of the embodied carbon of buildings are based on the principles of Life Cycle Assessment (LCA), which is an analytical tool for the systematic and quantitative evaluation of the environmental impacts of a product or service system through all stages of its life (see figure 2). In an LCA study, emissions of GHGs are reported in the environmental impact category known as 'Global Warming Potential' or GWP.

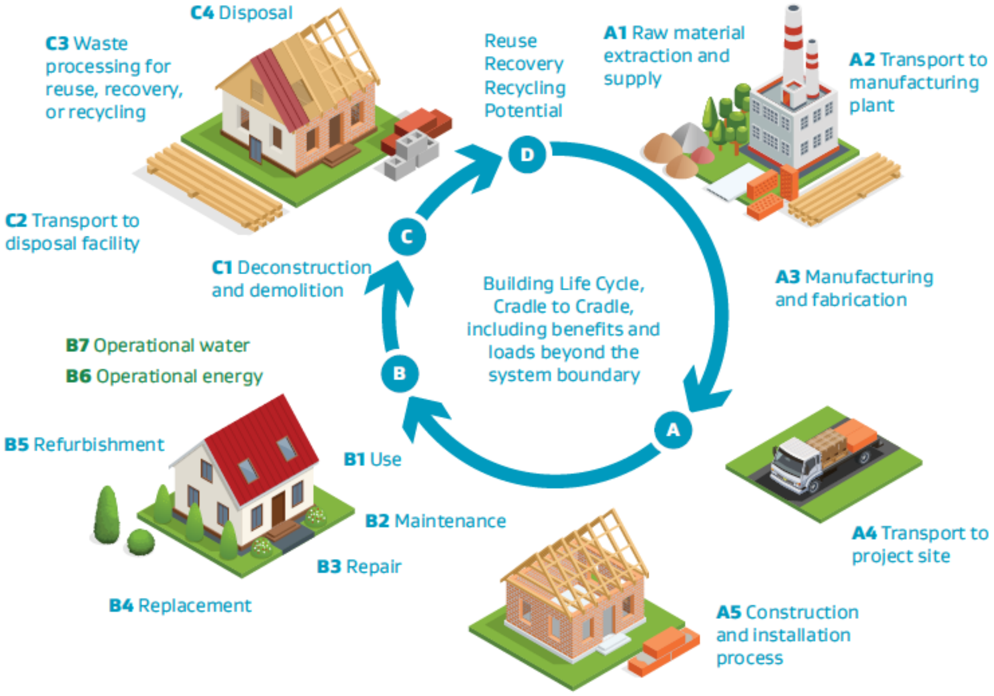


Figure 2: Life cycle stages of a building for the purposes of LCA (MBIE, August 2020)

A large proportion of embodied carbon emissions occur at the material production and construction phase, indicated by A1-A5 in figure 2, sometimes termed ‘upfront embodied carbon’. However, embodied emissions occur at other lifecycle stages too: during the building’s use stage when components are maintained and replaced (B1-B5), and when the building reaches its end-of-life (C1-C4), as indicated in figure 3.

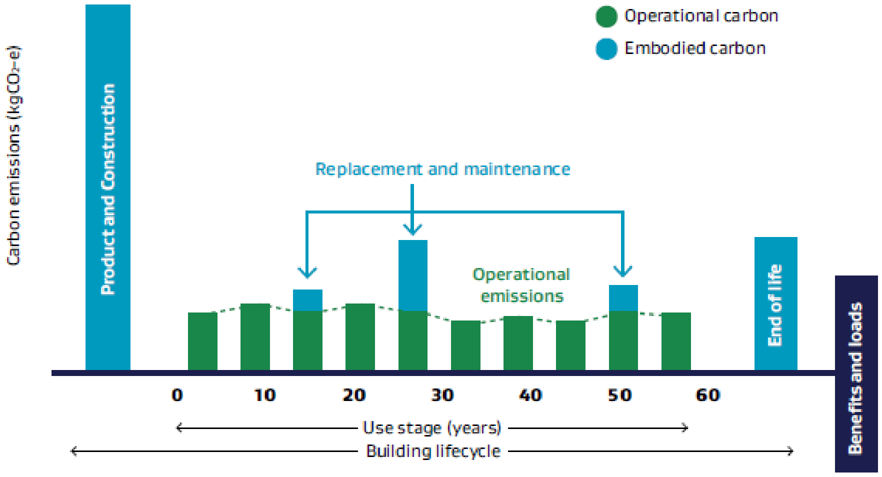


Figure 3: Operational and embodied carbon emissions over a building lifecycle (MBIE, August 2020)

When elements of the building are reused or recycled for use in other buildings, these processes will likely emit GHGs, but may also result in savings of embodied carbon, if it offsets the use of virgin materials in those other buildings. These are reported (in D) as loads and benefits beyond the ‘system boundary’, the ‘system’ being an LCA term for the entity being assessed, which in this context is the original building being assessed.

