Research Report

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

Prepared for MBIE
Prepared by Beca Limited, Aurecon New Zealand Limited and Holmes Limited

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Revision History

Revision Nº	Prepared By	Description	Date
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Document Acceptance

Action	Name	Signed	Date
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on behalf of	Beca Limited		

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.

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 typical 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 as follows:

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 $MtCO_2e$ and 7.4 $MtCO_2e$** 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 New Zealand's 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.

1 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 more informed decisions around the costs and benefits of low carbon and resilient buildings.

MBIE have engaged Beca (with Aurecon and Holmes as subconsultants) to assess the upfront embodied carbon impact of structural strengthening versus building an equivalent new building for two case studies.

This report 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.

The report also considers how the quantitative study outcomes might apply at a national scale, and identifies some of the associated data uncertainties.

1.1 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[1].

1.2 Alignment with government priorities

The findings from this research will provide initial estimates of carbon emissions which could potentially be avoided through the upgrade and ongoing use of New Zealand's existing seismically-deficient building stock.

Identifying opportunities to avoid carbon emissions is a priority. Avoided emissions through building and construction can minimise the cost liability to New Zealanders in delivering on the emission reductions that are needed to meet national climate targets, including the Nationally Determined Contribution under the Paris Climate Agreement and the Climate Change Response (Zero Carbon) Amendment Act.

The findings of this work may be used by MBIE to inform the direction of the climate change work programme. To date, MBIE's climate change work programme has focused on reducing embodied emissions

[1] Uncertainty, intertia and forcing functions: how to overcome barriers to low-carbon design in structural engineering (Moses, 2023) https://www.sesoc.org.nz/static/Documents/Conference/2023/SESOC2023-0011-Moses-11-34-Moses-Phoebe-11-34-Moses-Phoebe.pdf

from new building work, and this research offers an opportunity to explore the potential avoided emissions from making greater use of existing buildings.

The retention of existing building stock may offer greater upfront embodied carbon savings than is practical and cost efficient to achieve in new buildings, with today's technologies and building practices.

A priority of the Building and Construction portfolio is to deliver an improved approach to the EPB system by reviewing current settings. This research will provide evidence on the potential emissions impacts of different options that come out of that review.

The Joint Committee for Seismic Assessment and Retrofit have a working group reviewing simplified strengthening options for URM buildings. This work aligns with the direction of the research undertaken here, in that the easier (and more cost effective) seismic strengthening becomes, the greater the potential for avoided upfront embodied carbon emissions.

2 Methodology

2.1 Overview

The image below provides a high-level overview of the methodology used for this research.

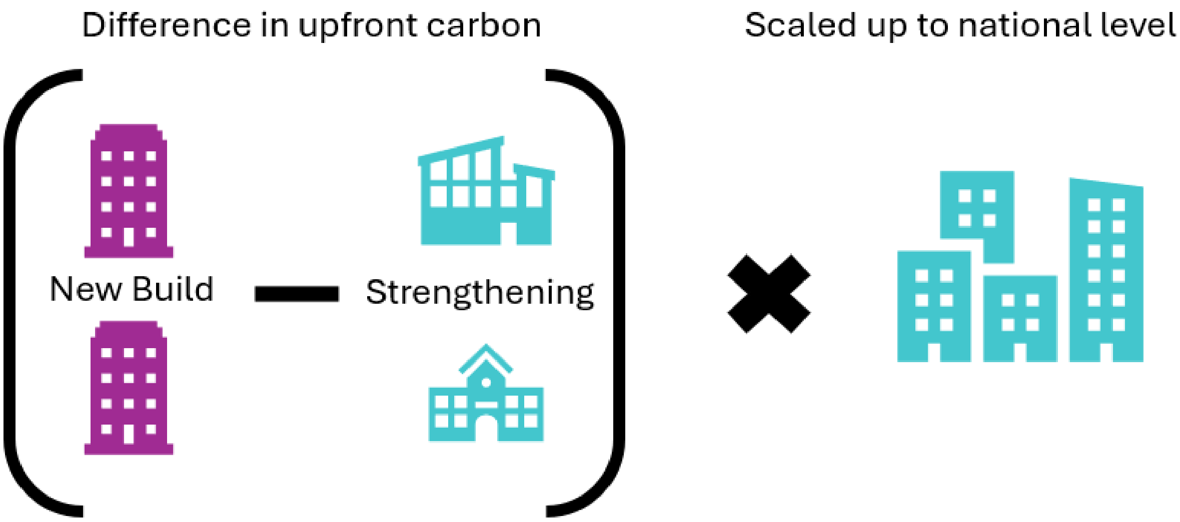

Figure 1: Research methodology

The research team have used a Life Cycle Assessment (LCA) methodology to calculate the impacts in the first stage of the research. 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. Upfront 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 (refer Section 2.4). 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 of rebuild and strengthening options if applied to the national stock of seismically deficient buildings.

2.2 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.

2.2.1 Building 1: Two-storey unreinforced masonry

This is a two-storey unreinforced masonry (URM) building in Auckland CBD with a single basement level, and was constructed prior to 1900. The building has timber floors with a lightweight timber roof. The 300mm thick URM walls form the lateral load resisting system in both directions.

The building was identified as having an earthquake rating of <34%NBS and strengthening was undertaken between 2017 and 2019 to address these seismic deficiencies to achieve a seismic rating of 67%NBS. The extent of the strengthening included:

- Infilling the voids of an existing ground floor wall with reinforced concrete
- M16 wall ties between the first floor and the URM walls
- 19mm ply diaphragm to the first floor
- 12mm ply ceiling diaphragm
- Restraining the roof parapets to all perimeter URM walls
- Additional 90x90 timber (structural grade SG8) post at basement
- 89x6 steel square hollow section (SHS) columns at ground level
- Additional 250x45 timber (structural grade SG8) joists at level one and ceiling level
- New steel parallel flange channel (PFC) strengthening at ground floor and level one

Alongside the seismic strengthening, there was significant work undertaken to upgrade the building services and architectural fit-out of the building. The following items have also been included in the scope of the LCA:

- New timber stair at basement level
- Strap and line flooring at ground floor
- New timber framed internal partition walls, lined with plasterboard
- New tile lining to floor and walls
- New laminated timber to floor
- Suspended ceiling to ground and first floor
- New internal doors
- Full reroof in steel cladding
- New lighting, ventilation and heating equipment and distributed service elements (as indicated on Building Consent documentation)

2.2.2 Building 2: Mid-rise reinforced concrete building

This is a four-storey building located in Wellington CBD. The building was constructed prior to 1935 with reinforced concrete framing and infill unreinforced masonry walls, supported by strip and pad footing on concrete piles. There are also some non-loadbearing URM walls to the interior of the building.

Strengthening and interior repairs were conducted first in the 1990s, and again in 2012, to retain the historic value of the building. The earlier strengthening scope comprised additional sprayed concrete shear walls at ground level, which have been calculated and reported separately as "previous seismic strengthening". The building was later identified as having an earthquake rating of <34%NBS, and further strengthening was undertaken to address these seismic deficiencies to a seismic rating of 100%NBS. The previous strengthening work has not been included in the total values, as most existing building stock of this age will have some level of existing strengthening. This research looks at the level of intervention required on current building stock, not at the sum total of all strengthening work undertaken.

The strengthening scope comprised:

- Two new footings and screw piles central to the building under new reinforced concrete shear wall.
- New steel square hollow section (SHS) posts at various locations at all levels.
- Replacement of inner leaf of URM external walls at ground level with 100mm reinforced concrete walls.
- New 100mm sprayed reinforced concrete wall on ground floor internal walls.
- New 150mm reinforced concrete wall between ground floor garage and flat.
- Existing bathroom wall strengthening with starter bars at all levels.
- Replacement of the internal non-loadbearing URM walls with plasterboard timber-framed walls at all levels.

