Understanding potential avoided upfront carbon emissions through strengthening of seismically-deficient buildings

P. Moses & J. Wang
Beca, Auckland, New Zealand.

A. Scott & E. Blewden
Aurecon, Wellington, New Zealand.

A. Thompson
Holmes, Auckland, New Zealand.

K. Symons
MBIE, Wellington, New Zealand.

Thanks are given to MBIE for funding this research.

ABSTRACT

Under the Earthquake Prone Building (EPB) legislation, many buildings are approaching deadlines for seismic upgrades. Among other options, building owners are often faced with the decision whether to demolish and rebuild, or strengthen their building.

The purpose of this research is to provide evidence that supports applying an embodied carbon 'lens' to this decision-making. This paper summarises the full report findings (Moses et al., 2024). The upfront carbon emissions (Life Cycle Modules A1-A5) savings of strengthening, over demolishing and rebuilding, seismically deficient buildings is calculated. This is based on two typical building typologies: a two-storey unreinforced masonry building in Auckland and a mid-rise reinforced concrete building in Wellington.

Findings reveal significant carbon savings for strengthening over demolishing and rebuilding. For the Auckland URM building, strengthening resulted in 130 kgCO2e/m², compared to an average of 775 kgCO2e/m² for a new build—an 83% reduction. For the Wellington building, emissions were 53 kgCO2e/m² versus an average of 775 kgCO2e/m², a 93% reduction. Strengthening of all seismically-deficient buildings in New Zealand may avoid between 1.5 to 7.4 MtCO2e, supporting New Zealand's climate goals. While

operational emissions are higher in older buildings than in new buildings, these differences are overshadowed by the upfront emissions of new construction.

Policy incentives for "greener" refurbishments, such as low-energy systems, are proposed to enhance both carbon savings and building reuse viability. Recommendations include policy adjustments to embed carbon considerations in building regulations, research to refine cost and emission estimates, and public awareness to shift preferences towards strengthening. Limitations include uncertainties in data and modelling assumptions, emphasizing the need for further studies.

1 EXECUTIVE SUMMARY

Under the Earthquake Prone Building (EPB) legislation, many buildings are approaching deadlines for seismic upgrades. Among other options, building owners are often faced with the decision whether to demolish and rebuild, or strengthen, their building. This paper is a summary of the full report commissioned by MBIE (Moses et al., 2024).

The purpose of this research is to provide evidence that supports applying an upfront embodied carbon ‘lens’ to decision-making (or building system policy review), through comparing the likely upfront carbon emissions (Life Cycle Modules A1-A5) from strengthening versus replacing an asset. This is based on two building typologies: a two-storey unreinforced masonry building in Auckland (Building 1) and a mid-rise reinforced concrete building in Wellington (Building 2). The results of the study are summarised below:

Building	**Strengthening intensity (A1-A5)**	**Average new-build intensity (A1-A5)**	**Saving (%)**	**Saving (total – A1-A5)**
Building 1	130 $kgCO_2e / m^2$*	775 $kgCO_2e / m^2$	83%	645 $kgCO_2e / m^2$
Building 2	53 $kgCO_2e / m^2$*	775 $kgCO_2e / m^2$	93%	722 $kgCO_2e / m^2$

*The largest contributors are building services and construction stage emissions, which have high levels of uncertainty.

For both buildings (across different seismic regions and building categories), the upfront embodied carbon impact of strengthening is significantly lower than the upfront embodied carbon impact of demolition and redevelopment. Both buildings included aspects of non-seismic refurbishment as well as seismic strengthening, all of which have been accounted for in the assessment.

Whole-of-life carbon emissions include embodied and operational emissions. Operational carbon emissions of existing buildings are likely higher than new-builds, however this difference is typically small compared to the difference in up-front carbon.

Scaling of the data, accounting for uncertainties, estimates a range in the total opportunity for avoided upfront embodied carbon emissions of between 1.25 MtCO2e and 7.4 MtCO2e through strengthening and refurbishing our most seismically-deficient buildings in New Zealand, rather than demolishing them. This is approximately the same impact as the avoided emissions from New Zealand Steel operating an electric arc furnace for 5 years, or from a year of not constructing new buildings.