The ‘modules’ A1-A5, B1-B7, C1-C4 and D are defined in a framework set out in international standards for LCA in construction (BSI 2011, BSI 2012+2019, ISO 2017), shown in figure 4.

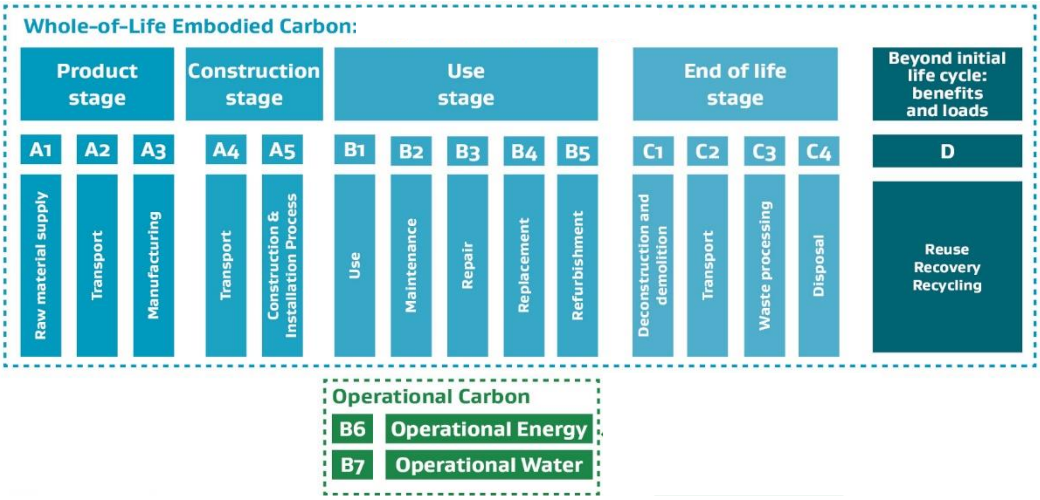


Figure 4: Module framework for LCA of buildings (MBIE August 2020)

In an LCA study, environmental impacts at each life cycle stage are reported against the respective module code (A1, B3, C1-C4 etc.), with GHG emissions reported in the Global Warming Potential environmental impact category. Note modules B6 and B7 are the emissions due to the use of energy and water in the building while it is operational. However modules B1-B5 also occur during the ‘Use’ life cycle stage, and are a result of the use, maintenance, repair, replacement and refurbishment of physical elements of the building. Any repair or replacement to building components following seismic damage are therefore accounted for in these modules. Improvements to the seismic resilience of a building will reduce the emissions at these stages after a seismic event, and hence reduce whole-of-life embodied carbon.

NEW ZEALAND REGULATORY CONTEXT

Government action to address climate change

The Climate Change Response (Zero Carbon) Amendment Act 2019 (known as the Zero Carbon Act) commits New Zealand to net zero carbon emissions as a nation by 2050. It provides a framework by which New Zealand can develop and implement clear and long-term climate change policies that contribute to the global effort, under the Paris Agreement, to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels.

The Zero Carbon Act set up a series of emissions budgets, over 5 year periods, which the government is required to meet, to act as a pathway towards the 2050 targets. It also established the independent Climate Change Commission to provide expert advice and monitoring to help keep successive governments on track to meeting these long-term climate goals.

The New Zealand Government has recognised the buildings and construction sector as one of five key sectors of the New Zealand economy (alongside agriculture, transport, waste and industry & power) that will need to make significant changes to its emissions profile, if we are to meet the challenging climate targets that have been set. Accordingly, the Building System Performance (BSP) Branch of the Ministry of Business, Innovation and Employment (MBIE) launched the Building for Climate Change (BfCC) programme in 2020. This programme has been set up to drive transformational changes, including new regulations, to deliver emissions reductions from the building and construction sector and increase the climate resilience of buildings.

In August 2020, the BfCC programme consulted the public on two Frameworks that set out proposals for the reduction of operational and embodied carbon emissions of buildings (figure 5).