As well as the strengthening work, some minor upgrades to finishes and fittings were undertaken. Most of the building used a 'make-good' approach to building elements and surfaces. The scope of the non-strengthening work undertaken concurrently comprised:

- Replacement of roof membrane for leakage issue.
- Replacement of vinyl flooring and carpet at all levels.
- Replacement of the entry door for all apartment units.
- Replacement of discrete light fittings, and space heating units (as indicated on Building Consent documentation).
- Concealment of steel SHS columns with plasterboard at various locations.

2.3 Scope

The scope of the assessment includes all structural, architectural and services upgrades (including both strengthening elements and non-seismic refurbishment elements). Table 1 outlines the scope of inclusion for this assessment based on the MBIE methodology, including all mandatory elements.

Table 1: Scope as defined in MBIE Methodology

Building System	Mandatory	Voluntary (included)	Voluntary (excluded)
Ground Work	• Substructure/foundations • Earth retaining structures • Basements		• Vegetation • Hard landscaping • Ancillary buildings • External services, including drainage
Structure	• Ground floor structure Upper floor(s) structure • Load bearing systems: gravity and lateral structural frames and walls • Roof structure	• Stairs • Lifts and escalators	• Temporary works (formwork, scaffold etc.) used during construction that are not reused
External envelope	• Cladding/façade primary elements (weather exposed layer, structural support system) • External wall insulation • Roof covering and insulation		• Cladding/façade secondary elements (seals, brackets etc.)

Sensitivity: General

Building System	Mandatory	Voluntary (included)	Voluntary (excluded)
	• External windows and doors		
Non-structural internal elements	• Non-loadbearing walls • Internal doors • Floor and wall finishes	• Ceilings	• Fixtures, fittings furniture
Building services	• HVAC equipment	• Water, drainage, electrical services • Other building systems such as fire and security systems	

2.4 System boundary

For the purposes of this study, the scope of assessment is 'Cradle to practical completion', Modules A1-A5 as outlined in Appendix A (known as upfront embodied carbon).

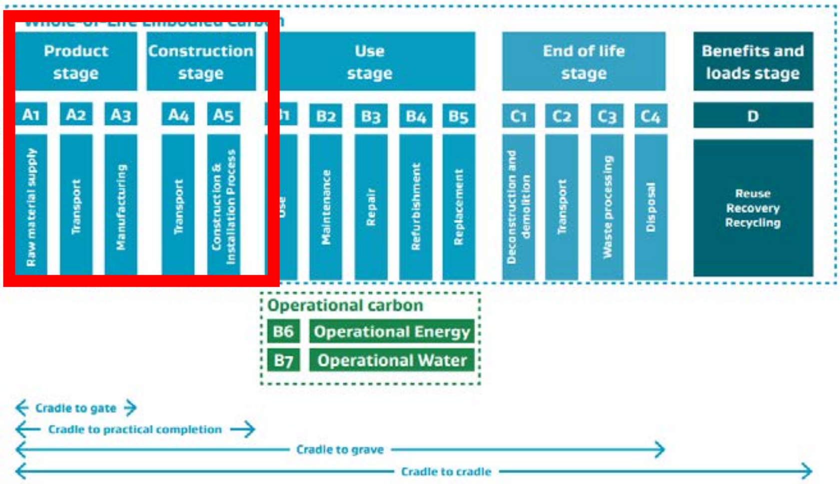

Figure 2: Assessment boundary (Life Cycle Stages)

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.

What about operational efficiency?

Operational carbon emissions of existing buildings are, on average, higher than new buildings. This is due to system and envelope inefficiencies as well as the use of on-site fossil fuels. However, until many years have passed, this impact is small when compared to upfront embodied carbon emissions, as indicatively shown in the figure below.

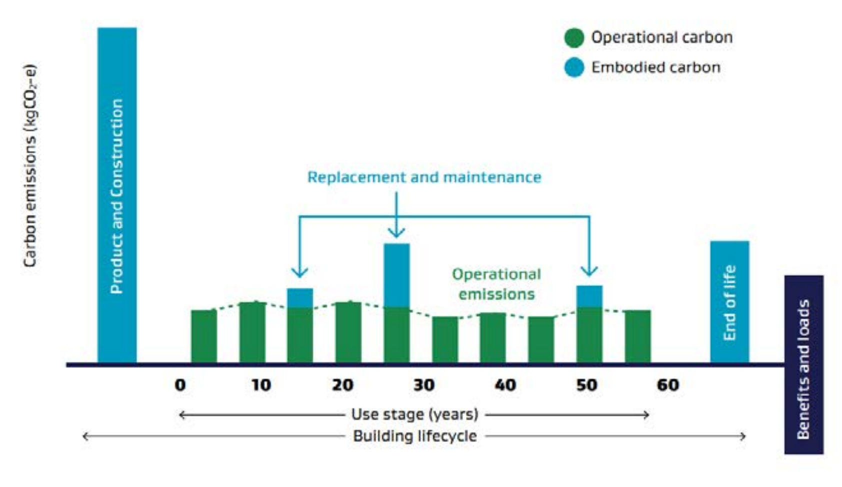

Figure 3: Operational and embodied carbon emissions over the life cycle of a building (MBIE, 2020)

Building seismic strengthening provides an opportunity to address building operational carbon through system upgrades, however, this can also be addressed at later stages of the building life cycle.

While theoretically possible for a more energy efficient new building to have lower whole-life carbon emissions than a less energy efficient existing building, differences in whole-life carbon emissions will most likely be dominated by differences in upfront embodied carbon of the retrofit and alternative new-build work.

2.5 Assumptions, inputs and data

A detailed breakdown of inputs, assumptions and level of data quality for the upfront carbon assessment has been provided in Appendix A.

2.6 One Click LCA

The assessment has been carried out with the One Click LCA software. The software holds 11 third party certifications and complies with over 30 certifications and standards for Life Cycle Assessment, including Green Star (Australia and New Zealand). The software includes curated and verified global and local databases. The up-to-date list of integrated databases can be found here: https://www.oneclicklca.com/support/faq-and-guidance/documentation/database/.

One Click LCA has been third party verified by ITB for compliancy with the following LCA standards: EN 15978, ISO 21931–1 and ISO 21929, and data requirements of ISO 14040 and EN 15804. The full compliancy documentation is available at:

https://www.oneclicklca.com/support/faq-and-guidance/documentation/compliancy-and-certifications/.

All of the datasets in the tool comply with ISO 14040/14044 and for the most part with EN 15804.

2.7 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 Appendix A for a detailed breakdown of building metadata).

For comparative purposes, the same LCA boundary has been taken (A1-A5). While there would be some upfront 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 new-build upfront embodied carbon intensity comprises average data from seven similar multistorey buildings (across retail, health, and commercial office typologies) in Auckland, Wellington, Christchurch, and Whangārei. 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.

Figure 4 indicates the range of values associated with each building element for the seven new build projects.