Policy recommendations could explore mechanisms and policy settings that maximise the retention of existing building stock. Managing earthquake risks to acceptable levels under the Earthquake Prone Building (EPB) system presents an opportunity to embed these incentives in existing frameworks. The benefits of avoided embodied emissions are clear and could reduce the cost of achieving climate change targets.

Furthermore, incentives that encourage “greening” refurbishments (lower energy mechanical systems and improved thermal efficiency, for example) could offer co-benefits in both reducing operational carbon emissions, and increasing the commercial viability of reuse. Thus, encouraging reuse over demolition and supporting the realisation of substantial avoided emissions in upfront embodied carbon.

2 INTRODUCTION

MBIE's climate change work programme is supporting the building and construction sector to reduce emissions in a number of ways, including developing better information and evidence base to support the shift to low carbon and resilient buildings. The aim is for this evidence base to inform policy decisions and enable the sector to make informed decisions around the costs and benefits of low carbon. resilient buildings.

This paper explores the potential upfront embodied carbon emissions avoided from carrying out strengthening work on seismically deficient buildings, compared to demolishing and rebuilding. Two different buildings, representing common earthquake-prone building typologies, have been assessed. Scaling these results nationally has also been considered.

2.1 The case for reusing existing buildings

There are multiple potential benefits of building reuse, including avoiding upfront embodied carbon emissions and preserving cultural heritage. The business case for continued use of existing buildings can struggle due to challenges such as:

- uncertainties in existing building documentation,
- perceived risk associated with existing building work and forecasting project scope,
- financing constraints, and
- timeframes for legislative requirements.

Under the current Earthquake Prone Building (EPB) system, there are hundreds of buildings reaching their deadline for completing seismic work. Many building owners are currently working through different business cases to consider options for strengthening or demolishing their buildings.

It is currently difficult for building owners to recognise direct value in avoided emissions, and therefore challenging to meaningfully include this in their decision-making. However, there could be opportunities for policy incentives to provide some value recognition (Moses, 2023).

3 METHODOLOGY

A Life Cycle Assessment (LCA) methodology has been used to calculate the impacts in the first stage of the research. A LCA includes quantifying the environmental impacts of a building across its entire life cycle, across various environmental indicators. The focus of this study is the Global Warming Potential (GWP) indicator, which is a measure of greenhouse gas emissions, such as carbon dioxide (CO_2) and methane.

Whole of life carbon emissions are generally broken into embodied and operational emissions. Embodied carbon emissions are from the materials and products that form the building and can occur right across the building's life cycle (MBIE, 2020). This assessment follows the methodology outlined in MBIE's Whole of Life Embodied Carbon Assessment: Technical Methodology (February 2022), referred to in this report as the MBIE Methodology, but is limited to upfront embodied carbon only. The second stage of this research involves scaling up building-level upfront embodied carbon assessments of rebuild and strengthening options, to determine national-level upfront embodied carbon impacts.

3.1 Building typologies

To quantify the impacts of strengthening at a building level, two different existing building typologies have been chosen which are common among those identified as <33% NBS. The two building typologies are:

- A two-storey unreinforced masonry (URM) building with timber floors.
- A mid-rise reinforced concrete pre-1976 building with masonry infill/short column issues.

These typologies were selected in agreement with MBIE, based on the experience of the research teams' respective organisations. A real-life example of each typology, including strengthening designs submitted for Building Consent, was selected amongst existing historical projects from within the research teams.

3.2 Scope

The scope of the assessment includes all structural, architectural and services upgrades (including both strengthening elements and non-seismic refurbishment elements).

3.3 System boundary

For the purposes of this study, the scope of assessment is 'Cradle to practical completion', Modules A1-A5. This has been selected as the most appropriate scope for this particular study, of which the aim is to understand the likely upfront embodied carbon emissions saved through strengthening existing buildings versus demolishing and building new – in the context of the Earthquake Prone Building Methodology. Although there are likely to be some differences in upfront embodied carbon from ongoing refurbishments and end of life scenarios for building elements, these are generally considered to be minor in nature compared to the scale of upfront embodied carbon emissions differential.