BUILDING PERFORMANCE

Transforming Operational Efficiency

Building for climate change programme

August 2020

BUILDING PERFORMANCE

Whole-of-Life Embodied Carbon Emissions Reduction Framework

Building for climate change programme

August 2020

Figure 5: The two BfCC frameworks put to public consultation in August 2020

Whole-of-Life Embodied Carbon Emissions Reduction Framework

The Whole-of-Life Embodied Carbon Emissions Reduction Framework (the Framework) proposed requirements for an embodied carbon assessment of new building projects as a condition of obtaining a building consent. Initially the requirements would be only mandatory disclosure of the embodied carbon, assessed according to an agreed methodology. Subsequently caps would be introduced, which would set the maximum embodied carbon for a building, in kg CO_2-e/m^2. These would need to be met in order to obtain a building consent, and they would decrease over time, in accordance with the requirements to meet the legally binding national emissions budgets, and ultimately zero carbon at a national level by 2050.

The proposals within the Framework received broad public support: over 360 consultation responses were received, and 74% of respondents supported a cap on embodied carbon (MBIE January 2021). Furthermore, the Climate Change Commission's final advice to the New Zealand Government specifically recommended that measures should include: "*Encouraging construction based on low-emissions designs and practices to reduce building energy use and embodied emissions*." (He Pou a Rangi 2021).

The Framework proposed three objectives to achieve reductions in embodied carbon, derived from the method of calculating the embodied carbon of a building (figure 6).

kg CO_2-e	=	m^2	x	kg material/m^2	x	kg CO_2-e/kg material
Whole-of-life embodied carbon		New building efficiency		Material efficiency		Carbon intensity

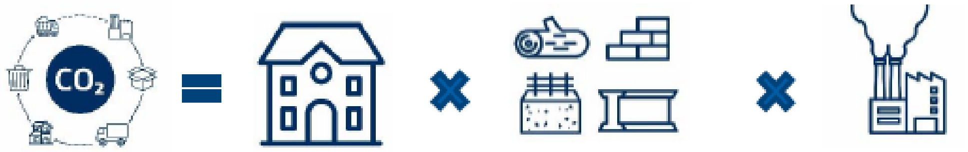


Figure 6: The proposed objectives of the Framework (MBIE, August 2020)

Emissions reductions at a national level across the building and construction sector are achieved by reducing some, or all, of these factors:

- **New building efficiency:** how much we build new, and of what quality,
- **Material efficiency:** how much material we use to do that, and
- **Carbon intensity**: how much emissions those materials create.

Improving building resilience contributes to the first and second of these objectives, because by making buildings more robust and last longer, we reduce what we will need to build in the future, and also reduce the need to replace building elements over the lifecycle. However there can be a perception of a trade-off between increased resilience and greater material efficiency when looking to minimise embodied carbon.

Consultation feedback on the Framework indicated that the biggest barrier preventing more widespread assessment of embodied carbon in buildings was the lack of an agreed methodology. Accordingly, such a methodology is currently being developed, with the aim of providing consistent, transparent and widely accessible assessments, which directly lead to the desired outcome of reduced embodied emissions. This methodology will need to consider how the potential carbon benefits of a building with greater seismic resilience will be accounted for, and can be compared with a building of lower resilience but possibly greater material efficiency.

Seismic resilience in building regulations

Achieving a balance between resilience and material efficiency is not just a question of minimising embodied carbon, but is also critical for informing broader conversations around the future of seismic risk and building performance in New Zealand. Triggers for these conversations include the imminent update of the National Seismic Hazard Model (NSHM), covering advances in earthquake science and experience gained from earthquakes that have occurred over the last few decades. In response to these triggers, MBIE commissioned a group of experts, the Seismic Risk Working Group, to provide advice on how the updated NSHM could be applied within the Building Code (MBIE November 2020). In response to the advice received, MBIE is currently developing a Seismic Risk Work Programme (SRWP) to ensure:

- Policy/risk settings are clear and transparent,
- Seismic design provisions contribute to consistent building performance,
- Seismic loading provisions are appropriate, considering the uncertain nature of earthquakes.

Successful delivery of the SRWP will rely on input from key stakeholders, including the New Zealand structural engineering community, and resilience and material efficiency will be important considerations for any solutions developed.