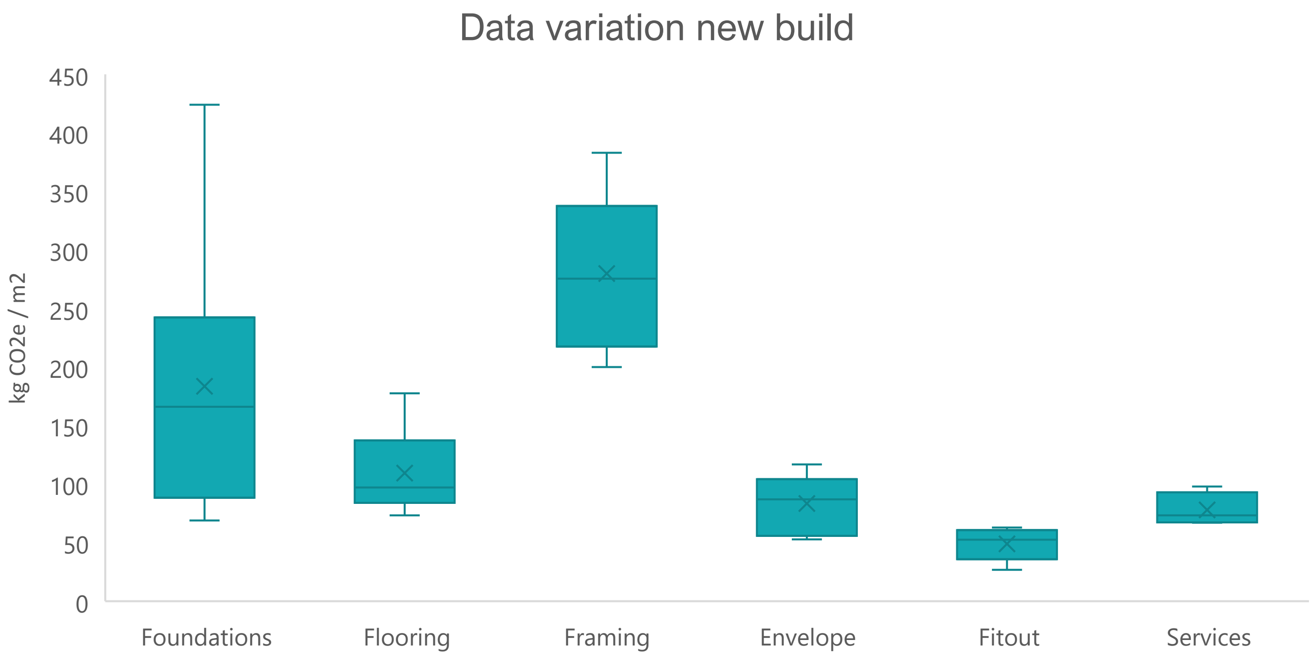

Figure 4: Data variation for each building element within a typical multistorey new build in New Zealand

Clearly, the most variable building element upfront embodied carbon from the sample set is foundations (more than +/- 50%), whereas the variation in flooring, framing and non-structural elements is generally within +/- 20%. Therefore, it is reasonable to assume that the values below represent plausible upfront embodied carbon intensities for new multistorey buildings.

The average upfront embodied carbon intensity for each building element is shown below in Figure 5.

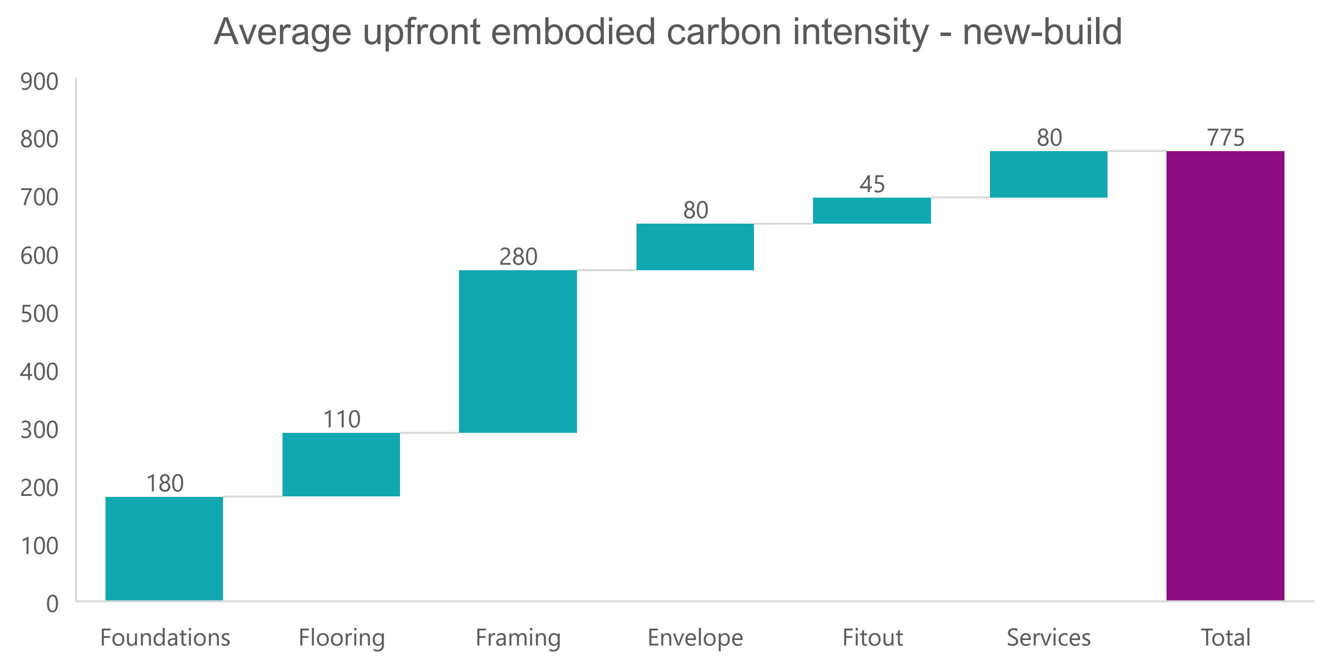

Figure 5: Upfront embodied carbon broken down into building elements for an average new-build

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. As discussed in Section 2.4, it is possible for some new buildings to have lower whole-of-life carbon outcomes than some refurbishments, and this should be reviewed on a case-by-case basis.

2.8 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.

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

- Indicative Cost-Benefit Analysis Model for Earthquake-prone Building Review (2012, Martin Jenkins) (CBA Report) – also referenced in the Regulatory Impact Statement of 2012[2]
- 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.

[2] Earthquake-prone Building Policy Review: Regulatory Impact Statement (MBIE 2012)

2.8.1 Applying a range of uncertainty to upfront embodied carbon results

For this study, based on readily available information, cost is used as an indicator of the potential range of upfront embodied carbon impacts of strengthening work. The CBA Report details the plausible range in costs of strengthening to remove earthquake-prone status from different building ages and typologies, targeting different levels of seismic performance. It allows for the potential impact of target %NBS on effort involved to be considered. The cost of strengthening is reported on a $/m^2 basis, and increases as the target seismic performance also increases.

For any given building, we consider it reasonable to assume the carbon impacts of strengthening to follow the trend of cost, but the extent (and carbon impact) of non-structural refurbishment is largely independent of the level of strengthening. Two ranges have been selected for Building 1 and Building 2, as detailed in Section 3.5.

Both buildings were strengthened to levels greater than mandatory minimum thresholds, which is not unusual for buildings in major cities - some markets demand a higher level of strengthening than mandatory minimums to be commercially viable. It is unknown what %NBS will be targeted by buildings in the future, but it is likely many will only strengthen to the minimum threshold. This variation is expected to be captured in the sensitivity analysis undertaken in Section 3.5, and has been discussed further in the results.

There are several weaknesses to using the CBA Report. Firstly, cost is not a reliable indicator to compare the demolish and rebuild scenario to strengthening, as the cost of strengthening a building is not proportional to the material used. Cost is often disproportionate to the material quantities used in a strengthening upgrade, compared to a demolition and rebuild. Therefore, the data is only used as a coarse indicator for the range of material quantities (and hence upfront embodied carbon) associated with strengthening and non-structural refurbishment.

Secondly, it is difficult to determine where the two assessed buildings might fall on the range of costs provided. In the absence of specific cost information for the projects, the buildings are assumed to fall in the middle of the range. Sensitivity studies have been undertaken to assess what the impact would be if they were taken to be the upper-bound or lower-bound in the range.

