Can circular economy construction methods support flood resilient public housing?

A case study that explores how CEC can support structural and social resilience

Research Report
November 2024

THIRD STUDIO

F. Gordon Wilson Fellowship for Public Housing 2023

Te Kāhui Whaihanga
New Zealand Institute of Architects

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Executive Summary

This report details a 12-month research project that investigates the potential of circular economy construction (CEC) systems to enhance flood resilience in public housing in Aotearoa. It explores the connections between structural resilience and social resilience alongside industry and community perspectives, revealing a complex landscape of opportunities, challenges, and innovative thinking. The research uncovered the complex interplay between technological innovation, social needs, and environmental challenges.

Recent extreme climate events in Aotearoa have underscored the need for housing practices that support both structural and social resilience. With two-thirds of New Zealanders living in flood-prone areas, the scope of the research narrows to CEC timber framing systems and explores the opportunities and challenges of implementing such a system in Aotearoa compared to typical building practices we see currently. The research methodology includes a literature and precedent review, industry engagement, and interviews with key industry and community leaders. It develops design principles for flood-resilient housing and presents three scenarios to compare possible solutions.

The preliminary research delves into international and local approaches to flood-resilient housing, the integration of mātauranga Māori, and the potential of CEC methods. Key points include:

Flood-resilient housing

Internationally, flood management is shifting from risk-based to resilience-based approaches, with examples from the Netherlands, Pacific Islands, the UK, and the US highlighting various strategies such as proactive water management, indigenous knowledge, and modular construction. In Aotearoa, case studies from Hawkes Bay, Auckland, and Tāneatua illustrate different flood-resilience strategies, emphasizing the importance of site-specific solutions and community involvement.

Mātauranga Māori and climate resilience

Traditional Māori knowledge offers valuable insights into climate resilience, with practices such as establishing settlements in safe locations and using marae as welfare hubs during climate events. The holistic and community-oriented approach of mātauranga Māori contrasts with Western linear construction processes, making it highly valuable for building social resilience.

Circular economy construction methods

CEC systems aim to minimize waste and maximize resource efficiency through design for disassembly, use of recycled materials, and modular construction. These systems can support climate-resilient housing by reducing environmental impact, improving resource efficiency, and fostering community resilience.

Industry and community engagement

Interviews with industry experts and community leaders reveal a need for simple, affordable, and innovative housing solutions that are financially and environmentally sustainable. There is a lack of research and built case studies on the connection between CEC systems and housing, highlighting the need for further investigation and pilot projects.

Design principles for flood-resilient homes

The report outlines high-level design principles, including considering site context, increasing site permeability, and using materials and construction methods that facilitate quick recovery after flood events.

Case study

The case study firstly evaluates various commercially available timber CEC systems and presents three design scenarios that were analysed by industry and community leaders.

» Evaluation Criteria: Criteria include local sourcing, movability, assemblability, suitability for public housing, and potential to speed up drying post-flood.

» CEC Systems Evaluated: Systems include U-Build (UK), Easy Housing (Uganda), XFrame (Aotearoa), WikiHouse (UK), and EasyBuild (Aotearoa).

XFrame was selected for the design scenarios due to the systems' alignment with the design principles.

Design scenarios

» Scenario 1: Typical Approach: Conventional construction with a concrete slab foundation and timber framing. Challenges include long drying times post-flood and limited salvage options.

» Scenario 2: Bunker Approach: Hybrid design with a concrete lower storey and XFrame upper storey. Offers flood resilience but has permeability issues in urban settings.

» Scenario 3: Hybrid CEC Approach: Fully modular design using XFrame for structural wall elements. Emphasises disassembly, relocation, and quick recovery post-flood.

The research highlights the need for flood-resilient housing that balances structural, social, and environmental considerations. CEC systems offer innovative solutions but face challenges such as high upfront costs and lack of built case studies. Further research and pilot projects are needed to demonstrate the value of CEC systems and develop comprehensive frameworks for flood-resilient housing. The research underscores the potential of CEC systems to create adaptable, sustainable, and resilient housing solutions in flood-prone areas, while also identifying the challenges and opportunities for their implementation.

Overall, the research demonstrates that flood-resilient housing requires a holistic, adaptive approach. By integrating technological innovation, environmental sustainability, and cultural sensitivity, we can develop housing solutions that protect both physical infrastructure and community well-being.

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About the Authors

This collaborative research is led by architectural and urban design practice, Third Studio, the inaugural recipients of the F. Gordon Wilson Fellowship for Public Housing.

Our practice is focused on empowering communities, rangatahi and mana whenua with tools and processes that support their agency in shaping the built environment. Leading this exploration are Ellie Tuckey (pākehā) and Mitra Homolja (tauiwi), weaving their architectural and urban design expertise, experiences working alongside community groups and personal experiences living in a Kāinga Ora home.

This research represents an opportunity for us to integrate our personal narratives and professional expertise into a meaningful investigation. It is important to acknowledge that while we deeply value and seek to understand the wisdom of mātauranga Māori, this research does not claim to be Kaupapa Māori. We recognise the boundaries of our perspectives and positionality, and thus, we do not seek to speak on behalf of mana whenua or claim authoritative knowledge. Our collaboration is grounded in a commitment to gaining contextual insights and enhancing research integrity through engagement with real-life community contexts. We intend to contribute respectfully and responsibly to discussions on urban resilience and community empowerment, striving to enrich the discourse with our diverse perspectives and experiences.

Part 1

INTRODUC

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Background

Recent extreme climate events in Aotearoa have underscored the challenges, opportunities, and shortcomings of current housing practices, highlighting the need for a deeper understanding of housing can support structural and social resilience.

Around two-thirds of New Zealanders reside in naturally flood-prone areas (McSaveney, 2006).

Key Term

Circular Economy

An economic model designed to minimise waste and make the most of resources. A circular economy aims to keep resources in use for as long as possible, extract the maximum value from them while in use, and then recover and regenerate products and materials at the end of each service life.

Climate-related flood risks in Aotearoa and Te Awa Kairangi ki Tai (Lower Hutt)

Urban development and planning has resulted in about two-thirds of New Zealanders now residing in naturally flood-prone areas (McSaveney, 2006). In addition to housing, sites of social resilience such as health centres, community hubs and marae are also at risk. Māori communities are particularly vulnerable with 80% of marae situated on flood-prone land (Stewart, 2023).

Like many regions around the country, Wellington faces increasing coastal hazards, heavy rain, erosion and landslides, droughts and other biosecurity issues (Ministry for the Environment, n.d.) due to the changing climate. Within the region, Te Awa Kairangi ki Tai (Lower Hutt) is Aotearoa's most densely populated flood plain. The river, Te Awa Kairangi, is prone to flooding, the foreshore is slowly sinking, and sea level rise is looming.

Construction in flood-prone areas

Despite increasing risks from climate-induced flooding, housing construction continues and Te Awa Kairangi ki Tai is on a trajectory to increased density. Kāinga Ora is actively constructing public housing in flood-prone areas such as Waiwhetū, Wainuiomata, Moera, Boulcott, and Petone, where 1-in-100-year flooding events are likely to occur at much greater frequency than their name would suggest (Greater Wellington Regional Council). Conventional construction methods for housing pose liabilities during severe flood events using construction methods that are intended for permanence. There is little financial incentive to adapt construction processes and materials, which would support more resilient homes and communities.

The circular economy in Aotearoa's construction industry

The circular economy is posited to provide some "systemic, synergistic solutions" for climate action that bridge mitigation and adaptation (Elobeid & Schnitger, 2023).

Aotearoa's building and construction sector "consumes more than 50% of all raw materials while simultaneously generating more than half of all waste sent to landfill" (Finch et al., 2017). From a mitigation perspective, research shows that circular economy construction (CEC) systems can improve resource efficiency and environmental sustainability whilst reducing operational costs, leading to healthier and more resilient communities. Simultaneously, CEC systems can support adaptation to a changing environment via resource efficiency and modular design practices (Elobeid & Schnitger, 2023).

Key Term

Circular Economy Construction (CEC)

Building and construction systems which adhere to the principles of circular economy.

An Aotearoa New Zealand approach to flood resiliency

Mātauranga māori is crucial to building climate resiliency and it is important to emphasise that it is localised. Knowledge and priorities vary from community to community, iwi to iwi, hapu to hapu.

Each group is facing different climate risks based on their geographic and socio-economic contexts. Therefore, conversations and planning for mitigation, adaptation and/or re-location are highly complex and needs resourcing.

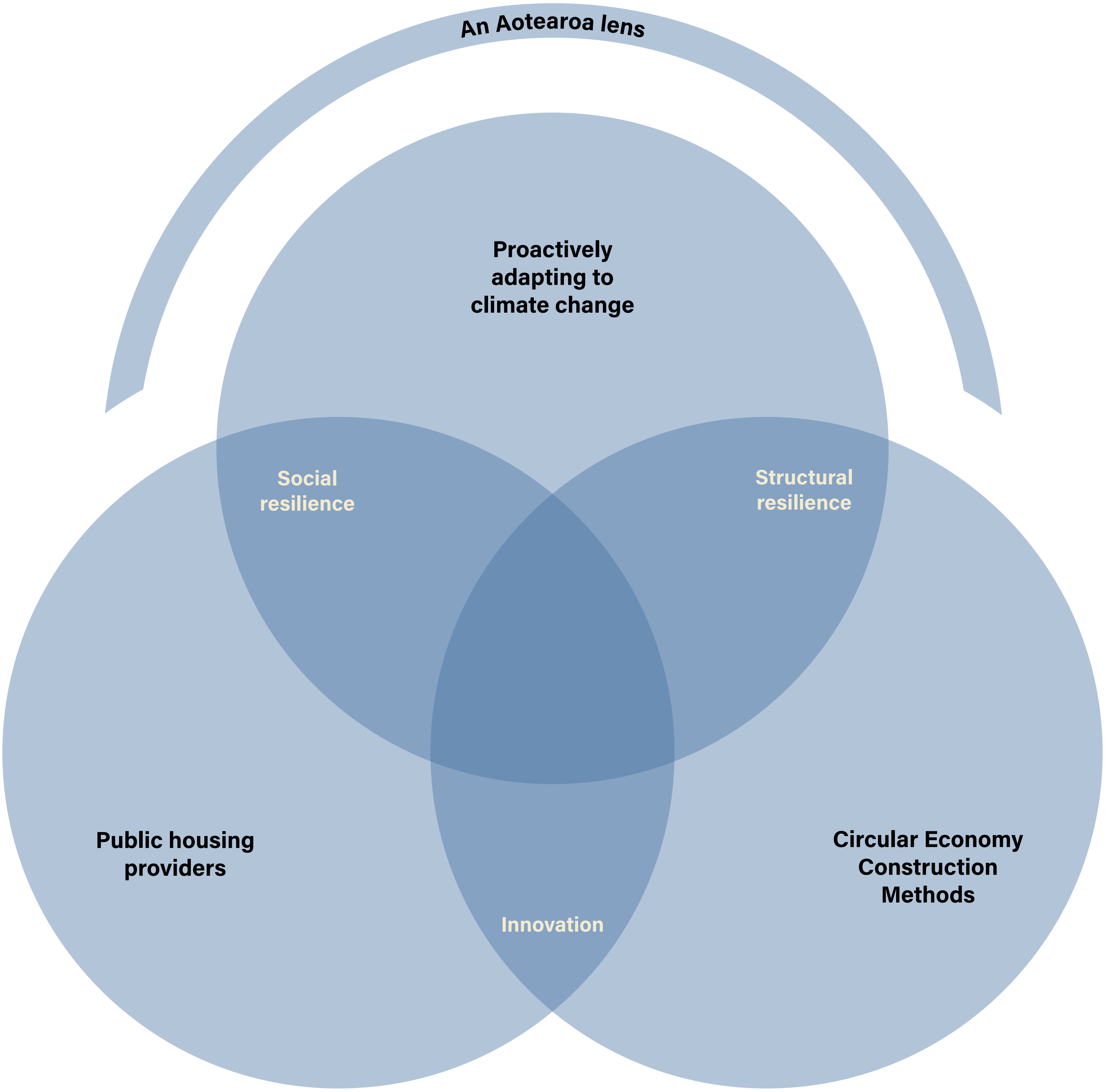
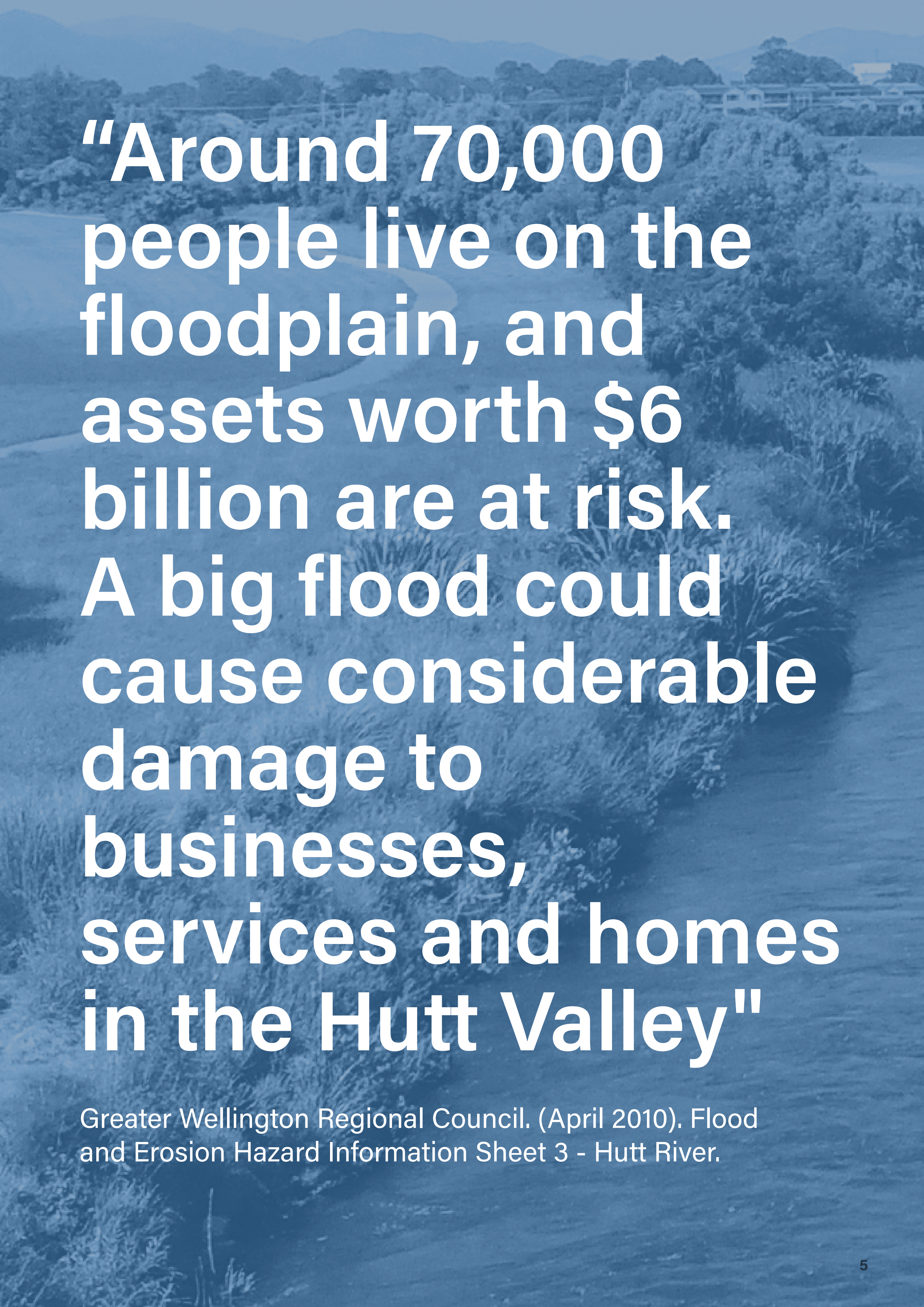


Fig.1. Overlapping research lenses.