For a building in New Zealand, it is likely that at some point within its lifetime it will be affected by a seismic event. Few large modern buildings in New Zealand are designed to respond elastically to Ultimate Limit State (ULS) seismic events. In general terms, the risk of a ULS seismic event is low, but the risk of a lower magnitude seismic event is much higher. Hence, if we are to minimise whole-of-life embodied carbon of a building, it is reasonable for the likelihood of damage to a building across a range of seismic event magnitudes be considered in regulatory minimum settings. The carbon impact of each seismic event magnitude, or ‘carbon risk’ could then be considered alongside the financial, operational and safety considerations.

BREAKDOWN OF EMBODIED CARBON IN BUILDINGS

New-build construction

An analysis of the embodied carbon of building elements has been carried out by MBIE for ten non-residential building projects in New Zealand, using data from projects that used the eTool methodology and software tool, see figure 7. This analysis includes replacement of components over the lifetimes of the buildings, end-of-life impacts and subsequent potential loads and benefits (modules A1-A3, B3-B4, C1-C3 and D).

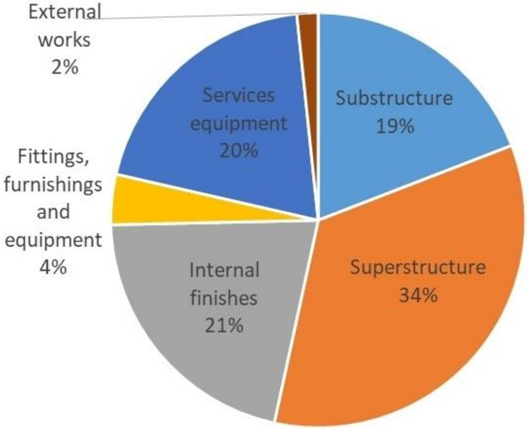


Figure 7: Breakdown of the embodied carbon of 10 New Zealand buildings by element

All building designs will be unique, but it is a common finding across all building types that the primary structure represents a significant proportion of the total embodied carbon, as reflected here. It also highlights that non-structural elements such as internal finishes, façade, fittings and building services equipment also contribute significantly, especially when their replacement due to normal wear and tear during the lifetime of the building is factored in. Any damage to these elements incurred during a seismic event will therefore result in greater emissions in modules B3 and B4, due to additional repair and replacement work.

It follows that, whilst every effort should be made to use material efficiently in the design of the primary structure to reduce embodied emissions from these elements, since the behaviour of the structure will determine the level of damage incurred by the building as a whole, including non-structural elements, this must be carefully considered as part of a design process to reduce whole-of-life embodied carbon.

Seismic repairs

There are tools available to support the assessment of likely damage in seismic events, such as the Performance Assessment Calculation Tool (PACT) and Performance Estimation Tool (PET) developed by the Federal Emergency Management Agency (FEMA) in the US (FEMA P-58). These allow different scenarios to be assessed to support designers when considering resilience and are useful for the purposes of identifying critical elements that contribute to damage, and the corresponding carbon impacts.

FEMA have also conducted studies into the impact to embodied carbon of repairs required after seismic events (Huang & Simonen 2019). Figure 8 illustrates a key finding of this study: the carbon impact of seismic damage is heavily weighted towards the non-structural components of the building, for all lateral systems (Note: BRBF=Buckling Restrained Braced Frames, SCBF=Special Concentric Braced Frame, SMRF=Special Moment Resisting Frame, RCMRF=Reinforced Concrete Moment Resisting Frame, RCSW=Reinforced Concrete Shear Wall; Risk Category II and IV are approximately equivalent to NZS1170.0 IL 2 and 4).

The embodied carbon of glass and gypsum products is greater than for many other products (Simonen et al 2018). When considering 'carbon risk', the impact of the high embodied carbon of glass and gypsum products is exacerbated by their fragility and likelihood of damage during seismic events. Choosing a structural system that limits damage to non-structural components could have a significant impact on reducing the risk of substantial embodied carbon emissions after a seismic event.