Thirdly, the data used for the CBA report is over a decade old – and was collected under the old regime for identifying and assessing potentially earthquake prone buildings. Therefore what a 67% NBS-strengthening looks like today, versus what it looked like at the time of the report, is different. There is no straightforward way to adjust this quantitatively, therefore this uncertainty has been ignored. It is assumed to be minor in comparison with other uncertainties.

2.8.2 Scaling results to a national level

The second step taken in scaling results uses all of the data sources described above. The CBA report estimated that in 2012 there were 15,000-25,000 commercial and public buildings (including apartments) with <33%NBS seismic rating, which at the time comprised ~10% of the total building stock. The current number of unremediated buildings on the EPB register is ~5,500 and expected to rise by thousands[3] (noting there are many seismically-deficient buildings which do not appear on the register but would likely be assessed as <34%NBS). Based on this, and correspondence with researchers at the University of Auckland[4], the authors estimate the current number of seismically deficient buildings relevant to this report to be within the range of 10,000-15,000 buildings[5]. There is a high level of uncertainty associated with all these numbers,

[3] Seismic Risk Guidance for Buildings (MBIE 2022), https://www.building.govt.nz/assets/Uploads/getting-started/seismic-risk-guidance-for-buildings.pdf
[4] Personal email correspondence with Prof. Jason Ingham, University of Auckland (6 August 2024).
[5] This excludes buildings which score (or are likely to score) > 34% NBS under the current regime, but which in some cases may still require further voluntary strengthening for commercial viability (due to market drivers).

however, the authors have some confidence that the actual number of seismically deficient building is in the order of magnitude of thousands (but likely not tens of thousands) of buildings.

This study therefore will present the outcomes of upfront embodied carbon saved associated with a pool of 10,000-15,000 seismically-deficient buildings across Aotearoa NZ (5 million – 8 million m^2 GFA).

Key CBA Report data is summarised below.

- >30% of New Zealand's total existing building stock is in the Auckland region, with a further ~10-15% each in Christchurch and Wellington regions.
    - Building 1 is in Auckland, and Building 2 is in Wellington.
- The average area of all buildings built pre-1935 is 518m^2, and 758m^2 for buildings built between 1935-1976.
    - Building 1 is 668m^2, and Building 2 is 532 m^2, both close to these average values.
- 42% of the non-residential building stock at the time of the CBA report was built pre-1976. The CBA report only considered potential EPBs for buildings built before this year.
    - Both Building 1 and Building 2 were built pre-1976.
- ~28% of buildings built pre-1976 assessed by territorial authorities (TAs) with good levels of data were <33%NBS (7 TAs, representing ~36% of the total number of pre-1976 buildings in New Zealand). Combined with data from an additional 16 TAs with average quality data, this suggested that across New Zealand, ~24% of all buildings built pre-1976 could be <33%NBS.

Therefore the buildings chosen are likely to be a good representative sample. The upfront embodied carbon of each building assessed in this study is reported on a $kgCO_2e/m^2$ basis.

3 Results

3.1 Building 1: Two-storey unreinforced masonry

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

Table 2: Summary of Building 1 results

Scope (elements)	Scope (modules)	Upfront embodied carbon ($kgCO_2e$ / m^2)
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

Figure 6 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.

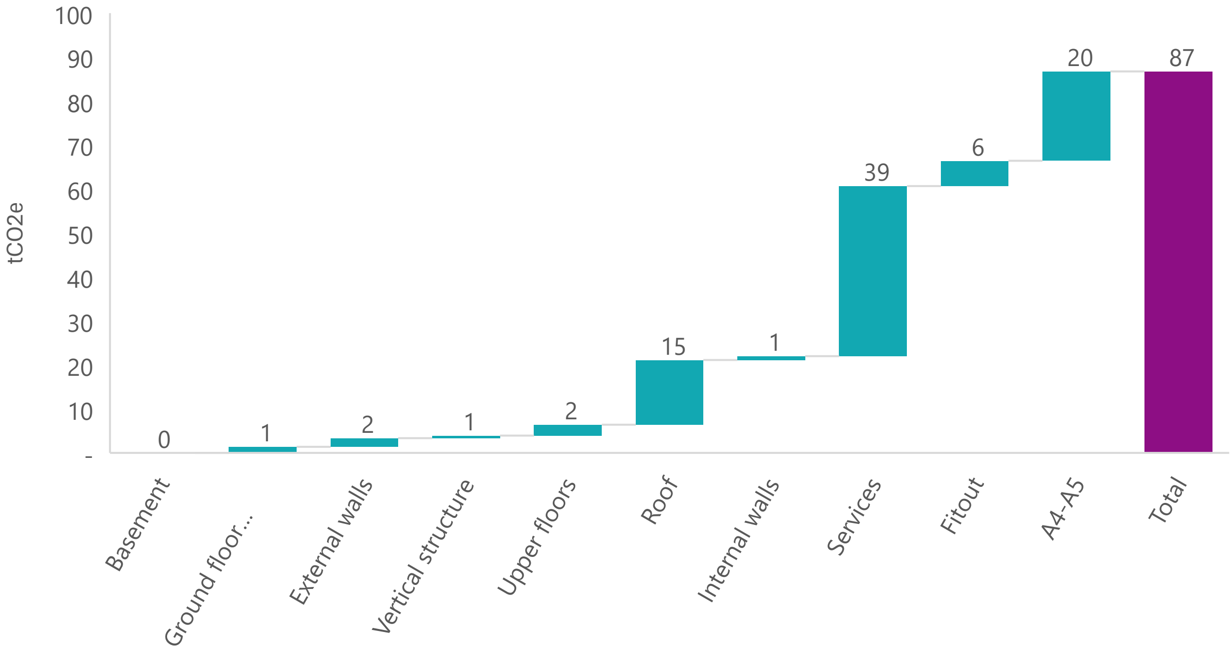

Figure 6: Upfront embodied carbon broken down by building element, Building 1

Figure 7 below indicates the most impactful materials in the strengthening work, for Modules A1-A3.

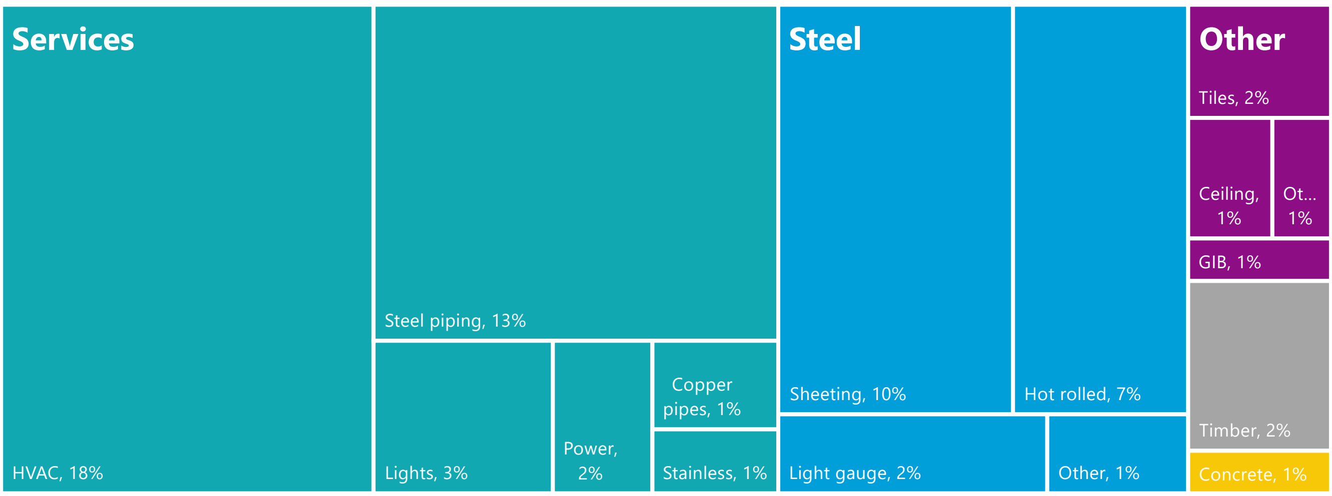

Figure 7: Upfront embodied carbon (A1-A3 only) broken down by material type, Building 1 strengthening

3.2 Building 2: Mid-rise reinforced concrete building

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

Table 3: Building 2 results summary

Scope (elements)	Scope (modules)	Upfront carbon intensity
All building elements	A1-A5	53 $kgCO_2e / m^2$
Excluding building services	A1-A5	50 $kgCO_2e / m^2$

Scope (elements)	Scope (modules)	Upfront carbon intensity
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 8 and Figure 9 show the upfront embodied carbon emissions breakdown by building element, and by most impactful materials.

