The
Resilient Buildings
Project

The Resilient Buildings Project

Relating Societal Expectations to Building Seismic Performance: Report for Stage 3

FINAL REPORT

FEBRUARY 2024

nzsee NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING
Toka Tū Ake EQC

Project team

Shannon Abeling (University of Auckland) (Lead author),
Sarah Beaven (University of Canterbury),
Charlotte Brown (Resilient Organisations),
Dave Brunsdon (Kestrel Group),
Hugh Cowan (Hugh Cowan Consulting) (Project Director),
Caleb Dunne (Toka Tū Ake EQC),
Ken Elwood (University of Auckland),
Helen Ferner (New Zealand Society for Earthquake Engineering) (Project Lead),
John Hare (Holmes NZ LP),
Derek Gill (NZIER), and
Rob Jury (Beca).

Acknowledgements

This project was initiated by the New Zealand Society for Earthquake Engineering (NZSEE) with funding for the project from Toka Tū Ake EQC. In addition the lead author was supported through a University of Auckland Post Doctoral fellowship funded by Toka Tū Ake EQC.

The authors gratefully acknowledge the many people who have participated in the workshops or have otherwise contributed through interviews, shared information and associated research to our understanding of how society uses buildings and expects them to perform. We want to acknowledge subject matter experts Mike Stannard, Pam Johnston, Tal Sharrock-Crimp and Kay Saville-Smith whose insights into the New Zealand built environment and associated economic analysis matters greatly assisted the project team. Also reviewers Professor Mary Comerio, Associate Professor Julia Becker and Alistair Cattanach who identified key missing elements in the framework and a range of important clarifications. Their input and perspectives were an invaluable addition to the project.

The Resilient Buildings Project has drawn on knowledge contributed by technical societies (NZSEE and SESOC), research consortia (QuakeCoRE) and research institutions (Universities and CRIs) – all having supported the project through the provision of advice and active participation in workshops and meetings, all of whom we wish to acknowledge as providing very valuable support for the project.

Citation

Please cite this report as:

Abeling, S., Ferner, H., Cowan, H., Gill, D., Brown, C., Beaven, S., Brunsdon, D., Hare, J., Jury, R. (2024). The Resilient Buildings Project. Relating Societal Expectations to Building Seismic Performance: Report for Stage 3. NZSEE report.

Contents

For appendices please refer to separate volume.

Report at a Glance

How do New Zealanders in the 2020s want buildings to perform during and after an earthquake?

Do current regulatory and technical approaches to seismic risk management provide buildings that meet expectations? If not, what framework should be used to guide the changes in required seismic standards, codes and practices in New Zealand?

The Resilient Buildings Project explores these questions. In the previous phase of this project, qualitative research was conducted to better understand current societal expectations of building performance during earthquakes. The key findings included that, while life safety is non-negotiable (as is provided in the current Building Code), people want more out of their buildings. Among those involved in the study, there was a desire for buildings to be resilient enough to reduce social disruption and speed economic recovery after an earthquake.

The main focus of this report is on Stage 3 of the Resilient Buildings Project, in which we developed a framework to guide the development of seismic standards, codes, and practices in New Zealand.

The key insights from the work includes:

- **The Earthquake Performance Outcome (EPO) Framework establishes a systematic way to map building performance to building user outcomes.**
    - The EPO Framework articulates key social, economic and environment outcome indicators and shows how they relate simply and directly onto dimensions of building performance to reduce injury, protect property and reduce loss of amenity and function.
    - The accompanying building usage categorisation system identifies the types of building types (such as marae and aged care facilities) whose functionality after an earthquake would be particularly valued by their communities and would warrant higher seismic performance standards.
- **The EPO framework was also used to assess the current Building Code against the findings from the societal expectations research.**
    - While the current Code is consistent with those expectations for protecting life safety (i.e., minimising deaths and injuries), in the event of moderate and strong shaking, the current Code falls significantly short of societal expectations on protection of property and return to function.
    - This means that people would prefer buildings that sustained less earthquake damage and were able to retain function or return to function much sooner than the current Code delivers.
- **Enabling work undertaken evaluated the cost implications of improving seismic resilience and identified opportunities within the building system to improve seismic resilience.**
    - An initial review of existing evidence suggests that the cost premiums for increasing the seismic resilience of new buildings is low (~0-2%) of construction costs.
    - At first sight, this suggests that there is case that there are highly cost-effective interventions that would improve new building resilience in New Zealand.

  - There are opportunities for change both within design codes and outside (including building industry practices and land use planning) to improve seismic resilience of buildings.

Who is this report for?

This report is primarily targeted at individuals and agencies working on reviewing building standards, codes, and practices that shape the seismic resilience of New Zealand's building stock.

The findings will be useful to building designers. There is work underway, informed by this work, to create guidance documents directly aimed at building owners, designers, and tenants.

The report will also have relevance to international audiences who are revising and enhancing their seismic building standards and codes.

Executive Summary

The Resilient Buildings Project

The seismic provisions of the current New Zealand Building Code have evolved from standards first introduced in the 1930s, after building damage caused multiple fatalities in historical earthquakes in Napier and Hastings. The New Zealand Code, like those of many seismically active countries, focuses on building performance that minimises injuries and preserves life during earthquakes. Over the last decade of earthquakes (including the 2010-2011 Canterbury earthquake sequence and the 2016 Kaikōura earthquake), code-compliant buildings generally met these objectives for life safety. However, seismic damage often prevented the reoccupation of buildings causing lengthy delays in the resumption of normal building functions.

The Canterbury Earthquakes Royal Commission recommended that the treatment of seismic risk be reviewed to ensure that arrangements for incorporating relevant knowledge of seismic hazard and risk over time are harmonised with reasonable societal expectations of building performance during earthquakes. This required that work be done to better understand the aspects of building seismic performance that New Zealanders most value.

The Resilient Buildings Project was set up to begin this work. A NZSEE initiative, funded by Toka Tū Ake EQC, the Resilient Buildings Project was set up to gather evidence of contemporary expectations concerning the seismic performance of buildings, and to develop a framework to enable those expectations to be translated into what this means for building level performance outcomes. The immediate aim of the RBP is to inform future revisions of codes and technical standards and inform wider building industry practices. The overarching purpose of the Resilient Buildings Project is to undertake activities and research that will ultimately improve the overall seismic performance of new buildings, resulting in a range of positive outcomes from immediate (post-earthquake) to longer term (decadal) impacts (Figure E1).

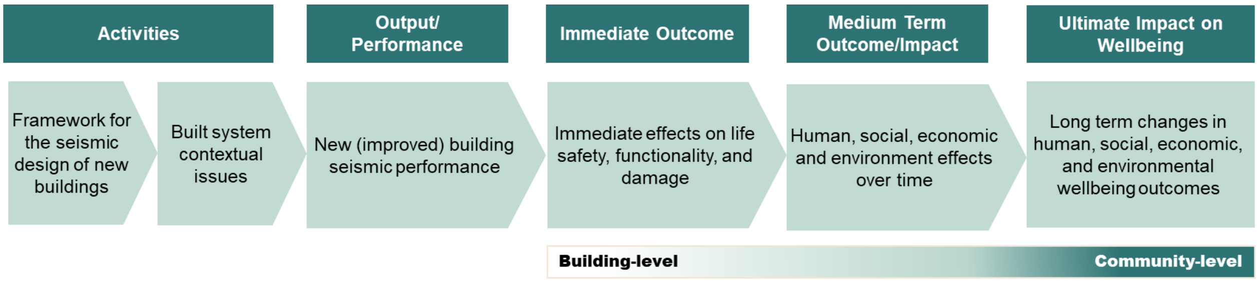


Figure E1. Intervention logic diagram for activities undertaken by the Resilient Buildings Project

Stage 1 of the Resilient Buildings Project focused on establishing the need and vision for the project.

Stage 2 undertook research to understand New Zealand building users' expectations for the seismic performance of buildings.

Stage 3 of the Resilient Buildings Project (this report) built on the previous stages by developing a framework that relates user expectations to building level performance outcomes. Through an expert workshop process, the societal expectations collected in Stage 2 of the Resilient Buildings Project were used to:

1. Develop a performance outcome framework,
2. Develop a categorisation system for building usages, and
3. Evaluate the gap between the current Code provisions and expectations captured in Stage 2.

Stage 3 also involved some enabling work around pathways to improve resilience in our built environment, both within and beyond our current Building Code.

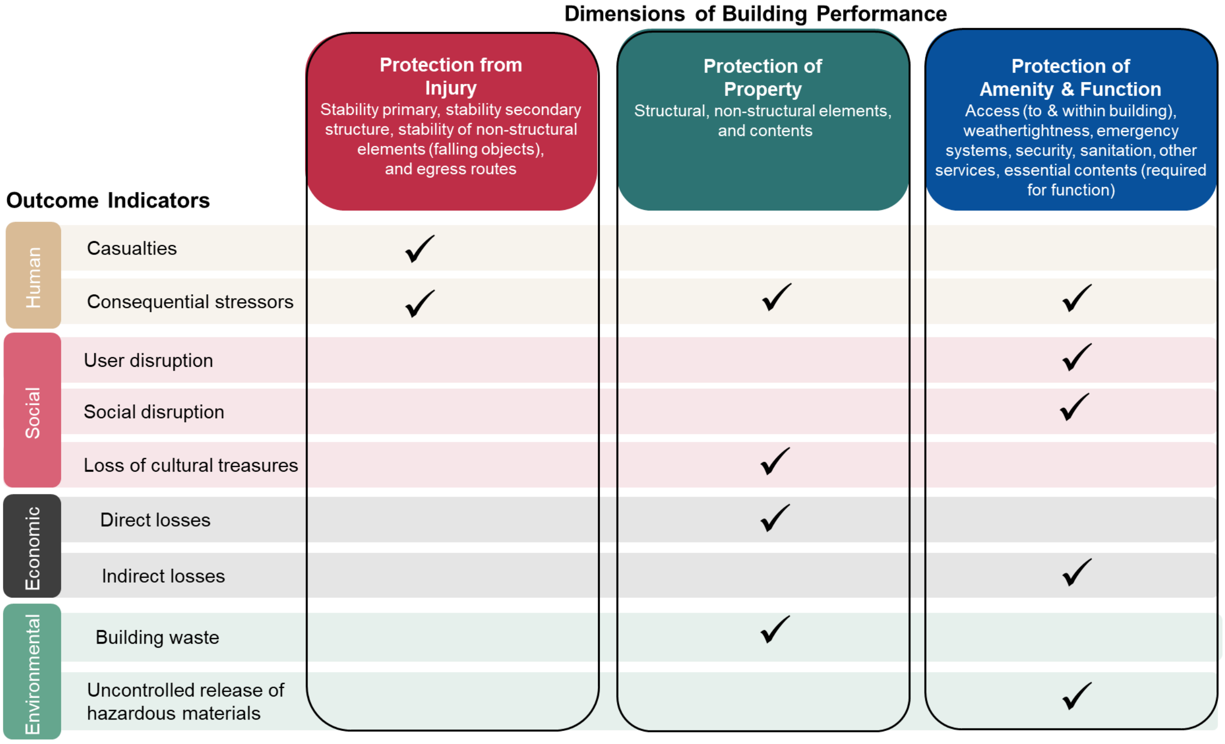
Earthquake Performance Outcome Framework

The Earthquake Performance Outcome (EPO) framework establishes a systematic way to map building performance to building user outcomes (and vice versa). The EPO framework, as shown in Figure E2, comprises a set of outcome indicators that describe the effects that building performance or damage can have on building users and the community following an earthquake. These outcome indicators are grouped into human, social, economic and environmental wellbeing categories. The outcome indicators are then mapped to three dimensions of building performance relevant to earthquake shaking: protection from injury, protection of property, and protection of amenity and function. These are defined as:

- **Protection from Injury:** building performance that causes damage and may result in physical or mental harm to building occupants or passers-by.
- **Protection of Property:** building performance that results in physical damage and the financial and environmental burden of repair or replacement.
- **Protection of Amenity & Function:** building performance that disrupts building usage, excluding disruptions caused by structural or non-structural instability.

The dimensions of building performance have been mapped to the most directly relevant aspect of a building’s performance where the onset of loss/failure of this indicator is first relevant. That is, from onset of any physical damage (protection of property), onset of loss of normal building functionality (protection of amenity and function) or structural failure (protection from injury).

The framework has been designed to be agnostic to building type and usage. It can be applied to all types of residential and commercial properties, including single family homes and multi-unit residential buildings, single storey industrial and commercial facilities, multi-storey developments, and specialised use buildings of all types and sizes. The intention is that the framework can be used in the future to set performance objectives relevant to any given building or building type, with a clear value chain evident between the performance objective and desired societal outcomes.



Dimensions of Building Performance

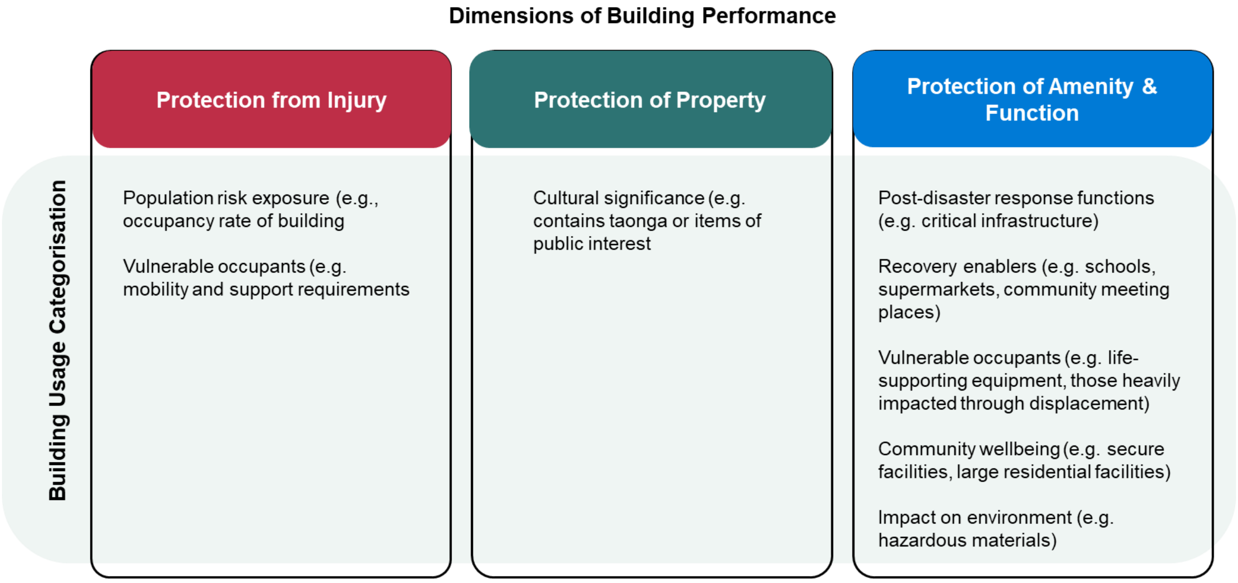
Outcome Indicators		Protection from Injury Stability primary, stability secondary structure, stability of non-structural elements (falling objects), and egress routes	Protection of Property Structural, non-structural elements, and contents	Protection of Amenity & Function Access (to & within building), weathertightness, emergency systems, security, sanitation, other services, essential contents (required for function)
Human	Casualties	✓		
	Consequential stressors	✓	✓	✓
Social	User disruption			✓
	Social disruption			✓
	Loss of cultural treasures		✓	
Economic	Direct losses		✓	
	Indirect losses			✓
Environmental	Building waste		✓	
	Uncontrolled release of hazardous materials			✓

Figure E2. Relationship between outcome indicators & dimensions of building performance

Building Usage Categorisation

To complement the EPO framework, a building categorisation system was developed to identify building usages that may benefit from higher performance objectives than others. The system developed is based on (1) *why* certain buildings are valued by their communities and (2) the *consequences* that would result from these important buildings being damaged.

Building usage categories are based on those that are likely to have higher consequences of failure (in terms of human, social, economic, and environmental impacts) relative to 'typical' buildings. The building usage categorisation system can be used to evaluate any building use case including both residential and commercial. The building usage categories each relate to one dimension of building performance within the EPO. The categories are summarised in Figure E3.Within the EPO framework, each dimension of building performance can be considered separately. As such, our vision is that each building usage group can have performance objectives set that prioritises the dimension(s) of building performance most critical to it.



Dimensions of Building Performance

	Protection from Injury	Protection of Property	Protection of Amenity & Function
Building Usage Categorisation	Population risk exposure (e.g., occupancy rate of building Vulnerable occupants (e.g. mobility and support requirements	Cultural significance (e.g. contains taonga or items of public interest	Post-disaster response functions (e.g. critical infrastructure) Recovery enablers (e.g. schools, supermarkets, community meeting places) Vulnerable occupants (e.g. life-supporting equipment, those heavily impacted through displacement) Community wellbeing (e.g. secure facilities, large residential facilities) Impact on environment (e.g. hazardous materials)

Figure E3. Building usage categorisation

Evaluation of Current Code against Societal Expectations

One of the key objectives of the Resilient Buildings Project was to evaluate the extent to which the current Building Code meets current societal expectations. The Stage 2 research produced a snapshot of societal expectations, providing a data point that could be used to assess whether the current Code is meeting building user expectations, within an order of magnitude.

Using the EPO framework, qualitative loss exceedance curves were derived for each dimension of building performance. By way of example, a mid-rise multi-use building in Wellington was considered in terms of (1) what the project team *believe, based on observation and experience,* compliance with current Code can achieve and (2) what the project team infer the New Zealand public expects of their buildings in earthquakes based on the Stage 2 societal expectations research. We focused on the Code's requirements for the design and construction of structural and non-structural building elements. The likelihood of an outcome severity was estimated for different levels of shaking, see Figure E4.