3.4 Equivalent new building assumptions

No design or detailed assessment has been undertaken to estimate the upfront embodied carbon emissions from building a new replacement building. For the purpose of estimating upfront embodied carbon emissions saved, equivalent new-build upfront embodied carbon rates for seven typical multistorey buildings in New Zealand have been used (refer full report for a detailed breakdown of building metadata). This data set does not capture regional variation, however, regional variation is expected to be low compared to other factors such as ground conditions and choice of structural framing.

For comparative purposes, the same LCA boundary has been taken (A1-A5). While there would be some embodied carbon impacts associated with the demolition of the old buildings, these are negligible compared to Modules A1-A5 for the new building (less than 1%) and are therefore excluded.

The average upfront embodied carbon intensity for a new building is 775 kgCO^2e / m^2, with a lower-bound value of 550 kgCO^2e / m^2 and an upper-bound value of 978 kgCO^2e / m^2.

This assumes no specific low-carbon considerations have been made beyond typical current business-as-usual practice in the design or construction phase of the new building. For example, no mass timber buildings, or buildings which have specified low-carbon materials have been included in this average. The average upfront embodied carbon intensity for each building element is shown below in Figure 1.

3.5 Scaling methodology

It is difficult to scale the results of this study from a single building level to apply to all seismically deficient buildings in New Zealand. There are many variables that will impact the upfront embodied carbon of strengthening work, and there is poor data to make estimates at a national scale. These variables include seismic hazard zone, complexity of upgrade, size of building, structural system, and the age of the building.

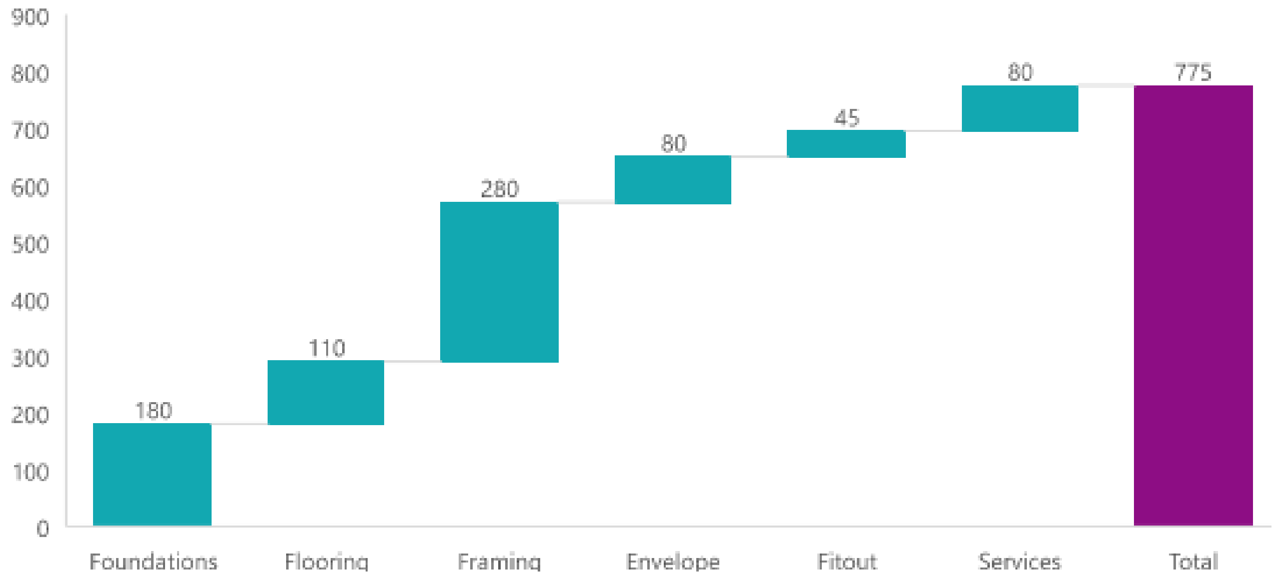

Figure 1: Upfront embodied carbon broken down into building elements for an average new-build

The data available to the researchers used for the scaling is as follows:

- Indicative Cost-Benefit Analysis Model for Earthquake-prone Building Review (CBA Report) – also referenced in the Regulatory Impact Statement of 2012 (MBIE, 2012).
- Earthquake-prone Building Register (as of June 2024).
- Anecdotal evidence from practitioners in the seismic strengthening space.