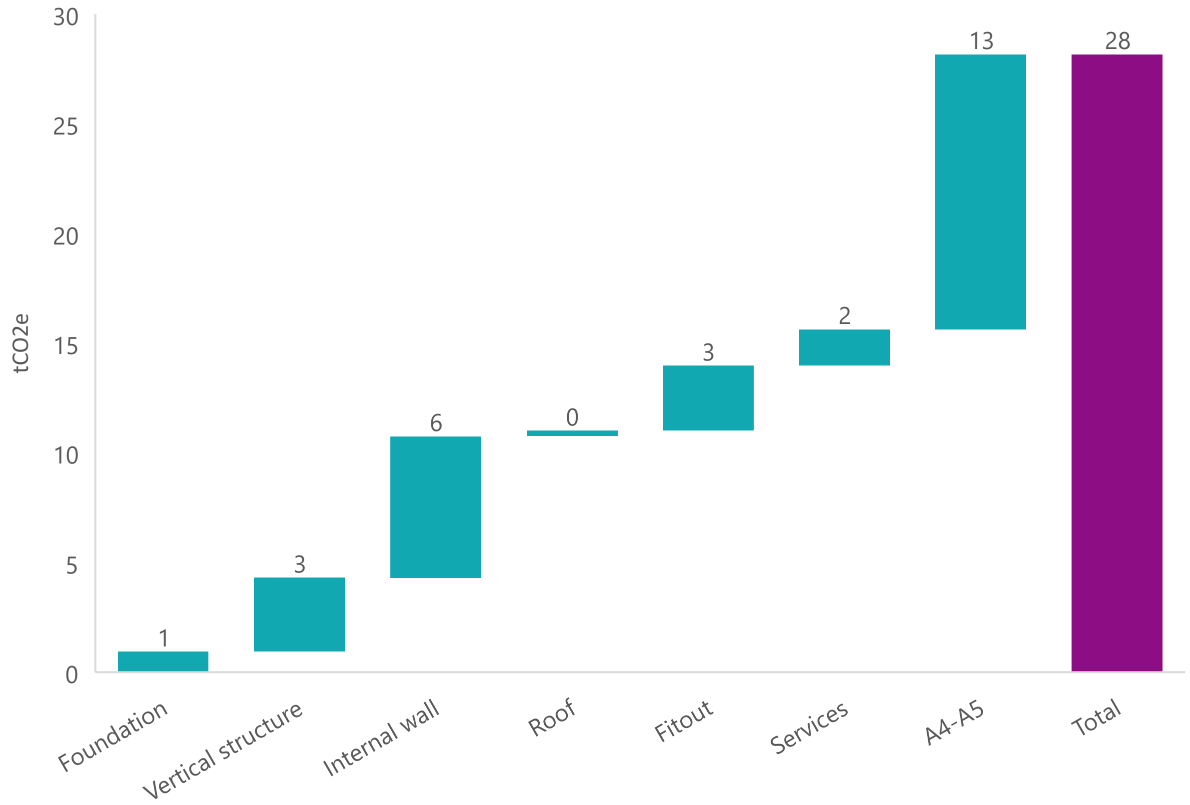

Figure 8: Upfront embodied carbon (A1-A3 only) broken down by building element, Building 2

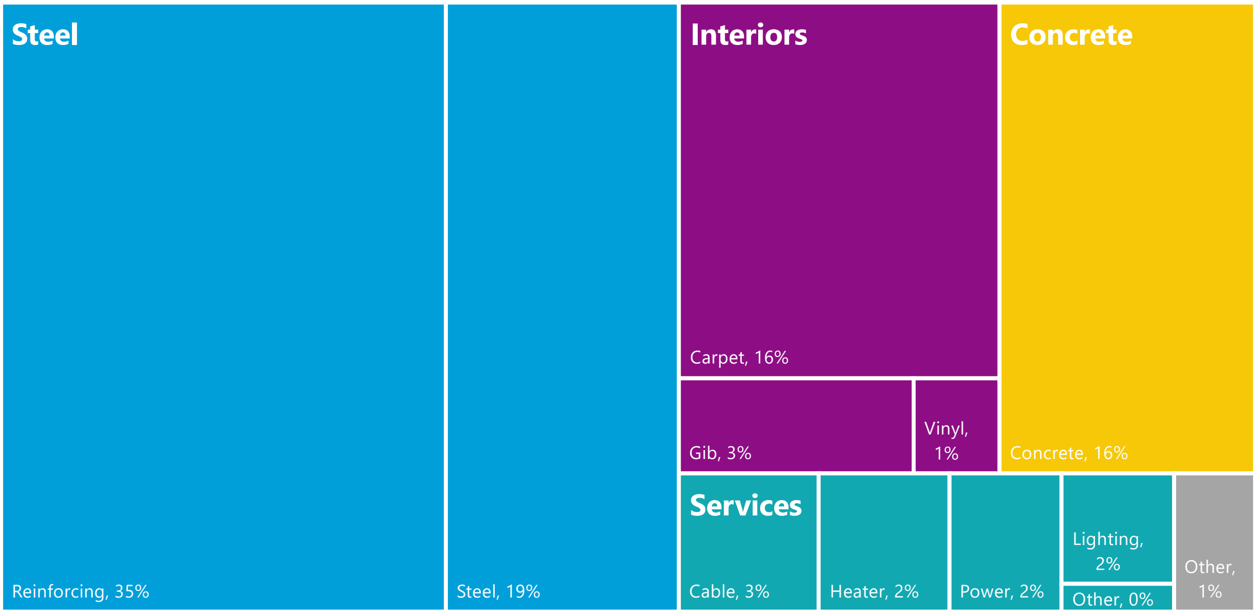

Figure 9: Upfront embodied carbon broken down by material type, Building 2 strengthening

3.3 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 presented in Section 2.

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 4: Summary comparison between upfront embodied carbon intensities of strengthening work to new build (Modules A1-A5, full element scope)

Building	GFA	Strengthening upfront embodied carbon intensity	New-build upfront embodied carbon intensity (average)	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 $kgCO_2e / m^2$

3.4 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.

- o 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.
  - o 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.
  - o 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.
  - o 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 strengthenings replaced façade elements, and neither comprised a full strip back to structure.

3.5 Scaling of results

3.5.1 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.

Building 1 is a URM building constructed pre-1935 and strengthened to 67%NBS. This level of strengthening representative of the appropriate level of strengthening to de-risk a seismically deficient building for a 50-year service life extension[6]. For the purposes of scaling (not necessarily representative of reality), it is assumed that the extent of strengthening and fit-out undertaken on this building is representative of the average amount of work that would be undertaken to strengthen a building of this type at <33%NBS. As discussed in Section 2, this goes beyond what could be considered a "make good" approach, which is also a common approach.

It includes strengthening details that would typically be seen in an earthquake prone URM building, including tying the walls to the floors, creating a floor and roof diaphragm, and restraining parapets. As discussed in Section 2.2.1 the level of fitout and services upgrade in Building 1 goes beyond a 'make good approach'. Therefore, taking this as the average amount of strengthening work for the purposes of scaling is considered a conservative approach for Building 1.