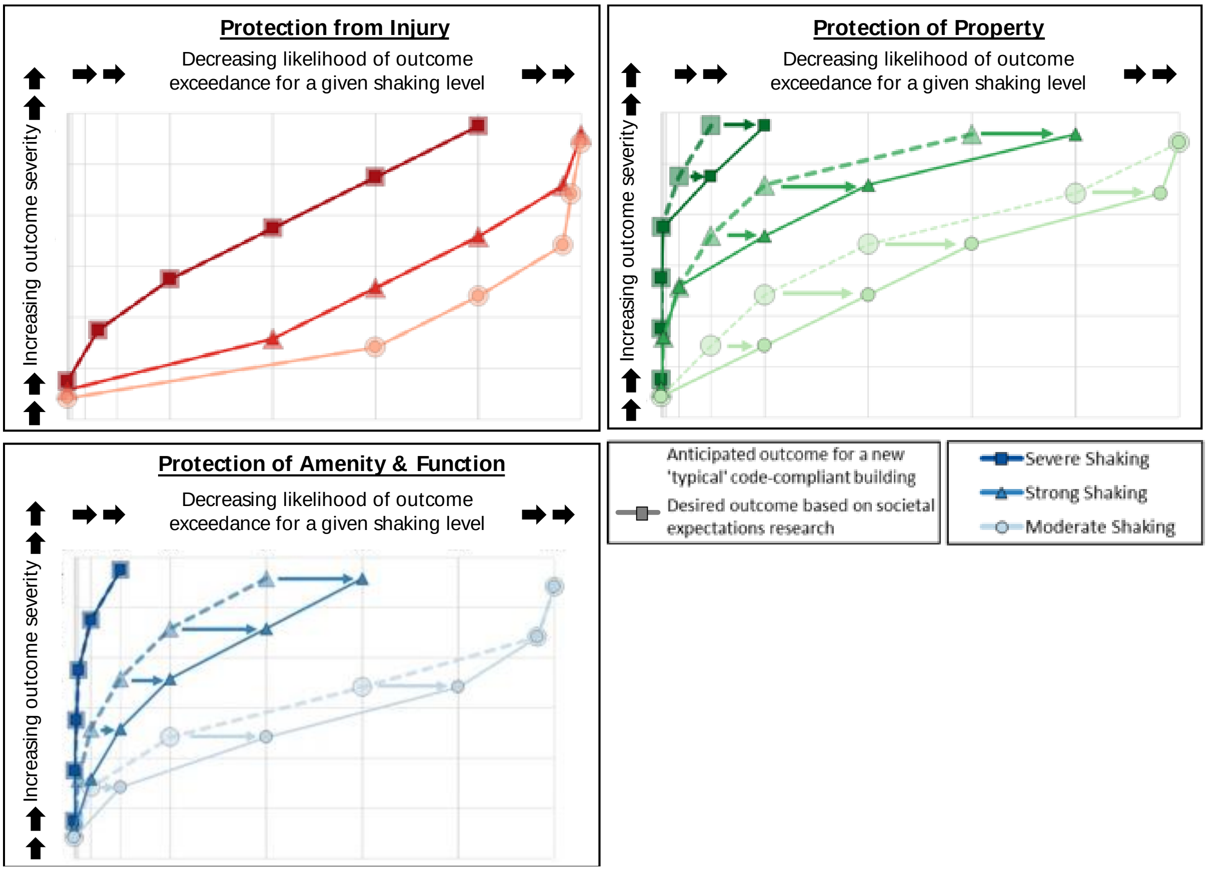


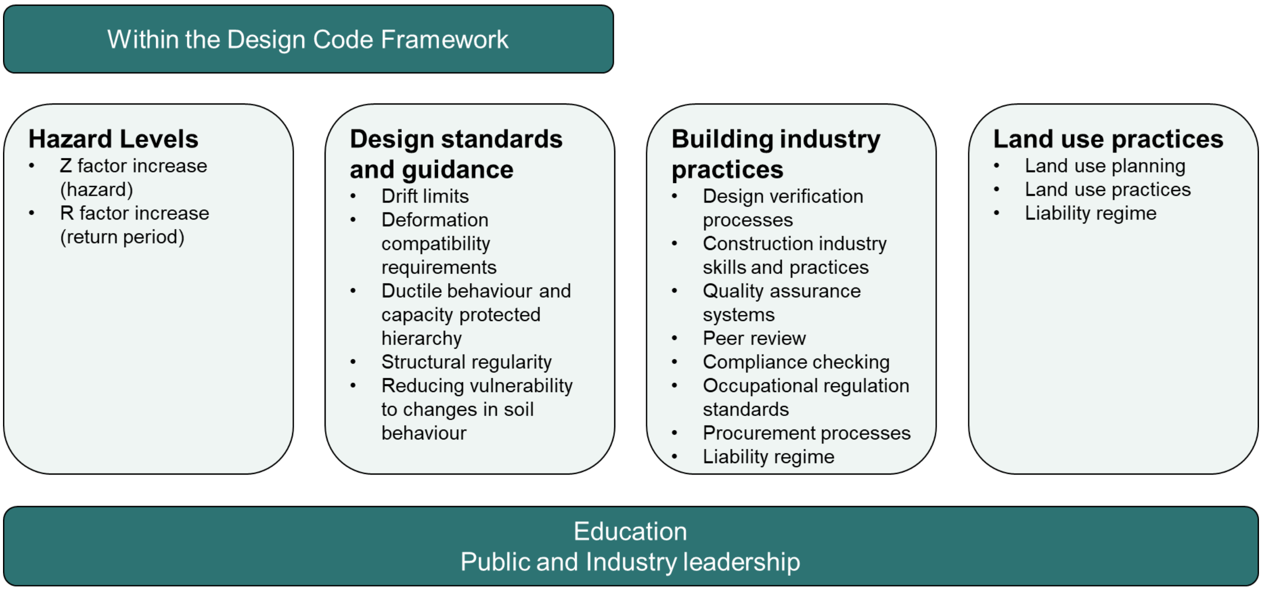
Figure E4. Loss exceedance curves, showing the anticipated and desired outcomes for a new 'typical' code-compliant building for each dimension of building performance.

- For *Protection from Injury*, the desired outcomes captured in the societal expectations research (i.e., relating to injuries and deaths) broadly align with the current Code requirements for the design and construction of structural and non-structural building elements.
- For *Protection of Property*, by contrast, the current Code provides less protection than the desired outcomes expressed in the societal expectations research. The research reflected that, without consideration of the costs of achieving higher seismic performance, people desire less social and economic disruption following moderate and strong earthquakes and are concerned about the environmental impacts of widespread building damage/demolition following a severe earthquake.
- For *Protection of Amenity and Function*, similarly, the desired outcomes captured in the societal expectations research relating to disruption, exceed what the current Code provides in moderate and strong shaking. People expect buildings to retain function or return to function much sooner than the current Code delivers.

This analysis indicates that if societal expectations are to be better met, protection of property, and amenity and function will need further consideration in the design and construction of new buildings than is currently the case, in addition to the current life safety focus.

Building System Scan

Much of Stage 3 focussed on tools and analyses around current Building Code settings as a mechanism for enhancing the resilience of New Zealand's building stock. However the project team identified there are other mechanisms that can and should be considered alongside a revision to the Building Code or preparation of guidance documents for the design of above code minima. Figure E5 summarises the range of mechanisms available to the sector to support design and construction of more resilient buildings.



Within the Design Code Framework

Hazard Levels
- Z factor increase (hazard)
- R factor increase (return period)

Design standards and guidance
- Drift limits
- Deformation compatibility requirements
- Ductile behaviour and capacity protected hierarchy
- Structural regularity
- Reducing vulnerability to changes in soil behaviour

Building industry practices
- Design verification processes
- Construction industry skills and practices
- Quality assurance systems
- Peer review
- Compliance checking
- Occupational regulation standards
- Procurement processes
- Liability regime

Land use practices
- Land use planning
- Land use practices
- Liability regime

Education
Public and Industry leadership

Figure E5. Opportunities identified to manage seismic risk in New Zealand

Cost Implications

In undertaking this work we have been conscious of concerns that improving building resilience will result in a significant increase in construction costs. While it was premature to explore the cost implications until more detailed proposals for enhancing seismic performance were developed, the project scope did include an exploration of the available evidence on the cost premium for constructing more resilient new buildings.

The available evidence suggests the cost premium for increasing the resilience of *new* buildings is not large (less than 2%), and the cost of some improvements is negligible. At first sight, this suggests that there is a case that there are highly cost-effective interventions that would improve new building resilience in New Zealand that need to be explored and developed further.

Conclusions

Our findings indicate a gap exists between what the current Building Code achieves and what is expected of it, particularly with respect to the protection of property and protection of amenity and function. The project also highlighted that there are a number of building usage groups that may benefit from enhanced seismic performance, beyond what is covered by current Importance Level settings.

The EPO Framework introduced here offers a tool to address these discrepancies by enabling consideration of outcome-focused design objectives that explicitly map to the different dimensions of building performance associated with damage and disruption in addition to life safety.

This EPO framework can be used to inform performance objectives in future design codes and guidelines. It can also be used to guide building owners and engineers when considering options to improve the resilience of individual buildings. The EPO framework, in particular the outcome indicators, could also be used to inform and evaluate other potential initiatives (e.g., changes to building industry practices and land use planning) to mitigate seismic risk and improve building performance.

Decisions on future seismic performance settings are beyond the scope of the Resilient Buildings Project. However, the project findings highlighted that New Zealanders would prefer buildings that sustained less earthquake damage and were able to retain function or return to function much sooner than the current Code delivers. It has also highlighted the opportunity for seismic settings to be better tailored to the specific performance needs of different building usages. The project has identified a range of opportunities for change both within design codes and outside (including building industry practices and land use planning) to improve seismic resilience of buildings.

Next Steps

The overarching purpose of the Resilient Buildings Project is to improve the overall seismic performance of new buildings in New Zealand. The aim is that by focussing on improving the resilience of new buildings the overall resilience of the built environment will be raised over time to the benefit of all New Zealanders.

The project was designed with a number of aligned initiatives in sight. The Resilient Buildings Project is currently informing the direction of the MBIE Seismic Risk Working Group in its considerations of future changes to design approaches. It is also informing the MBIE Low Damage Seismic Design Project, which aims to produce guidance documents for building owners and engineers considering and designing above code minimum buildings.

NZSEE has planned a number of immediate steps to socialise the project findings and advocate for change. These include creating a policy brief for wider dissemination and presenting at conferences. In addition, a workshop is recommended to align, coordinate, and plan future efforts towards improving seismic resilience. The focus of the workshop would be on exploring critical issues highlighted by the project, including risk tolerance settings and willingness to pay for reducing seismic risk in buildings, and how these may be addressed.

1. Introduction

1.1. A Decade of Disruption

New Zealand has experienced a decade of damaging seismic events. Since 2010 there has been a series of significant earthquakes, most significantly the 2010-2011 Canterbury earthquake sequence and the 2016 Kaikōura earthquake. Prior to this, it had been 70 years since any urban centres had been significantly affected by earthquakes. The impacts of mass casualties, massive costs of reconstruction, and slow complex recoveries with many unforeseen effects harmed communities with no prior lived experience of such trauma and disruption.[1]

Physical and psychological impacts have touched numerous families and neighbourhoods,[2345] while enormous financial costs of damage have been largely met by insurance markets and Government. It is increasingly apparent that risk transfer via insurance will continue only at a cost and availability that is driven by the underlying risks and their uncertainties. For decades New Zealand was relatively benign from an insurance perspective, but the recent earthquakes and dramatically rising losses due to severe weather events have caused global reinsurance markets and local insurers to update their views of New Zealand risk.[6]

The impacts of recent events have revealed the need for greater clarity of oversight, roles, and responsibilities for assessing and managing seismic risk,[7,8] and for administering the building regulatory framework and the performance expected of it.

Buildings typically span decades of use and may experience multiple earthquakes or repeated repurposing of function. Minimising the likelihood of death and injury in earthquake or fire has been a fundamental imperative for building design standards for over 50 years. However, there are other desirable performance outcomes that have gained prominence during recent years, including, for example, the ability to shelter in place in multi-storey residential buildings after a significant event, and the need to swiftly restore economic and social well-being and reduce waste.

---

[1] See for example: Parker M, Steenkamp D. (2012). The economic impact of the Canterbury earthquakes. Reserve Bank of New Zealand: Bulletin, 75 (3): 13-25; Royal commission report CERC, 2012 Canterbury Earthquakes Royal Commission Final Report; Environment Canterbury. (2013). *Natural Environment Recovery Programme for Greater Christchurch*, Whakaara Taiao (R13/68). Christchurch, New Zealand: Environment Canterbury; Potter SH, Becker JS, Johnston D, Rossiter KP (2015) An overview of the impacts of the 2010-2011 Canterbury earthquakes. *International Journal of Disaster Risk Reduction*; 14 (1): 6-14; Stevenson JR, Becker J, Cradock-Henry N, Johal S, Johnston D, Orchiston C, Seville E. (2017). Economic and social reconnaissance: Kaikōura earthquake 2016. Bulletin of the New Zealand Society for Earthquake Engineering; 50 (2): 343-351;
Fleisher S. (2019). Wellington City's emergency management response to the November 2016 Kaikoura earthquake. *Australasian Journal of Disaster and Trauma Studies*; 23 (2): 91-99.

[2] Johnston, D., Standring, S., Ronan, K. *et al.* The 2010/2011 Canterbury earthquakes: context and cause of injury. *Nat Hazards* 73, 627–637 (2014). https://doi.org/10.1007/s11069-014-1094-7.

[3] Beaglehole B, Boden JM, Bell C, Mulder RT, Dhakal B, Horwood LJ. The long-term impacts of the Canterbury earthquakes on the mental health of the Christchurch Health and Development Study cohort. Australian & New Zealand Journal of Psychiatry. 2022;0(0). doi:10.1177/00048674221138499.

[4] Martin J. Dorahy & Lee Kannis-Dymand (2012) Psychological Distress Following the 2010 Christchurch Earthquake: A Community Assessment of Two Differentially Affected Suburbs, Journal of Loss and Trauma, 17:3, 203-217, DOI: 10.1080/15325024.2011.616737.

[5] Heetkamp, T., & De Terte, I. (2015). PTSD and resilience in adolescents after New Zealand earthquakes. *New Zealand Journal of Psychology*, *44*(1), 32. https://www.psychology.org.nz/journal-archive/NZJP-Volume-44-No-1-2015.pdf#page=31.

[6] https://www.stuff.co.nz/business/95119148/german-reinsurer-munich-re-warns-quake-insurance-could-be-hard-to-find.

[7] https://canterbury.royalcommission.govt.nz/.

[8] https://dpmc.govt.nz/sites/default/files/2021–01/report-of-the-public-inquiry-into-the-earthquake-commission.pdf.

1.2. Rethinking Seismic Performance

The seismic provisions of the current New Zealand Building Code have evolved from standards first introduced in the 1930s, after building damage caused multiple fatalities in historical earthquakes in Napier and Hastings. The New Zealand Code, like those of many seismically active countries, focuses on building performance that minimises injuries and preserves life during earthquakes. Over the last decade of earthquakes, code-compliant buildings generally met these objectives for life safety. However seismic damage often prevented the reoccupation of buildings causing lengthy delays in the resumption of normal building functions.

Knowledge of seismic hazard in New Zealand has advanced significantly from scientific research and the establishment of GeoNet in the early 2000s, and from damaging earthquakes locally and worldwide. The potential scale and frequency of earthquake shaking across much of the country are now understood to be higher than previously thought.[9] New Zealand's strong legacy of earthquake engineering design can mitigate those threats to life safety if applied consistently,[10] but the urban landscape has also been changing with more multi-storey development, in-fill housing, and growing pressures to extend development onto land where drainage and site instability can amplify building vulnerabilities to shaking and other hazards.[11] In parallel, communities and their experiences of, and expectations for, disruption following seismic events is changing.

The recent seismic events and related learning in New Zealand have provided strong drivers to redevelop the current approach, considering the perspective and expectations of building users. The Canterbury Earthquakes Royal Commission of inquiry (2012) recommended that the treatment of seismic risk in building standards should be reviewed to ensure that current knowledge of seismic hazard and risk are harmonised with societal expectations of building performance in earthquakes. These recommendations are mirrored by Tanner et al (2020) who proposed that understanding societal expectations of building performance at the community as well as at the individual building level should be reflected in the objectives of seismic codes and standards.

An overview of the current building control system in New Zealand is provided in Appendix A.

1.3. The Resilient Buildings Project

The Resilient Buildings Project (RBP) was set up in response to these observations and recommendations. A NZSEE initiative, funded by Toka Tū Ake EQC, the Resilient Buildings Project was set up to gather evidence of contemporary expectations concerning the seismic performance of buildings, and to develop a framework to enable those expectations to be translated into what this means for building level performance outcomes. The immediate aim of the RBP is to inform future revisions of codes and technical standards. The overarching purpose of the RBP is to undertake activities and research that will ultimately improve the seismic performance of new buildings.

---

[9] National Seismic Hazard Model Revision Project Assurance and 'Lessons' Review. https://nshm-static-reports.gns.cri.nz/NSHM/ScienceReports/NSHM%20Project%20Assurance_FINAL%20DRAFT_28Jul22.pdf

[10] https://www.nzsee.org.nz/db/PUBS/Earthquake-Design-for-Uncertainty-Advisory_Rev1_August-2022-NZSEE-SESOC-NZGS.pdf.

[11] Analysis of local government plan changes resulting from the Medium Density Residential Standards and the National Policy Statement on Urban Development. EQC Resilience Report published 2020.

Stage 1 of the RBP focussed on establishing the need and vision for the project. Stage 2 aimed to understand New Zealand building users' expectations for the seismic performance of buildings. The aim of Stage 3 (the focus of this report) was to develop a way to relate user expectations to building performance outcomes in a manner that can support the subsequent development of building performance objectives and design approaches. Stage 3 also aimed to undertake some enabling work around pathways to improved resilience.

Stage 3 set out to achieve the following specific objectives:

- To evaluate and triangulate the Stage 2 Societal Expectations research (though expert evaluation and third party research) identifying gaps and inconsistencies where they exist.
- To develop a framework for mapping societal expectations (at a community level) to performance outcomes (at a building level).
- To develop a system for grouping building usage based on desired performance outcomes.
- To explore the gap between the expectations for building seismic performance captured in Stage 2 with the outcomes delivered by the current Code.
- To undertake enabling works to understand the range of levers available to build resilience in our building stock.
- To explore current evidence on the potential cost implications of enhancing the resilience of our building stock.

Stage 3 of the RBP is designed with a number of aligned initiatives in sight. The RBP will inform a review of current Building Code clauses and seismic risk settings, being undertaken by MBIE and the Seismic Risk Working Group, to ensure they articulate societal expectations and are reflected in the Building Act.[12][13] The RBP will also inform the ongoing production of engineering design guidance documents; for example, performance frameworks to guide building owners and engineers in the setting of performance objectives for the design of above-code minimum buildings, such as the MBIE Low Damage Seismic Design project.

1.4. Stage 3 Approach

Stage 3 of the Resilient Buildings project was based around a series of expert workshops (Appendix B) and collaborative development of analysis and outputs, predominantly involving the project team. The project team included members selected for different skill sets and experience, including social science, structural engineering practice, research and code writing, economics, insurance, risk governance and public policy (refer Table 1). Where necessary, periodic engagement with other subject matter experts and larger groups of external researchers and practitioners was undertaken to augment the analysis (refer Table 2).

---

[12] While Stage 2 of the RBP collected data on societal expectations and we have used this data to inform Stage 3, it is the Building Code development process that will contemplate the extent to which the expectations collected translate into minimum code settings. This will include consideration of cost implications and policy efficacy.

[13] Ministry of Business Innovation and Employment (2020) Seismic Risk and Building Regulation in New Zealand, Findings of the Seismic Risk Working Group. New Zealand Government, Wellington. 50pp.