“Around 70,000 people live on the floodplain, and assets worth $6 billion are at risk. A big flood could cause considerable damage to businesses, services and homes in the Hutt Valley"

Greater Wellington Regional Council. (April 2010). Flood and Erosion Hazard Information Sheet 3 - Hutt River.

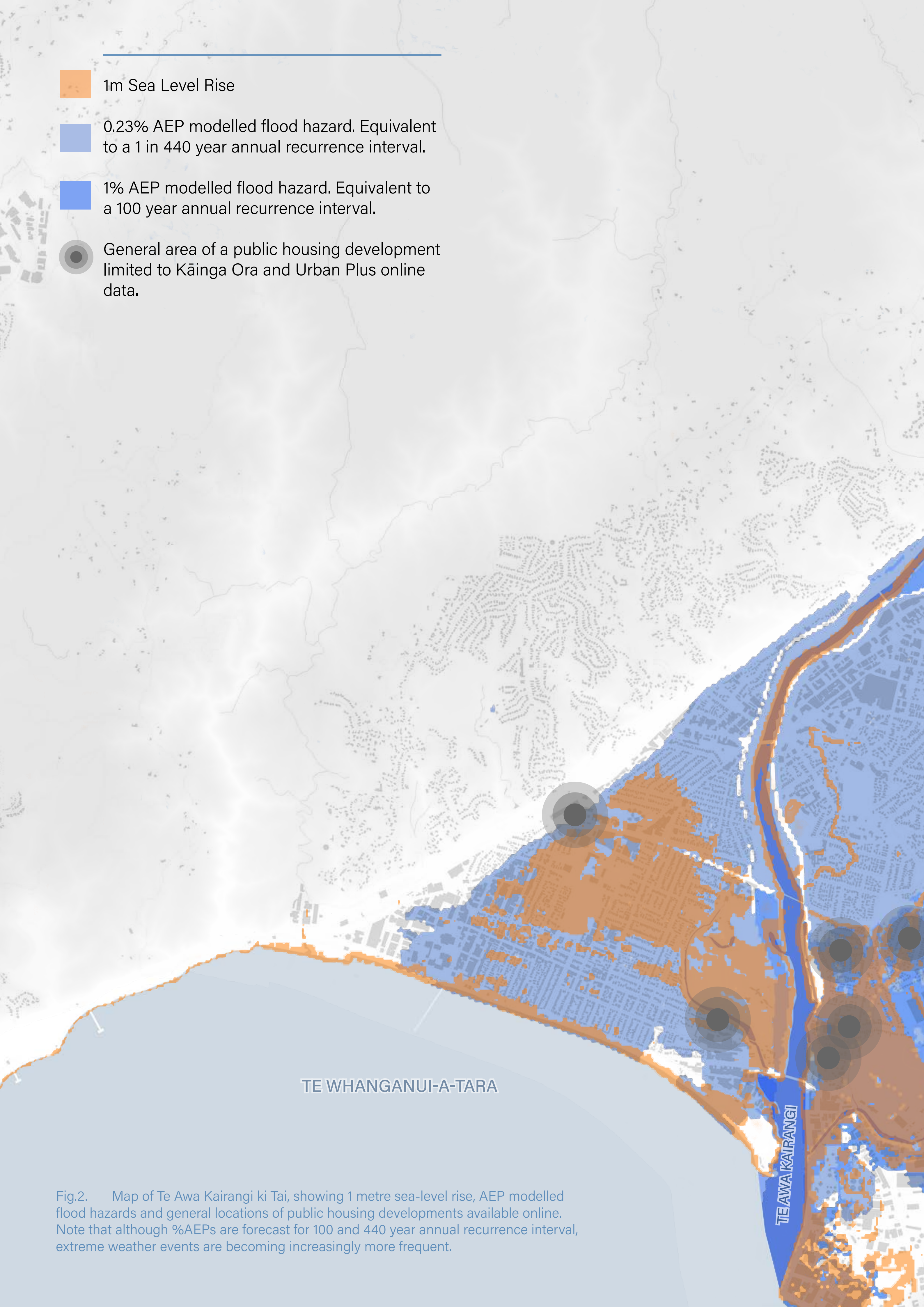
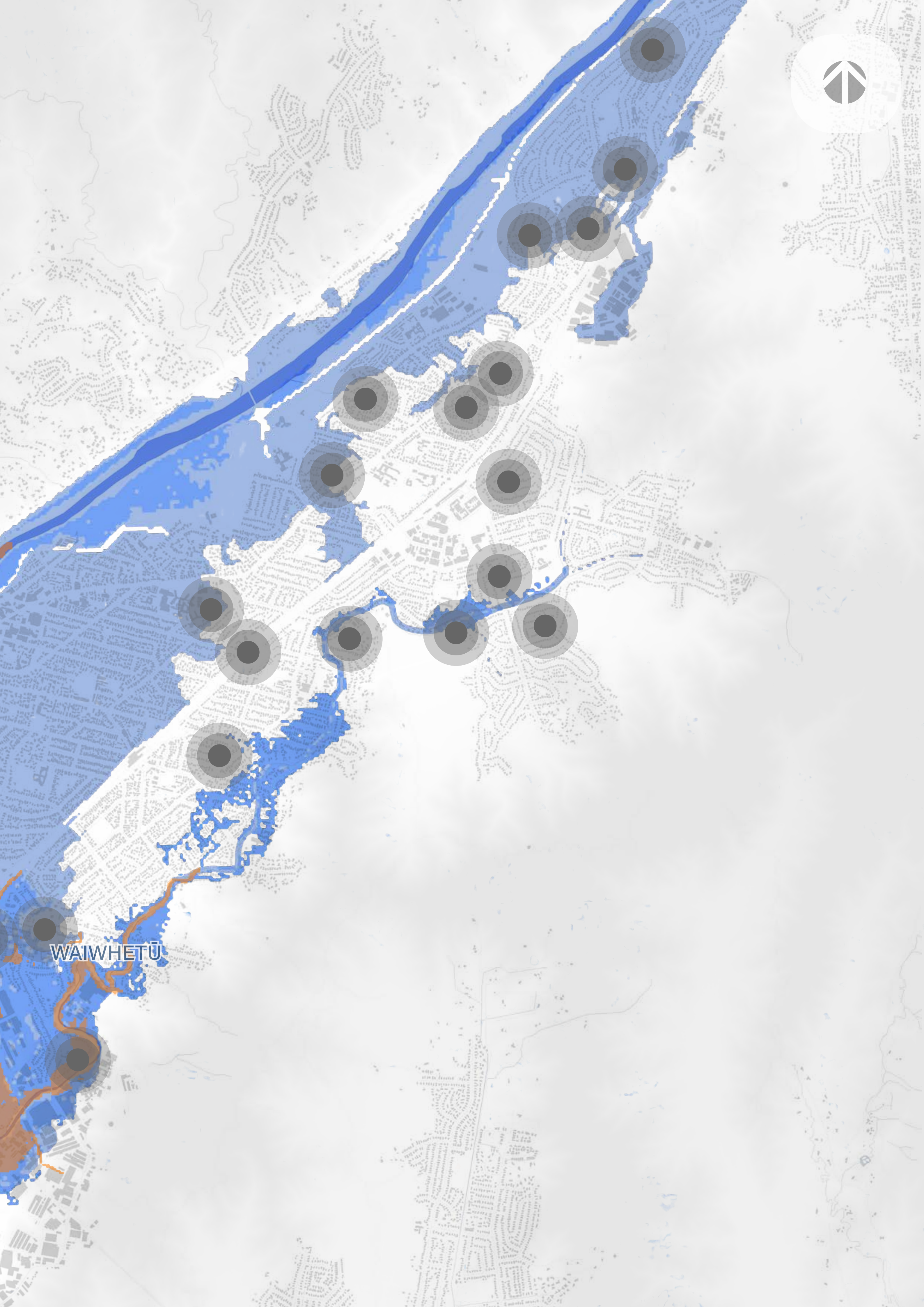


Fig.2. Map of Te Awa Kairangi ki Tai, showing 1 metre sea-level rise, AEP modelled flood hazards and general locations of public housing developments available online. Note that although %AEPs are forecast for 100 and 440 year annual recurrence interval, extreme weather events are becoming increasingly more frequent.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Scope

This case study explores circular economy construction systems which enable change-of-use and end-of-life recovery. These systems have the potential to create resilient public housing, that, in turn, supports social and climate justice in Aotearoa.

The scope has been narrowed to timber framing systems given that most homes in Aotearoa are built to NZS 3604 timber framing standards.

The result is a timber CEC case study exploring 'a' solution to flood-resilient homes and communities, that both housing providers and communities can consider for their context.

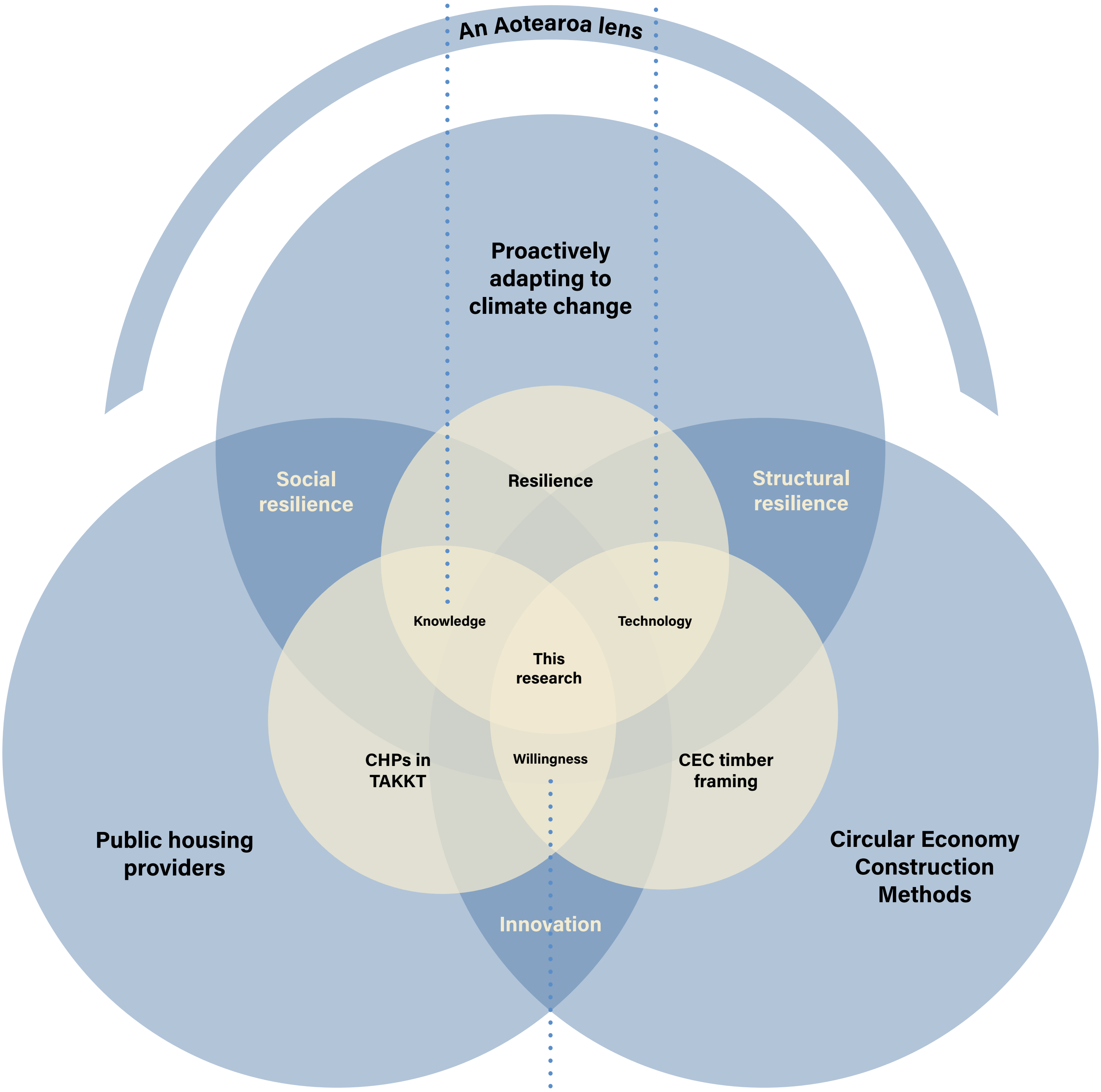
It is a bite-size piece of research and forms further avenues of enquiry for the construction industry and communities to explore in their local context.