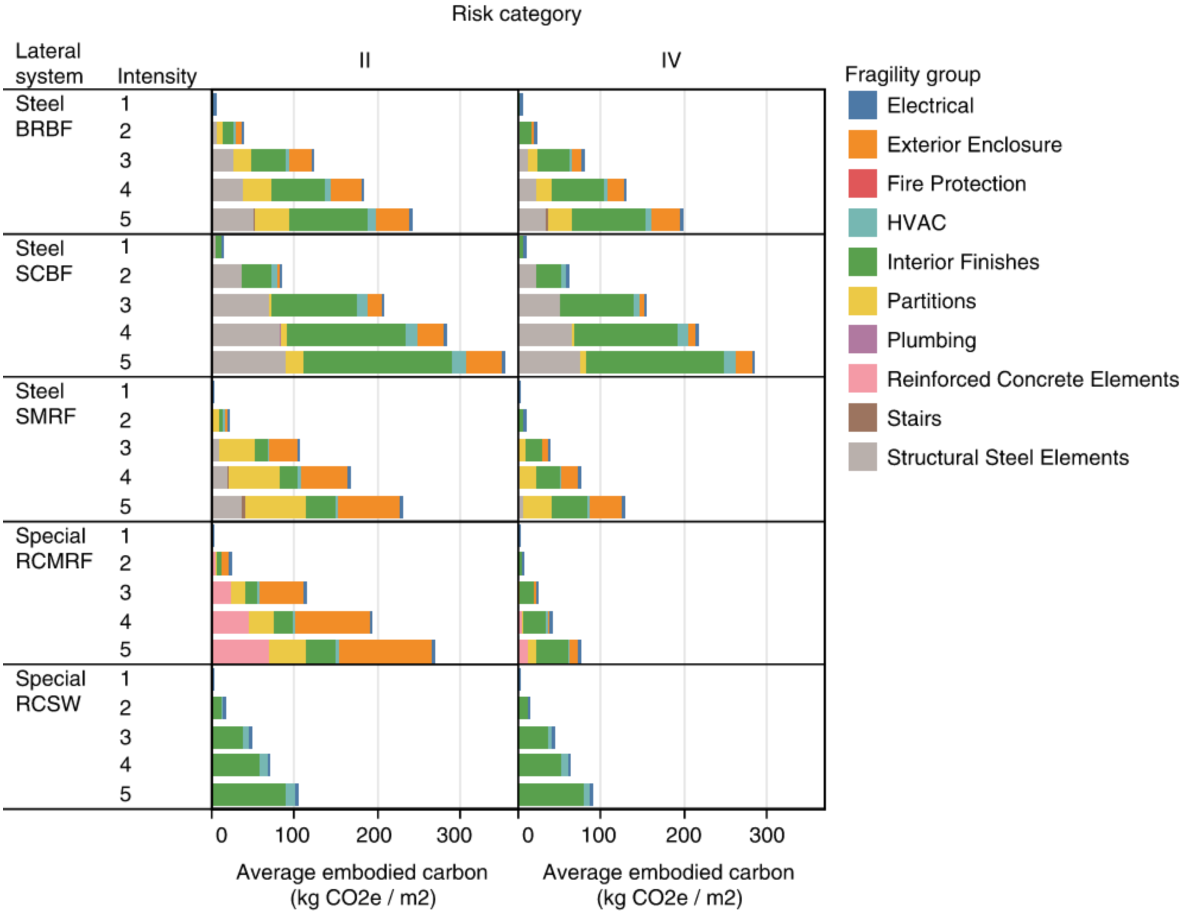


Figure 8: Average carbon emissions of repairs for a number of different seismic scenarios (1-5 in increasing intensity) and structural frames. (Huang & Simonen 2019).

It is important to note that the figure 8 is only presented for the purposes of highlighting potential locations of carbon risk. The actual relationship between seismic damage and carbon risk will vary greatly from building to building. For example, warehouses with minimal fit-out and services are unlikely to have such a significant contribution from cladding and internal finishes, but there may be key high-value, high-carbon components such as generators, chiller units, server rooms etc., where limiting the risk of seismic damage may significantly reduce embodied carbon.

Using resilience to reduce embodied carbon

The impact on resilience needs to be considered in design decisions that seek to reduce embodied carbon through greater material efficiency. Figure 9 is an extract from the Royal Institute of Chartered Surveyors (RICS) methodology for embodied carbon (Lockie & Berebecki 2012). This is an example of the impact that measures to reduce embodied carbon incorporated in the design process, including greater material efficiency, can have on the total embodied carbon of a building. However, it is noted that this is for a building in a non-seismic area. Analysis of seismic damage scenarios and consideration of whole-of-life carbon may well lead to some cases where a higher embodied carbon option for the foundation or structural frame may be justified, in order to protect and reduce the ‘carbon risk’ to non-structural components that would otherwise be prone to damage.