Table 1 Project team members

Project Team Member	**Area of Expertise**
Shannon Abeling	Engineering Research
Sarah Beaven	Social Science Research
Charlotte Brown	Social Science Research
Dave Brunsdon	Engineering Practice and Recovery Management
Hugh Cowan	Insurance, Risk governance
Caleb Dunne	Policy
Ken Elwood	Engineering Research
Helen Ferner	Engineering Practice
Derek Gill	Economics, Policy
John Hare	Engineering Practice
Rob Jury	Engineering Practice, Building Code writing

Table 2 Additional subject matter experts

Subject Matter Experts	**Area of Expertise**
Mike Stannard	Performance-based regulatory systems and seismic risk settings
Pam Johnston	Land use planning
Tal Sharrock-Crimp	Economic analysis
Kay Saville-Smith	Urban development
Michael Bealing	Economic analysis

A significant aspect of Stage 3 is the application of an expert overlay on the findings from the societal expectations. Stage 3 aimed to develop a way to relate user expectations for the seismic performance of buildings (collected in Stage 2) to building level performance outcomes in a manner that can support the subsequent development of building performance objectives and design approaches. As such this process involves a considerable degree of interpretation. The professional judgment intrinsic to this work is differentiated in the report from the views of original respondents and we have aimed to uphold throughout this work the following key principles of systems analysis:[14]

- Principle of Requisite Detail – there is a minimum level of detail in a (system) model for adequately emulating the reality which is intended to be modelled. Do not over-simplify the assessment to the extent that what is being modelled is not captured.
- Principle of Decision Invariance – the system should be sufficiently detailed so that the addition of further refinement will not affect the decision. There is no value in making the

---

[14] Hare, J. (2021) Our use of engineering models. SESOC Conference, Hamilton 5-6 July 2021. 11 pp. And references therein.

model more complicated or comprehensive if the additional detail makes no difference to the outcome; or obscures the outcome.

- Principle of Consistent Crudeness – the choice of the level of detail of the parts of an engineering system must, to some extent, be governed by the crudest part of the system.[15]

For a more detailed description on the project approach and structure, please refer to Appendix B. Appendix B also includes details of a range of engagement activities and workshops with the wider engineering and disaster research community in New Zealand and internationally.

1.5. Report Overview

This report focuses on the activities undertaken in Stage 3 of the Resilient Buildings Project. The report is laid out as follows:

Section 2:	Provides a summary of societal expectations research.
Section 3:	Describes the Earthquake Performance Outcome (EPO) framework which maps societal outcome indicators with dimensions of building performance.
Section 4:	Provides a building usage and categorisation system to support development of performance objectives.
Section 5:	Evaluates whether the current Code matches the societal expectations collected in Stage 2, using the EPO framework.
Section 6:	Explores the possible mechanisms and levers in the building system for enhancing the resilience of our building stock.
Section 7:	Provides an overview of the cost implications of improving resilience of our buildings.
Section 8:	Outlines the overall conclusions and next steps.
Section 9:	Project glossary.

---

[15] Our approach has focused effort on identifying the variable(s) most important to achieving desired outcomes and impacts, mindful that refining knowledge of a single variable in a problem where other lesser-known variables may have equal influence would be of little value.

2. Stage 2: Societal Expectations Research

In 2021, the Resilient Buildings Project conducted interviews and convened geographically based focus groups to understand societal views on seismic risk in New Zealand. The research involved 59 individuals and a total of 140 hours of face-to-face engagement. Participants were deliberately chosen to span and represent a range of building user groups, industries, and interests; public and private sector; rural and urban context; low and high seismic hazard zones.

The aim of the research was to understand how performance expectations for buildings change based on building use and geographical context, how and why risk tolerance varies across different community settings, and the importance of seismic risk relative to other demands on the built environment. The research focussed on understanding societal expectations for the relative performance of buildings across building types within a community. The work did not explicitly explore trade-offs required (including willingness to pay) for increased seismic performance at building level.[16]

The findings[17] showed that risk perceptions and building performance expectations are diverse, but life safety remains of central importance in our built environment.[18] In particular, the work highlighted a strong desire to ensure protection of vulnerable persons.[19]

Participants also emphasised the need to focus on reducing disruption through the swift restoration of economic and social wellbeing as well as the reduction of environmental impacts associated with earthquake damage (Figure 1). For example, social recovery following an earthquake would be supported through return to service of buildings that enable equitable access to essential goods and services, sustain social connection,[20] and restore normalcy and cultural identity.

---

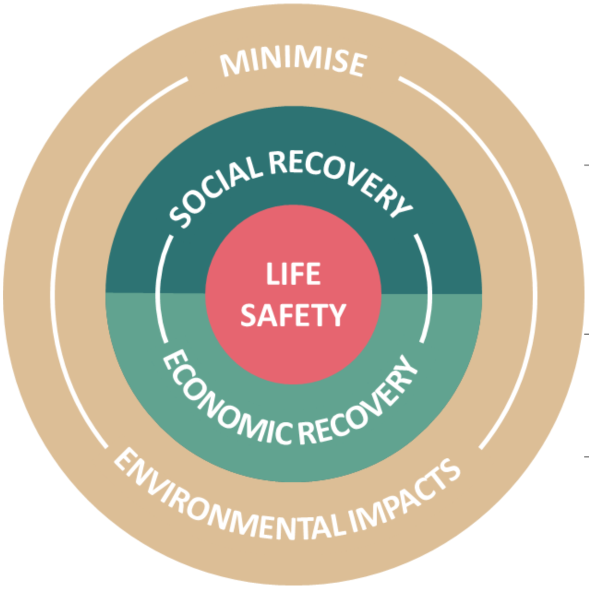
[16] Willingness to pay and other trade-off considerations require specific information about costs and options to achieve desired performance. This work will have to be undertaken in subsequent work.

[17] The findings of the societal expectations research were published in a main report, with two complimentary data reports.
Main Report: https://www.nzsee.org.nz/db/PUBS/RBP_SocietalExpectationsReport-FINAL-for-Release.pdf
Focus Group Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Focus-Group-Report-final.pdf
Interviews Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Interviews-Report-FINAL.pdf.

[18] This is consistent with research that shows that earthquake safety is a key influencer in rental and purchase decisions of residential apartments. Blake,D.; Becker,J. S.; Hodgetts, D.; Elwood, K.J. The Impact of Earthquakes on Apartment Owners and Renters in Te Whanganui-a-Tara (Wellington) Aotearoa New Zealand. *Appl. Sci.* **2021**,*11*,6818. doi.org/10.3390/app11156818.

[19] Research is underway in New Zealand to develop an Earthquake Casualty Model for New Zealand. The research will look at the key drivers for earthquake injury and fatality. See for example, Horspool, N., Elwood, K., Johnston, D., Ardagh, M. (2020). Factors influencing casualty risk in the 14th November 2016 Mw7.8 Kaikōura, New Zealand earthquake. International Journal of Disaster Risk Reduction. Vol51, 2020, 101917, ISSN 2212-4209, doi.org/10.1016/j.ijdrr.2020.101917.

[20] International research shows the importance of social capital to support disaster recovery. For example, see Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. American Behavioral Scientist, 59(2), 254–269, doi.org/10.1177/0002764214550299.



1: LIFE SAFETY

Avoid mass casualty events
Protect vulnerable persons
Ensure safety at mass gathering points
Preserve high value skills and resources
Support immediate response activities

2: SOCIAL RECOVERY

Ensure equitable access to essential goods and services
Enable effective governance
Have plans to connect
Return a sense of normalcy
Retain a sense of place and cultural identity

3: ECONOMIC RECOVERY

Restore enabling services and industries
Enable people to work
Build business confidence

4: MINIMISE ENVIRONMENTAL IMPACT

Minimise waste generation
Avoid hazardous waste or potential public health risks
Reduce embodied carbon

Figure 1 Priorities for the seismic performance of buildings from the 2021/22 societal expectations research.

Both expectations for performance (at building level) and tolerance to damage and disruption (at community level) were explored during the research. The research highlighted that risk tolerance is highly context dependent: depending on the risk owner, trade-offs between costs and benefits and also the geographic and community context. While the inquiry into tolerable risk levels has informed Stage 3, the analysis in this report is predominantly based on the generalisable societal expectations explored in the research. In particular, we focus on interpreting and translating the causal relationships between disruption to buildings and community impact and the relative importance of different building types and functions.

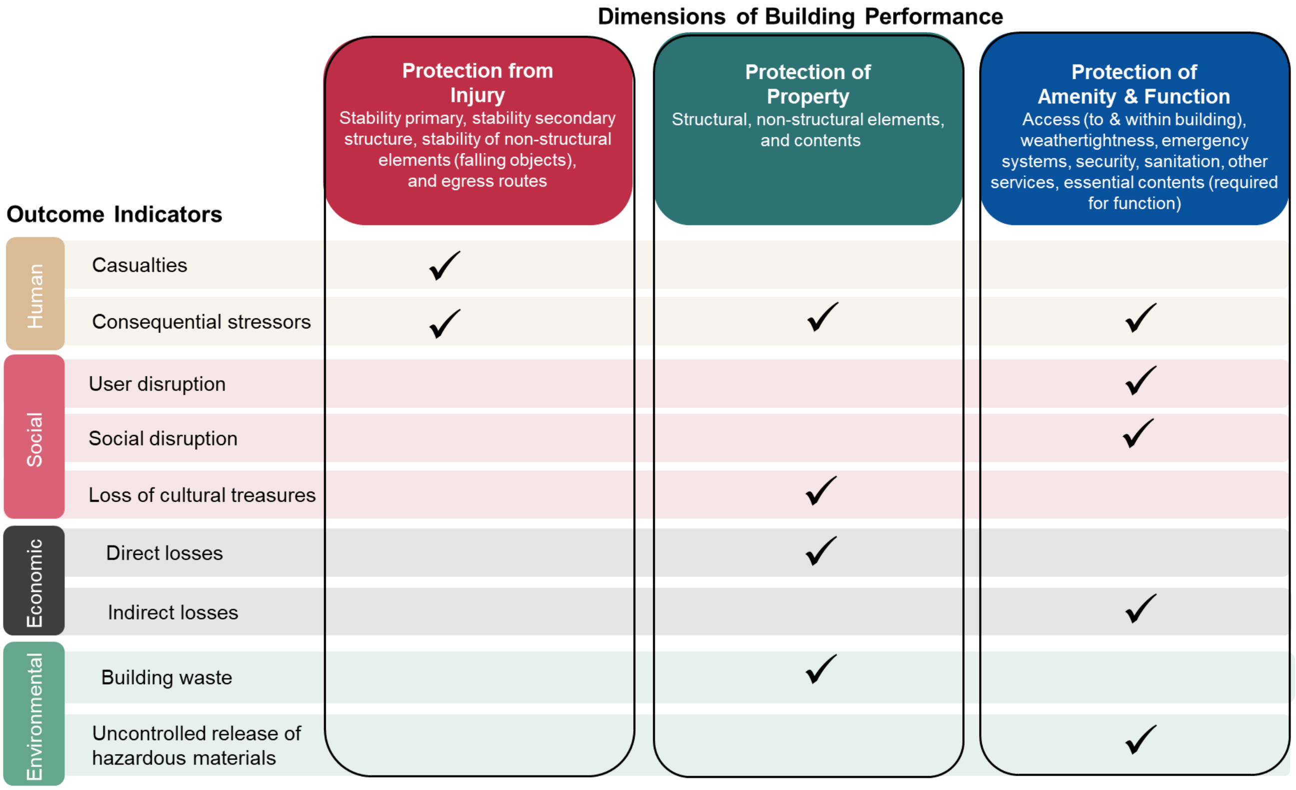
Like all social norms, expectations are dynamic and change in response to broader social trends and events. The research findings represent a snapshot of societal expectations at the time the data was gathered. To make the research findings as enduring as possible the focus of the societal expectations research was on gathering a diverse range of perspectives to understand how expectations are formed and the relative expectations across individuals and communities. Despite best efforts, we are aware that some perspectives are not well represented (for example, Māori perspectives) and some elements important to risk tolerance discussions were not explicitly addressed (for example, willingness to pay). These limitations have been acknowledged and/or accounted for where applicable in the analysis in this report.

Key findings from the societal expectations research related to the dimensions of building performance and associated consequences are summarised in Appendix C and D.

3. The Earthquake Performance Outcome Framework

3.1. EPO Framework in a Nutshell

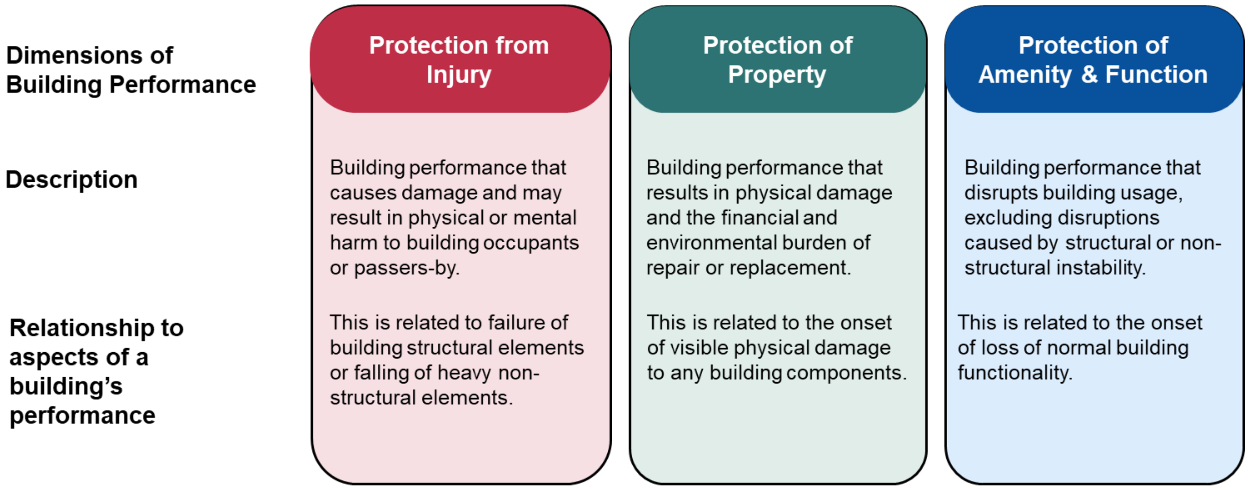
The Resilient Buildings Project set out to describe the consequences associated with the seismic performance of buildings that are both specific to building users' needs and meaningful to decision-makers. The Earthquake Performance Outcomes (EPO) framework, developed by the Project team through a series of workshops, establishes a systematic way to map building performance to building user outcomes. The EPO framework, as shown in Figure 2, comprises a set of outcome indicators that describe the effects that building performance can have on building users and the community following an earthquake. These outcome indicators are grouped into human, social, economic and environmental wellbeing categories. The outcome indicators are then mapped to three dimensions of building performance relevant to earthquake shaking: protection from injury, protection of property, and protection of amenity and function. As shown in Figure 3, the dimensions of building performance relate to failure of building structural elements, onset of visible physical damage, and onset of loss of normal function, respectively.



Dimensions of Building Performance

	Outcome Indicators	**Protection from Injury** Stability primary, stability secondary structure, stability of non-structural elements (falling objects), and egress routes	**Protection of Property** Structural, non-structural elements, and contents	**Protection of Amenity & Function** Access (to & within building), weathertightness, emergency systems, security, sanitation, other services, essential contents (required for function)
Human	Casualties	✓		
	Consequential stressors	✓	✓	✓
Social	User disruption			✓
	Social disruption			✓
	Loss of cultural treasures		✓	
Economic	Direct losses		✓	
	Indirect losses			✓
Environmental	Building waste		✓	
	Uncontrolled release of hazardous materials			✓

Figure 2 EPO framework



Dimensions of Building Performance	Protection from Injury	Protection of Property	Protection of Amenity & Function
Description	Building performance that causes damage and may result in physical or mental harm to building occupants or passers-by.	Building performance that results in physical damage and the financial and environmental burden of repair or replacement.	Building performance that disrupts building usage, excluding disruptions caused by structural or non-structural instability.
Relationship to aspects of a building's performance	This is related to failure of building structural elements or falling of heavy non-structural elements.	This is related to the onset of visible physical damage to any building components.	This is related to the onset of loss of normal building functionality.

Figure 3 Dimensions of Building Performance

The framework has been designed to be agnostic to building type and usage. It can be applied to all types of residential and commercial properties, from single family homes to multi-storey developments. The intention being that the framework can be used to set performance objectives relevant to a given building or building type, with a clear value chain evident between a performance objective and desired societal outcomes.

The dimensions of building performance are mapped back to the outcome indicators where there is the strongest, most direct, causal relationship. For example, if a building contains important cultural treasures, then *Protection of Property* will be important. Another example, if a building's function has a high value to the community, such as a school, then interventions that enable *Protection of Amenity and Function* will reduce *Social disruption*. In this latter example, while the building is damaged (and there is property loss) it is the loss of function not the direct damage that users of a school will be affected by. Therefore, *Protection of Amenity & Function,* rather than *Protection of Property*, is mapped back to *User disruption* and *Social disruption.*

The EPO framework provides a mechanism to relate societal expectations to building seismic performance. The primary purpose of the framework is to help decision-makers identify ways to develop targeted interventions that improve the seismic resilience of buildings. It has been developed to be a tool that is comprehensive and flexible enough to be interpreted by writers of codes, standards, and guidelines as well as by people designing individual buildings of any use.

The EPO framework has a range of features and attributes, including that it:

- identifies the range outcome indicators important to contemporary New Zealanders,
- identifies and considers three distinct and separate dimensions of building performance,
- indicates how broad outcome indicators may be related to different dimensions of building performance, helping to link building standards with the community they serve,
- is applicable for all building types and usages including emergent building types,
- allows flexibility for setting different objectives for different building types and usages, depending on the outcome indicators relevant to that building type,
- is outcome focussed and does not prescribe how outcomes are achieved, thus allowing flexibility of design approaches, and
- can support deliberations around code and building standard changes as well as discussions between building owners and designers about the desired performance objectives for a proposed building.

Further details on the framework are provided in the following sections and in Appendix E, F and G.

3.2. EPO Framework Development

The societal expectations research highlighted the key impacts of building disruption on building users and the community. The research also explored the causal relationships between damage and loss of function of buildings on those broader impacts. Because the societal expectations were often articulated at the community level, the contributing performance of *individual buildings* had to be inferred from generalised expectations of outcomes. Expert workshops with the project team were used to support the translation between the societal expectations research and building performance. Where judgments on societal expectations extend beyond the direct findings of the research and reflect expert opinions, they are noted as such to avoid conflation of the data published separately.

When translating the societal expectations research to building performance outcomes for new buildings, the RBP has focused on exploring consequences that are site-specific (i.e., at the individual building level) but that, on aggregation, have community-level impacts. Community resilience is a product of the design (and performance) of individual buildings over decades because buildings are planned, financed, and constructed by different owners at different times.