The primary research question is:

How can **timber circular economy construction systems** support **structural resilience** in public housing and the **social resilience** of communities?

- What CEC timber framing technologies are there?
- What are their upfront costs versus their lifelong costs?
- Can CEC methods be low cost?
- How do they respond to flooding events? Is this better or worse than conventional timber framing?

- Are CHPS considering structural resilience of the homes they're building? Why? Why not?



- What building techniques are CHPs considering?
- Are they willing to consider something that is not mainstream?

Fig.3. Positioning the research.

Methodology

This area of research is complex and has wide-reaching issues. The objective of this project is to understand the synergies between housing, CEC and flood-resilience in order to create and compare a control scenario with a CEC scenario.

The research is structured as follows:

1. Literature and precedent review

» Review relevant literature and precedents of CEC, flood resilient housing and mātauranga Māori and housing.

2. Industry engagement and interviews

» Engage with the architectural industry to get a sense of the perspectives held by industry professionals.

» Interview key industry and community leaders (architects, CEC practitioners, community housing providers, and housing experts).

3. Design Principles

» Develop baseline design principles for flood-resilient housing.

4. Scenario development

» Assess timber CEC systems for resilience performance and practicality.

» Create three housing scenarios which prompt conversations with communities, architects and organisations about the possible CEC solutions for flood-resilient houses.

5. External review and critique

» Consult architectural professionals, CEC experts and community leaders to discuss the possible opportunities and challenges each scenario provides.

6. Analysis and discussion of findings

7. Dissemination of research

» Compile findings into a comprehensive report and presentation with key insights, analysis, discussion, and recommendations for next steps.

» Present findings through workshops and publish in relevant journals.

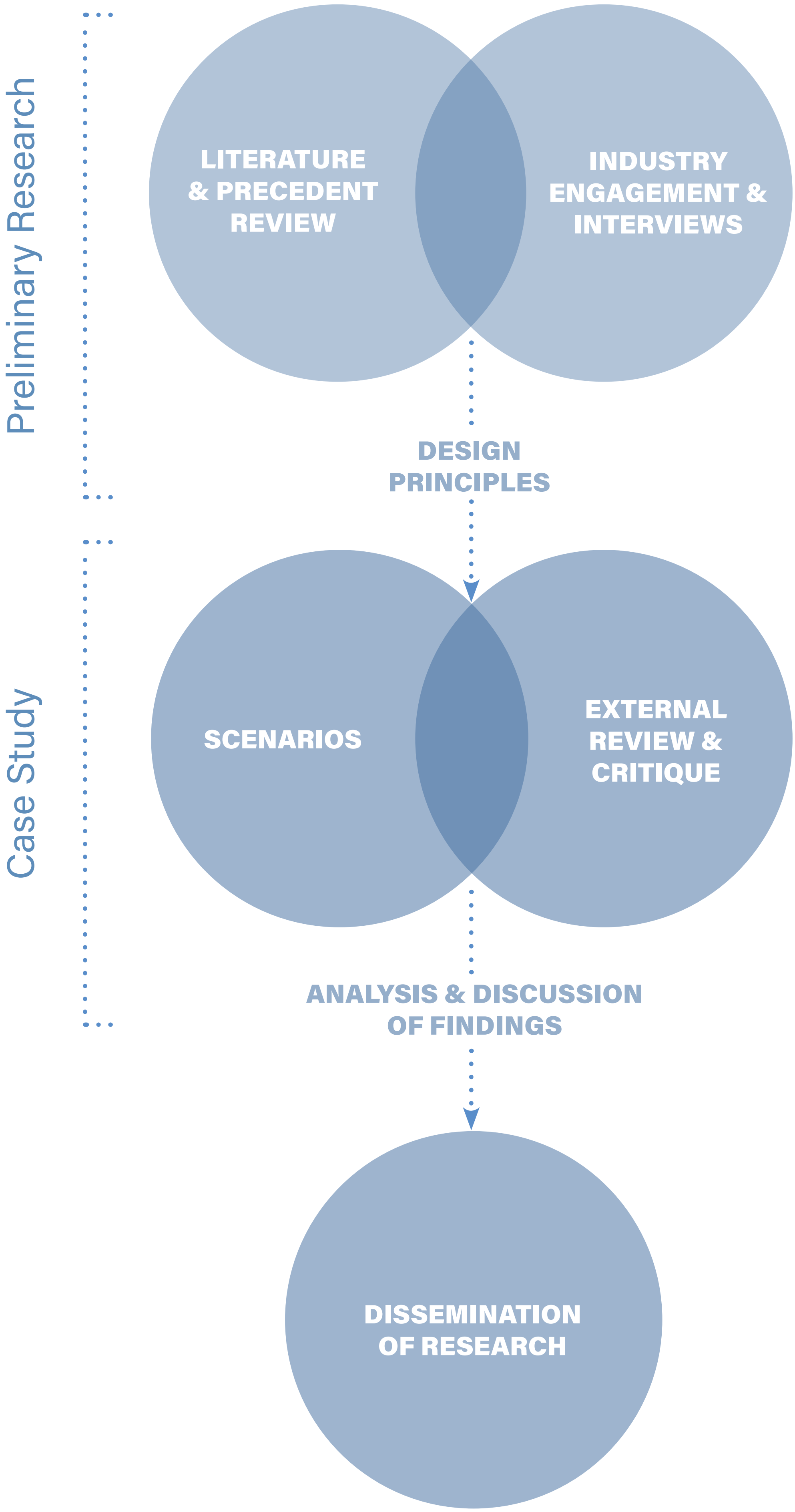
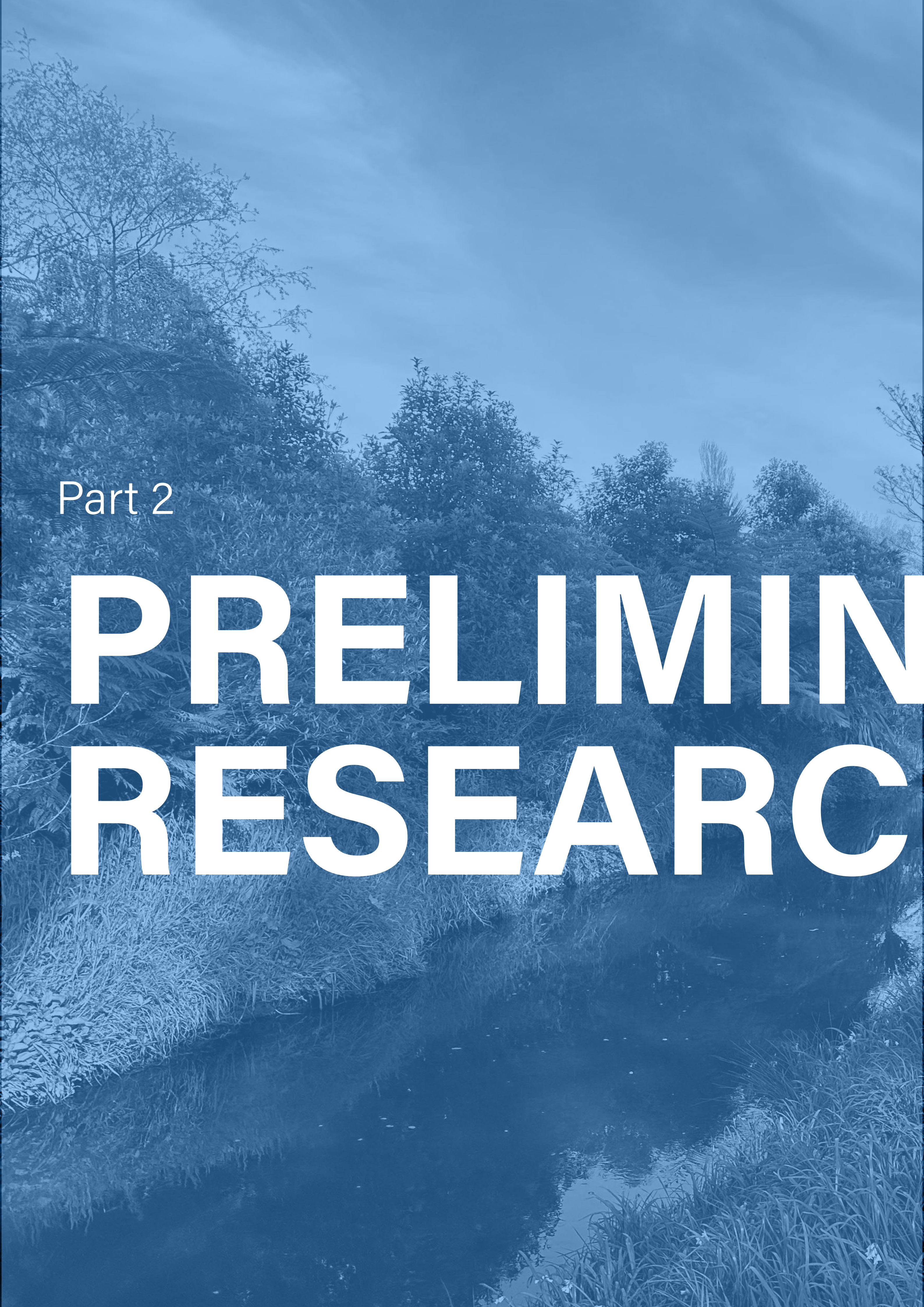


Fig.4. Research methodology.



Part 2

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Literature and Precedent Review

1. Flood Resilient Housing
2. Kaupapa Māori Approaches to Climate Resilience and Construction Innovation
3. Circular Economy Construction Methods

Flood Resilient Housing

In Aotearoa and abroad, there is a growing call for building more resilient cities (Hughes & Sharman, 2015) to improve the social resilience and structural resilience in flood events. Holistic investigation into flood-resilient homes is required across scales: city infrastructure, urban design, buildings, down to finishes and details. This research focuses on the building scale and identifies building features that support structural and social resilience in flood events. The United Nations Environment Programme points out:

> **"A home is intrinsically linked to human health, well-being and, now, climate risk reduction" (United Nations Environment Programme, 2021).**

International approaches to flood-resilient housing

Internationally, flood management is shifting from risk-based to resilience-based and flood-vulnerable communities are increasingly moving from solutions that are 'fail-safe' to 'safe-to-fail' (Wang, et al., 2022; Hughes & Sharman, 2015; Webb, Taishi, Kammila, & Kurukulasuriya, 2023).

Proactive and protective approaches in the Netherlands

For centuries, the Netherlands has invested in water resilience measures that take a proactive and protective approach. For example, Dutch urbanist Anne Loes Nillesen explains how the Dutch dike ring system is cost-effective, but limits the feasibility of investing in individual building flood-proofing due to high costs and intensive structural measures (Nillesen, 2022). 'Flood-proof' or 'water-robust' housing is being designed and constructed to withstand the impacts of flooding and minimise damage to the structure and its contents.

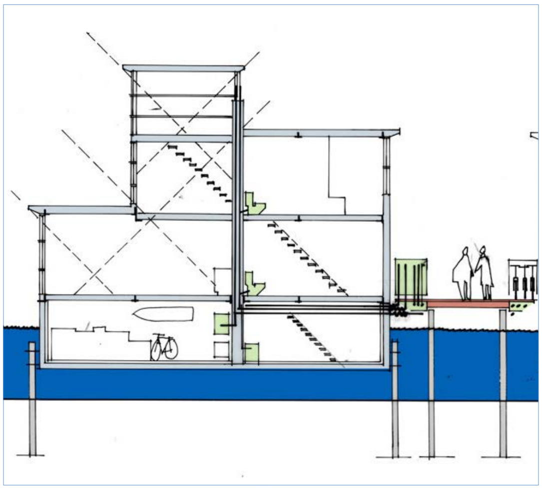


Fig.5. A cross section of a floating amphibious house.

Indigenous knowledge and managed retreat in the Pacific Islands

Pre-globalisation, Pacific Island societies tended to build homes away from coastlines and used flood-resistant structural systems such as raised floor levels, stretchable structural connections and walls that can let air or water pass through (Nunn, et al., 2024). Rising sea levels and the devaluation of traditional Indigenous knowledge (Nunn, et al., 2024) have contributed to many low-lying island nations now being some of the most at risk from coastal flooding and cyclones. Resilience strategies in Kiribati and Tuvalu have included "raising our islands" (Pala, 2020), coastal protections (UNOPS, 2023; Webb, Taishi, Kammila, & Kurukulasuriya, 2023), managed retreat and provisions for large-scale evacuation (BBC, 2024).

Fig.6. Flooding of elevated homes in Tuvalu.

Emergency response and recovery in the United States

In contrast, the United States has traditionally focused more on emergency response and recovery rather than prevention, leading to significant damages and a planned failure to protect (Merrell, 2022). This approach encourages the use of federal flood insurance and grants for infrastructure and housing replacement. The recovery process is often lengthy and challenging for vulnerable populations and frequent evacuations of coastal residents are necessary. Because of this, there has been a shift towards a more protective approach.

Fig.7. Volunteers help clear Main Street of debris after floodwaters subsided in Highland Falls, New York.

From prevention to adaptation in the UK and Australia

In the United Kingdom and Australia, the built environment is demonstrating a shift from "one which tries to prevent flooding, to one that is adapting to cope with the impacts of floods and that can ultimately recover quickly from these disruptive events" (Baker, 2017). Commenting on the UK's out-of-date post-flood approaches, the UK Building Research Establishment (BRE) explain that:

> **"Once the house has dried out, then [builders] very likely put plasterboard back in, install a new chipboard kitchen, and use non-water resistant flooring and insulation materials. If the home were to flood again in the future, all of these would be damaged once again" (BRE, 2017).**

Both countries have recently produced comprehensive building guidance for flood-resilient design which involves using materials, construction systems, and design types that can withstand substantial and repeated inundations (Queensland Reconstruction Authority, 2019).