The CBA Report has a cost category matching this building description. Figure 10 (taken and marked up from the CBA Report) shows the cost/m^2 to strengthen a range of different building typologies from earthquake-prone status to 34%, 67% or 100%NBS. A range of values is provided with an upper and lower

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[6] Guidance for Territorial Authorities and Property Owners on ISAs (NZSEE, 2014), https://www.nzsee.org.nz/db/PUBS/AISPBE/NZSEE_ISA_Guide_for_TAs_and_Owners_Ver2_Nov14.pdf

bound. Depending on the building typology, there are green, blue or red markers shown on the graph to represent the range. Please note the study shows two sets of values (blue and red markers) for "Unreinforced masonry" and does not differentiate – the red-coloured markers have been used for this study, as this set of data appears across all strengthening targets.

As this building targeted 67% NBS strengthening, the range of values in the middle of the graph have been used (marked up in blue). The graph has been annotated to clearly show the average, upper-bound and lower-bound values, with the variation from average (expressed as a percentage) also calculated and indicated on the graph.

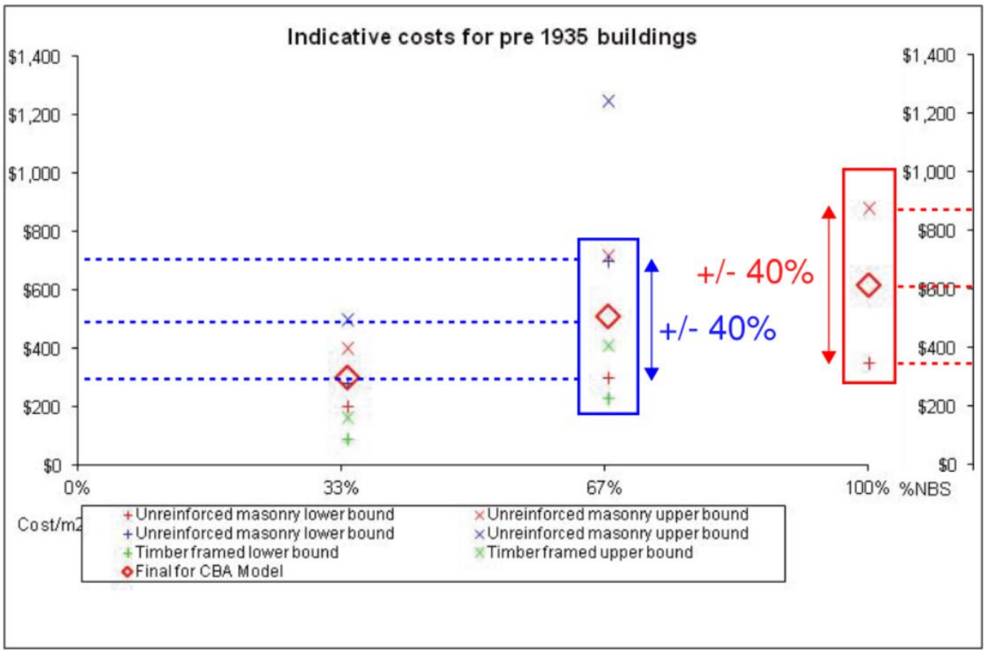

Figure 10: Cost range for pre-1935 buildings seismic strengthening, showing average, upper and lower-bounds

Building 2 is a pre-1976 building with a reinforced concrete frame and double-leaf external URM infill walls, strengthened to 100%NBS. For the purposes of scaling, it is assumed that the level of seismic strengthening and fit-out undertaken on this building is representative of the average amount of strengthening work for a building of this type at <33%NBS. It includes strengthening details that would typically be seen in a concrete-framed building with URM infill walls, including replacing the internal leaf of external wall infill with a reinforced concrete wall, and providing additional lateral out-of-plane restraint to the outer leaf of the external walls. It also includes the replacement of non-loadbearing internal URM partitions with lightweight partitions. As discussed in Section 2.2.2, the level of fitout and services for Building 2 is considered a 'make good' approach, and therefore taking this as the average for the purposes of scaling is considered appropriate. The CBA Report does not have specific cost data relating to this category of building – the closest equivalent is assumed to be for pre-1935 URM building strengthened to 100%NBS.

The value range from Figure 10, taken from the CBA Report, is used to apply error margins to the upfront embodied carbon results of each building. The error margins to be applied to Building 1 are indicated on the left (in blue), and the error margins to be applied to Building 2 are indicated on the right (in red).

As indicated in the value range associated with strengthening a URM EPB (Building 1) to 67%NBS is +/- 40%. The value range associated with strengthening a URM EPB (Building 2) to 100%NBS is also +/- 40%.

Therefore a margin of error of +/-40% is expected on the results of the upfront embodied carbon assessments of the strengthening building work.

While this cannot be taken as a like for like comparison for the expected range of upfront embodied carbon emissions, it gives an indication of the potential variation of material quantities (and hence upfront embodied carbon) associated with strengthening buildings of a similar age and typology.

The upfront embodied carbon associated with strengthening Building 1 was 130 $kgCO_2e/m^2$. Applying the +/- 40% uncertainty noted above, assuming it represents average performance, would result in a range of **78 $kgCO_2e/m^2$ – 182 $kgCO_2e/m^2$**.

The upfront embodied carbon associated with strengthening Building 2 was 53 $kgCO_2e/m^2$. Applying the +/- 40% uncertainty noted above, assuming it represents average performance, would result in a range of **32 $kgCO_2e/m^2$ – 75 $kgCO_2e/m^2$**.

A sensitivity analysis has been undertaken on the results above to test how variable outcomes would be if the two buildings assessed were not average for their building type. These results are summarised in Tables 5 and 6 below.

Table 5: Sensitivity analysis – strengthening of Building 1

Scenario	Lower-bound	Average	Upper-bound
Building 1 at middle of range of outcomes	78 $kgCO_2e$ / m^2	130 $kgCO_2e$ / m^2	182 $kgCO_2e$ / m^2
Sensitivity 1: Building 1 at lower-bound of range	*130 $kgCO_2e$ / m^2*	*217 $kgCO_2e$ / m^2*	*303 $kgCO_2e$ / m^2*
Sensitivity 2: Building 1 at upper-bound of range	*56 $kgCO_2e$ / m^2*	*93 $kgCO_2e$ / m^2*	*130 $kgCO_2e$ / m^2*

Table 6: Sensitivity analysis – strengthening of Building 2

Scenario	Lower-bound	Average	Upper-bound
Building 2 at middle of range of outcomes	32 $kgCO_2e$ / m^2	53 $kgCO_2e$ / m^2	75 $kgCO_2e$ / m^2
Sensitivity 1: Building 2 at lower-bound of range	*53 $kgCO_2e$ / m^2*	*88 $kgCO_2e$ / m^2*	*124 $kgCO_2e$ / m^2*
Sensitivity 2: Building 2 at upper-bound of range	*23 $kgCO_2e$ / m^2*	*38 $kgCO_2e$ / m^2*	*53 $kgCO_2e$ / m^2*

3.5.2 Step 2 and summary

As detailed in Section 2.8, 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 total ranges of outcomes are shown indicatively on the figure below.