Building codes implicitly recognise that impacts at a community level will, in large part, be mitigated through the design of individual buildings and lifeline infrastructure systems to support resilience.[21] Additionally, achieving outcomes at a societal level must rely on dependencies among many aspects of the built environment.[22] Opportunities for enhancing resilience through consideration of risk and performance at a community level (e.g., considering urban density, community risk factors,[23] etc.) also need to be considered but are outside the scope of this work.

Figure 4 illustrates the intervention logic that was used to develop the EPO Framework.

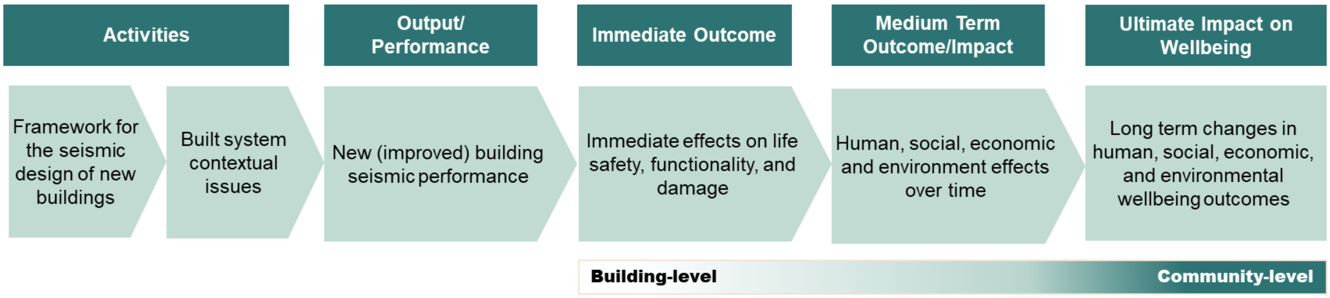


Figure 4 Intervention logic for the EPO framework

---

[21] Considering performance at the individual building level to improve community resilience is also the approach proposed in the NIST-FEMA Special Publication FEMA P-2090/NIST SP-1254 *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (available at https://doi.org/10.6028/NIST.SP.1254).

[22] These dependencies are complex. Expected recovery timeframes for infrastructure services has been identified by NIST-FEMA as a significant challenge in their work toward functional recovery. NIST-FEMA (2021). Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time, NIST_FMEA Special Publication FEMA P-2090/NIST SP-1254/January 2021.

[23] There is a range of recent research looking at how community context affects decisions about seismic performance. For example Hoang et al. (2021) identified proximity to roads and built-up areas an important factor in prioritisation of seismic retrofitting of buildings. Hoang, T., Noy, I., Filippova, O., and Elwood K., (2021), Prioritising earthquake retrofitting in Wellington, New Zealand. *Disasters,* 2021, 45(4): 968–995.

The following definitions have been adopted:

Impacts:	Broad long-term effects on wellbeing. Impacts are typically location-specific and evaluated at the community level.
Outcomes:	Specific short-to-medium-term effects on wellbeing. Outcomes are typically site-specific and evaluated within the individual building footprint.
Indicator:	An observable criterion that describes, measures, or otherwise summarises an effect.[24] Indicators may be direct (e.g., shaking damage) or consequential (e.g., the casualties that may result from the damage).

The terms ‘outcome’ and ‘impact’ are often used interchangeably – different sources use the terms in opposite ways. For the purposes of this framework, outcome refers to the specific short-to-medium-term effects, measured within the building footprint, and impact refers to broader long-term direct and indirect effects on wellbeing (beyond the building footprint).

Long-term, community-level impacts such as urban degeneration, fluctuations in GDP, and long-term environmental impacts are beyond the scope of the performance outcome framework. A brief discussion on impact indicators, which are measured at the community level, is provided in Appendix E.

3.3. Outcome Indicators

The consequences of seismic performance described in the EPO framework are referred to as outcome indicators. Outcome indicators can be direct or indirect and span both immediate outcomes and longer-term impacts.

Direct outcomes are consequences apparent immediately, or shortly after, the earthquake occurs and can be linked unambiguously to building damage.

Indirect outcomes are secondary effects that are often a result of a direct outcome. For example, a building that functions as a retail store may have structural damage that makes it unsafe to occupy. This will result in the direct outcome of user disruption, while the business is unable to operate from the premises. An indirect outcome would be the financial losses that the business incurs while not operating.

Outcomes and impacts have been categorised by Community Wellbeing.[25] For the purposes of this project, community wellbeing has four categories:

- **Human** wellbeing includes people’s physical and mental health.
- **Social** wellbeing involves capabilities and capacity of people to engage in work, study, recreation, and social activities. It includes the norms, rules, and institutions that influence the way in which people live and work together and experience a sense of belonging. Includes trust, reciprocity, the rule of law, cultural and community identity, traditions and customs, common values, and interests.

---

[24] Kay, E., Stevenson, J., Bowie, C., Ivory, V., & Vargo, J. (2019). The Resilience Warrant of Fitness Research Programme: Towards a method for applying the New Zealand Resilience Index in a regional context. (https://resiliencechallenge.nz/wp-content/uploads/NZRI_Regional_Applications_Research_Report_June_2019.pdf).

[25] For the purposes of this assessment, the wellbeing definitions are based on the Taituarā community wellbeings (https://taituara.org.nz/Article?Action=View&Article_id=216), with some influence from the Treasury Higher Living Standards Framework (www.treasury.govt.nz/information-and-services/nz-economy/higher-living-standards/our-living-standards-framework).

- **Economic** wellbeing includes physical assets, usually closely associated with supporting material living conditions; includes building, equipment, and infrastructure damage and the loss of income/productivity associated with damage to these. The employment and wealth necessary to provide many of the requirements that make for social wellbeing, such as health, financial security, and equity of opportunity.
- **Environmental** wellbeing involves all aspects of the natural environment needed to support life and human activity, including air quality, land, soil, water, plants and animals, minerals, and energy resources.

The scope of the outcomes, and the outcome indicators developed, were informed by the Stage 2 Societal Expectations research. The Project team collated and categorised the core and most impactful concepts emerging from the research. The outcome indicators defined for this framework are summarised in the subsections below. Further commentary is provided in Appendix E.

3.3.1. Human Outcomes

The outcome indicators related to human wellbeing are *casualties* and *consequential stressors*.

Casualties is a direct outcome that is measured in the number of deaths or injuries that result from the failure of structural and non-structural elements.

Consequential stressors are broad indicators intended to capture the indirect effects that building owners and users experience because of their experience during earthquake shaking, the damage that the building sustains, loss of amenity and function in their buildings, and the stress of the recovery process. Consequential stressors are measured by the number of people affected as well as the acuteness and duration of the stressor.

3.3.2. Social Outcomes

The outcome indicators related to social wellbeing are *user disruption*, *social disruption*, and *loss of cultural treasures*.

User disruption is a direct outcome and is defined as the inability to use a building for its intended function following an earthquake due to building damage. Here we are considering only damage within the building footprint because this may be influenced by design, whereas wider (neighbourhood) disruption is not. The severity of user disruption is measured as the extent and duration of disruption to building use.

Social disruption is a broad indicator that is intended to assess the indirect effects that damage to an individual building has on the surrounding community. The severity of social disruption is measured by the extent and duration of the disruption on the community and will be influenced by how significant the building is to the community.

Loss of cultural treasures is a direct outcome and reflects a desire expressed by the social research participants to protect cultural assets (buildings or contents) in order to preserve cultural identity and maintain a sense of place in their communities. The severity of a loss of cultural treasure is measured by the extent of damage to the asset and whether it can be repaired or replaced.

3.3.3. Economic Outcomes

The outcome indicators related to economic wellbeing are *direct losses* and *indirect losses*.

Direct losses are the financial costs associated with the repair and/or replacement of building elements and contents damaged in an earthquake. It is measured in dollars.

Indirect losses are the consequential financial losses associated with disruptions to building use. This could include loss of income due to business interruption during repair work or expenses incurred renting a property while repairs are being undertaken or loss of market position. Indirect losses are measured in dollars.

3.3.4. Environmental Outcomes

The outcome indicators related to environmental wellbeing include the *uncontrolled release of hazardous materials, building waste* from demolition or debris from damage, and the *operational and embodied carbon* required to repair and rebuild structures.

Building waste is a direct outcome indicator that is measured by the amount and nature of building debris that will be sent to a landfill during the repair or replacement process. It is a proxy for the operational and embodied carbon[26] required to repair or rebuild structures though we did not attempt to measure this for the purposes of this Project.

Uncontrolled release of hazardous materials is a direct outcome indicator associated with the toxicity and scale of pollution and the longevity of its impact on human health and the environment.

3.4. Dimensions of Building Performance

'Dimensions of building performance,' describe the critical aspects of seismic building performance. Dimensions of building performance *are not* performance objectives; they are simply a way to categorise different elements of building performance.

The three dimensions of building performance were developed through a workshop process with the Project team. The dimensions of building performance relevant to earthquake shaking in the EPO framework are:

- **Protection from Injury**: building performance that causes damage and may result in physical or mental harm to building occupants or passers-by. This is related to failure of building structural elements or falling of heavy non-structural elements.
- **Protection of Property**: building performance that results in physical damage and the financial and environmental burden of repair and replacement. This is related to the onset of visible physical damage to any building components.
- **Protection of Amenity & Function**: building performance that disrupts building usage, excluding disruptions caused by structural and non-structural instability. This is related to the onset of loss of normal building functionality.

There are summarised in Figure 3.

The purpose of categorising building performance into these three dimensions is to assist code writers, building designers, and users in identifying the performance aspects most important to achieving desired performance outcomes.

---

[26] Gonzalez RE, Stephens MT, Toma C, Dowdell D. The Estimated Carbon Cost of Concrete Building Demolitions following the Canterbury Earthquake Sequence. *Earthquake Spectra*. 2022;38(3):1615-1635. doi:10.1177/87552930221082684.

This is a shift from current Code, which focuses primarily on life safety and considers amenity and functionality but only at very low levels of earthquake shaking. Figure 5 illustrates how the dimensions of building performance map to the current Building Code.

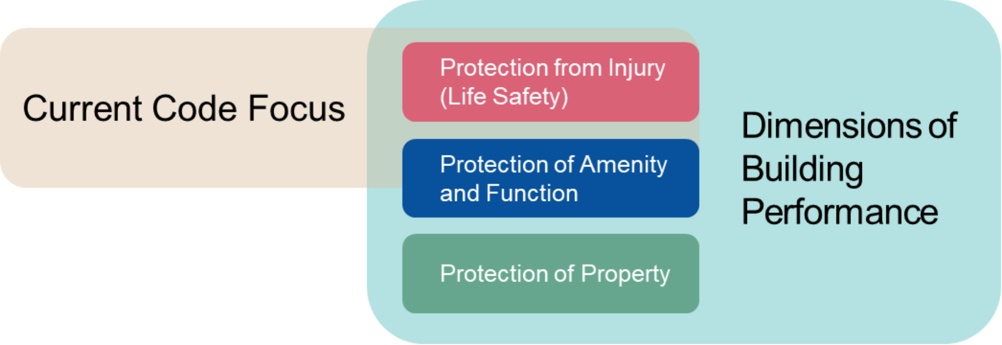


Figure 5 Proposed dimensions of building performance relative to current Building Code focus

To enable implementation of the EPO framework and the establishment of performance objectives, the dimensions of building performance have been further broken down into performance indicators.

The performance indicators for protection from injury include (1) stability of the primary structure, (2) stability of the secondary structure, (3) stability of non-structural elements that present a falling hazard, and (4) maintenance of egress routes.

The performance indicators for protection of property include (1) damage to structural elements, (2) damage to non-structural elements, and (3) damage to contents.

The performance indicators for protection of amenity and function include maintenance or protection of (1) access to the building, (2) accessibility within the building, (3) weather tightness, (4) emergency systems, (5) security systems, (6) sanitation, (7) other building services and (8) contents that are required for function.

Performance indicators for each dimension of building performance are intended to be considered independently, as the performance targets will likely vary between the different dimensions.

The proposed indicators are intended to be used to help identity critical building attributes for each dimension of building performance, agnostic of building type and usage. We recognise that buildings comprise complex systems and it may initially appear there is overlap between some of the proposed indicators and the dimensions of building performance. The indicators have been related to the most directly relevant aspect of a building's performance where the onset of loss / failure of this indicator is first relevant. That is from onset of any physical damage (protection of property), onset of loss of normal building functionality (protection of amenity and function) or structural failure (protection from injury).

The indicator groupings are informed by New Zealand's approach to seismic design whereby buildings are expected to suffer initial damage at lower levels of shaking than would cause loss of building functionality. Building damage that may result in personal harm (life safety) will occur at significantly higher levels of earthquake shaking again. For example, damage to any of the building elements (protection of property) may be expected occur at relatively low levels of earthquake shaking compared with loss of stability of the structure (protection from injury). In specialised settings like hospitals and research labs, (e.g., a sterile or negative pressure environment), the requirements may span several dimensions of performance.

As performance objectives for individual building types are developed, greater emphasis may be placed on some performance indicators than others. For example, when considering protection of amenity and function after a major earthquake, secure facilities such as banks will likely prioritise security above all else, whereas large apartment complexes may prioritise sanitation to ensure the building remains occupiable. This is further discussed in Section 4.1.

The notion of ‘repairability’ is a metric sometimes associated with building performance. Under the proposed framework, ease and cost of repair is viewed as a design consideration made when determining how to meet desired performance outcomes. In the EPO framework, repairability (or time, cost and disruption due to repair) is considered when looking at the continuum of desired outcomes for *Protection of Property* and *Protection of Amenity and Function*.

Refer to Appendix F for further explanation of the dimensions of building performance and definitions of the performance indicators.

Mapping Dimensions of Performance to New Zealand’s Current Building Design Settings

New Zealand’s approach to seismic building design has developed over more than 50 years with a focus on elastic deformation at lower levels of shaking and utilizing ductility in key structural elements at higher levels of earthquake shaking to prevent sudden building failure. The current New Zealand building standard reflects these principles by incorporating three design points; an ultimate limit state (ULS) and two serviceability limit states (SLS1 repair not required and SLS2 operational continuity maintained), Standards New Zealand (2004).[27] However, the primary focus is on life safety with amenity and functionality performance only mandated at very low levels of earthquake shaking (SLS1) and for a narrow range of buildings, those such as hospitals and emergency services required in the immediate post disaster environment (SLS2), Standards New Zealand (2002).[28]

Despite the EPO framework being designed independent of the constraints or approach of the current Code, the project team recognise the connections evident between the three design points outlined above, and the dimensions of building performance in the EPO framework.

Refer to Appendix A for more information on the current New Zealand Building Code settings.

---

[27] Standards New Zealand (2004). *NZS1170.5 Supp1:2004 Structural design actions Part 5: Earthquake actions – New Zealand – Commentary*, Wellington, New Zealand: Standards New Zealand.

[28] Standards New Zealand (2002). *NZS 1170.0:2002 Structural Design Actions. Part 0: General Principles.* Wellington, New Zealand: Standards New Zealand.

3.5. Evaluating Dimensions of Building Performance

To enable the evaluation of intervention options and support the eventual establishment of performance objectives it is necessary to define scales to evaluate outcome severity for each dimension of building performance. By mapping outcomes against likelihood of exceedance over a range of different shaking levels, interventions can be evaluated and the overall impact on outcomes (social, human, economic and environment) can be assessed.

For each dimension of building performance, three measurable (at the building level) direct outcome metrics have been identified that relate to each dimension of building performance. For example, for Protection from Injury, *fatal injuries*, *non-fatal injuries*, and *egress* were selected as measures to describe the how a building would perform (or should perform) in a particular earthquake*.* Indirect outcomes were not included, because of the numerous external factors that can influence them.

The continuums of outcome severity for each of the metrics use a 6-point scale, with severity classes being (1) none/insignificant, (2) minor, (3) moderate, (4) high, (5) severe, and (6) catastrophic. These allow choices for policy settings and to indicate alternative possible outcomes. The severity classes are unique to each building dimension but recognise that each building dimension relates separately to a different aspect of a building's performance. They do not map to one another across the different dimensions. That is, a catastrophic outcome for protection from injury is unrelated to a catastrophic outcome for protection to property. How these dimensions map to each other, and to overall impact, is work that is still to be done. The scales are also not intended to be linear. That is, the difference between none and minor is not necessarily the same as the step between moderate and high, but rather identify key measurable points relevant to each separate scale.

The framework allows for the inclusion of additional (or other) metrics for the three different building dimensions. This enables metrics to be added where needed to evaluate or set performance objectives for highly specialised building types, for example hospitals.

Protection from Injury

The continuum of outcome severity for protection from injury has been divided into three categories: *fatal injuries*, *non-fatal injuries*, and *egress,* as shown in Table 3. This distinction was made because the Stage 2 societal expectations research found that people are generally intolerant of deaths but are slightly more accepting of injuries in severe shaking. Egress was included as a category linked to casualties because of the potential for additional trauma from entrapment.

Protection of Property

The continuum of outcome severity for the protection of property is described in Table 4. The range of direct outcomes has been described using three categories: *overall extent of damage*, *financial cost*, and *waste cost*.

- Overall extent of damage defines the amount of damage that is likely to occur that would result in the costs described in the other categories (financial and waste).
- Financial cost describes the expenses associated with building repair or replacement. These costs are expressed relative to the building value.
- *Waste* is a direct outcome metric that is measured by the amount and nature of building debris or demolition material that will be stored or sent to a landfill during the repair or

replacement process. It is a proxy for the operational and embodied carbon[29] required to repair or rebuild structures though we did not attempt to measure that in this Project.

Protection of Amenity and Function

The continuum of outcome severity for protection of amenity and function is described in Table 5. The range of user disruption outcomes has been described using three categories: *Level of function (business-as-usual purpose)* (immediate post-event), *duration of disruption*, and level of function (*alternative function)* (immediate post-event).

- Level of function *(business-as-usual purpose)* (immediate post-event) describes the types of functions that are available immediately after ground shaking, the scale of modifications needed to support the intended function, and the degree of amenity loss.
- Duration of disruption describes the extent function is impacted while repairs are undertaken as well as the expected time to complete those repairs.
- Level of function (*alternative function)* (immediate post-event) is an extra category that describes planned purposes to which a building might be put after an event, even with limited functional capacity. This is included to help guide the development of performance objectives if a building's future usages might foreseeably include alternative functions post-event.

Because the level of function (immediate post-event) and duration of disruption are not necessarily directly related (e.g., damage that causes moderate disruption to function may take years to repair), other methods may need to be developed for defining outcome severity for amenity and function.

Details of metric selection and outcome severity scales for the different dimensions of building performance are described in Appendix G.

---

[29] Gonzalez RE, Stephens MT, Toma C, Dowdell D. The Estimated Carbon Cost of Concrete Building Demolitions following the Canterbury Earthquake Sequence. *Earthquake Spectra*. 2022;38(3):1615-1635. doi:10.1177/87552930221082684.