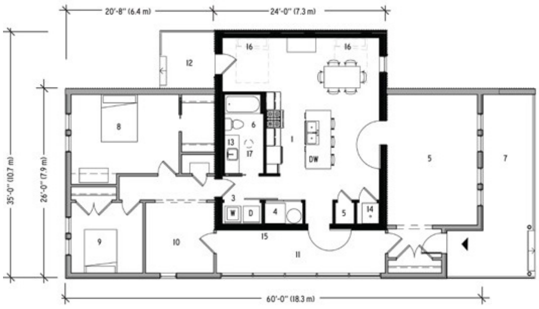


Fig.8. CORE House, designed to address the local vernacular by combining two single-cell homes: a centrally located "Safe House" acts as the hearth and divides a "Perimeter House" (Architect Magazine, 2013).

A "triage" approach

Similarly, the 2021 'Practical Guide to Climate-resilient Buildings & Communities' from the UN Environment Programme discusses a "triage" approach, which involves designing buildings that can be quickly reconstructed or repaired after disasters like floods. This involves ensuring the core building structure is strong and designing other systems and spaces in a modular manner so that they can be repaired without preventing the community from using the building entirely (see Fig X of CORE House).

In the longer term, a "triage" approach involves designing buildings for ease of reconstruction or deconstruction, allowing them or their materials to be used in another location if necessary. The UN Environment Programme states:

> **"A building that can be uninstalled, moved, and re-installed can provide communities with more flexibility to relocate as needed when faced with disasters and a changing climate" (2021).**

Fig.9. Ushijima Architect's small wood-clad house, raised on a concrete base to help mitigate the risk of flooding.

Fig.10. Greenslade Reserve in Northcote Development is a stormwater detention basin as well as a sports ground and park. It collects water and redirects it away from homes.

"Concrete slab floors are now the most common type of ground floor in New Zealand homes."

(Building Performance, 2023).

Aotearoa's approaches to flood-resilient housing

Case studies in Hawkes Bay, Auckland and Tāneatua highlight varying approaches to flood resilience. In the Esk Valley, thousands of residents whose homes were damaged or destroyed by the 2023 flood are being warned not to rebuild "the same house as before, as some insurance companies are suggesting, with a concrete slab laid at ground level" (Marriage, 2023). Instead, experts point out that the homes which outlasted the 2023 and similar 1938 floods survived primarily because they were above the valley floor which acts as a natural flood path. New or replacement homes are recommended to be sited on the hillside or "on posts so that the 'ground' floor level stands well above the valley floor" (Marriage, 2023).

More than a year since the 2023 Auckland Anniversary Weekend floods, people are still waiting to return to their homes, or are living in damp housing. The consequences of living in homes that have not dried adequately post-flood include "mould growing in every single room" leading to some residents having "developed a permanent cough" (Ikram, 2024).

Fig.11. Te Kura Whare is Living Building Challenge certified.

Flood resilient architecture in Aotearoa

Some homes that survived the 2023 floods did so due to flood-resilient urban design and architecture. For example, Greenslade Reserve was designed within a housing development as a sports ground, transforming into a stormwater retention basin in a flood event. In the 2023 flood, the urban environment around the housing development successfully diverted floodwaters to the retention pond, preventing homes from being damaged (Kāinga Ora, n.d.). Similarly, Te Kura Whare in Tāneatua utilises a "storage pond capacity sized for 100-year flood" and elevated floor level to mitigate the risks of being situated on an alluvial floodplain (Living Certified: Te Kura Whare, n.d.).

Fig.12. Te Kura Whare utilises a storage pond and landscaping to retain and redirect water.

“About one in seven New Zealanders live in areas prone to flooding. That's 675,000 people and more than $100 billion worth of homes” (Macdonald, 2023).

When structural resilience is not enough

Other homes in Auckland were already elevated on posts, however, residents indicate that structural resiliency does not necessarily equate to emotional resiliency and wellbeing in flood events. For example, a resident in Henderson who was affected by 10 floods in seven years urges communities to reconsider continuing to build in flood-prone areas due to the physical and emotional burden:

> **“The emotional trauma is extreme by this stage [...] the fact that there is discussion that more houses should be put up on poles to keep people safe is ridiculous and very upsetting. The way we live is not how anyone should live" (Macdonald, 2023).**

The social resilience of communities in a flood event can be significantly impaired by non-resilient housing and lack of clear information:

> **“Decisions and uncertainties about housing can be major stressors after disasters. Both relocating and remaining in place after a disaster have been associated with a range of poor psychological outcome [...] harm to the natural environment and natural resources can cause distress and grief [including] psychological, physical, and spiritual health impacts that result from the threat of climate change. Māori can be particularly affected because of their genealogical relationship to the whenua and their role as guardians and protectors of te taiao. In te ao Māori, a ‘natural hazard’ can be a tīpuna or atua” (Extreme Weather Research Platform - MBIE, n.d., p. 13).**

Flood-resilience experts agree that long-term change is complex given our attachment to building homes in flood-prone areas near rivers and coastlines. In addition, building socially resilient communities often draws upon the symbiotic connection between people, water and land (Mannakkara, Wilkinson, & Milicich, 2017). Like the countries discussed in the previous section, there is a strong trend in Aotearoa to adapt to living with the water. For housing, this means:

» Short-term: retrofitting homes to improve flood resistance (preventing water from entering) and flood resilient (making it quickly re-livable after a flooding event).

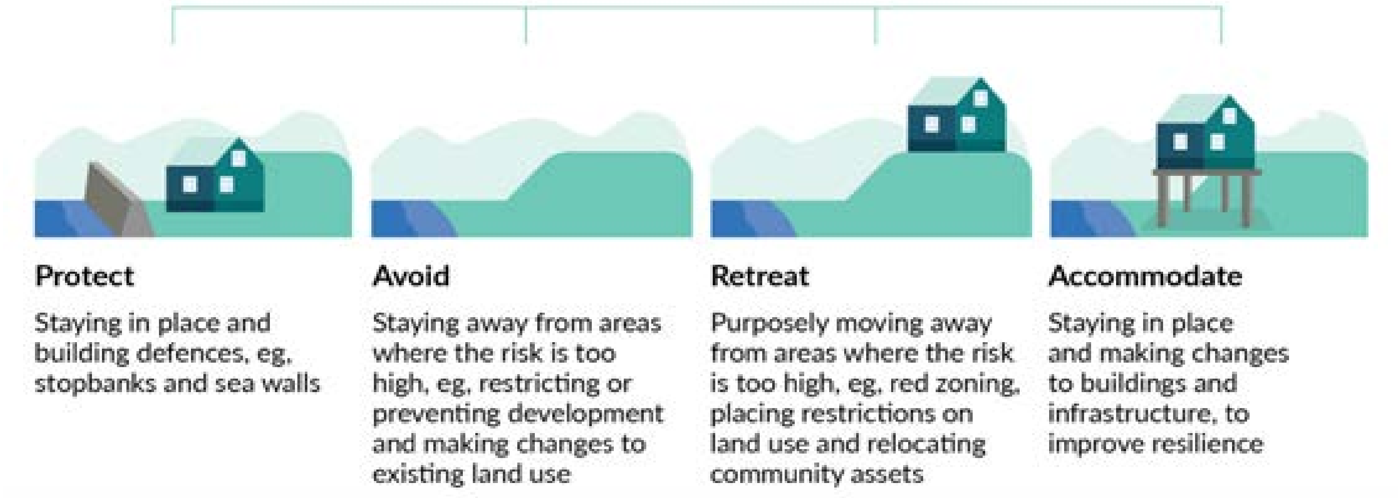
» Mid-term: building new homes and rebuilding flood-damaged homes with adaptable and flexible solutions rather than returning homes to pre-flood states.

» Long-term: an integrated approach that considers flood resistance and resilience alongside community-led retreat.

The future of flood-resilient housing

To achieve this, Aotearoa’s current approach to conventional house-building needs to change. In ‘Flood Resilient Communities: a Framework and Case Studies,’ New Zealand-based engineers Hughes and Sharman (2015) state:

> **“In order to achieve meaningful change in what is a complex area, a shift needs to occur from a traditional, centralised approach to flood management and planning, to a more experimental and open approach [...] A new approach would be adaptable and flexible, and would embrace innovation - with a focus on “soft” options that increase the flexibility of a system and enhance its adaptive capacity, also known as “low-regret strategies” (Fankhauser et al., 1999; IPCC, 2012)."**



Protect

Staying in place and building defences, eg, stopbanks and sea walls

Avoid

Staying away from areas where the risk is too high, eg, restricting or preventing development and making changes to existing land use

Retreat

Purposely moving away from areas where the risk is too high, eg, red zoning, placing restrictions on land use and relocating community assets

Accommodate

Staying in place and making changes to buildings and infrastructure, to improve resilience

Fig.13. The PARA framework is used to explain the different methods people might use to adapt to a changing climate.

"Around 10,000 houses in Auckland, Wellington, Christchurch and Dunedin could become uninsurable by 2050 because of coastal flooding from sea-level rise" (Ministry for the Environment, 2023).

The PARA framework (figure 13) is used internationally and in Aotearoa New Zealand to explain different strategies communities might follow to adapt to climate change. The 'retreat' and 'accommodate' strategies tend to impact house design the greatest.

A note on managed retreat

Managed, or community-led retreat is the adaptation approach that receives the most media attention but arguably is the most unclear on how to achieve it for homeowners situated in flood-vulnerable areas. Case studies in Aotearoa (Christchurch, Mātata) focus on retreat occurring after an event has destroyed homes (Curtis, 2022; Ministry for the Environment, 2022) while government strategies and academic advice generally suggest "the ability to be pro-active is key" (Curtis, 2022). Studies show that relocatable building design is a common approach in New Zealand planning instruments for enabling managed retreat, however "a lack of implementation support exists for managed retreat policies, particularly in relation to relocatable buildings" (Hanna, White, & Glavovic, 2017).

> **Drying out a house, particularly in winter, can take several months and in some cases more than 4 months. "Where time is critical, it may be more practical to replace timber that is wet than wait for it to dry"**
> (BRANZ, 2021).

Building features for structurally flood-resilient housing

Strategies and advice for how housing can accommodate floodwaters line up with the international guidance for dry-proofing and wet-proofing discussed earlier and detailed below. In Aotearoa there are too many examples of repairing homes too quickly post-flooding, leading to leaky, mouldy, damp homes, affecting structural and social resiliency (BRANZ, 2021).

Some of the ways housing can be structurally resilient include:

Wet Proofing: Wet-proofing allows water to enter and leave a building without causing significant damage. This approach acknowledges that some water infiltration is inevitable during floods but aims to minimise harm.

» Frangible architecture: Also known as 'planning for damage,' elements are designed to be easily broken to prevent critical structural failure. For example, frangible cladding will break and provide openings in the building envelope to ensure that floodwaters enter and exit the home without destroying the wall structure.

» Stretchable structural connections: Related to frangible architecture, connection techniques such as lashing can allow a building to flex under strain and prevent breakage.

» Multiple Storeys and Exits: Allocating less critical functions to ground levels to mitigate flood impacts. Designing for above-ground-level exit points such as balconies and skylights is important for emergency exiting.

» Water-Resistant Materials: Using materials that can withstand moisture damage, be easily dried, and be easily cleaned.

» Non-Toxic and Replaceable Materials: Using materials that do not pollute water and are easily replaceable post-flood.

Drainage Systems: Incorporating effective drainage channels, membranes, and automatic pumps to remove floodwater. This includes being able to gain access to pockets of trapped water and debris to remove it.

Fig.14. A house on stilts in Kuttanad area of Alappuzha district of Kerala.

Dry Proofing: Dry-proofing focuses on preventing floodwater from entering a building altogether.

» Flood Barriers and Seals: Using flood-proof seals for doors and windows, one-way valves in mains drains, and ventilation covers to prevent water infiltration. Dry-proofing measures such as this focus on preventing floodwater from entering a building altogether. However, it's generally considered a short-term solution. While it can be effective in specific cases, it may not provide long-lasting protection against all flood scenarios.

» Elevation - Raised Floor Level: Building on stilts or creating a raised threshold. Elevating a house only reduces flood risk up to a certain flood level and risk still remains if larger floods occur above this level. In addition, the cost to elevate a home can sometimes be prohibitive and outweigh the costs of other resilient design options.

» Flotation - Amphibious Buildings: Using construction technology that allows a building to be positioned on land during normal circumstances, but float in case of a flood.