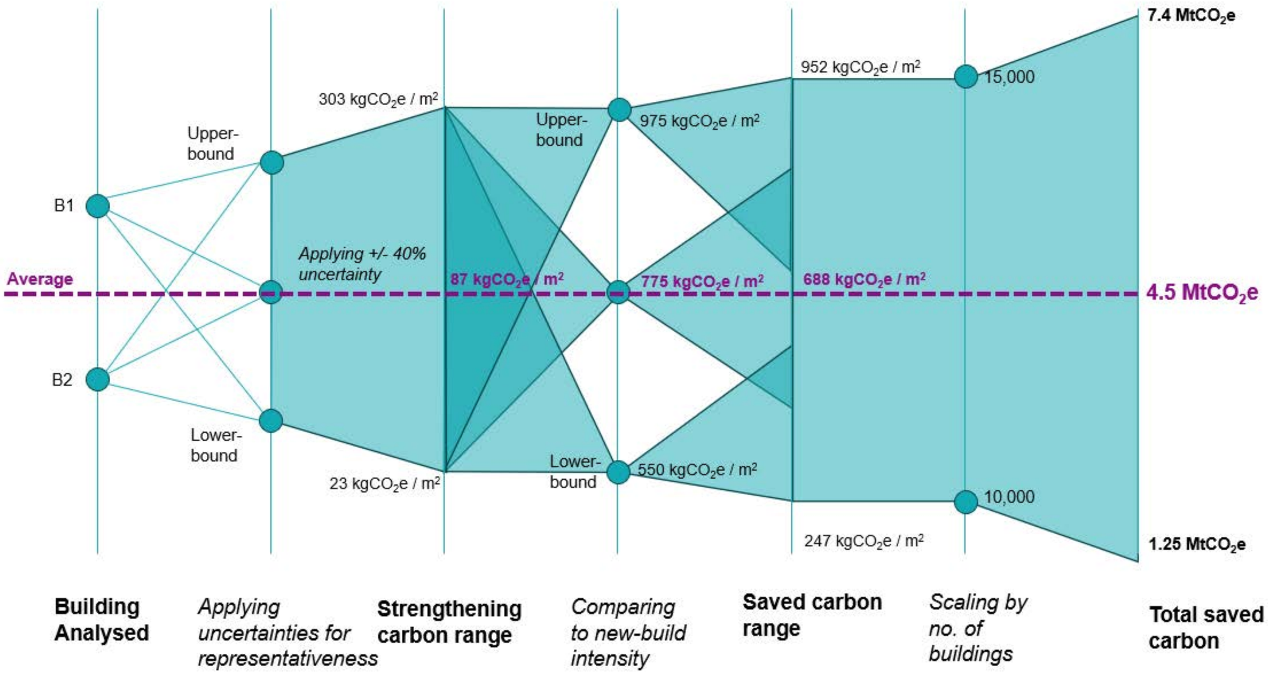

Figure 11: Indicative ranges of outcomes showing uncertainties (not to scale)

The table below summarises these results.

Table 7: Summary of results

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 $MtCO_2e$**

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[7]
- ~1 years' equivalent of upfront embodied carbon savings from not building at all[8]
- ~9 years' worth of embodied carbon savings as a result of mandatory requirements to assess embodied carbon[8]

[7] Ministry for the Environment (2023) https://environment.govt.nz/news/government-partnership-with-nz-steel-set-to-unlock-massive-emissions-reductions/

[8] Reducing embodied carbon: quantifying the impact of structural design and seismic resilience, and how they support government climate change objectives (Symons et al., 2023) https://www.sesoc.org.nz/static/Documents/Conference/2023/SESOC2023-0059-Symons_et_al-59-110-Symons-Katie-59-110-Symons-Katie.pdf

4 Conclusions

When typical construction practices are followed, strengthening of existing seismically deficient buildings is estimated to present a potential saving in upfront embodied carbon compared to demolition and rebuilding in the order of 688 $kgCO_2e$ / m^2 GFA. This accounts for approximately 4.5 $MtCO_2e$ of avoided upfront embodied carbon emissions, when applied to the estimated current seismically-deficient building stock in New Zealand.

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 given the immediate impact of these, 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.

5 Next steps

- Further research could be undertaken to provide a clearer picture for both policy makers and building owners to appreciate the benefits of strengthening over demolition and rebuilding. A significant part of this would be understanding the cost of different strengthening schemes.
- Work with the Joint Committee for Seismic Assessment and Retrofit to provide guidance for the sector on the upfront embodied carbon associated with different strengthening and retrofit options.

6 Limitations

Please note the following limitations related to this report:

- Structural and architectural quantities have been based on the “For Building Consent” documentation available for each of the buildings. This take-off has been undertaken by building professionals, but has not been verified by a registered Quantity Surveyor.
- Building Services quantities have been based on information in the “For Building Consent” architectural documentation where available. Where the scope of refurbishment inferred a wider replacement of distributed elements (e.g. cabling, ductwork) – generic industry allowances have been used in the assessment.
- Fittings, fixtures, soft furnishings and furniture have been excluded from the assessment.
- Materials and quantities are generally limited to what was present on the drawings made available to the authors. Where insufficient information was provided, this has been supplemented by conservative engineering judgement. The assessment is limited to the information provided.
- Subject to data quality and updates which occurred during construction, there remains uncertainty about the exact quantity of upfront embodied carbon emissions from the strengthening.
- This assessment was prepared for the use of the Ministry of Business, Innovation and Employment only for the purpose described in the commissioning agreement and is not to be relied upon by any third parties.
- The outputs are based on database values available within One Click LCA, which uses a variety of standard assumptions and relies on a range of different databases.

A

Appendix A – LCA Assumptions and Inputs

Data inputs and assumptions

Module A1-A3

Module A1-A3 includes the emissions associated with the production of materials. Quantities for A1-A3 have been extracted from Issued for Construction (IFC) and Building Consent (BC) drawings. These include structural drawings, architectural drawings and interior fitout drawings. Quantities have been calculated using excel, where small assumptions have been made such as plasterboard thickness, spacing of studs, and weight of suspended ceiling steel supports. Where assumptions have been made to fill data gaps, these have erred on the conservative side. A 20% allowance has been applied to structural steel quantities to allow for connections not captured in drawings.

As per the hierachy as outlined in the MBIE methodology, data selections prioritise Environmental Product Declarations (EPDs) over generic data. Where detailed in the documentation, the specific product EPD has been selected as a representative. Where the specific supplier is unknown, a representative product has been selected based on standard industry practice.

Table A1: Data sources

Building Element	Representative product	Data quality level as per MBIE methodology
Structural Steel (Hot rolled sections)	Infrabuild, hot rolled structural steel section, EPD	3
Structural steel(Hollow sections)	HSS, Structural hollow steel section, cold rolled, generic	2
Steel reinforcing	Pacific Steel, Reinforcement Bar, EPD	5
Concrete	Allied, Ready-mix Concrete Wellington and Auckland plants, EPD	4
Timber	WPMA, Softwood timber from pine, kiln-dried, sawn, EPD	4
Plasterboard	GIB, gypsum plasterboard, 10mm, EPD GIB, gypsum plasterboard, 13mm, EPD	4*
Steel cladding	Colorsteel, Endura, EPD	5*
Plywood	Carter Holt Harvey, Structural plywood, EPD	4
Insulation	Pinkbatts, Glass wool insulation, EPD	4
Fibre cement	James Hardie, fibre cement for external application, EPD	3
Suspended ceiling	Rondo, hot dipped zinc-coated galvanised steel ceiling product, EPD	4
Suspended ceiling	KNAUF, Armstrong acoustic ceiling panel, EPD	3
Aluminium	Aluminium sheet, 0% recycled content, generic	1
Doors	WPMA, Softwood timber from pine, kiln-dried, sawn, EPD	2
Roof membrane	Bitumen-polymer membrane roofing, 2 layer, fully torched (EWA), EPD	3
Vinyl floor	KALEI, Expanded vinyl(PVC) flooring rolls, generic	2

Building Element	Representative product	Data quality level as per MBIE methodology
Carpet	CIAL, Tufted carpet tiles, EPD	4
Tiling	Ceramic tiles, Italian average, 10mm, 19.9 kg/m2 (Confindustria Ceramica), EPD	3
Laminate	Tarkett, Laminated flooring, EPD	3

*Noting this EPD is expired, but still the most appropriate representative data source.