Table 3. Continuum of outcome severity related to Protection from Injury

Outcome Severity	Fatal Injuries	Non-Fatal Injuries	Egress
None/Insignificant	• No loss of life.	• Few if any minor injuries.	NA
Minor	• No loss of life.	• Minor to a small to medium number of people. • Few if any moderate injuries. • Few if any significant injuries.	NA
Moderate	• No loss of life.	• Minor injuries to a medium to large number of people. • Moderate injuries to a small to medium number of people. • Few if any significant injuries.	NA
High	• One or more, localised single loss of life. • No instances of multiple loss of life at a location within building.	• Extensive minor injuries. • Moderate injuries to many people. • Significant injuries to a medium number of people.	• Ability to evacuate building possible for most able-bodied people. • Some vulnerable people may require rescue by specialised rescue teams.
Severe	• Single loss of life in multiple locations throughout building and/or • One or more instances of multiple loss of life at a location within building.	• Extensive minor & moderate injuries • Significant injuries to many people.	• Ability to evacuate building limited for some able-bodied people. • Most trapped/ injured occupants or vulnerable people require assistance to escape requiring specialised rescue teams.
Catastrophic	• Large numbers of loss of life.	• Extensive significant injuries.	• Ability to evacuate building limited for most people. • Many trapped occupants.

Table 4. Continuum of outcome severity related to Protection of Property

Outcome Severity	**Overall Extent of Damage**	**Financial Cost**[30]	**Waste Cost**[31]
None/Insignificant	No measurable impact	*No measurable impact.*	TBD
Minor	Damage to building or facility contents is minimal in extent and minor in cost.	*Within operating budget* • Low cost (e.g., <5% building replacement value[32]	TBD
Moderate	Damage to building or facility contents may be locally significant but generally moderate in extent and cost.	*Within typical insurance deductible* • Moderate cost (e.g., ~ 10% building replacement value)	TBD
High	Damage to building or facility contents may be locally significant and generally high in extent and cost.	*Within event scenario expected loss limit* • High cost, (e.g., ~ 20% building replacement value)	TBD
Severe	Damage to building or facility contents may be locally total and generally severe in extent and cost.	*Repairable damage* • Severe cost, (e.g., ~ 40% building replacement value)	TBD
Catastrophic	Damage to building or facility contents may be total.	*Irreparable damage* • Building written off, (total building replacement value)	TBD

---

[30] Estimates of the percentages of replacement value in this chart are indicative only. The values will depend on how repair costs are calculated (i.e. what is included). More data and analysis is necessary to establish these values.

[31] Waste Costs is a direct outcome that is related to building performance and was highlighted as a concern in the societal expectation research. However, the Project has not quantified a metric for measuring outcome severity that is applicable to all building types.

Table 5. Continuum of outcome severity related to Protection of Amenity and Function

Outcome Severity	Level of Function (business-as-usual purpose) (immediate post-event)	Duration of Disruption	Level of Function (alternative function) (immediate post-event)
None/Insignificant	• Building usage remains as pre-event. • Building usage unaffected for all.	• No displacement of occupants.	N/A
Minor	• Minimal modifications required to carry out normal functions. • Intended functions are supported. • Modifications have minor impact on amenity (i.e., user comfort, including psychological response).	• Repairs cause minimal disruption to function (**days to weeks**) and can be scheduled for time building is less occupied.	N/A
Moderate	• Modifications required to carry out normal functions. • Basic intended functions are supported. • Modifications have moderate impact on amenity.	• Repairs likely to cause minor to moderate disruption to function. • Repairs carried out with the possibility of people being displaced (within building) for part or all of the repair time. (order of **weeks to months**)	N/A
High	• Normal function is limited as several modifications are required to carry out basic intended functions. • Modifications have major impact on amenity.	• Repairs likely to cause moderate to severe disruption to function. • Many repairs require people and the building functions to move out for the repairs to be completed (order of **months**)	Basic alternative post-event functions possible
Severe	• Only the most basic intended functions (e.g., shelter) are supported. • Modifications have extreme impact on amenity.	• Significant disruption to building occupants and building functions while repairs are carried out (order of **years**)	Shelter in place
Catastrophic	• Building is non-functional.	• Total disruption to building occupants and functions. **Permanent** loss of function.	Building is not safe for occupancy (red-tagged)

3.6. Applying the Framework

Because the framework is agnostic to building type and usage, effective implementation requires context. The process of applying the EPO framework to identify building-specific performance objectives is outlined in Figure 6.

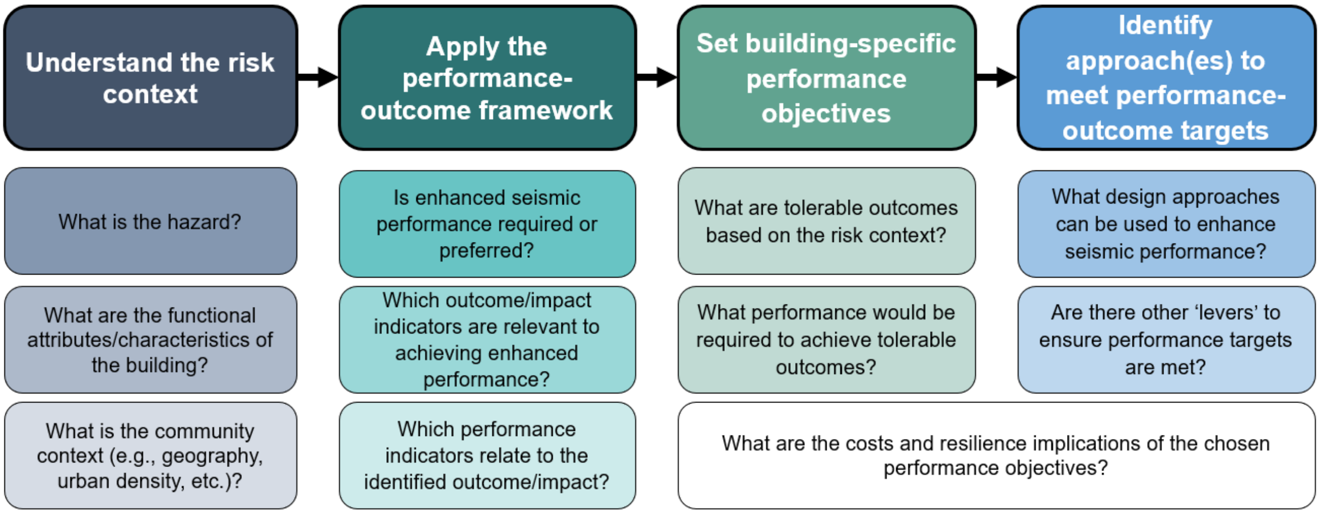
First, policy makers, or building designers, need to understand the risk context. This includes the hazard (here indicated by a level of earthquake shaking), the functional attributes or characteristics of the building or group of buildings (e.g., the building usage and its importance to the community), and the community context (e.g., geography and urban density).

Once this is known, the framework can be used to gauge whether the building, or group of buildings, may require better-than-typical performance by identifying specific outcome indicators that reflect the risk context and performance indicators relevant to achieving desired outcomes.

Building-specific performance objectives can then reconcile the inferred link hazard level with the building performance required to achieve desired outcomes (e.g., in a rare and significant earthquake, the building will be designed to prevent collapse, thereby protecting the lives of building occupants).

The selection of treatment options to meet the performance-outcome targets then can be related to building design (e.g., by using a higher than typical hazard factor, or designing for structural regularity) or using other ‘levers’ to reduce damage, for example, siting on better ground or improving construction industry skills and practices. Possible ways to manage seismic risk are discussed further in Section 6.

Both the performance objectives and the approaches to meet performance-outcome targets need to consider cost-benefit implications. These are discussed further in Section 7.



Understand the risk context	Apply the performance-outcome framework	Set building-specific performance objectives	Identify approach(es) to meet performance-outcome targets
What is the hazard?	Is enhanced seismic performance required or preferred?	What are tolerable outcomes based on the risk context?	What design approaches can be used to enhance seismic performance?
What are the functional attributes/characteristics of the building?	Which outcome/impact indicators are relevant to achieving enhanced performance?	What performance would be required to achieve tolerable outcomes?	Are there other ‘levers’ to ensure performance targets are met?
What is the community context (e.g., geography, urban density, etc.)?	Which performance indicators relate to the identified outcome/impact?	What are the costs and resilience implications of the chosen performance objectives?	

Figure 6 Context of applying the performance-outcomes framework to set performance objectives

4. Building Usage Categorisation System

4.1. Approach

The EPO Framework maps outcomes to dimensions of building performance. The framework is designed so that it can be used to develop performance objectives for any building, or groups of buildings, and their specific performance requirements. This is important because the societal expectations research highlighted that building usage significantly affects the impact of damage and disruption and desired speed of re-occupation following an earthquake.

As part of Stage 3, the RBP project team undertook an exercise to identify building usages that have higher consequences of failure than others (in terms of human, social, economic, and environmental impacts).

The current New Zealand Building Code uses Importance Levels to identify certain buildings that need to be designed to a higher standard. The higher standards are based on whether the building has higher occupancy, hazardous materials, or has a post-disaster response function (see Appendix A for more information). The Building Usage Categorisation System here aims to identify whether there are additional groups of buildings that may benefit from higher standards and to create a nomenclature around the performance outcomes that might be desired for each building group. It is based on the societal expectations research findings from Stage 2. Whether or not these groups should be recognised in the design Code, as opposed to being left to market, is future work to be done by others. Regardless, the building categorisation provided here may also be useful to building owners when determining whether or not they should consider enhanced seismic performance in their building.

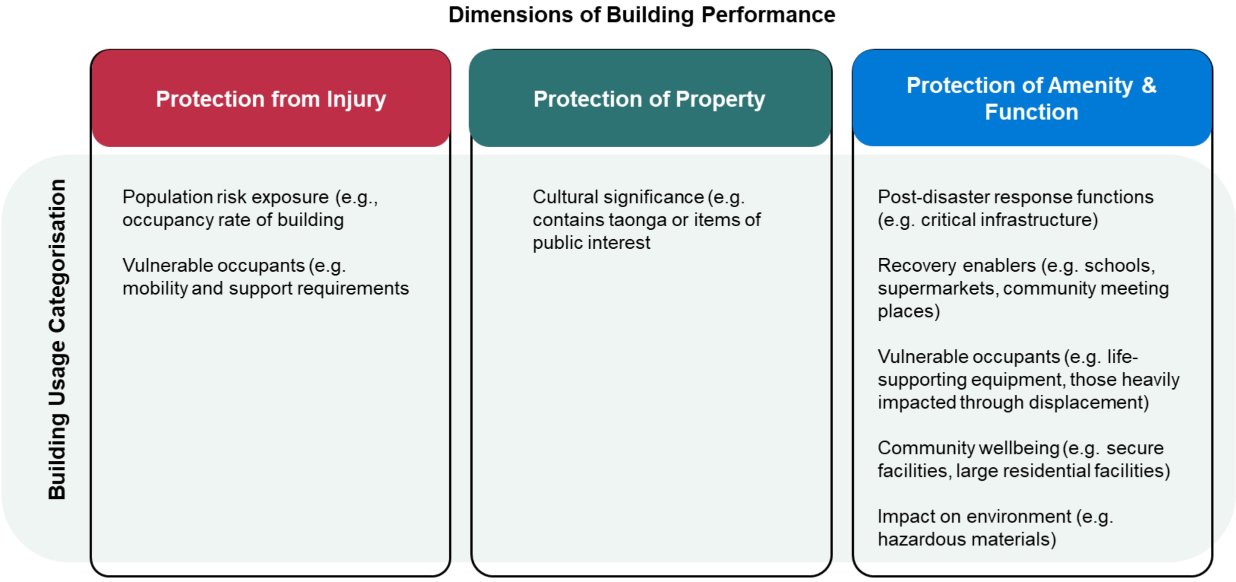
The Stage 2 societal expectations research clearly showed that some building usages are valued more than others. For example, buildings that serve vulnerable people or enable social connection following an earthquake were highly valued. Similarly buildings where impacts may cause significant community disruption post-earthquake are valued (e.g. multi-unit residential dwellings). In general, buildings were viewed as less important if there were readily available alternatives to their use (e.g., office blocks where workers could work from home).

The importance of buildings also differed depending on the geographic and community context. Buildings located along major arterial routes were understood to have the potential to cause acute consequences for impeding post-disaster response and recovery if they were damaged in an earthquake. Additionally, expectations for building performance differed between urban and rural settings. For example, some rural communities had strong social and economic ties to a particular business or primary industry processing plant. In built-up urban areas some people would prefer enhanced seismic performance given the concentration of risk in those areas. For example, disruption to medium and high density housing could create a challenge post-earthquake if residents were displaced.[33]

---

[33] The RBP recognises that these geographical and community considerations are important to improving seismic resilience in New Zealand. However, these issues are outside of the scope of the proposed framework. Performance objectives related to these aspects should be assessed at the community level.

The Building Usage Categorisation System, summarised in Figure 7, was developed based on (1) *why* certain buildings are valued by their communities and (2) the *consequences* that would result from these important buildings being damaged.



Protection from Injury	Protection of Property	Protection of Amenity & Function
Population risk exposure (e.g., occupancy rate of building Vulnerable occupants (e.g. mobility and support requirements	Cultural significance (e.g. contains taonga or items of public interest	Post-disaster response functions (e.g. critical infrastructure) Recovery enablers (e.g. schools, supermarkets, community meeting places) Vulnerable occupants (e.g. life-supporting equipment, those heavily impacted through displacement) Community wellbeing (e.g. secure facilities, large residential facilities) Impact on environment (e.g. hazardous materials)

Figure 7 Building Usage Categorisation System

The categorisation was informed by the societal expectations research, other disaster recovery research, and through the expert workshop process described in Section 1.4. The process focussed on understanding and categorising the underlying reasons for higher expectations or performance needs for different building uses.

For each dimension of building performance, we identified building use attributes that might influence a need for enhanced seismic performance. We then identify the consequences of failure for each building attribute. The consequence ratings used in the assessment are summarised in Table 6. We have primarily included those building uses where the consequence of failure is critical or serious. However, we have also included some building uses which may require additional consideration in some instances.

Table 6.Consequence categories for building performance

Consequence Severity	Description
Extreme	Building or building system failure would have catastrophic human, social, economic, or environmental consequences on the community or nation. (Extreme consequences were out of scope for RBP)
Critical	Building or building system failure would have severe human, social, economic, or environmental consequences for the community.
Serious	Building or building system failure would have high human, social, economic, or environmental consequences for building users or the community.
Typical	Building or building system failure would have ordinary human, social, economic, or environmental consequences for building users or the community.
Low	Building or building system failure would have minimal human, social, economic, or environmental consequences for building users and the community.

Within the EPO framework each dimension of building performance can be considered separately. As such, our vision is that each building usage group can have performance objectives set that prioritise the dimension(s) of building performance most critical.

For example, large stadiums might need enhanced seismic performance to reduce injury, but have few requirements for damage prevention or ensuring ongoing functionality. Whereas, supermarkets might need enhanced seismic performance to ensure ongoing functionality but not necessarily enhanced protection from injury. The differing performance requirements across the dimensions of building performance would then inform design decisions such as building form, stiffness and regularity, and non-structural element bracing requirements.

Further commentary on how and why buildings were categorised and more on the building types included within each category is provided in Appendix H.

4.2. Building Categories

4.2.1. Protection from Injury

The building usage attributes that influence injury outcomes are *population risk exposure* and *impact on vulnerable occupants, see* Table 7.

Findings from the societal expectations research reflected the belief that there should be higher protection from injury in buildings with high occupancy rates, given the concentration of risk/people in these buildings. Structures may be considered 'high occupancy' based on (a) the maximum number of people in a building at any time, (b) the maximum number of people in a single area at any time, (c) the average number of people in building at any one time, or (d) the average weekly usage (i.e., person-hours per week).[34]

Singling out buildings with *vulnerable occupants* reflects the additional risk faced by occupants that require extra assistance to take cover or evacuate post-event. A key finding from the societal expectations research was that vulnerable people should be protected.[35] Types of occupants considered vulnerable in terms of life-safety risk are those with mobility limitations (e.g., users of hospitals, aged care residents) and those that may require direction or management (e.g., dementia care patients, pre-schoolers, prisoners).

While not included in the categorisation, the choice occupants have to enter a building or not, the likelihood there are sleeping occupants within the building, and the familiarity of building users with the building layout or location,[36] could also be factors that indicate a need or desire for enhanced protection from injury.

---

[34] Average weekly usage is suggested as a risk exposure metric in the 2021 BRANZ report 'Managing earthquake-prone council buildings – a decision making framework'. resorgs.org.nz/wp-content/uploads/2021/12/EQ-Prone-Buildings-Framework-Dec21.pdf.

[35] Vulnerable persons are disproportionately affected by disasters internationally. A recent report from cbm outlines the impacts and challenges faced by those with disabilities and the need to include disability concerns in disaster risk reduction activities. https://www.cbm.org.au/wp-content/uploads/2022/07/CBM-Inclusion-Advisory-Group-IAG-Our-Lessons-report-May-2022.pdf.

[36] Tourists are often less prepared for natural disasters and may not know what to do to protect themselves. See for example Fountain, J., & Cradock-Henry, N. A. (2020). Recovery, risk and resilience: Post-disaster tourism experiences in Kaikōura, New Zealand. *Tourism Management Perspectives*, *35*, 100695. https://doi.org/https://doi.org/10.1016/j.tmp.2020.100695.

Table 7. Building usage categorisation for enhanced protection from injury

Building Usage Attributes	**Consequence Severity**		
	Serious	**Ordinary**	**Low**
Population Risk Exposure	• Facilities with high[1] occupancy rates	• Facilities with normal[1] occupancy rates	• Facilities with low[1] occupancy rates
Vulnerable Occupants	• Facilities likely to have high rates occupants with mobility limitations • Facilities likely to have occupants that require direction or management		

[1]Definitions of high, normal, and low occupancy rates not provided, and are to be determined in the future by others, similar to current provisions within NZS1170.

4.2.2. Protection of Property

Buildings that may require enhanced performance to prevent property loss are identified in Table 8. The building usage attributes that influence outcomes of property damage are *cultural significance*.

There are few building usages that specifically require enhanced performance to reduce damage. The societal expectations research highlighted the importance of protecting cultural capital in New Zealand. Facilities that house cultural treasures or have a high cultural value (e.g., museums) have a serious consequence of damage.[37] The project team also identified that facilities that house important public interests (e.g., police data centres) have a serious consequence of failure.

While not included in the categorisation buildings with high economic value (building or contents), or buildings with financially vulnerable occupants (with limited financial means to repair damage or replace damaged contents) may have cause for enhanced protection from property damage. Enhanced protection of property may also be suitable where environmental impacts (release of hazardous substances or impact of waste/carbon effects if they are damaged) want or need to be reduced.

Table 8. Building usage categorisation for enhanced protection of property

Building Usage Attributes	**Consequence Severity**
	Serious
Cultural Significance	• Facilities that house cultural treasures or have a high cultural value • Facilities that house important public interests

4.2.3. Protection of Amenity & Function

Buildings that require enhanced performance to prevent injuries are identified in Table 9. The consequence measures related to damage are impacts on the *post-disaster response*, *recovery*, *vulnerable occupants*, *community wellbeing*, and *the environment*.