Design for de-/ re-construction

- Design for prefabrication, preassembly and modular construction
- Simplify and standardise connection details (screws, bolts, nails, etc.)
- Simplify and separate building systems
- Minimise building parts and materials
- Select fittings, fasteners, adhesives, sealants and other items that allow for disassembly
- Design to allow for deconstruction logistics
- Design with reusable materials
- Design for flexibility and adaptability

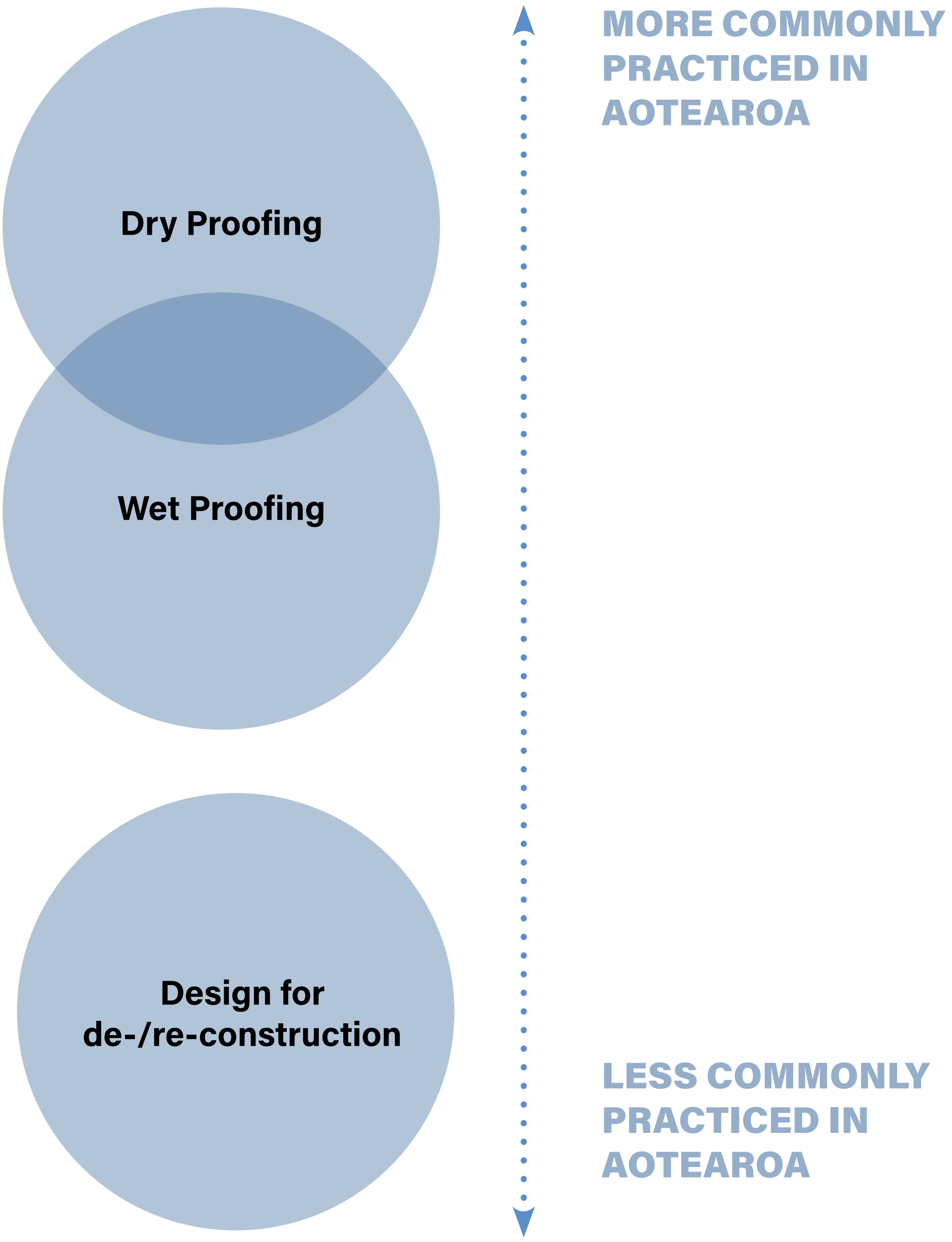


Fig.15. Strategies for structurally resilient housing in flood-prone areas.

Kaupapa Māori Approaches to Climate Resilience and Construction Innovation

Key Term

[1]Mātauranga Māori

The body of knowledge originating from Māori ancestors, including the Māori world view and perspectives, Māori creativity and cultural practices (Te Aka Māori Dictionary).

Key Term

[2]Kaupapa Māori

Māori approach, Māori topic, Māori customary practice, Māori institution, Māori agenda, Māori principles, Māori ideology - a philosophical doctrine, incorporating the knowledge, skills, attitudes and values of Māori society (Te Aka Māori Dictionary).

Key Term

Whakaaro Māori

Related to Kaupapa Māori, whakaaro Māori refers to Māori ways of thinking and understanding (Te Aka Māori Dictionary).

Building features for structurally flood-resilient housing

The value of mātauranga Māori[1] to Māori and non-Māori in Aotearoa is well substantiated. Given the existing body of research, this framework will not deep dive into why kaupapa Māori[2] is important, but rather point out some key points in the context of climate resilience, housing and circular economy.

Kaupapa Māori and climate-resilience

Mātauranga Māori offers vital insights for climate resilience discussions in Aotearoa. Morton (2023) states that when it comes to mitigation, adaptation, re-location and managed retreat:

> **"Māori have long demonstrated practices which resonate with the philosophy of managed retreats, via cultural restriction or avoidance of certain activities, tikanga-based resource management, and adaptive re-settlement."**

Prior to colonisation, some responses to flooding and other severe weather events included:

- » Establishing communities and settlements in climate-resilient locations, particularly away from water.
- » Relocation of settlements out of areas that became hazardous into areas that were deemed safer. A textual analysis identified 51 examples of "pā relocating in response to natural hazards" pre- and post-colonisation (Bailey-Winiata, 2024).
- » The use of front porches in wharepuni (sleeping houses) as a "moderating zone" – a "uniquely Māori adaptation to climate" (Brown, 2014).
- » Structures like pātaka being lifted off the ground for protection from various threats such as flooding.

In contemporary times, responses to flooded homes from iwi and hapū have included using marae as welfare hubs and housing whānau for extended periods post-climate events (Manaaki Whenua Landcare Research, 2023). In an article on the iwi response to flooding in the southern Rangitīkei region, McLachlan & Waitoki (2020) write about "examples of tribal infrastructures being used as shelters, kitchens, and coordination hubs for psycho-social responses highlighted the ability of local tribes to respond more quickly than civil defence or other aid organisations".

The use of marae as a place of both physical and social refuge is seen across Māori communities. As well as a "physical place for safety, refuge, and response after a disaster," marae are an "important building block in Māori communities for improving the resilience of the built and social environment" (Boston, 2022). Although this research does not focus on community spaces, it is important to note the connection and proximity of housing to community spaces is critical for physical safety and social resilience.

Climate resilience was, and is, practised differently from iwi to iwi and hapū to hapū. Mātauranga Māori is context-based, community-orientated and more holistic in its approach than Western, neo-liberal notions of linear construction processes, making it highly valuable to building social resilience. Yet despite its growing recognition, and the disproportionate affects of sever weather events on Māori (Ministry for the Environment Manatū Mō Te Taiao, 2022), the practical application of mātauranga to emergency management remains limited (Rout, et al. 2024).

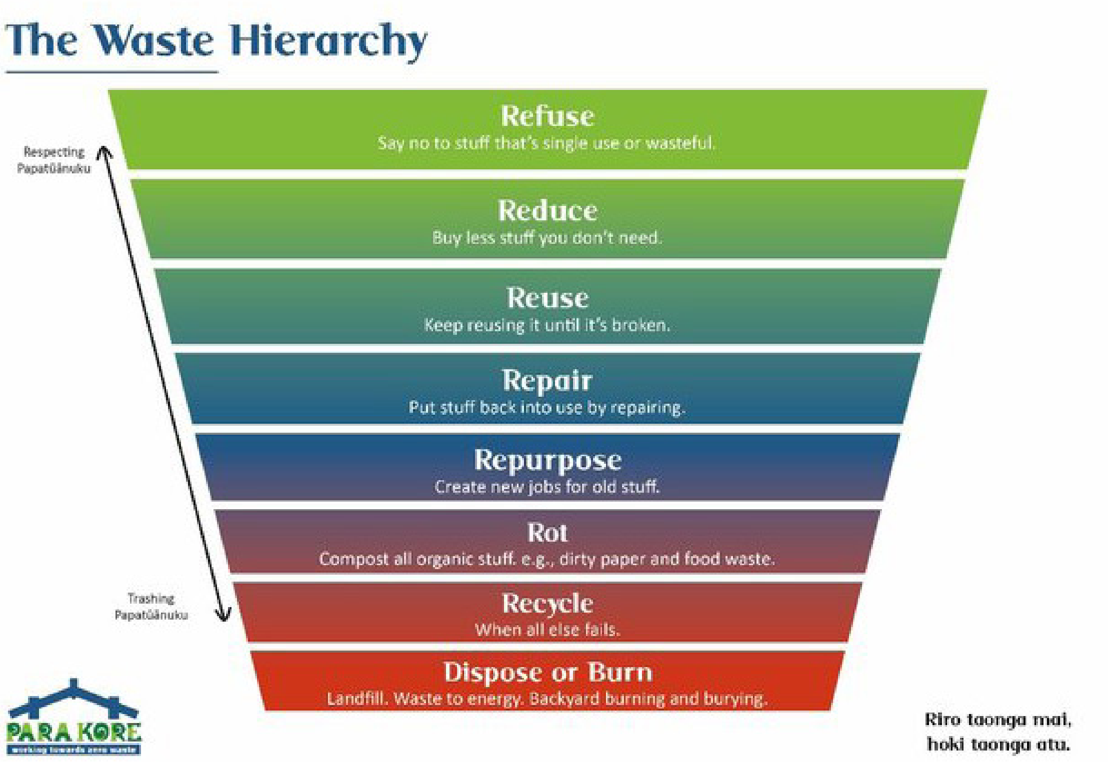


Fig.16. Para Kore Waste Hierarchy.

Supporting Māori to lead the conversations about climate adaptation and construction innovation is crucial to achieving localised, transformative outcomes for communities. Support can come in many forms not limited to, funding, diverse expertise, accessible information and tools to lead and implement. This research aims to be one of the many tools to get climate-resilient housing conversations in motion.

Māori perspectives on circular economy

Although there are differing opinions about how whakaaro Māori connects with less holistic Western notions of circular economy, there is a view that because of its regenerative ethos, "whakaaro Māori naturally lends itself" to circular economy principles (Meha in Scion Research, 2019). In a report about the journey to a circular economy in the Waikato region, Bianchi and Yates (2022) state that "circular economy, or ōhanga āmiomio, is not a new concept [...] Aotearoa New Zealand is in a unique position because [the circular economy's] underlying principles are already a significant part of te ao Māori".

Bianchi and Yates (2022) assert that circular economy principles have "broader benefits across the environmental and social spheres" and can create "small, closed-loop systems at the local and regional level that aim to create more local employment, knowledge and community resilience resulting in increased wellbeing".

Figure 16 depicts Para Kore's Waste Hierarchy diagram (Para Kore Marae Inc), showing the difference between traditional waste management and a kaupapa Māori circular economy. Emphasis is placed on the idea that "recycling" and "disposal" are quite low on the hierarchy.

In summary, there is a strong connection between kaupapa Māori and localised, climate-resilient construction innovation in Aotearoa. In addition, Mātauranga Māori's holistic and community-oriented approach contrasts with Western linear construction processes, making it highly valuable for building social resilience.

Circular Economy Construction Methods

Construction methods in Aotearoa need to allow for flexibility as community aspirations and planning legislation evolve to improve how people live alongside te Taiao and the changing climate. Submitters to the National Climate Adaptation Plan (Ministry for the Environment Manatū Mō Te Taiao, 2022) specifically urged the government to "support development of more circular and local economies at both national and local levels to increase New Zealand's economic and financial resilience" (p. 72). But how is the construction industry supporting structural and social resiliency? Our hunch is that Circular Economy Construction Systems (CECs) are one piece of the complex puzzle.

What is the circular economy?

There is no one definition of circular economy. Related to the concept of "cradle-to-cradle," the circular economy is a regenerative economic model designed to minimise waste and make the most of resources. In a typical linear economy, products are made, used, and then disposed of as waste.

In contrast, a circular economy aims to keep resources in use for as long as possible, extract the maximum value from them while in use, and then recover and regenerate products and materials at the end of each service life. It aims to decouple economic growth from the consumption of finite resources, reducing environmental impacts and promoting sustainable development. It's seen as a viable alternative to the typical linear economy, which is often criticised for its resource-intensive and wasteful nature.

Circular economy construction (CEC) "in the built environment requires buildings to be designed for deconstruction and material recovery" (Finch, 2020). Some aspects include:

» Design for Disassembly

» Use of Recycled and Renewable Materials

» Prefabrication and Modular Construction

» Adaptive Reuse and Renovation

» Life Cycle Assessment

» Resource Recovery and Waste Management

» Circular Business Models

How can CE principles support climate-resilient housing?

Applying circular economy principles to public housing in New Zealand can contribute to environmental sustainability, improve resource efficiency, reduce operational costs, and create healthier and more resilient communities. It aligns with broader national goals of reducing carbon emissions and promoting sustainable development.

CEC systems could be part of the approach to tackling climate resilience of housing in Aotearoa because they:

» Decrease waste: the construction industry is among the most environmentally harmful industries globally, including in Aotearoa, where "the building and construction sector [...] consumes more than 50% of all raw materials while simultaneously generating more than half of all waste sent to landfill" (Finch et al., 2017). Currently, if buildings are uninhabitable, they are either demolished and disposed of, or left in the landscape to potentially leech into the environment.

» Use and reuse sustainable materials and practices: current NZS 3604

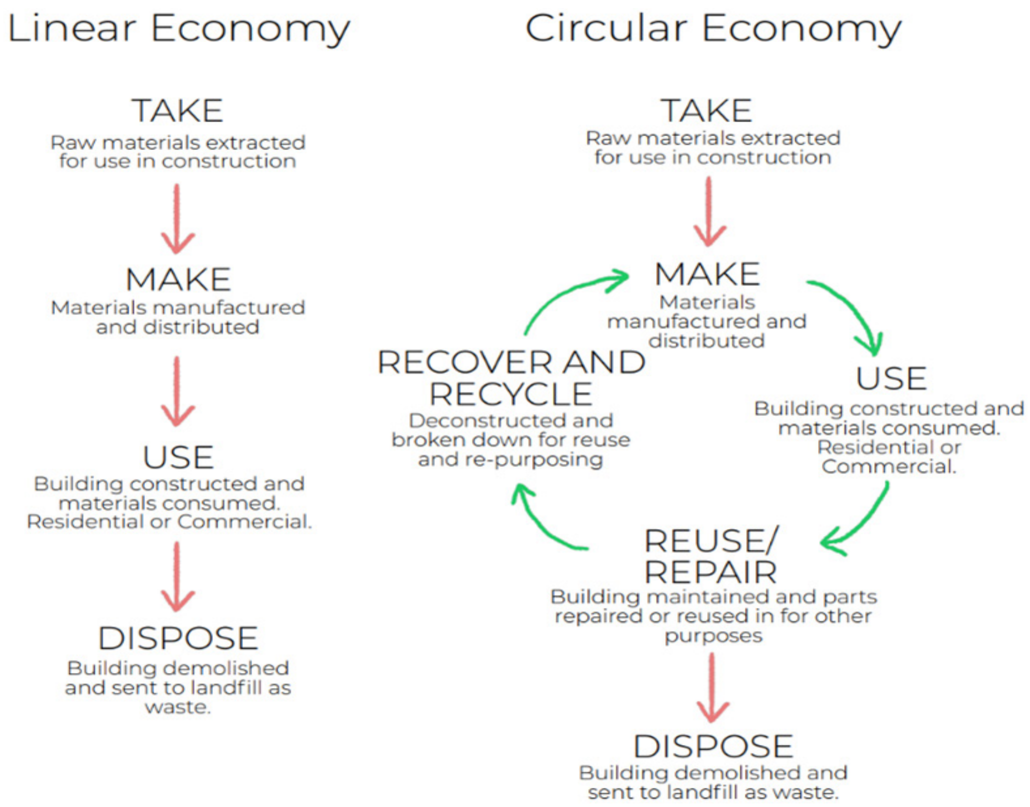


Fig.17. Orr's depiction of a linear economy compared to a circular economy.

timber buildings use materials such as glues, tapes and nails which make buildings difficult to recycle or salvage upon demolition. Additionally, chemically treated timber limits the reuse of offcuts and deconstructed timber.