Scaling of the results occurs in two steps:

1. Apply a range of uncertainty to the values obtained through the study.
2. Multiply this range of upfront embodied carbon results (on a per m^2 gross floor area, or GFA, basis) by the total expected area of seismically-deficient buildings in New Zealand. This second step will also have an associated range of uncertainty.

Refer to full report for a more detailed explanation of these two steps.

4 RESULTS

4.1 Building 1: Two-storey unreinforced masonry

The table below summarises the key upfront carbon impacts of the strengthening of Building 1.

Table 1: Summary of Building 1 results

Scope (elements)	Scope (modules)	Upfront embodied carbon
All building elements	A1-A5	130 $kgCO_2e$ / m^2
Excluding building services	A1-A5	70 $kgCO_2e$ / m^2
All building elements	A1-A3	101 $kgCO_2e$ / m^2
Excluding building services	A1-A3	41 $kgCO_2e$ / m^2

The figure below provides an overview of upfront embodied carbon broken down into building elements, highlighting key carbon 'hotspots'. Results are reported in line with the building element breakdown, rather than by 'strengthening' and 'non-strengthening' work undertaken, to align with standard carbon reporting.

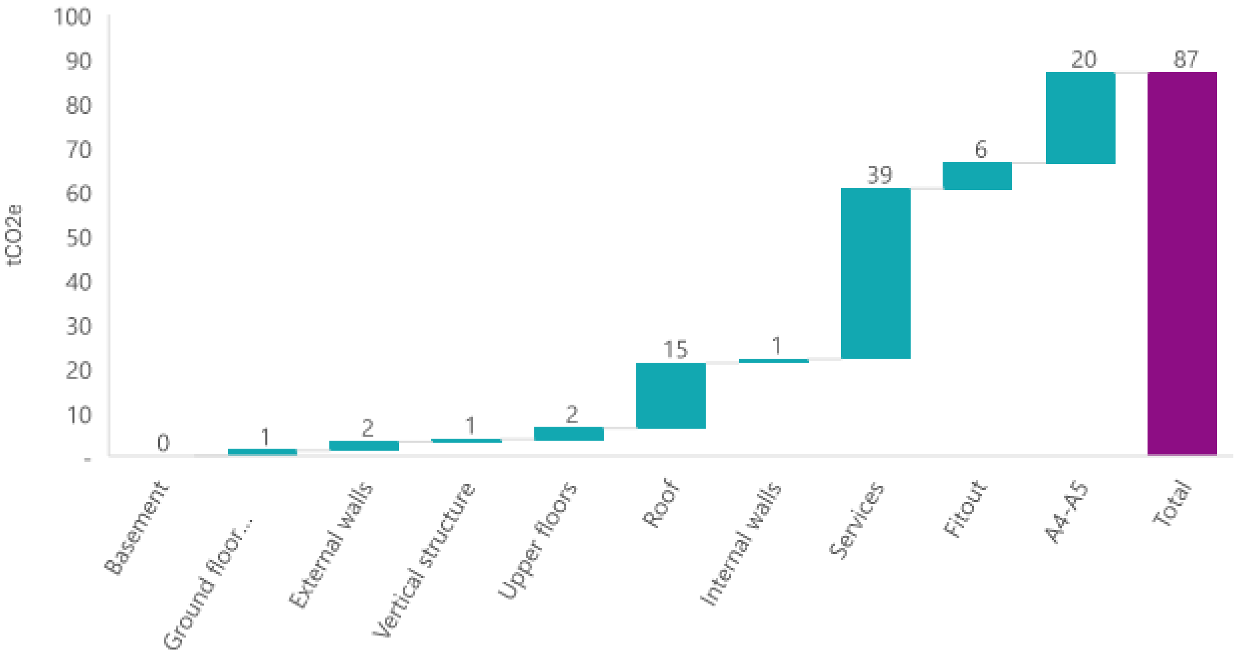

Figure 2: Upfront embodied carbon broken down by building element, Building 1

4.2 Building 2: Mid-rise reinforced concrete building

The table below summarises key upfront embodied carbon results for the strengthening of Building 2.