---

[37] Recent research by Hoang et al (2021) indicated that market forces typically ignore life safety and socio-cultural significance of buildings. See Hoang, T., Noy, I., Filippova, O., and Elwood K., (2021), Prioritising earthquake retrofitting in Wellington, New Zealand, Disasters, 2021, 45(4): 968−995.

Post-disaster response functions represent buildings that are critical after a major event. The societal expectations research showed that people expected continued operation of emergency services after a major earthquake, so that those who need help can receive it. Buildings identified as critical in the early response phase included hospitals or other medical centres, emergency operations centres, fire stations, police stations, and ambulance depots.[38] Furthermore, the preservation of buildings with the functional capacity to sustain life was identified as being particularly important if failure could hinder other lifesaving functions (e.g., loss of function in an aged care facility may increase demand on the hospital).

Recovery enabler represents buildings that support community recovery following a major earthquake. The societal expectations research highlighted that buildings that enable individual independence in recovery (e.g., essential retail such as supermarkets and petrol stations), economic recovery (e.g., critical infrastructure, facilities that provide care for dependants such as child-care centre, schools, and aged care), or social cohesion (e.g., marae or other established community hubs) should have enhanced performance to prevent disruption.

Vulnerable occupants represents buildings where users depend heavily on the functions of the building. The societal expectations research highlighted several building types that are important for protecting the physical and mental health of vulnerable occupants. Buildings are considered to have critical disruption consequences if a significant percentage of occupants rely on services or equipment within the building to support life (e.g., ventilators or dialysis systems). Buildings are considered to have a serious disruption risk if a significant percentage of occupants will require relocation if the facility is non-functional. This includes buildings that contain welfare centres, aged care,[39] and possibly public housing.

Community wellbeing support represents buildings that communities rely on to function normally. The social research showed that communities highly value their critical infrastructure and buildings or facilities that would cause significant disruption in the community were they to fail. Therefore, buildings and facilities are considered to have critical disruption consequences if they provide essential public utilities to communities (e.g., power-generating facilities, telecommunication facilities, water treatment, and wastewater treatment facilities, and other public utilities).

Buildings that are secure facilities (e.g., prisons and forensic mental health), contain contents with high community value not designated as post-disaster (e.g., wholesale food distribution centres, essential goods manufacturing facilities, facilities with medical imaging equipment), or are residential facilities for medium to high-density housing would have serious consequences if disrupted.[40][41]

Environmental risk represents buildings where there would be environmental consequences associated with the loss of containment of hazardous materials. Following the precedent set by the existing Building Code, facilities are considered a critical disruption risk if loss of containment

---

[38] This is consistent with provisions for importance level 4 buildings in the New Zealand Building Regulations 1992, Schedule 1 clause A3.

[39] See for example the impacts of evacuation due to natural hazard in Cacchione PZ, Willoughby LM, Langan JC, Culp K. Disaster strikes! Long-term care resident outcomes following a natural disaster. J Gerontol Nurs. 2011 Sep;37(9):16-24; quiz 26-7. doi: 10.3928/00989134-20110810-50. Epub 2011 Jun 2. PMID: 21634311; PMCID: PMC4391199.

[40] While studies are limited, there is evidence of the effects of post-disaster relocation on physical and mental health. See Uscher-Pines L. Health effects of relocation following disaster: a systematic review of the literature. Disasters. 2009 Mar;33(1):1-22. doi: 10.1111/j.1467-7717.2008.01059.x. Epub 2008 May 21. PMID: 18498372.

[41] Recent research by Blake et al. argues that targeted preparedness measures are needed to specifically address the needs of inner-city dwellers. See Blake, D., Becker, JS, Hodgetts, D., Hope, A. (2022), The 2016 Kaikōura Earthquake: Experiences of safety, evacuation and return for apartment dwellers in Te Whanganui-a-Tara (Wellington), Aotearoa New Zealand, International Journal of Mass Emergencies and Disasters.

of hazardous materials held on the premises can cause hazardous conditions that extend beyond property boundaries and a serious disruption risk if loss of containment would cause hazardous conditions that do not extend beyond the property boundaries.

While not included in the categorisation, enhanced protection of amenity and function may also be suitable for the following building usages:

- Facilities vital for economic output (regional or national) and/or vital for employment in regional area,
- Facilities where damage may cause disproportionate uninsurable loss,
- Facilities that house agencies for recovery,
- Community facilities that contribute to cultural identity, contribute to community connection and/or a sense of place,
- Facilities with occupants sensitive to visible damage, and
- Accommodation facilities.

Table 9. Building usage categorisation for enhanced protection of amenity and function

Building Usage Attribute	**Consequence Severity**	
	Critical	**Serious**
Post-disaster Response Functions	• Buildings and facilities that provide essential services (power, water, communications) • Buildings and facilities with special post disaster functions • Medical emergency or surgical facilities • Emergency service facilities such as ambulance, fire, police and related vehicle garages • Designated emergency shelters, and centres, and ancillary B	
Recovery Enabler	• Power-generating facilities, telecommunication facilities, water treatment, and waste water treatment facilities, and other public utilities	• Facilities that enable individual independence in recovery (e.g., schools, preschools, supermarkets) • Facilities that enable economic recovery • Facilities that enable social cohesion (community meeting places)
Vulnerable Occupants	• Facilities with specialised life-supporting equipment on which vulnerable occupants rely	• Facilities with vulnerable occupants that will require relocation if function is lost
Community Wellbeing Support	• Power-generating facilities, telecommunication facilities, water treatment, and waste water treatment facilities, and other public utilities	• Secure facilities • Other facilities that contain contents with high community value not designated as post disaster (e.g., wholesale food distribution centres, essential goods manufacturing facilities, laboratories, medical imaging facilities) • Large residential facilities and medium density housing, where there is limited means to provide alternative basic services (water and sanitation) if reticulated networks are disrupted and people need relocating
Impact on the Environment	• Loss of containment of hazardous materials is capable of causing hazardous conditions that extend beyond property boundaries	• Loss of containment of hazardous materials is capable of causing hazardous conditions that does not extend beyond property boundaries

5. Evaluation of Current Code Against Societal Expectations

5.1. Approach

One of the key objectives of the Resilient Buildings Project was to evaluate the extent to which the current Building Code meets current societal expectations. The Stage 2 research findings represent a snapshot of societal expectations at the time the data was captured. This provides a data point that could be used to assess whether the current Code was meeting building user expectations within an order of magnitude.

The EPO framework (Section 3) provides a vehicle to evaluate the gap between current Code, and current societal expectations. It allows for expectations of performance to be assessed against the three dimensions of building performance.

The assessment process herein also illustrates the potential for how the EPO framework could be used to support the code writing process.

To evaluate the gap between what the code currently delivers, and the desired performance expressed in the societal expectations research, qualitative loss exceedance curves were derived by the project team for each dimension of building performance. A 'typical' mid-rise multi-use building in Wellington was considered in terms of (1) what the project team *believe* compliance with current Code can achieve*, based on observation, experience, and professional judgement,* and (2) what the project team infer the New Zealand public expects of their buildings in earthquakes based on the Stage 2 societal expectations research.

The likelihood of an outcome severity was estimated for different levels of shaking.

The estimates of outcome likelihoods for the typical buildings designed and constructed in compliance with the current Code are based on expert opinion of the project team and include consideration of structural and non-structural elements. The estimates for what the New Zealand public expects of their buildings is based on the project team's interpretation of the earlier findings from the societal expectations research undertaken in Stage 2.[42][43] Outcome severity ratings were based on the tables in Section 3.5.

The 'typical' building considered in this exercise was envisaged as being representative of a new IL2 building in New Zealand[44]. Following the principle of consistent crudeness,[45] and given the non-specific building description paired with the qualitative nature of the descriptions of both hazard and outcome severity, the goal of this exercise was to achieve *accuracy* of gap

---

[42] The assessment is undertaken considering general expectations. The 2021/22 societal expectations research showed that expectations are varied across the community and considerable value judgement is necessary to determine specific levels of tolerance to disruption. Tolerable outcomes (at community level) need to be determined through a cost-benefit analysis that considers outputs from research such as the Resilient Buildings Societal Expectations research (Brown et al. (2021) and cost benefit analysis. Decisions around tolerable level of risk must be made in consideration of both cost and benefit. As such, our work focuses on an order of magnitude assessment against the broad expectations elicited only.

[43] Some of the challenges of establishing tolerable or acceptable levels of risk are set out in May PJ. (2001). Societal Perspectives about Earthquake Performance: The Fallacy of ''Acceptable Risk''. Earthquake Spectra; 17 (4): 725–737. doi:10.1193/1.1423904.

[44] Whilst the presented plots are to be interpreted as building type and location agnostic, the working group conceptualised a 'multi-use, mid-rise building in Wellington' during the exercise for consistency in judgement.

[45] Hare, J. (2021) Our use of engineering models. SESOC Conference, Hamilton 5-6 July 2021. 11 pp. And references therein.

identification not a refined *precision* of estimation. We judge that our estimations are within an order of magnitude of what actual performance may deliver or desired outcomes may be.

Three qualitative levels of earthquake shaking were considered in this exercise: intermediate, strong, and severe (Table 10). These levels of shaking are site-specific and deterministic. That is, they are meant to represent the shaking felt at a single building location.

The assumptions, procedures, and results of this exercise are detailed in Appendix I and summarised below. They are effectively the reverse of how the EPO framework could be used to support code writing.[46]

For a description of the derivation of the example shaking intensity refer to Appendix J.

Table 10. Descriptions of intermediate, strong, and severe shaking

Shaking Level	Description	Likelihood of Earthquake Shaking	Example Shaking Intensity
Intermediate	Shaking is generally felt outside and by almost everyone indoors. Most sleepers are awakened. Unfixed items may topple, possible damage to vulnerable buildings. [Example: 2007 Gisborne earthquake].	People living in moderate to high seismicity areas are likely to experience this level of shaking more than once in their lifetime.	Peak ground accelerations are in the range 0.2-0.3g within a radius of 10-50 km. Duration of shaking in the range 10-20 seconds.
Strong	General alarm. People may experience trouble standing and the steering of vehicles may be affected. Localised ground deformation and damage to buildings and infrastructure. [Example: 2016 Kaikoura earthquake at the Wellington waterfront]	People living in moderate to high seismicity areas may experience this level of shaking at least once in their lifetime.	PGAs are in the range 0.3-0.5g over a radius of 50-100 km. Duration of shaking in the range 60-90 seconds
Severe	Alarm approaches panic. Widespread ground deformation and damage to buildings and infrastructure. [Example: 1855 Wairarapa earthquake]	People living in moderate to high seismicity areas may experience this level of shaking once in a few generations. Unlikely to be experienced in a single lifetime.	PGAs are in the range 0.5->1.0g over a radius of 100-500 km. Duration of shaking exceeding two minutes.

---

[46] We envisage that the EPO framework could be used to support subsequent code writing in the following way: first, acceptable consequences for each outcome indicator and corresponding dimensions of building performance would be determined (informed by the Stage 2 research findings). Then the process will involve identifying aspects or elements of a building relevant for that “dimension” and determining the state within each element that delivers the acceptable outcome or performance. Then performance objective for each element and state would be set and design points established.

5.2. Results

5.2.1. Protection from Injury

The Stage 2 societal expectations research indicated that desired outcomes relating to injuries and deaths broadly align with the current New Zealand Code requirements for design and construction of structural and non-structural building elements. The following points are highlighted:

- Safety is non-negotiable.
- New Zealanders have a very low tolerance for loss of life regardless of shaking intensity.

Based on our interpretation, expectations for protection from injury in large earthquakes is largely (within an order of magnitude) catered for within current Code settings, refer Figure 8.

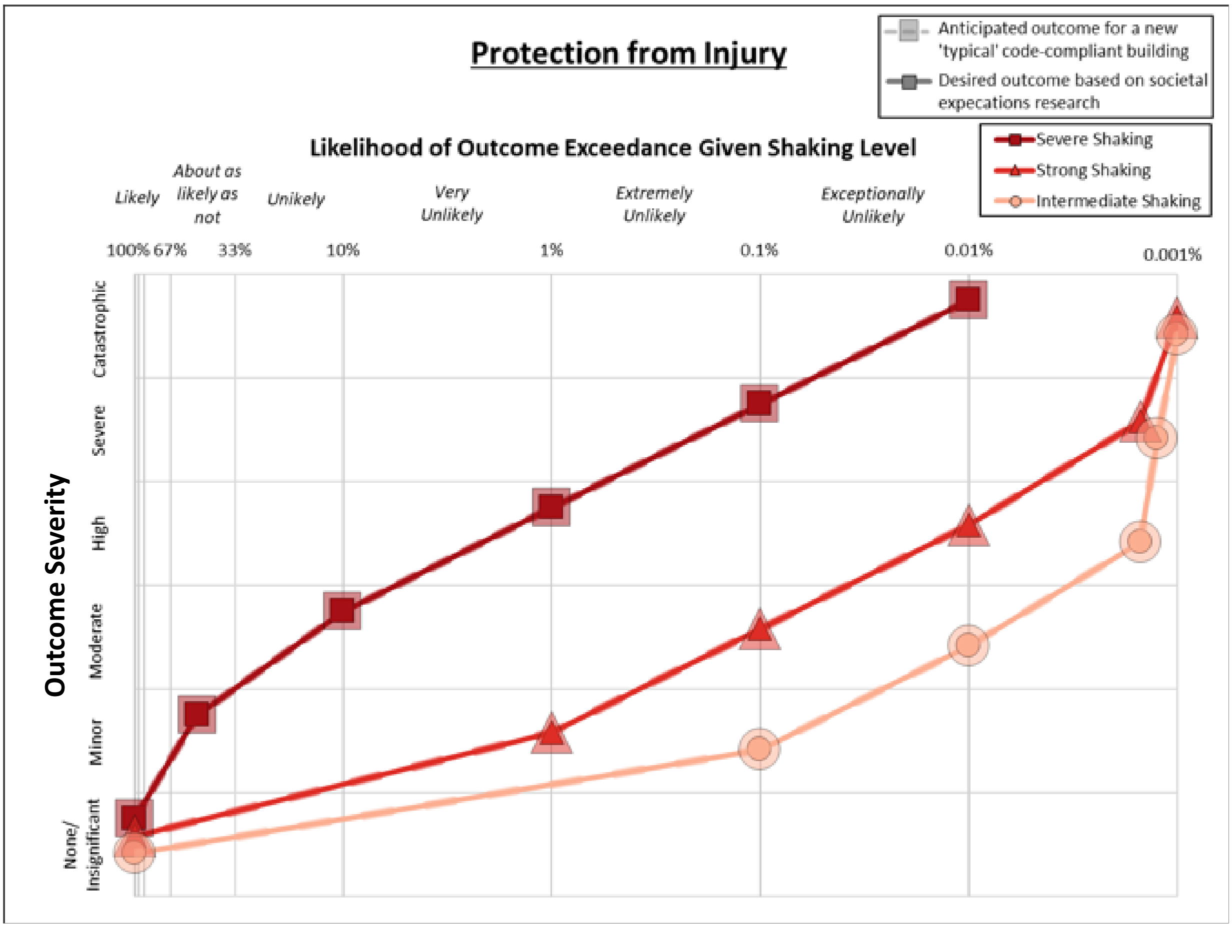


Figure 8 Loss exceedance curves, showing the anticipated and desired outcomes for a new ‘typical’ code-complaint building in terms of Protection from Injury. Preferences generally align with the current New Zealand Code requirement.

5.2.2. Protection of Property

Our interpretation of the Stage 2 societal expectations research indicated that desired outcomes relating to damage exceed (by an order of magnitude) what the current Code provides in moderate, strong, and severe shaking. The following points are highlighted:

- There is generally greater tolerance for the direct environmental and economic consequences of damage associated with protection of property than there is for the outcomes associated with protection from injury.

- We compared our interpretation of the societal expectations with our anticipated outcomes and concluded that there is roughly an order of magnitude difference between expectations and current Code settings. This indicates that the onset of damage would need to be 'delayed' and levels of damage in general reduced to meet societal expectations.
- For intermediate shaking, the research showed most were not accepting of significant amounts of damage.
- For strong shaking, the research showed that most were accepting of some damage but did not want costly or highly disruptive repairs (i.e., causing user displacement from a building) or total building replacement.
- For severe shaking, the research highlighted that many felt that lasting environmental impacts from widespread building demolition were intolerable.

This analysis, refer Figure 9, suggests that protection of property is not currently well served in the Building Code.

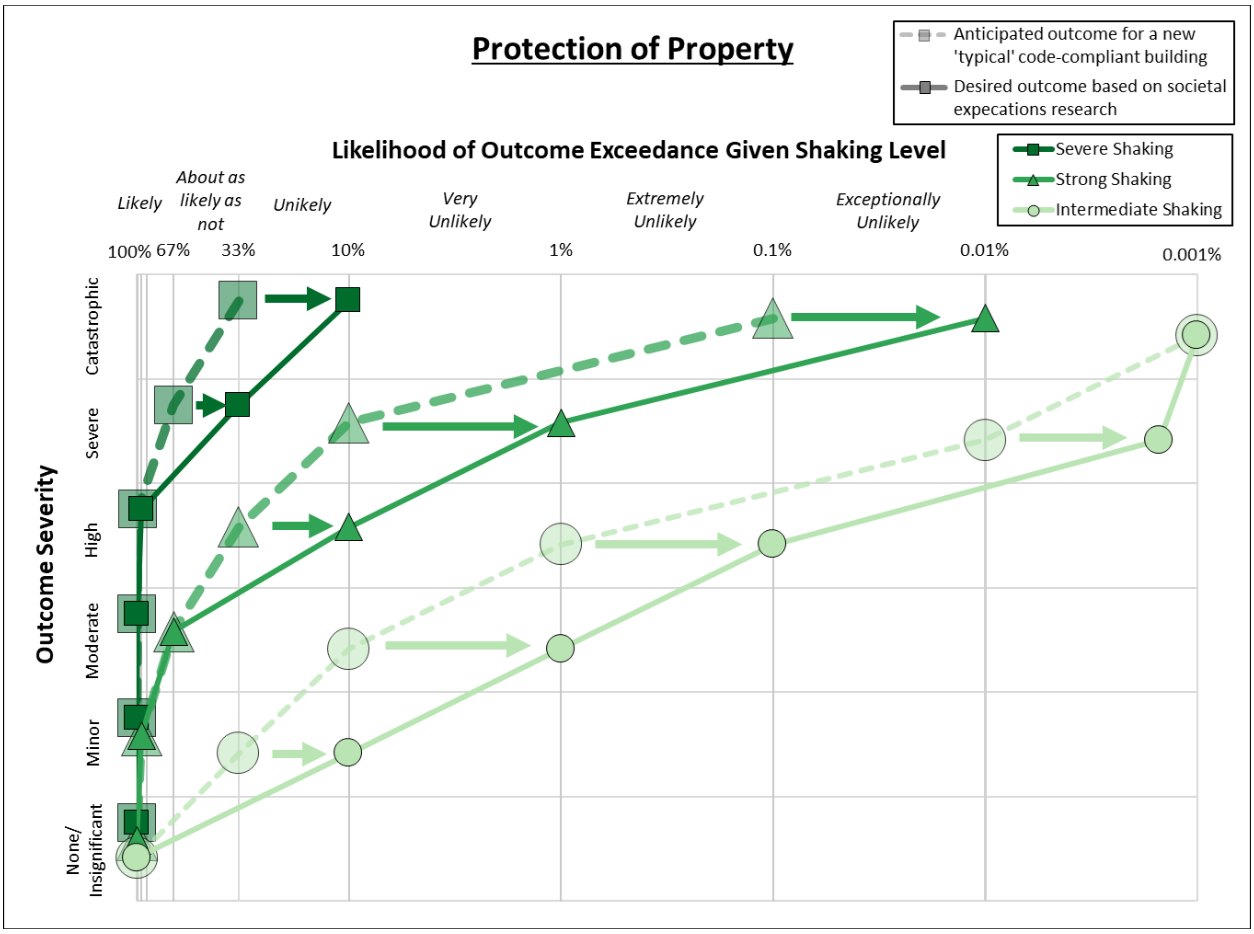


Figure 9 Loss exceedance curves, showing the anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of Protection of Property

5.2.3. Protection of Amenity & Function

Our interpretation of the Stage 2 societal expectations research indicated desired outcomes relating to amenity and functionality exceed (by an order of magnitude) what the current Code provides in intermediate and strong shaking, with people expecting buildings to retain function or return to function much sooner than the current Code delivers, refer Figure 10. The following points are highlighted:

- There is generally greater tolerance for the disruption associated with protection of amenity and function than there is for the outcomes associated with protection from injury.
- For intermediate shaking, the expectation is that there will not be significant disruptions, which is not guaranteed by current Code minima settings.
- For strong shaking, people generally expect that they will retain more function or return to function much sooner than the current Code minima are likely to achieve.
- For severe shaking, functionality isn't expected of many 'typical' buildings.