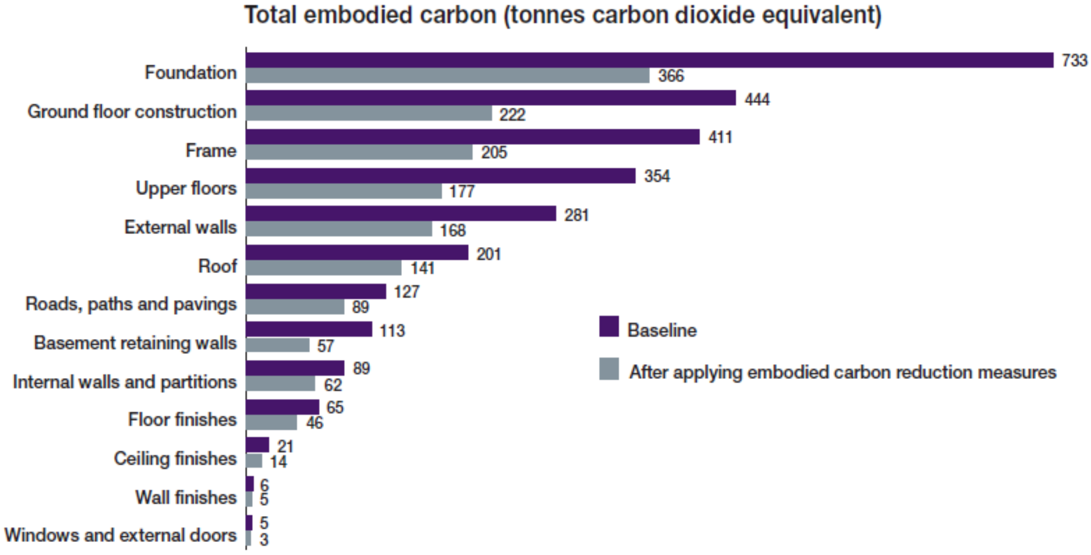


Figure 9: Effect of carbon reduction measures on embodied carbon of a building (Lockie & Berebecki 2012)

The challenge for today’s structural engineers is to find a ‘sweet spot’, where a building is sufficiently seismically resilient, but also uses material appropriate and efficiently to minimise embodied carbon over the lifetime of the building. Engineers need to be aware of the impacts of both resilience and material efficiency on whole-of-life embodied carbon to enable them to make informed design decisions about the ‘carbon risk’.

Further work is required to understand the reality of the perceived trade-off between resilience and material efficiency. ‘Low damage’ buildings that are specifically designed to be seismically resilient (by, for example, concentrating damage from seismic loads into easily replaceable components for the sake of reducing widespread damage to other structural and non-structural building elements), may also be materially efficient when compared to other buildings. Such design solutions, that offer both materially efficient and resilient buildings, should be explored for their potential to be reproduced widely, to reduce whole-of-life embodied emissions.

CONCLUSIONS

The operational and embodied carbon emissions attributable to buildings in New Zealand are significant, and there is growing pressure on the building and construction sector to reduce them. As in other sectors, the New Zealand Government is taking action to drive transformational change, including new regulations, to deliver these emissions reductions.

Following broad support in consultation feedback on a proposed Framework for addressing the embodied carbon of buildings, MBIE’s Building for Climate Change programme is progressing the development of proposals that include mandatory requirements for the assessment of embodied carbon at building consent stage, and eventually the introduction of caps on embodied carbon.

An objective of the Framework is to increase the efficiency of material use in buildings, which should result in reduced embodied carbon at the product stage. However, the emissions from potential repair and replacement of building elements due to seismic damage also need to be considered. There is evidence to show that these emissions are disproportionately from fragile, non-structural components, and tools exist to assess the likelihood of these potential emissions, or ‘carbon risk’.

The design of primary structural elements in a building has a major impact on the whole-of-life embodied carbon, as they represent a significant proportion of the ‘upfront’ embodied carbon. The performance of the primary structure also determines the level of damage to both structural and non-structural elements in a seismic event, and therefore impacts subsequent emissions due to the repair and replacement of these elements.

Balancing the carbon cost of seismic repairs, refurbishment work and seismic strengthening to get an overall net benefit may require assessing a number of different scenarios. Designers need to be aware of the impacts of both resilience and material efficiency considerations on embodied carbon to enable them to make informed design decisions about the carbon risk, and find the ‘sweet spot’ where the embodied carbon is minimised.

Further work is required to understand the reality of the perceived trade-off between building resilience and material efficiency. Design solutions that are both resilient and materially efficient may exist, and these should be exploited as a way of reducing the whole-of-life embodied carbon of buildings in New Zealand.

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