» Use a methodology that can support houses to adapt over time: Currently, typical construction methods aim to provide solid structures with a long lifespan (the NZ Building Code specifies no less than 50 years) and do not consider how housing can be altered or moved as the needs of tenants change and the climate changes.

What is good CEC?

To understand the basics of circular economy, we can look at the example of the humble glass milk bottle. Traditionally these would be collected, cleaned and refilled – the collection and cleaning part is key to enabling "circularity" in the milk bottles in addition to the ability to reuse the glass. Technically, many products can be deemed "circular" but there are a lot of caveats to making sure the system it's used in is also circular. For example, if the product is glued to something else then it makes it much harder to recycle/reuse the original "circular" product, and you might end up ruining its reuse potential.

Building a holistic circular construction industry for housing is complex. Elements to consider include:

» Re-centring traditional mātauranga for building innovation place-based practice

» Sustainable and local timber supply

» Re-skilling architects, engineers, builders, and tradespeople in CEC

» Resource Recovery and Waste Management

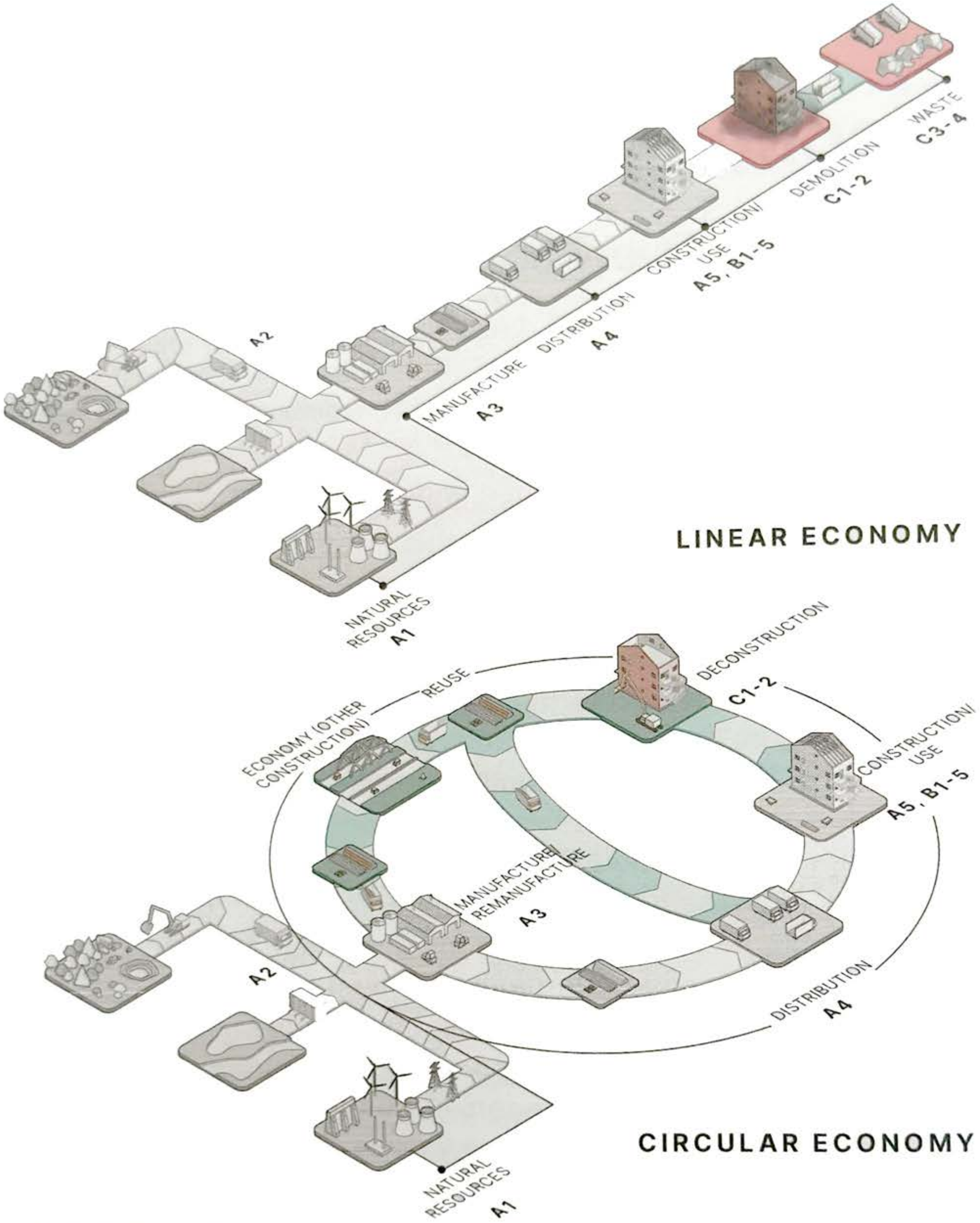
» Life Cycle Assessment (examples in figure 19)

» Collaboration and Partnerships

» Circular Business Models

» Market Demand and Consumer Awareness:

» Regulatory and Policy Support



A1 - 3 (Production Stage)
- A1 - Raw material extraction
- A2 - Transport to manufacturing site
- A3 - Manufacturing

A4 - 5 (Construction Stage)
- A4 - Transportation to construction site
- A5 - Installation / Assembly

B1 - 5 (Use Stage)
- B1 - Use
- B2 - Maintenance
- B3 - Repair
- B4 - Replacement
- B5 - Refurbishment

C1 - 4 (End of Use Stage)
- C1 - Deconstruction & demolition
- C2 - Transport
- C3 - Waste processing
- C4 - Disposal

Fig.18. Keena and Friedman's (2024) lifespan of the building environment process, comparing the linear economy model of construction to a circular economy. This highlights the flaws in linear processes and the opportunities circular economy systems have.

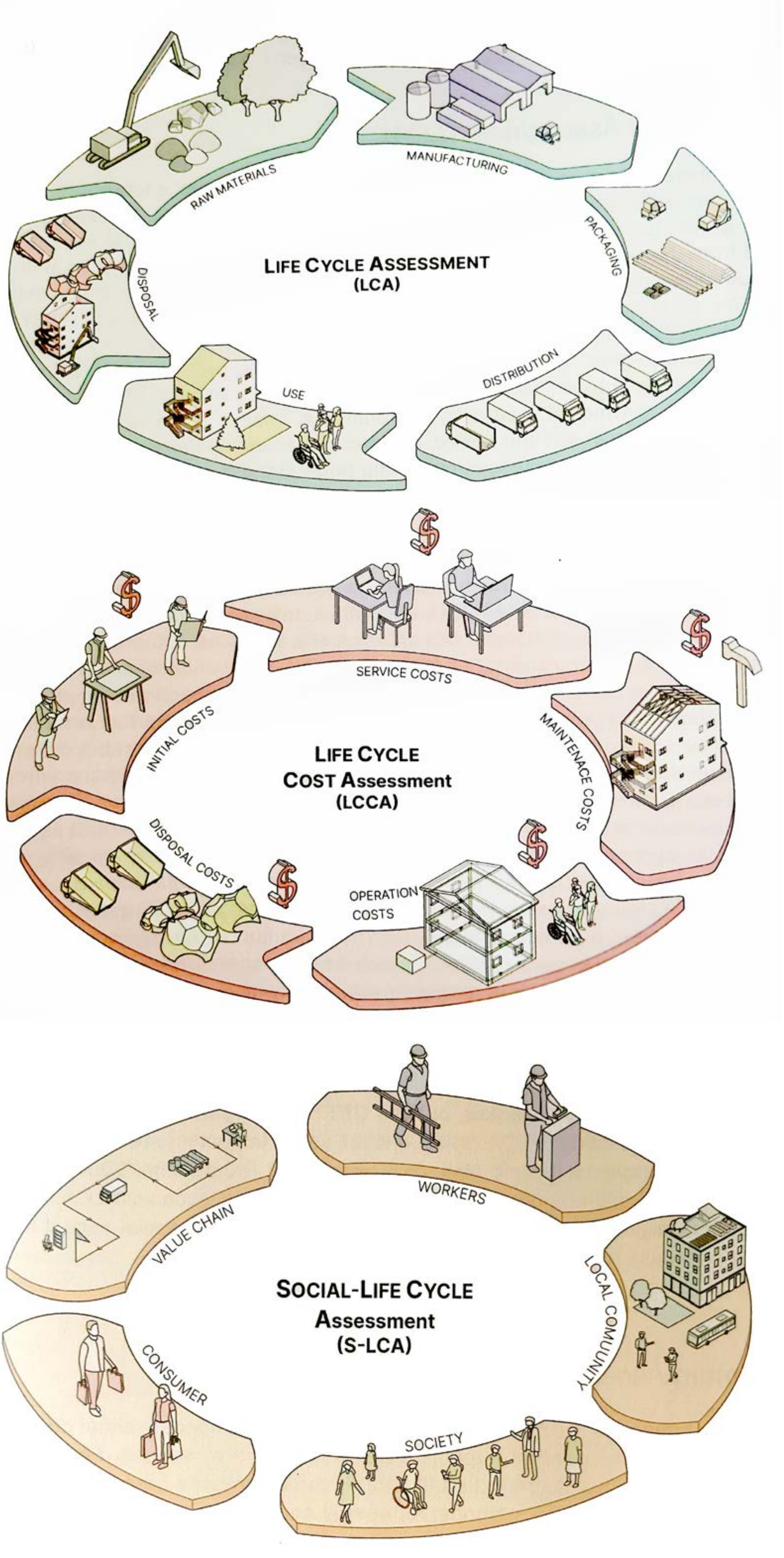


Fig.19. Keena and Friedman's (2024) holistic life cycle design thinking in the built environment, showing the various types of monitoring and planning that goes into successful circular economy systems. Note the distinct emphasis on the importance of social-life cycle assessments, from the workers who help produce CEC outcomes to the communities who benefit from them.

Current limitations and barriers of CEC housing in Aotearoa

In Aotearoa, the adoption of circular economy construction systems faces complex and compounding challenges. Some of these include:

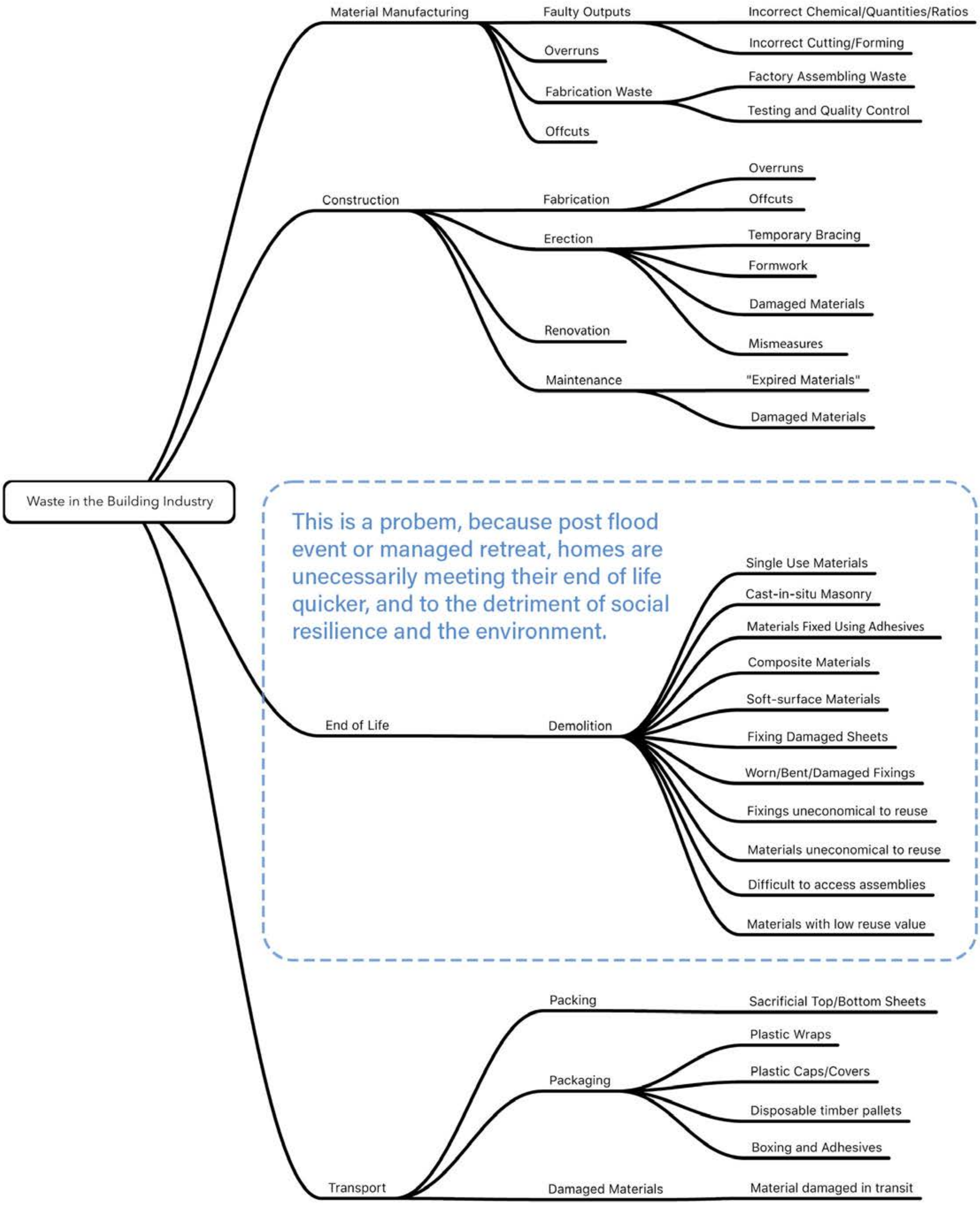
» Economies of scale: crucial for cost efficiency, economies of scale remain elusive due to the emerging stage of circular construction practices. While there are long-term benefits such as reduced resource consumption and environmental impact, the upfront costs deter many builders and developers who lack immediate incentives for change.