This analysis suggests that protection of amenity and function is not currently well served in the Building Code, refer Figure 11.

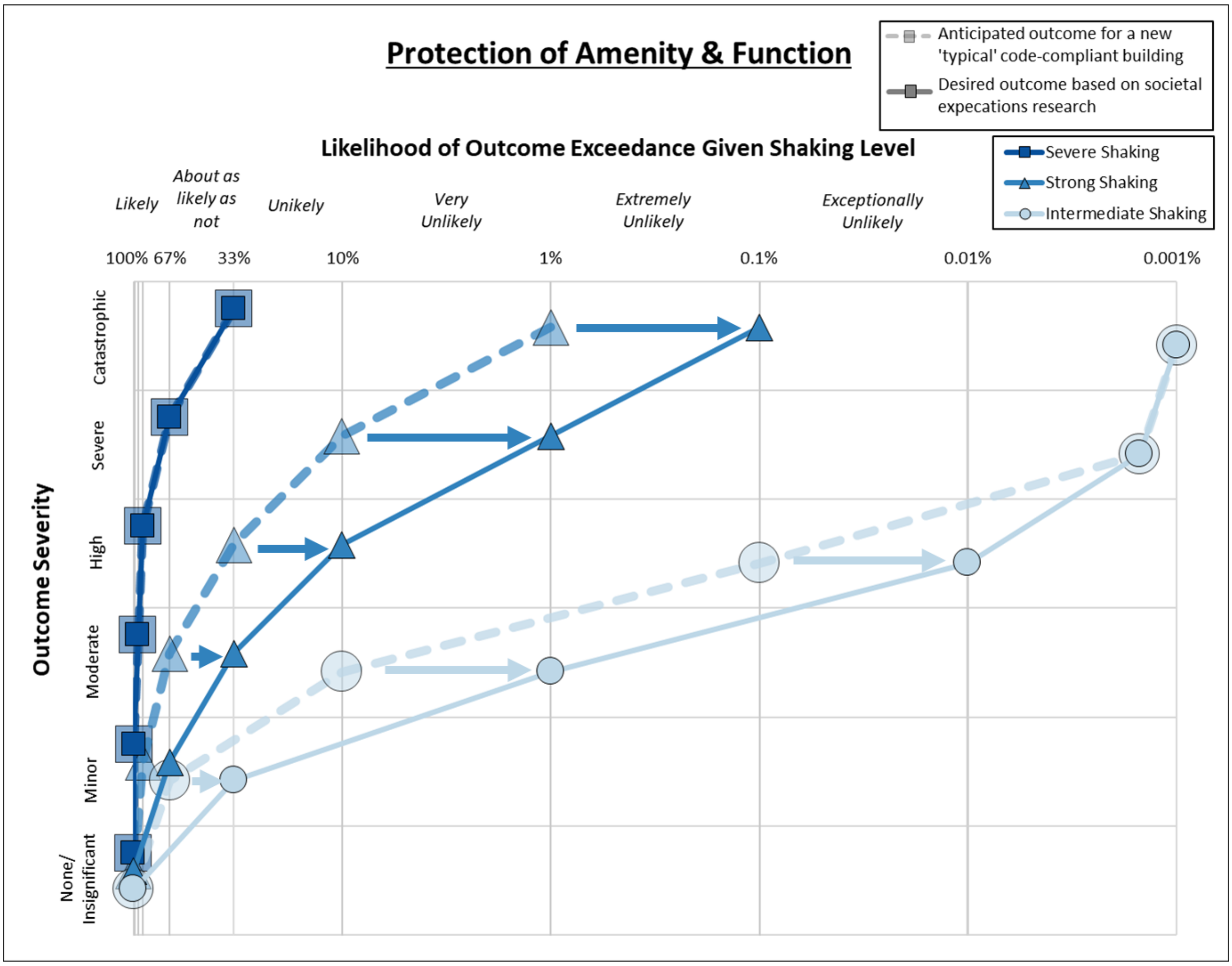


Figure 10 Loss exceedance curves, showing the anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of Protection of Amenity and Function

6. Building System Scan

Much of Stage 3 focussed on tools and analyses around current Building Code settings as a mechanism for enhancing the resilience of New Zealand's building stock. However, there are other mechanisms that can and should be considered alongside any revision to the building loading standard NZS1170.

As part of Stage 3 of the Resilient Buildings Project, a series of workshops were held with the project team and subject matter experts to explore the mechanisms available to improve the resilience of our building stock to seismic events.

The design and construction of a new building is a complex business that involves many different activities, including initial design, procurement, funding, construction, and compliance processes. It is a process that involves many different people. This complexity poses challenges as well as opportunities for managing seismic risk at the different stages in the planning, design, and construction process. Figure 11 identifies opportunities to manage seismic risk in New Zealand within the building system.

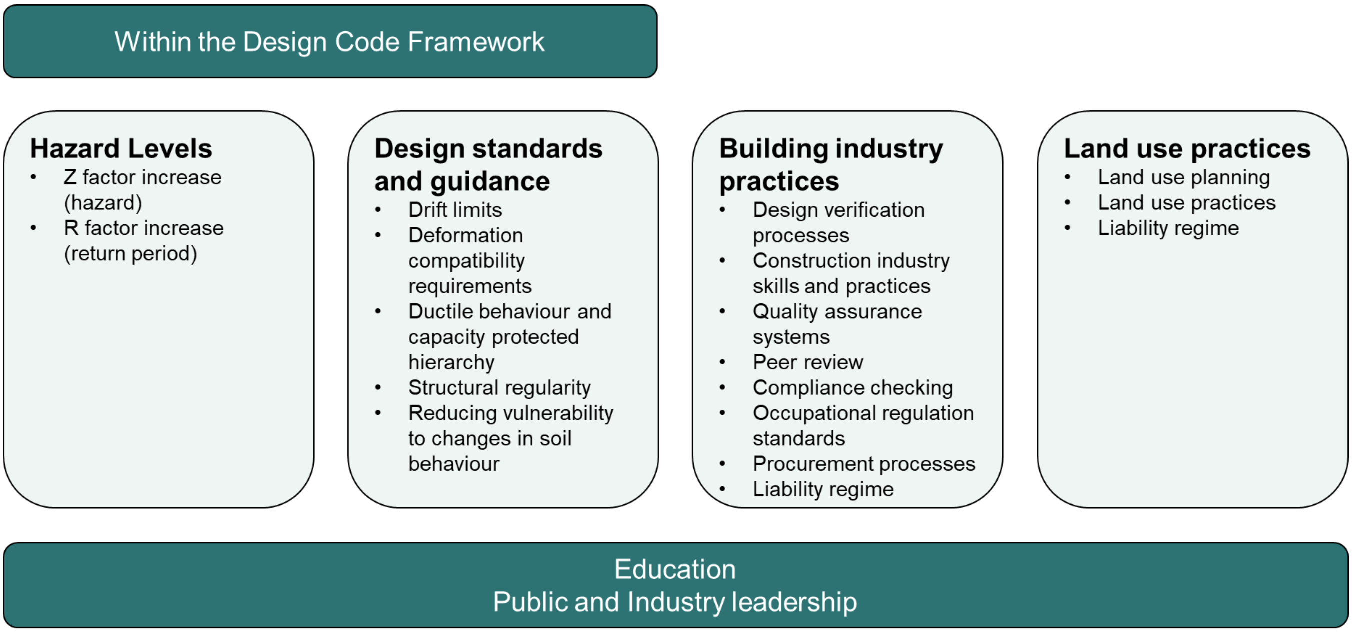


Figure 11 Opportunities identified to manage seismic risk in New Zealand

Within the Design Codes

Opportunities to manage seismic risk during the design process include, but are not limited to:

- Changing seismic hazard levels within the design Code framework - the loadings standard settings, including the hazard level ('Z' factor) are one option for managing the risks or the return period 'R' factor.
- Mandating the observance of sound design principles focussed on achieving consistent seismic performance.

The EPO framework presented here explicitly considers outcomes that include life safety, but also the protection of property and protection of amenity and functionality. This contrasts with the current seismic risk settings of the Building Code which address life safety but mandate only limited mitigations for damage.

There is the potential to mitigate social and economic impacts through its amenity objectives. However, for most structures the serviceability limit state (SLS1) in the loadings standard is currently set for very modest levels of ground shaking and therefore is not a focus for designers. The exception is buildings categorised as structures with special post disaster functions (IL4 buildings). These buildings have more substantial serviceability limit state (SLS2) requirements. This is where the framework can offer practical insights into potential code changes, for minimum settings and/or as a guide for higher (preferred settings) beyond code-minimum levels.

The recent joint NZSEE/SESOC/NZGS advisory on designing for uncertainty[47] highlighted matters that are not directly addressed by the current Code, but which designers should adopt as part of the underlying design philosophy. Those, if applied consistently, will limit damage and maintain functionality in moderate to severe earthquakes. The mechanisms include drift limits, regularity limits, and deformation compatibility requirements. Some or all these mechanisms could, for example, be explicitly included in future Code revisions.

Matters Beyond Code Measures

While approaches to reduce seismic risk within the design Code are important, other mechanisms in conjunction may be equally important to improve building seismic performance.

Many of the most critical observed failures of modern buildings have been related to significant non-compliances[48], so any adjustment of design settings may be futile without consideration of how the compliance regime might enforce them. Building industry practices and land use practices are key determinants of building performance in earthquakes because they embody cultural and political perceptions of hazard and risk. These practices are governed largely by perceptions of risk proximity – the “where and when” – but influenced by experience and the accountabilities of those involved in the building development process.

Where accountabilities are dispersed among building owners, designers, cost estimators, contractors and regulators, the risks, and the rewards for public and industry leadership remain ill-defined. The EPO framework, therefore, provides a potentially valuable tool to “tune” risk treatment options to societal expectations for injury prevention, damage reduction, and avoidance of prolonged disruption.

The EPO framework does not stipulate how the outcome “targets” for seismic performance should be attained. Instead, it invites consideration of the wider built-environment context in which a range of “pinch points” can affect design and construction practices and, therefore, the resilience (or risk) of New Zealand buildings. Appendix K describes observations to indicate where changes to wider industry practices may be possible or desirable to improve the seismic resilience of new buildings.

Examples of possible changes include quality assurance systems and robust independent peer reviews, occupational regulation settings, construction procurement processes and construction compliance systems, and, crucially, liability management settings. Other possible changes extend to land use practices, which are particularly relevant to site stability and foundation design.

---

[47] https://www.nzsee.org.nz/db/PUBS/Earthquake-Design-for-Uncertainty-Advisory_Rev1_August-2022-NZSEE-SESOC-NZGS.pdf.
[48] https://canterbury.royalcommission.govt.nz/.

7. Cost Implications

Applying the EPO framework and evaluating different intervention options to improve outcomes, requires an understanding of the cost and implementation risks of options. Work is needed to understand the cost effectiveness of the different 'levers' identified as having potential to improve seismic resilience, as this work would inform the ranking of potential effort. Additionally, cost-benefit analyses would identify efficient combinations of options.

A pilot approach to assessing *cost effectiveness* has been developed to frame a dialogue with construction industry leaders about options for improving the seismic resilience of buildings (Appendix L). The specific design levers or other codified practices by which seismic performance objectives are achieved are not within the project scope, but examples are mentioned where useful to illustrate our reasoning.

Consideration of non-Code factors influencing seismic resilience has also been necessary because the requirements for engineering design must be proportionate to the capacity of industry to deliver them. Where other factors or industry practices are judged to materially influence risk outcomes for earthquakes, the potential 'levers' for changing those issues need to be identified and considered.

The impact on construction cost is a key consideration for any changes that aim to enhance seismic resilience. While detailed analysis of cost implications can only occur once firm proposals are available to be costed (and consequently, is outside the scope of Stage 3), we have undertaken a first-pass review of the cost implications. Specifically, we explored the question – *Is there a cost premium for provisions to increase seismic resilience for new buildings? If so, what are the implications of any cost premium for the cost effectiveness of measures to increase building resilience?*

An objection that often emerges from key stakeholders is the concern that increasing the seismic components of the Building Code will result in significant increases in the costs of new builds at a time when construction costs are already rapidly escalating. In a straw poll at the 2023 NZSEE conference cost was seen as "the biggest barrier to improving the resilience of our building stock." This is an intriguing finding as the evidence suggests that the cost premium to design new buildings to higher seismic resilience standards is small and it is other issues which dominate total construction costs. We observe construction costs in Wellington are lower than in Auckland despite the seismic hazard factor being three times higher as shown in Table 11 below.

For new buildings, there is a disconnect between the worm's eye view and the bird's eye view of the new building cost premium. From a worm's eye view any increase in costs that can't be fully passed on, eats into narrow profit margins. Looking from a top-down bird's eye view, the 'stylised fact' that emerges from a range of mainly US studies is that the cost premium is low. Improving seismic resilience of say 50% adds comparatively little to new building construction costs, with a midpoint estimate of 1% (in a range of 0-2.0% depending on building type) and even less to purchase costs.[49]

---

[49] NIBS 2019 Mitigation Saves p369 – 370. The 'gold standard ' study cited can be found here https://www.atcouncil.org/files/NIST%20GCR%2014-917-26_CostAnalysesandBenefitStudiesforEarthquake-ResistantConstructioninMemphisTennessee.pdf.

A New Zealand study found a similar cost impact: “The difference in cost is minuscule, usually ranging from 0.5% to 1.5%”.[50] However, the methodology was not as robust as the US NIBS study. We tested the US findings on the low-cost premium in a workshop with NZ experts. Ultimately, we could not identify any reason why the US estimates of the size of the cost premium should not apply to New Zealand.

In a similar vein, we tested whether changes in design practices (regularity, tying, and redundancy) involved any material increase in costs. We concluded that the capital cost implications are so minimal that they are within the 1% estimate above.

Supporting NZ evidence from 2019 is shown in Table 11.[51] It was noted,

> “*For an individual building, the cost will rise with the seismic load as more steel and concrete has to be added to achieve greater levels of resistance in the same structure. However, this changes when viewed at a system level, as other factors come into play. Other factors that may have more influence include:*
>
> - *Architectural design features (necessary to compete to attract tenants)*
> - *Higher market rents supporting more expenditure on the building*
> - *Higher land value requiring more intense development over which to amortise the land cost.”*

Table 11 below shows that commercial office construction costs in Auckland in 2019 were approximately 10% greater than Wellington despite the design seismic load demand being one-third as high. Indeed, there was a negative cost premium in the high-risk zone (Wellington) over other locations. Construction cost inflation since 2019 will have changed the absolute level of costs per square metre, however general price increases by definition would not affect the relative costs in different locations.

Table 11. Representative costs of construction in main centres 2019 (supplied by Rhodes and Associates, QS)

Region	**Wellington**	**Queenstown**	**Christchurch**	**Auckland**
Seismic Hazard Factor (Z)	0.4	0.32	0.3	0.13
Cost/m^2 typical commercial office space	$3,700	$4,000	$3,500	$4000

The initial conclusion from the available evidence is that the cost premia for designing new buildings to enhanced seismic requirements and more resilient non-structural design provisions are low. The evidence that construction costs are lower in Wellington than Auckland suggests the costs of seismic design are dominated by other factors. In short, seismic design is not a defining issue that determines total construction costs, provided a reasonable level of compliance is already achieved.

---

[50] del Rey Castillo, E., Gonzalez, V. & Clifton, G. (2021). *The cost of stronger and stiffer buildings in NZ - cost estimation tools, database development, initial results and future work*. SESOC Conference 2021, Claudelands, Hamilton, New Zealand.

[51] Hare, J. (2019). A different way of thinking about seismic risk: a call for debate. *Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 52, No. 3*, September 2019, pp141-149.

However, there may be a premium for imposing damage control measures on secondary structure and non-structural elements where either no requirements currently exist or where current requirements are poorly understood and enforced. This is because cost estimation databases used for planning new buildings may not have these non-structural costs of improving resilience included. These initial conclusions would need to be explored further as part of developing more detailed codes, standards, and guidelines applying to structural and non-structural seismic elements.

Another consideration is that many improvements can come from factors other than just adjusting demand. For example, we know from observation that buildings with regular structural layouts have far superior performance than irregular ones, but our design methods allow irregular configurations with only nominal design penalty. This penalty may be effective for reducing life safety hazard to acceptable levels but does little for damage and functionality. Factors such as regularity of structure, completeness of load paths, and siting have a far greater impact on the performance of buildings than the level of demand they were designed for. In fact, a lot of seismic design provisions could be seen as ways to facilitate the building of structures of dubious form on inappropriate sites.

A hidden benefit of addressing this issue is that regular buildings on good sites are generally less expensive to build – in other words, it is potentially via the use of more restrictive provisions, that both lower cost and better performance may be achieved.