Table 2: Summary of Building 1 results

Scope (elements)	Scope (modules)	Upfront embodied carbon
All building elements	A1-A5	53 $kgCO_2e / m^2$
Excluding building services	A1-A5	50 $kgCO_2e / m^2$
Previous 1990s strengthening (not included in totals)	A1-A5	5 $kgCO_2e / m^2$
All building elements	A1-A3	29 $kgCO_2e / m^2$
Excluding building services	A1-A3	26 $kgCO_2e / m^2$

Figure 3 shows the upfront embodied carbon emissions breakdown by building element.

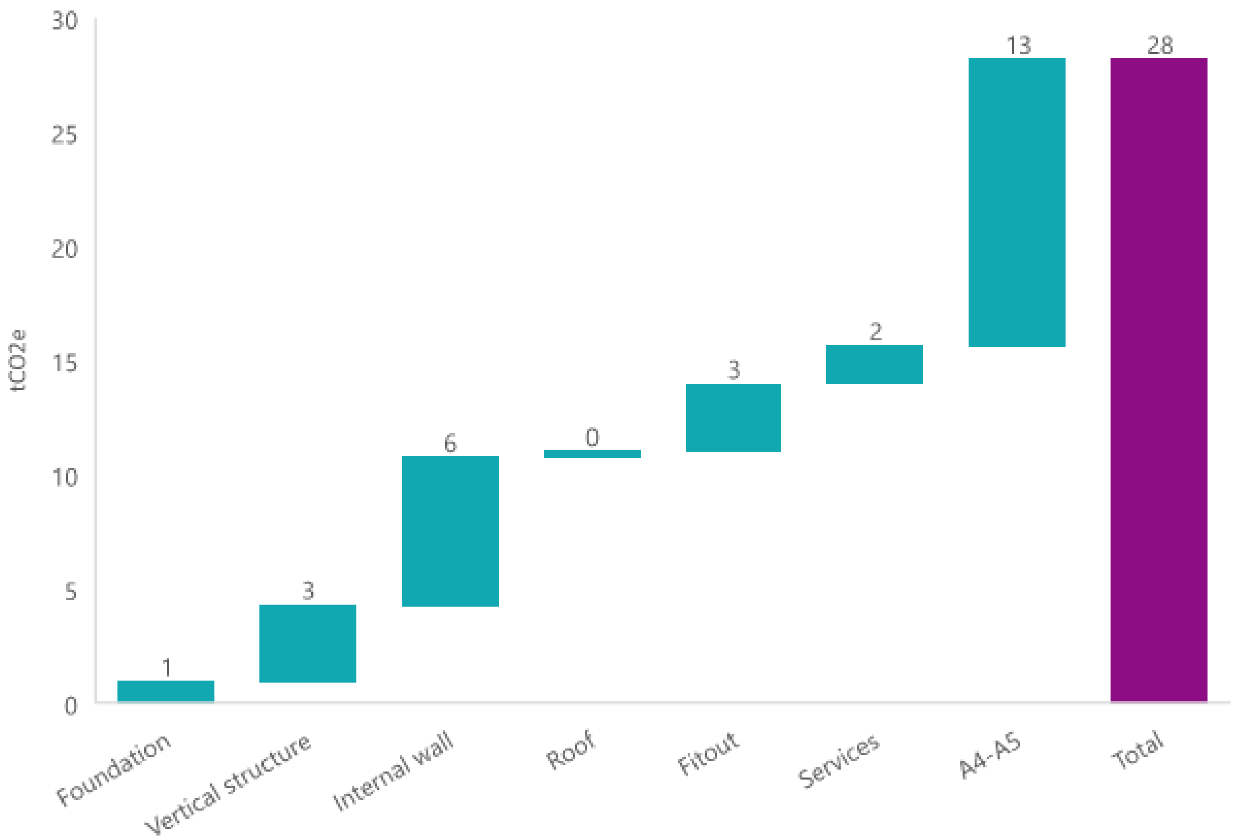

Figure 3: Upfront embodied carbon (A1-A3 only) broken down by building element, Building 2

4.3 Comparison to equivalent new-build

The table below indicates the expected difference in upfront embodied carbon intensity for the strengthened building to an equivalent new building, using the new building intensities summarised above.