Building Services

Building services have a large impact on the upfront embodied carbon emissions of strengthening work to existing buildings. The case studies documentation had limited information on the building services upgrades. Table A2 outlines the services that have been assumed for each building, based on indicative information in the drawings that have suggested upgrades to mechanical, hydraulic, electric and fire services. Building services have been represented by generic scenarios in One Click, applied on a square meter basis.

Table A2: Building services inclusions

Building 1: Two storey unreinforced masonry	Building 2: Mid-rise reinforced concrete building
- Lighting system (excluding cabling) - Supply and waste water system - Sprinklers - Ventilation system	- Emergency lighting - Fire detection system - Isolated electric heaters

Module A4

A4 distance assumptions are based on the BRANZ Construction transport datasheet, for Auckland and Wellington respectively. Table A3 outlines the three transport modes that have been used, and the representative selected in One Click. Although different sized trucks are likely used, a 16t to 28t truck has been used as a conservative proxy.

Table A3: Transport representatives

Transport mode	Representative	Emission factor ($kgCO_2e/tkm$)
Truck	Transport, truck, 16 to 28t, fleet average (AusLCI)	0.18
Ship	Transport, VCM freight ship (AusLCI)	0.0057
Concrete Mixer	Concrete mixer truck, appr. 8 m3, 50% fill rate	0.23

Module A5

Wastage rates for A5 are shown in Table A4 and have been extracted from the BRANZ Construction Site Waste Datasheet. Where these rates are not available for some materials, default wastage rates in the One Click software have been used.

Table A4: Wastage rates by material

Material	Wastage rate
Timber	10%
Concrete	4%
Steel reinforcement	5%
Structural steel	1%
Plasterboard	15%
Insulation	15%
Ceiling panels	8%
Fibre cement	18%
Tiles	10%
Flooring laminate	5%

Construction site impacts for Module A5 are based on a generic scenario in One Click, based on average construction site impacts for temperate and southern climates. This includeems 23.58 kWh electricity; 1.12 l diesel and 0.05l petrol per square metre GFA. It is acknowledged this scenario is based on new builds and therefore is likely to over account for the energy and fuel spent in the retrofit scenario.

Material Take-off

Table A5 and Table A6 include the bill of quantities for each building assessed in this study.

Building 1: Two storey unreinforced masonry

Table A5: Bill of Quantities Building 1

Building Element	Quantity	Unit
Basement		
Basement Timber Structure (90x90 SG8 + 150x150 bottom plate)	0.02	m^3
Masonry wall steel reinforcement	0.01	m^3
Basement timber stair	0.10	m^3
Basement Fire rated walls (plasterboard)	14.23	m^2
Basement Fire rated walls (timber framing)	0.09	m^3
Ground floor		
Ground Floor PFC	178.62	kg
Ground Floor SHS	188.84	kg
Ground floor timber 90x90 SG8	0.03	m^3
RC infill voids (30 MPa Concrete)	1.63	m^3
RC infill voids (reinforcing)	0.00	kg

Building Element	Quantity	Unit
Ground floor plywood flooring	3.98	m^3
Ground floor strap and line (timber)	0.20	m^3
Ground Floor strap and line (plasterboard)	0.95	m^3
Ground floor timber wall (framing)	0.94	m^3
Ground floor doors	0.32	m^3
Ground floor suspended ceiling (acoustic panel)	67.30	m^2
Ground floor suspended ceiling (galvanised steel supports)	168.25	kg
Ground floor column box out (plasterboard)	0.23	m^3
Ground floor column box out (battens)	0.07	m^3
First floor		
First floor structural ply	3.78	m^3
First floor timber joists	0.85	m^3
First floor PFC	343.38	kg
Additional steel allowance	68.68	kg
First floor M16	42.57	kg
First floor wall (plasterboard)	0.90	m^3
First floor wall (timber framing)	1.92	m^3
First floor door	0.12	m^3
Steel cladding	126.00	m^2
First floor ceiling insulation	7.46	m^3
First floor suspended ceiling (acoustic panels)	197.17	m^2
First floor suspended ceiling (galvanised steel supports)	492.93	kg
Internal partition walls (timber framing)	2.47	m^3
Internal partition walls (plasterboard)	2.68	m^3
Wall ceramic tiles	113.20	m^2
Floor ceramic tiles	43.58	m^2
Floor laminate timber	137.56	m^2
Roof plan		
Roof structural ply	4.33	m^3
Roof EA	587.66	kg
Roof CHS	41.14	kg
Roof cleat plate	0.001	m^3
Roof PFC	458.91	kg
Ceiling Joists	4.70	m^3
Additional steel allowance	217.54	kg
Roofing metal	363.16	m^2
Roofing purlins (timber)	0.60	m^3
Roof hatch	37.00	kg
Roof hatch framing H3.2	0.02	m^3
Roofing joists H1.2	0.03	m^3
Roof plywood gutter H3.2	0.84	m^3

Building Element	Quantity	Unit
Roof gutter Membrane	0.48	m^3
Roof Parapet colour steel	28.17	m^3
Roof timber nib wall H3.2	0.29	m^3
Roof timber nib wall Fibre cement sheet	0.12	m^3
Previous Strengthening		
Perimeter RC ground beam (concrete)	2.48	m^3
Perimeter RC ground beam (reinforcement)	0.02	m^3

Building 2: Mid-rise reinforced concrete building

Table A6: Bill of Quantities Building 2

Building Element	Quantity	Unit
Foundation		
Screw piles(Concrete)	0.31	m^3
Screw piles(Steel)	15.70	kg
Footing(Concrete)	0.94	m^3
Footing(Steel)	126.39	kg
Superstructure		
Steel columns		
150 x 6 SHS	298.16	kg
150 x 6 SHS(Grout)	0.22	m^3
100 x 6 SHS	190.05	kg
75 x 6 SHS	436.80	kg
Internal Wall		
100mm RC wall(Concrete)	3.00	m^3
100mm RC wall(Steel)	341.48	kg
150mm RC wall(Concrete)	0.67	m^3
150mm RC wall(Steel)	94.20	kg
100mm Sprayed RC wall(Concrete)	1.05	m^3
100mm Sprayed RC wall(Steel)	125.60	kg
Bathroom wall starter bars	26.69	kg
25% of overall steel for connection	502.08	kg
GIB wall- GST132 13mm GIB braceline	58.76	m^2
GIB wall- GST132(Timber framing)	0.31	m^3
GIB wall- GNT 104 10mm GIB braceline	227.76	m^2
GIB wall- GNT104(Timber framing)	0.60	m^3
Concealed column cover-	6.03	m^2

Building Element	Quantity	Unit
10mm GIB standard		
Concealed column cover- 13mm GIB standard	0.68	m^2
Roof		
Bitumen membrane(assumed bitumenous)	118.5	m^2
Fitout		
Apartment entrance door(Timber)	0.25	m^3
Carpet	307	m^2
Vinyl floor	38.80	m^2

New-build examples

The table below provides a high-level summary of the properties of the seven buildings used as a reference for the study.

Building	Location	Function	Scope (building elements)	Year of LCA
Building A	Wellington	Commercial office	Structure, envelope, base-build fitout, services	2023
Building B	Wellington	Commercial office	Structure, envelope, base-build fitout, services	2024
Building C	Wellington	Retail + commercial office	Structure, envelope, base-build fitout, services	2023
Building D	Tauranga	Retail + commercial office	Structure, envelope, base-build fitout, services	2023
Building E	Christchurch	Commercial office	Structure, envelope, base-build fitout, services	2024
Building F	Whangarei	Health	Structure, envelope, base-build fitout, services	2024
Building G	Auckland	Education	Structure, envelope, base-build fitout, services	2024