The experience of prolonged and costly earthquake-related disruption in recent years combined with the prospect of reduced earthquake insurance protection and higher risk premiums have begun to influence thinking about mitigation, but a puzzling question that emerged from the research is why we don't find many buildings in New Zealand constructed above Code when people seem to want more resilient buildings.

The stylised fact from interviews with industry experts (including BRANZ drawing on a series of studies of residential dwellings) is that new buildings above Code for seismic risk in New Zealand is so rare that the exceptions prove the rule. This raises a puzzle as the societal expectations research strongly suggested that Kiwis wanted buildings that are more resilient to earthquakes. Moreover, the research evidence cited above suggests that the direct cost premium for new buildings is minimal.[52] This puzzle arises because there is a *commitment problem*[53] arising from the interaction between the supply-side and demand-side factors in the construction industry.

A **commitment problem** is a situation in which people cannot achieve their goals because of an inability to make credible threats or promises.
A **commitment device** is a way of changing incentives so as to make otherwise empty threats or promises credible.

The problem with building above Code is the lack of credible commitment devices for the resilience of the buildings. Some structural features like base isolators can be easily observed but many others are hidden

---

[52] There is mixed evidence on the extent to which property prices and rentals reflects life safety factors. Hoang et al (2021) indicated that market forces typically ignore life safety. Blake et al found the exact opposite, while Timar Grimes & Fabling found that after the Christchurch earthquake property prices initially reflected relative seismic risk but this effect disappeared over a 2-3 year period. See Levente Timar, Arthur Grimes, Richard Fabling, That sinking feeling: The changing price of urban disaster risk following an earthquake, International Journal of Disaster Risk Reduction, Volume 31, 2018, Pages 1326-1336, ISSN 2212-4209.

[53] Commitment problem and commitment device are defined at https://www.econport.org/content/teaching/modules/NFG/Commit.html.

from view like ceiling bracing or regular structural system layouts.

There is substantial uncertainty associated with the performance of buildings and building elements in earthquakes. A commitment problem for the resilience of buildings arises because a combination of supply and demand side factors contributes to this uncertainty. On the supply side, building performance is the result of the complex interaction of sub-systems (design, construction, oversight) and how they respond to uncertain seismic shocks (direction, intensity, duration, periodicity). The complex web of supplier contracts (owner, developer, designer, developer, sub-contractors, tenants) makes monitoring and enforcing commitments practically impossible. This is accentuated on the demand side by fundamental uncertainty – ordinary people cannot be confident about representations of how a building will perform in response to future earthquakes. And because the value of increased resilience cannot be easily signalled and captured, contractors are incentivised to drive resilience out of buildings by reducing cost by, for example, reducing seismic bracing for non-structural elements. Future research could focus on exploring the levers that can be used to address the commitment problem.

8. Conclusions

8.1. Framing the Scope of Seismic Resilience

How do New Zealanders in the 2020s want buildings to perform during and after an earthquake?

Do current regulatory and technical approaches to seismic risk management provide buildings that meet expectations? If not, what frameworks should be used to guide the changes in required seismic standards, codes, and practices in New Zealand?

The Resilient Buildings Project was conceived to explore these questions and to consider how the findings would allow societal expectations to be considered more explicitly for design or construction. The findings revealed the need for a framework that explicitly maps building performance to building user and community outcomes.

To achieve these aims the Resilient Buildings Project has:

1. researched user's expectations for the seismic performance of buildings,
2. evaluated the gap between current code provisions and those expectations, and
3. developed the EPO framework that relate user expectations to the seismic performance of expected of buildings.

Completion of Stage 3 (this stage) marks the culmination of this work.

The EPO framework provides a tool to enable the conversion of societal expectations into performance outcome objectives (and vice versa). The framework is impartial to how desired performance may be achieved. No solutions are stipulated, and no absolute requirements are mandated.

Rather the framework helps show where factors additional to life safety may drive performance outcomes, which can be used to inform regulatory requirements for minimum acceptable compliance. Equally, the EPO framework can facilitate consideration of potentially higher preferred levels of seismic performance for different building usages, many of which may be explored by industry working with building owners and investors.

8.2. Do Buildings Designed to Current Code Meet Today's Expectations?

This work indicated that current societal expectations relating to injuries and deaths broadly align with the current New Zealand Code requirements for design and construction of buildings. Safety is considered non-negotiable and desirable at all levels of shaking.

However, outcome preferences relating to damage exceed what the current Code provides in moderate, strong, and severe shaking by an order of magnitude. Similarly, outcome preferences relating to amenity and functionality exceed what the current Code provides in intermediate and strong shaking by an order of magnitude, with people expecting buildings to retain function or return to function much sooner than the current Code delivers. If societal expectations are to be better met, protection of property and amenity and function will need to be explicitly considered for the design and construction of new buildings. Whether or not this is achieved through the Code or other non-regulatory mechanisms is work still to be undertaken.

Our findings indicate a gap now exists between what the current Building Code achieves and what is expected of it. The EPO Framework introduced here offers a tool to address these discrepancies by enabling consideration of impact-focused, design objectives that explicitly address the different dimensions of building performance associated with damage and disruption, in addition to life safety. This tool can be used both to inform performance objectives in future design codes and guidelines. It also provides a mechanism to guide building owners when considering options to improve aspects of resilience of individual buildings.

Furthermore, building uses that are likely to have heightened consequences of failure, relative to a ‘typical’ building, have been identified. These differ to those currently allowed for in the current importance level (IL) ratings. Understanding why certain buildings would benefit from enhanced performance will enable targeted implementation of higher performance objectives. Raising the standards of performance for these important buildings will improve overall community resilience and ensure that investment in seismic resilience is directed to buildings that have the most community benefit.

8.3. What Other Factors Shape Risk, and What About Cost?

Changes to Code settings are an obvious mechanism to respond to the gap between current Code settings and societal expectations of performance in earthquakes. However, we have also identified that other mechanisms are relevant to seismic risk management and improving building performance. These range from quality assurance systems and peer review of designs to occupational regulation of competencies, construction procurement processes, construction compliance systems and crucially, liability management settings. Other factors include land use practices, which are particularly relevant to building-site stability and foundation design. Our work has indicated that improving the seismic resilience of buildings does not necessarily involve additional cost.

Preliminary cost investigations, using available evidence on the cost premium for constructing more resilient new buildings, suggests that the premium is low. This implies that there are cost effective ways to achieve improvements in new buildings’ seismic resilience. However, our assessment also indicates that the way the construction industry operates delivers imperfect signals about costs and benefits, resulting in misapprehensions about the affordability of seismic resilience. Part of the development of changes proposed to improve new building resilience, should include an assessment of the costs and benefits.

Decisions on future seismic performance settings are beyond the scope of the Resilient Buildings Project. However, the project findings highlighted that New Zealanders would prefer buildings that sustained less earthquake damage and were able to retain function or return to function much sooner than the current code delivers. It has also highlighted to opportunity for seismic settings to better tailored to the specific performance needs of different building usages. The project has identified a range of opportunities for change both within design codes and outside (including building industry practices and land use planning) to improve seismic resilience of buildings.

8.4. Next Steps

The overarching purpose of the RBP is to improve the overall seismic performance of new buildings in New Zealand. This is an ongoing focus for NZSEE. The aim is that by focussing on improving the resilience of new buildings the overall resilience of the built environment will be raised over time to the benefit of all New Zealanders.

The project was designed with a number of aligned initiatives in sight. The RBP aims to inform future reviews of seismic risk settings so that societal expectations can be considered in the deliberations and potentially better reflected in future in the Building Act, Building Code and associated standards[54] [55]. It also aims to inform future industry practices focussed on improving the resilience of new buildings designed and constructed in New Zealand.

The RBP has already informed and continues to inform the direction of the MBIE Seismic Risk Working Group in its considerations of future changes to design approaches. The aim is to ensure our built environment contributes to better outcomes for society, recognising cost and sustainability. The RBP is informing the MBIE Low Damage Seismic Design Project, currently underway, which aims to produce guidance documents for building owners and engineers considering and designing above code minimum buildings.

Inevitably a sustained programme of research throws up a number of lines of inquiry about the framework that could usefully be explored further, a number are identified through the report and no doubt others will emerge.

The focus now, though, must be to harness the gains from the investment that has been made in the project and to improve the resilience of new buildings going forward. To fully realise the value of the project, effort is needed by all working to improve New Zealand's resilience including those in government, research groups, and practice.

NZSEE, as the initiator of this project, has planned some immediate next steps to support this process, with a focus on socialising the findings and advocating for change. These include:

- Developing guidance about the EPO framework to complement the policy brief prepared at the conclusion of Stage 2 of the project titled "*How do Kiwis want buildings to perform during and after an earthquake?*". This will explain the findings of the project in way that is easily accessible to both policy makers and the public.
- Socialising both of the societal expectations research findings and the EPO framework with the earthquake engineering community starting with a plenary session planned for the NZSEE conference in 2024.
- Informing and advocating both the Seismic Risk Working Group and Low Damage Seismic Design initiatives currently underway to encourage the incorporation of findings in future code revisions and design guidance for above code minima design.

NZSEE plans to then continue advocating for seismic resilience improvement, informing future updates to design standards along with design and construction practices.

Further and in addition to these NZSEE led initiatives, and as a first broader step in the endeavour a workshop is recommended. The aim of this workshop is to align, coordinate and

---

[54] While Stage 2 of the RBP collected data on societal expectations and we have used this data to inform Stage 3, it is the code development process that will contemplate the extent to which the expectations collected translate into minimum code settings. This will include consideration of cost implications and policy efficacy.

[55] Ministry of Business Innovation and Employment (2020) Seismic Risk and Building Regulation in New Zealand, Findings of the Seismic Risk Working Group. New Zealand Government, Wellington. 50pp.

plan future efforts toward improving seismic resilience. New Zealand has a relatively small resource base so coordination is necessary to avoid duplication of effort and maximise impact. It is recommended representation at this workshop be broad, cross disciplinary (economists, social scientists and engineers) and include groups from government, research, and practice.

The recommended focus of the workshop is key considerations for incorporating societal expectations into future overall seismic performance of new buildings in New Zealand. The workshop should explore how issues such as risk tolerance and willingness to pay for reducing seismic risk can be addressed. In addition, the workshops could build on the work done here to identify possible design and construction industry practices that can be implemented and used immediately (or with little effort) to improve the seismic resilience of new buildings. Identifying and actioning simple steps towards improved performance will create momentum for change.

Going forward the focus of seismic resilience work needs to extend beyond possible design focussed changes to include wider building industry and land use practices. These aspects are equally, if not more, important to improving seismic resilience.

9. Glossary

This glossary provides the working definitions for terms used within the Resilient Buildings Project. Commentary is provided where these definitions may vary from those provided by the Code and Standards.

Amenity

An attribute of, or system in, the building that provides services related to the use of the building by occupants or that contributes to the comfort of the occupants, and that is not necessary for the minimal protection of the occupants (for example an automatic sprinkler system is not an amenity).[56]

See also Function.

Commentary: The New Zealand Building Code defines amenity as 'an attribute of a building which contributes to the health, physical independence, and wellbeing of the building's users but which is not associated with disease or a specific illness.' We chose to use the ICCPC definition because it offers more specificity as to the building attributes that contribute to wellbeing and excludes the minimum protection of occupants from the definition.

Building Performance

Building performance is how a building responds to an exterior load.

Commentary: See commentary for 'Building Performance Objective.'

Building Performance Objective

A performance objective is defined when an aspect of building performance is paired with a hazard. These types of statements are typically qualitative and include terms such as 'low probability' and 'acceptable' or 'unacceptable'.

Commentary: New Zealand Building Code defines performance as 'The performance criteria the building must achieve. By meeting the performance criteria, the Objective and Functional requirement can be achieved.' Objective is defined as 'social objectives the building must achieve.' Functional requirement is defined as 'functions the building must perform to meet the Objective.' We chose to not use these definitions due to their ambiguity and circular referencing. Further discussion on Performance Objectives is provided in Appendix F: Dimensions of Building Performance.

Building Usage

A quality of a building or group of buildings relating to its use, function, or occupancy that might influence a need for enhanced seismic performance.

Commitment Problem

A situation in which people cannot achieve their goals because of an inability to make credible threats or promises.[57]

---

[56] International Code Council (ICC). (2021). *ICC Performance Code for Buildings and Facilities (ICCPC 2021).* https://codes.iccsafe.org/content/ICCPC2021P1

[57] Experimental Economics Center. (2006). *Commitment Problems and Devices*. https://www.econport.org/content/teaching/modules/NFG/Commit.html

Commitment Device

A way of changing incentives so as to make otherwise empty threats or promises credible.[58]

Cost Effectiveness

Cost effectiveness is defined as meaning the means of achieving a desired outcome at the lowest possible cost.[59]

Cost effectiveness in everyday language is ‘bangs for bucks’. It is a way to compare the outcome (bangs) and cost (bucks) of different interventions. Unlike cost-benefit analysis, cost effectiveness analysis does not attempt to value the outcomes delivered. It simply ranks interventions in terms of the cost of delivering a single outcome such as protection of function.

Dimension of Building Performance

The overarching goals for building seismic performance. The dimensions of building performance relevant to the Project are summarised in Figure 3.

Function

An attribute of, or system in, the building that contributes to the ability to fully utilise a facility. The basic functions of a building are to provide shelter and protection and to support activities within it.

See also Amenity.

Commentary: Function can be conceptualised in various ways, but for the purposes of this Project, ‘function’ is distinguished from ‘amenity’. This distinction follows terminology introduced by Professor Dirken (1972), who uses the terms primary and secondary functionality. Primary functionality (similar to our term ‘function’) means the utility value or effectiveness of a product. Secondary functionality (similar to our term ‘amenity’) is concerned with function as a bearer of meanings, as for example a building as a means of expressing status, evoking a sense of beauty or representing the kind of experiential values that are described in terms such as 'pleasant', 'pleasing' or 'attractive'.[60]

Impact

Broad long-term effects on wellbeing impacts. Impacts are typically location-specific and evaluated at the community level.

See also Outcome.

Commentary: The terms 'outcome' and 'impact' are often used interchangeably – and when defined so they are distinct, different sources used the terms in opposite ways. For the purposes of this Project, outcome refers to the specific short-to-medium-term effects, and impact refers to broader long-term direct and indirect effects on wellbeing. Impacts and outcomes can be either qualitative or quantitative.

---

[58] Ibid

[59] https://www.precursive.com/post/cost-effectiveness-vs-cost-efficiency-what-s-the-difference

[60] van der Voordt, van der, & Wegen, van. (2007). Architecture In Use (1st ed.). Taylor and Francis. Retrieved from https://www.perlego.com/book/1622142/architecture-in-use-pdf (Original work published 2007)

Indicator

An observable criterion that describes, measures, or otherwise summarises an effect. Indicators can be qualitative or quantitative.

Commentary: Definition is based on a definition provided by Kay et. al. (2019)[61].

Loss Exceedance Curve

As used here, a relationship between the degree of undesirable outcome (loss) and the expected value of the likelihood that the degree of loss is exceeded. Depicted with a curve in x-y space where x = exceedance likelihood and y = loss.

Commentary: Definition is based on a definition provided by Porter (2018)[62].

Onset of Damage

The initial shaking-induced damage to a building's elements. Includes damage to structural elements, non-structural elements, and essential contents.

Outcome

Specific short-to-medium-term effects on wellbeing. Outcomes are typically site-specific and evaluated within the individual building footprint.

See also Impact.

Commentary: The terms 'outcome' and 'impact' are often used interchangeably – and when defined so they are distinct, different sources used the terms in opposite ways. For the purposes of this Project, outcome refers to the specific short-to-medium-term effects, and impact refers to broader long-term direct and indirect effects on wellbeing. Impacts and outcomes can be either qualitative or quantitative.

Risk

The likelihood and consequences of a hazard[63] (CDEM Act 2002).

Shelter-in-Place

The use of a structure to temporarily separate individuals from a hazard or threat. Sheltering in place is the primary protective action in many cases. Often it is safer for individuals to shelter-in-place than to try to evacuate. Sheltering in place is appropriate when conditions necessitate that individuals seek protection in their home, place of employment, or other location when disaster strikes (FEMA-P2005).[64]

---

[61] Kay, E., Stevenson, J., Bowie, C., Ivory, V., & Vargo, J. (2019). The Resilience Warrant of Fitness Research Programme: Towards a method for applying the New Zealand Resilience Index in a regional context. https://resiliencechallenge.nz/wp-content/uploads/NZRI_Regional_Applications_Research_Report_June_2019.pdf

[62] Porter, K. (2018). *A Beginner's Guide to Fragility, Vulnerability, and Risk*. University of Colorado Boulder. Retrieved Aug. 2018, from http://www.sparisk.com/pubs/Porter-beginners-guide.pdf

[63] Civil Defence Emergency Management Act (CDEM Act) 2022. https://www.legislation.govt.nz/act/public/2002/0033/latest/DLM149789.html?search=ts_act%40bill%40regulation%40deemedreg_Civil+Defence+Emergency+Management_resel_25_a&p=1

[64] FEMA. (2019). *Post-Disaster Building Safety Evaluation Guidance, FEMA P-2055.* https://www.fema.gov/sites/default/files/2020-07/fema_p-2055_post-disaster_buildingsafety_evaluation_2019.pdf

Vulnerability

The degree of some undesirable outcome. Vulnerability measures the potential for loss.

Commentary: Definition is based on commentary provided by Porter (2018).

Wellbeing

Wellbeing is when 'people are able to lead fulfilling lives with purpose, balance and meaning to them'.[65] Wellbeing is a multi-faceted concept. For the purposes of this Project, four categories of wellbeing were considered:

- **Human** wellbeing includes people's physical and mental health.
- **Social** wellbeing involves capabilities and capacity of people to engage in work, study, recreation, and social activities. It includes the norms, rules and institutions that influence the way in which people live and work together and experience a sense of belonging. Includes trust, reciprocity, the rule of law, cultural and community identity, traditions and customs, common values, and interests.
- **Economic** wellbeing includes physical assets, usually closely associated with supporting material living conditions; includes building, equipment, and infrastructure damage, and the loss of income/productivity associated with damage to these. The employment and wealth necessary to provide many of the requirements that make for social wellbeing, such as health, financial security, and equity of opportunity.
- **Environmental** wellbeing involves all aspects of the natural environment needed to support life and human activity, including air quality, land, soil, water, plants and animals, minerals and energy resources.

Commentary: The wellbeing definitions are based on the Taituarā community wellbeings[66] with some influence from the Treasury Higher Living Standards Framework.[67]

---

[65] Government of New Zealand. (2019). The Wellington Budget, 30 May 2019. https://treasury.govt.nz/sites/default/files/2019-06/b19-wellbeing-budget.pdf

[66] Taituarā. (2022). *What are the wellbeings?* https://taituara.org.nz/Article?Action=View&Article_id=216\

[67] Te Tai Ōhanga The Treasury. (2021). *Our Living Standards Framework*. https://www.treasury.govt.nz/information-and-services/nz-economy/higher-living-standards/our-living-standards-framework