It has been assumed that an equivalent floor area of building is constructed for each of Building 1 and Building 2, to enable a like for like comparison. This is not likely to be the case in practice, however, for the purposes of this study it is appropriate – understanding the upfront embodied carbon investment required to deliver the same building function for an equivalent new building.

Table 3: Comparing upfront embodied carbon intensities of strengthening vs. a new building

Building	GFA	Strengthening upfront embodied carbon intensity	New-build upfront embodied carbon intensity (A1-A5)	Saving (%)	Saving
Building 1	668 m^2	130 $kgCO_2e / m^2$	775 $kgCO_2e / m^2$	83%	645 $kgCO_2e / m^2$
Building 2	532 m^2	53 $kgCO_2e / m^2$	775 $kgCO_2e / m^2$	93%	722 $kgCO_2e / m^2$

5 KEY FINDINGS AND DISCUSSION

For strengthening of both buildings, the most significant upfront embodied carbon emissions arise from building elements or life cycle stages which are subject to high uncertainty – in particular, building services and construction stage emissions (Modules A4-A5).

- The extent, and therefore the upfront embodied carbon impact of, building services replacement in a building strengthening can vary widely depending on the level of refurbishment undertaken concurrently. This is borne out through in the difference of results between Building 1 and Building 2 (refer Table 2 and Table 3, 60 $kgCO_2e$ / m^2 and 3 $kgCO_2e$ / m^2 respectively). For that reason, results have been communicated both including and excluding the impact of building services.
- Actual material wastage and on-site electricity and fuel usage through construction is unknown and relies on generic assumptions and scenarios which do not distinguish between new buildings and refurbishments. These scenarios are likely to be conservative for the building strengthening results, as they cover emissions associated with the construction of a new building.

For Building 1 and Building 2, the emissions related to the non-structural elements were more than twice as high as the structural elements. Impacts for Building 1 across non-structural elements were significantly higher than Building 2.

- Building 1 represents an instance of strengthening undertaken concurrently with a refurbishment and upgrade. Building 2 represents an instance of strengthening where a "make good" approach was taken to building services and fit-out.
- Both of these scenarios are common for building strengthening. In reality, it is likely that the upfront embodied carbon impact of non-structural elements will not be totally avoided during the building's life cycle, just delayed, if using a "make good" approach.
- The upfront embodied carbon intensity of the structural component of the strengthening is comparable between Building 1 and Building 2 – the majority of the difference arises from the non-structural elements (internal fitout, cladding replacement and building services).

The difference in upfront embodied carbon intensity of the strengthening between Building 1 and Building 2 is less than the total variation expected from a wider pool of examples. For instance, neither Building 1 nor Building 2 strengthening replaced façade elements, and neither comprised a full strip back to structure.

5.1 Scaling of results

5.1.1 Step 1 – applying a range of uncertainties to outcomes

For the purposes of the scaling and assumptions, we have aligned the descriptions of Building 1 and Building 2 (with respect to age and structure categories) with the CBA report. Based on comparing Building 1 and Building 2 strengthening to that detailed in the CBA report, a margin of error of +/-40% is expected on the results of the upfront embodied carbon assessments of the strengthening building work. Refer to the full report for further details on determining this margin of error.

5.1.2 Step 2 – multiply upfront embodied carbon results on a per m^2 gross floor area basis

The CBA report outlined that pre-1935 buildings had an average floor area of 518m^2, and the current number of seismically-deficient buildings in New Zealand relevant to this report has been assumed to be in the range of 10,000-15,000. Therefore the total floor area is expected to be in the range of 5,180,000 m^2 to 7,770,000 m^2.

There is no way of knowing using the current data what proportion of these buildings are similar to Building 1 versus Building 2 (or other types of buildings altogether). Therefore, the simplest way forward has been taken for this study – to assume average results across each variable.