» The industry's inertia is further compounded by norms favouring typical linear models: the lack of established resource markets hinders the widespread adoption of reclaimed materials needed for circularity. Despite this, industry and community must collaborate to drive innovation in construction, pivotal in combating climate change and achieving decarbonisation goals. Although it's acknowledged that the construction industry isn't solely responsible, it plays a key role in guiding society towards a circular economy. The AHURI Informing a Strategy for Circular Economy Housing in Australia notes this in their call to industry and government collaboration:

> **“Greater awareness of CE, through strategic research and discussion of results—as well as through demonstration of good practices—can foster new professional norms that prioritise sustainability, circularity and decarbonisation. These values must inform leadership, training and sense-making, as well as the setting of targets and key assessment frameworks, such as procurement and auditing of assets, and reporting" (Horne et al., 2023, p. 4).**

If Aotearoa never sets the frameworks for how it works, the industry will never be incentivised to work towards circularity.

» A lack of education about the circular economy makes it difficult for people to see or even test its viability: MBIE’s Circular Economy and Bioeconomy Strategy work has been halted ‘as it is considered a low-value programme when compared with other work on climate change’ (New Zealand Green Building Council, 2024). This suggests a perceived separation between circular economy and climate change adaptation. Horne et al. (2023) emphasise the industry’s role in shaping societal norms and fostering awareness of circular economy principles through strategic research and pilot projects. Educating stakeholders on circular construction is pivotal to overcoming industry reluctance. Therefore, despite significant challenges, concerted efforts by all stakeholders are essential to realise the transformative potential of circular economy practices in Aotearoa's construction sector. Approaches to bridging this gap include awareness building, skill development, policy support and demonstration projects.



This is a probem, because post flood event or managed retreat, homes are unecessarily meeting their end of life quicker, and to the detriment of social resilience and the environment.

Fig.20. Finch's linear material consumption model, showing how prevalent waste is in Aotearoa's linear building industry.

International case studies exploring circular economy housing as part of a climate change response

Fig.21. Arup's People's Pavilion.

Fig.22. KODA House by Kodasema.

People’s Pavilion by Arup
The Netherlands

This experimental circular economy building is underpinned by sustainability and material reuse. Made of entirely “borrowed materials” (Arup, 2017), the temporary building challenges norms and fosters innovation in design and material reuse by:

» Material borrowing and waste minimisation: concrete foundation piles and steel rods were repurposed from demolished structures, while the glass components were salvaged from greenhouse suppliers.

» Recycling: Over 9,000 colourful interlocking plastic tiles, made from recycled PET bottles adorned the pavilion's roof.

» Return and reuse: All borrowed materials were returned and repurposed after the pavilion's dismantling. This closed-loop approach minimises environmental impact and maximises resource efficiency.

KODA House by Kodasema
Estonia

Using primarily timber with a focus on prefab and modular building, these small “units” add flexibility in urban environments (Kodasema, 2022) by:

» Building smaller: designed to minimise environmental impact by promoting smaller living spaces

» Mobility and multi-functionality: the modular houses are movable, allowing for flexible urban infill where needed most. They serve multiple functions from residential units to commercial spaces

» Prefabrication with renewable materials: utilises primarily timber and offsite production methods, as well as trying to exceed construction standards for resilience. This approach reduces transportation-related carbon footprints and construction site disruptions.

Fig.23. Circle House's recycled material facade.

Fig.24. Easy Housing's prefabricated circular structures for homes.

Circle House by Vandkunsten, 3XN and Lendager Group

Denmark

Circle House, the "world's first Social Housing built with circular principles" (Vankunsten Architects, n.d.), exemplifies innovative approaches to waste minimisation. A pilot unit was built in 2020 and 60 units now exist. The project tackles circularity by:

» Designing for reversibility: The building is crafted to be disassembled, aiming to reuse 90% of materials without loss of value.

» A modular structural system with different typologies: the house utilises a limited range of components—two sizes of wall elements, two lengths of beams, and two lengths of deck elements—to enhance material reuse.

» Sustainable concrete integration: showcases prefabricated concrete elements, advancing sustainable practices within the national building culture.

» Using wood and recycled materials for non-structural elements

Easy Housing by Easy Housing Concepts Uganda Limited

Uganda

Easy Housing create homes that integrate circular economy principles and enhance livelihoods and resilience (Easy Housing, n.d.) by:

» Prefabricating and using circular materials: prefabricated in carpentry workshops, allowing for efficient assembly on-site. They use biobased materials like timber frames and natural insulation such as papyrus.

» Locally sourcing and using resilient supply chains

» Co-creating affordable housing with community: architects collaborate with communities to tailor home designs to fit local needs and cultural contexts.

» Creating climate resilience: incorporates passive design principles like natural ventilation and elevated floors to withstand extreme weather.

» Brokering inclusive partnerships: Easy Housing collaborates with finance partners to make sustainable home ownership accessible.

Fig.25. Houses which were reconfigured from old apartments at the Super Circular Estate.

Super Circular Estate
The Netherlands

Super Circular Estate revitalises the urban landscape of Kerkrade but also sets a precedent for sustainable urban restructuring for social housing (Urban Innovative Actions, n.d.) with:

» Community engagement and co-design: former inhabitants are actively involved in the co-design and operation of new collaborative economy services and facilities.

» Circular demolition and material reuse: the project aims to demolish outdated high-rise buildings while salvaging materials for reuse in new construction.

» Resource efficiency across 24 material streams: timber and metals are repurposed and recycled effectively.

» Addressing CO2 and water cycles: the project significantly reduces CO_2 emissions by approximately 805,000 kilograms and showcases a closed water cycle initiative for social housing

Fig.26. Milstein's prefabricated Bolt-Together House, recently renovated and repurposed.

Bolt-Together House by Jeff Milstein
USA

The 1970's Bolt-Together House was designed for disassembly and relocation, minimising environmental impact and allowing for flexibility in land use. Built with rough-sawn plywood panels bolted to a collapsible timber frame, the house embodies efficiency and sustainability principles ahead of its time (Lasky, 2024). It is:

» Mobile through modular design: it was conceived to be easily dismantled and moved, reflecting a sustainable approach to construction and land utilisation.

» Affordable and accessible: designed during a wave of eco-awareness in the 1970s, the house utilised minimal materials efficiently, emphasising affordability and accessibility.

» Prefabricated: features prefabricated components including rough-sawed plywood panels and timber posts and trusses. These components were designed to be easily transported and assembled on-site.

National case studies exploring circular economy housing as part of a climate change response

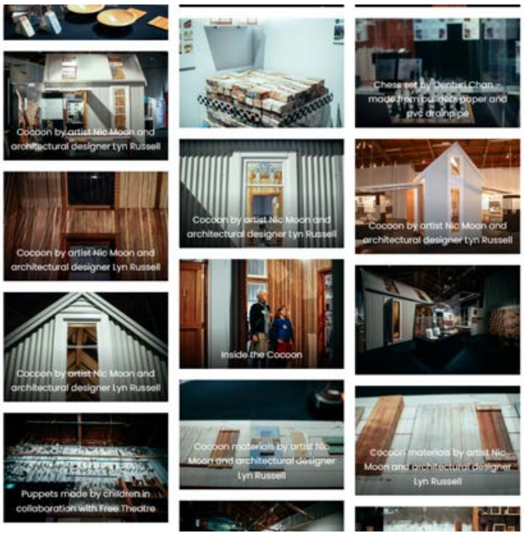


Fig.27. The Whole House Reuse exhibition that was created entirely from the salvaged materials of a home in Christchurch.

Whole House Reuse by Juliet Arnott and Kate McIntyre Christchurch, Aotearoa

This project turned an entire 1920's weatherboard home in Christchurch earmarked for demolition into nearly 400 meaningful artefacts through collaborative ingenuity and resourcefulness (Whole House Reuse, n.d.). The project highlighted:

» Diverse participation: more than 250 contributors globally devised innovative methods to repurpose every material from the home.

» Educating and awareness: the final exhibition at Canterbury Museum drew over 120,000 visitors, eliciting strong emotional responses and highlighting the transformative potential of repurposing underutilised resources.

» Circular economy example: demonstrated how sustainable practices can create value from discarded materials, shifting towards more resource-efficient ways to use construction materials.

Fig.28. Relocatable housing pods being installed on site in Tairāwhiti.

Relocatable Iwi housing lead by Toitu Tairāwhiti, Tairāwhiti, Aotearoa

In a section of the region where the "Waipaoa River burst its banks and caused widespread devastation," (Rosenberg, 2023) Toitu Tairāwhiti provided transportable homes for families that were affected by Cyclone Gabrielle. Local iwi had concerns over families being displaced, so they opted for installing self-contained homes which can be relocated when the time comes.

Although not specifically "circular," the notion of prefabricated structures being reused and moved when necessary is part of the conversation around circularity.

Industry Engagement

Third Studio attended the 2024 In:Situ Conference with support from the NZIA.

Conversations with industry professionals about flood-resilience and circular economy construction

At our designated stall, we showcased our research in its early stages to promote the Fellowship and discuss climate resilience in the architectural industry. An interactive prompt engaged professionals on the future of climate-resilient design, its significance, and challenges in housing. Most conversations were with recent graduates and industry newcomers. Notably, British architecture and design critic, Oliver Wainwright, presented on circularity and reuse, highlighting the importance of reuse and refurbishment in reducing landfill waste and lowering carbon emissions.
Key themes that came from our conversations included:

» There are differing ideas about what "climate resilience" is and how it is achieved.

» Architectural professionals were intrigued by the research, but the majority do not use circular economy construction methods in their practice.

» There is a concern among recent architectural graduates about how little climate resilience is being addressed in the industry, lack of innovation and perceived guilt over their role in maintaining the status quo.

Fig.29. Third Studio's stall at the 2024 In:Situ Conference, asking industry professionals to share their thought on flooding resilience and circular economy construction systems.

Fig.30. 2024 In:Situ Conference stalls.

Interviews with Community and Industry

Interviews were undertaken in early 2024 with community and industry experts to uncover common and diverging themes, and gaps in existing knowledge on the convergence of public housing, flood resilience, social resilience and circular economy construction systems.

Conversations were had with the following experts. Short biographies can be found in Appendix 3. Note, Participant Information Sheets and Consent Forms were used.

» **Ihaia Puketapu** (Te Āti Awa) - Local Mātauranga Māori, Commerce and Resource Management expert

» **Marko den Breems** – CEO at Isthmus, formerly Director of Architecture at Kāinga Ora

» **Kay Saville-Smith** – Director of CRESA

» **Julia Mandell** - Wilson Associates

» **Ged Finch** - XFrame

» **Luke Ransfield** (Ngāti Tukorehe, Ngāti Tu) - XFrame

» **Kristina Orr** - Temporary Emergency Housing researcher

The following is an analysis of the common and diverging themes that came out of the interview process. Four key themes have emerged:

1. Proactive housing responses to climate change
2. Mātauranga Māori and construction innovation
3. Social resilience and housing resilience
4. Circular economy construction systems in Aotearoa

Proactive housing responses to climate change

Key Term
CRESA
Centre for Research, Evaluation and Social Assessment.

The signs of change are here, we need to plan for adaptation now

In Te Awa Kairangi ki Tai, the urgency of adapting housing to climate change resonates deeply with local voices like Ihaia Puketapu who warns that with flood-prone areas, it is important to "act now, or be forced to act later." Recent cyclones around Aotearoa have highlighted vulnerabilities for Puketapu, putting into focus the need to plan early. In regards to adapting to climate or moving out of climate-prone areas, he notes:

> **“As best you can, you're trying to plan […] You're trying to educate and make the next successive generations understand why you're having to do that” (Puketapu, 2024).**

Developing resilience is resource-heavy and community/iwi need support

Puketapu notes that while iwi and hapu are having much-needed conversations about climate resilience, it is fatiguing and difficult for people to think about climate resilience when they are trying to live their day-to-day lives.

In a similar vein, Kay Saville-Smith of CRESA suggests that communities need to lead the way but shouldn’t be depleted of their resources to build resilience (Saville-Smith, 2024). Ihaia notes that as well as the mātauranga that kaumatua (elders, leaders) bring to the conversations, rangatahi (young people) have brought an important perspective on the climate change action they want to see, and hold their elders accountable to (Puketapu, 2024).

The breadth and complexity of the topics can be mentally and emotionally draining, and iwi and communities need support to make decisions that are best for them.

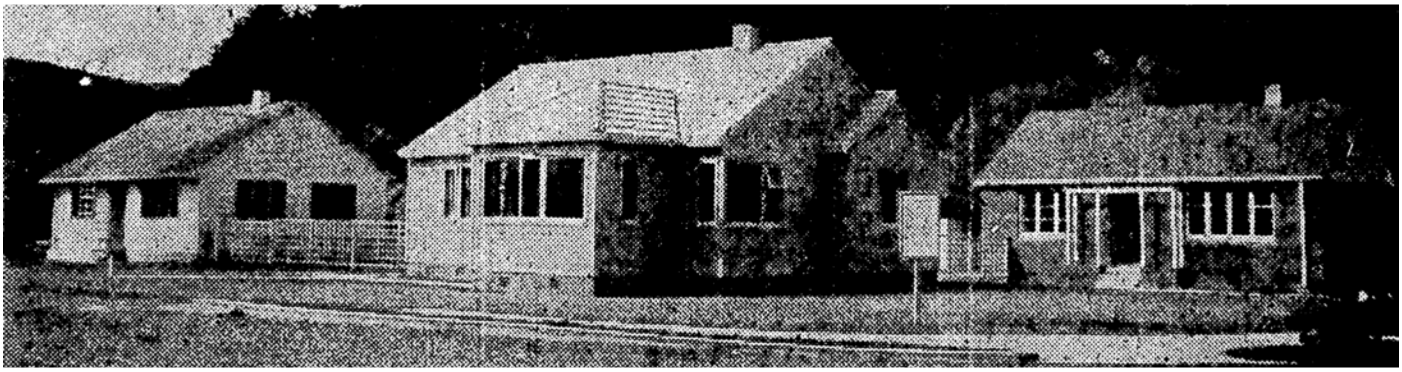


Fig.31. The first of the pre-fabricated cottages, built by the Department of Housing Construction (which has evolved into Kāinga Ora) in Naenae Lane, near Military Road, Lower Hutt. Evening Post. (1943).