The table below summarises these results.

Table 4: Summary of potential upfront embodied carbon savings

Average upfront embodied carbon intensity (strengthening)	Average upfront embodied carbon intensity (new build)	Average potential upfront embodied carbon emissions avoided
87 $kgCO_2e / m^2$	775 $kgCO_2e / m^2$	4.5 $MtCO_2e / m^2$

Put in context, the likely carbon emissions avoided if the seismically-deficient building stock is strengthened rather than re-built is equivalent to:

- ~5 years' worth of greenhouse gas emission savings from Glenbrook moving to an EAF (MoE, 2023)
- ~1 years' equivalent of upfront embodied carbon savings from not building at all (Toma et al., 2023)
- ~9 years' worth of embodied carbon savings as a result of mandatory requirements to assess embodied carbon

6 CONCLUSIONS

The potential avoided upfront embodied carbon emissions from strengthening seismically deficient buildings, as opposed to demolishing and rebuilding them, are substantial. This study has acknowledged the uncertainty of upfront embodied carbon emission intensity associated with strengthening scenarios, depending on a range of factors, including location, level and scope of retrofit, and age of building.

This report has not included operational emissions but has acknowledged the whole of life impacts arising from building operation. The study focuses on upfront embodied carbon emissions, and the significant contribution enabled savings would have towards meeting climate targets.

Historically, MBIE's climate change proposals for the building and construction sector have concentrated on reducing embodied emissions from new construction. This research highlights the potential for avoided emissions through the enhanced utilisation of existing buildings.

Additionally, this report provides insights for the ongoing review of the EPB (Earthquake-Prone Buildings) system by improving the understanding of the potential avoided upfront embodied carbon emissions associated with strengthening seismically-deficient buildings. Policymakers may consider this as a factor in determining regulatory settings which may inform decisions on strengthening buildings over demolition.

Policies aimed at alleviating the burden on EPB building owners could also incentivise concurrent non-seismic retrofit measures which reduce operational carbon emissions. Examples of such policies include incentives for upgrading existing building services or replacing on-site fossil fuel heating with electrified heating. These measures would result in ongoing reduced operational emissions, and through extending the usable life of the building, enable further avoided upfront embodied carbon emissions. Operational savings potentially offer cost benefits for building owners and tenants, while avoided embodied emissions contribute to minimising the cost burden of meeting national climate targets.

REFERENCES

Ministry for the Environment (MoE). *Government partnership with NZ Steel set to unlock massive emissions reductions*. https://environment.govt.nz/news/government-partnership-with-nz-steel-set-to-unlock-massive-emissions-reductions/ (Accessed July 2024)

Moses P (2023). "Uncertainty, inertia and forcing functions: how to overcome barriers to low-carbon design in structural engineering". *SESOC Conference,* 21-23 June 2023, Wellington, New Zealand, Paper No 11. https://www.sesoc.org.nz/static/Documents/Conference/2023/SESOC2023-0011-Moses-11-34-Moses-Phoebe-11-34-Moses-Phoebe.pdf

MBIE (2012). *"Earthquake-prone Building Policy Review: Regulatory Impact Statement".* Ministry of Business Innovation and Employment, Wellington, New Zealand. https://www.regulation.govt.nz/assets/RIS-Documents/ris-mbie-epb-dec12.pdf

Moses P, Blewden E, Wang J, Thompson A (2024). *"Understanding potential avoided upfront carbon emissions through strengthening of seismically-deficient buildings".* Report for MBIE, Wellington, New Zealand. https://www.building.govt.nz/assets/Uploads/getting-started/building-for-climate-change/understanding-potential-avoided-upfront-carbon-emissions-through-strengthening-of-seismically-deficient-buildings.pdf

Toma C, Stephens M, Symons K and Elwood K (2023). "Reducing embodied carbon: quantifying the impact of structural design and seismic resilience, and how they support government climate change objectives". *SESOC Conference,* 21-23 June 2023, Wellington, New Zealand, Paper No 59. https://www.sesoc.org.nz/static/Documents/Conference/2023/SESOC2023-0059-Symons_et_al-59-110-Symons-Katie-59-110-Symons-Katie.pdf