Solutions need to be simple and affordable

Saville-Smith highlights housing affordability as one of the crucial pieces in the feasibility puzzle of innovative design. The history of public housing in New Zealand has been one of significant innovation during particular periods, relative to new builds in the private sector. However,

> **"low cost housing in New Zealand has been underfunded for almost 35 years now. [There is a] need to think about how can we build better for low-cost housing which is going to service people who struggle in the housing market" (Saville-Smith, 2024).**

Similarly, Julia Mandell emphasises the connection between affordability and feasibility of innovative design. An architect with a background in flood-resilience research, she is conscious that climate resiliency is not just a construction issue but has wider urban design, infrastructure and "big system" implications. Mandell urges a focus on affordability and thinking about "simplicity and redundancy", theorising that "you need something that's going to stand up over time or if one piece breaks, you have another piece that can take its place" (2024).

Solutions might start small but can think big

Regarding the cost of innovation and change in the way NZ constructs public housing, Saville-Smith notes, "the problem with the building industry is there's a vicious cycle of blame that goes on. And that cycle of blame, essentially allows everybody to get off the hook" and remain with the status quo (Saville-Smith, 2024). This concern about the absolution of responsibility is a common thread across international policies for climate resilience and circular economy housing (Horne, 2023).

Like Mandell, Saville-Smith is conscious that there is a complex web of problems which government and industry can start tackling with small, but tangible steps. Currently, Aotearoa New Zealand does not build low-cost public housing that is financially or environmentally sustainable for tenants and Saville-Smith there is no "one" solution to this conundrum, but CEC systems could be part of "a" solution (2024).

There appears to be a lack of research on the connection between CEC systems and housing

The director of architecture at Kāinga Ora, Marko den Breems, states that the organisation is in the early stages of unpacking what climate-resilience means to their tenants and how to approach it. Their main foci, driven by MBIE's objective to increase a building's operational efficiency, are reducing carbon emissions, reducing water use and improving health and wellbeing through indoor environmental qualities (Kāinga Ora Homes and Communities, 2020). The interview with den Breems indicates there is a lack of government-led research into circular economy systems that will address the existing lack of built case-studies needed to encourage the adoption of innovative construction methods by housing providers and communities.

Mātauranga Māori and construction innovation

Education about housing alternatives is essential

In addressing housing challenges in Waiwhetū, Puketapu stresses the importance of diversifying building methods and educating iwi about alternatives, stating that there is "not only one way to build a house" (Puketapu, 2024).

People have historical, emotional and spiritual connections to the land which must be considered

The need for housing innovation sits within the social and cultural contexts of communities. Housing is underscored by the historical, emotional and spiritual connections communities have to the land, particularly Māori who whakapapa to the whenua. Leaders are grappling with the challenge of simultaneously protecting people, buildings and sacred sites like urupā from flooding.

Puketapu highlights instances across Aotearoa where erosion and cyclones threaten marae and urupā, necessitating the difficult task of relocating the remains of buried loved ones. He reflects, "I don't even know how I would mentally prepare to do that" (Puketapu, 2024), highlighting the emotional burden and testing of resilience communities in vulnerable areas are facing. This concern emphasises the need for housing solutions that not only withstand environmental pressures but also respect and protect the cultural significance of ancestral lands.

Looking to the past for guidance

Innovative housing should be inspired by traditional techniques, Māori traditions and environmental stewardship. There has been a call for investigating traditional Māori building practices, despite the cost associated with exploring innovative construction solutions.

There is a distinct connection between mātauranga Māori and construction innovation. There are examples of Māori building practices that can withstand flood events and revived construction methods (figure 33) that can withstand major earthquakes (Hoete & University of Auckland, 2023). In the face of looming climate challenges, understanding how we adapt is intrinsically linked to seeking guidance and leadership form Māori.

Fig.32. A view of the Te Awa Kairangi Hutt River estuary with Rimutaka Range in the background. Smith, W., M. (1853).

Fig.33. An endangered construction technique called 'mīmiro,' where timber portals use interlocking compression joints, instead of bolting parts together. EQC. (n.d.).

Social resilience and housing resilience

Agency can foster social resilience

Critical to the discussion about community resilience in the face of climate challenges is inclusive accessible design processes that ensure communities are supported to make their own decisions without being drained of their time and resources.

Mandell advocates for inclusive design processes that respect community complexities and aspirations, aiming to enhance project value by aligning with community needs, stating, "It's about giving communities the respect to trust them to understand the complexities and limitations, and to solve problems together in a way that incorporates their experience and goals" (Mandell, 2024).

Relatedly, Saville-Smith warns against the misuse of social resilience rhetoric and gives the example of a segment of the Christchurch earthquake response using the 'socially resilient communities' label to justify doing little else to support communities to rebuild. She emphasises, "if you have really got social resilience, you're really trying to ensure that people have agency, that they can make decisions, and therefore they need to be enabled to make decisions across scale" (Saville-Smith, 2024).

Housing models can foster social resilience

Community Housing Providers (CHPs) are a vital social infrastructure, enabling their community to design, build, and manage their own homes amidst a severe housing shortage. This initiative not only addresses immediate housing needs but also fosters employment opportunities and educational pathways, empowering individuals through skill development. Puketapu highlights innovative approaches within their iwi, utilising diverse housing models to achieve their aspiration of housing their people.

Circular economy construction (CEC) systems can foster social resilience

Ged Finch, a CEC expert, notes how the ability to adapt physical space can foster social resilience in communities, stating that it can foster "a sense of greater ownership, responsibility and permanence to that space" (Finch, 2024). For social housing tenants who may not have stability in their lives, being able to customise, adapt and personalise homes can be an important act of placemaking.

Circular economy construction systems in Aotearoa

Current barriers to circular economy construction systems in Aotearoa

Ged Finch and Luke Ransfield (Ngāti Tukorehe, Ngāti Tu) offer insights on the challenges of pursuing circular economy construction in Aotearoa. They believe that circular economy construction systems have a future in Aotearoa, but face many challenges in the roadmap towards feasibility, affordability and becoming a regular part of the architectural toolkit. Some of the current barriers to CEC in Aotearoa housing include:

» Purity paralysis: There is a strong emphasis on maintaining purity in Circular Economy and Construction (CEC) systems, which sometimes leads to a reluctance to take action. Despite this, there is a need to demonstrate proof of concept to ensure viability (Finch, 2024).

» Standardisation hurdles: The lack of standardised processes for utilising and certifying second-hand materials remains a significant barrier to advancing CEC products and processes. This ambiguity complicates efforts to establish clear guidelines and frameworks (Ransfield, 2024).

» Housing challenges: Circular practices face challenges in housing due to the substantial upfront costs and the tendency of occupants to maintain the same structures for extended periods, often 50 years or more. However, changing climate conditions may influence future reuse potentials.

» Aotearoa's construction barriers: New Zealand's construction industry encounters multiple systemic challenges that impede innovation. These include its small market size, limited supply chains, and stringent seismic building requirements, all of which increase costs and restrict flexibility in adopting new approaches. For example, integration challenges of CEC with existing building regulations like NZS3604 (Orr, 2024).

» Economies of scale: The residential construction sector operates with narrow profit margins, making it difficult for circular solutions to gain traction without clear economic advantages. This underscores the importance of developing compelling value propositions to encourage adoption.

» Relocation is possible, but complex: The logistical, technical, and financial challenges associated with physically relocating buildings (for example, managed retreat purposes) extend beyond considerations of material reuse alone.

Opportunities for circular economy construction systems in Aotearoa

Some of the potential opportunities include:

- Climate change is a catalyst for innovation: Climate change necessitates a shift towards alternative systems that can adapt and add value through circular design principles. Designing for circularity becomes imperative as climate change alters conventional paradigms (Finch, 2024).
- CEC Challenges in Flood-Prone Areas: While integrating climate resilience remains complex and resource-intensive, not all circular solutions are inherently climate-adaptable or appropriate (Ransfield, 2024). This complexity underscores the trade-offs involved in adopting circular solutions for such environments. Further investigation and pilot projects are needed to understand local needs and local solutions (Ransfield, 2024).
- Cost comparison of CEC: CEC systems typically incur a higher upfront cost compared to conventional systems. Although it can be a deterrent, this higher initial investment can be justified by the long-term benefits, and could potentially offset post-event repair costs.
- Advantages of prefabricated systems: Prefabricated systems mitigate on-site challenges like ad hoc decision-making by standardising construction processes.
- Adaptive interior design: Flexible interior designs that allow for personalisation and adaptation foster a stronger sense of ownership and responsibility among occupants. This psychological connection encourages better maintenance and care of properties, promoting long-term sustainability.
- Value demonstration through case studies: Conducting case studies and pilot projects is crucial for evaluating the technical, social, and climate impacts of circular solutions in real-world settings.
- Maintenance: CEC systems offer opportunities for easier maintenance, something that is a priority for many people across the country, particularly elderly people and people with accessibility needs.

Summary

Flood-resilience is a priority now

In Aotearoa and globally, there is a critical shift from traditional flood prevention to more adaptive, resilience-based approaches in housing. This involves designing homes and communities that can withstand and quickly recover from flood events, incorporating Indigenous knowledge, international best practices, and innovative construction methods to improve both structural and social resilience. Interview insights reveal that having agency to make informed decisions and adapt one's environment over time increases social resilience.

Mātauranga Māori provides essential insights for climate resilience and construction innovation in Aotearoa.

Historically, Māori communities have practiced climate resilience by establishing settlements in safe locations, relocating in response to hazards, and using traditional architectural knowledge. Contemporary responses include using marae as welfare hubs during climate events, highlighting the importance of community spaces for physical and social resilience. Mātauranga Māori's holistic and community-oriented approach contrasts with Western linear construction processes, making it highly valuable for building social resilience. Additionally, Māori perspectives align naturally with circular economy principles, promoting local employment, knowledge, and community resilience. In Ka mua, ka muri: Connecting tāngata to whenua through housing, Berghan et al, (2024) summarise their investigation with several key points:

» Securing the whenua (land) is crucial for establishing resilient kāinga (homes). This foundational step supports long-term stability and provides a base for all other aspects of home development.

» Creating accessible kāinga that accommodate all abilities supports cultural and social resilience by allowing people to stay connected to their whānau (family) and whenua throughout their lives.

» Holistic resilience beyond just the physical design of housing fostering community connections and behaviours help mitigate environmental impacts.

» Incorporating shared infrastructure, like laundry or transport services, enhances both physical and social resilience.

» Effective kāinga design involves long-term masterplanning including food production, energy generation, and recreation.

Construction methods in Aotearoa must adapt to evolving community aspirations and planning legislation, promoting flexibility and alignment with te Taiao and climate changes.

Circular Economy Construction Systems (CECs) can support structural and social resilience though research indicates there is no single solution to cost-effective, flood-resilient housing. Through design for disassembly, use of recycled and renewable materials, and adaptive reuse, CECs minimise waste, maximise resource use, and foster agency for people to change and improve their homes. Collaborative efforts and policy support are essential to overcoming challenges and advancing CEC practices in Aotearoa's construction industry.

While CECs offer promising solutions, research indicates they also face several challenges:

- Affordability is a key priority for innovative building systems to be adopted, otherwise, it's a 'nice to have.' CECs have higher upfront costs compared to conventional systems, though long-term benefits may offset post-flood repair costs.
- Lack of understanding about alternatives to conventional construction systems.
- Complex information that can be dense and time-consuming to comprehend, deterring housing providers and communities from considering something other than the status quo.
- Need for built case studies and pilot projects to demonstrate value before financial and emotional investment.
- Requirement for gradual introduction in less cost-sensitive sectors to refine approaches and drive down costs.

Managed retreat and relocation guidance needs urgent attention

Research indicates that practical implementation frameworks for managed retreat are still in development and few flood-prone communities in Aotearoa have clarity on a way forward. Communities show varied responses to relocation, significantly influenced by cultural and spiritual connections to whenua, which may deter them from leaving flood-prone areas. Historical and cultural links to living near water, combined with economic and planning obstacles, mean many people are reluctant to move from flood-prone areas. While severe climate-related events are increasing and sea-level rise looms, some communities don't yet perceive the risk as significant enough to warrant retreat. This highlights the complexity of balancing cultural ties with the need for flood-resilient housing solutions.

With all this in mind, could CECs enable retreat if it becomes a higher priority?

Should people choose to build in flood-prone areas, do CEC systems support resilience in flooding events?

There is a need for holistic investigation and proactive strategies, including modular construction, wet-proofing, dry-proofing, and designing for reconstruction to better manage and adapt to the impacts of flooding.

Considerations for the scenarios in the following section include but are not limited to:

Structural resilience considerations

» Stretchable structural connections

» Multiple Storeys and Exits

» Water-Resistant Materials

» Non-Toxic and Replaceable Materials

» Drainage Systems

» Elevation - Raised Floor Level

» Design for prefabrication, preassembly and modular construction

» Simplify and standardise connection details (screws, bolts, nails, etc.)

» Simplify and separate building systems

» Minimise building parts and materials

» Select fittings, fasteners, adhesives, sealants and other items that allow for disassembly

» Design to allow for deconstruction logistics

» Design with reusable materials

» Design for flexibility and adaptability

» Suspended timber floors

Social resilience considerations

» Can people rely on their homes for safety and comfort in the event of a flood?

» How quickly can people return to a dry, functional home after a flood?

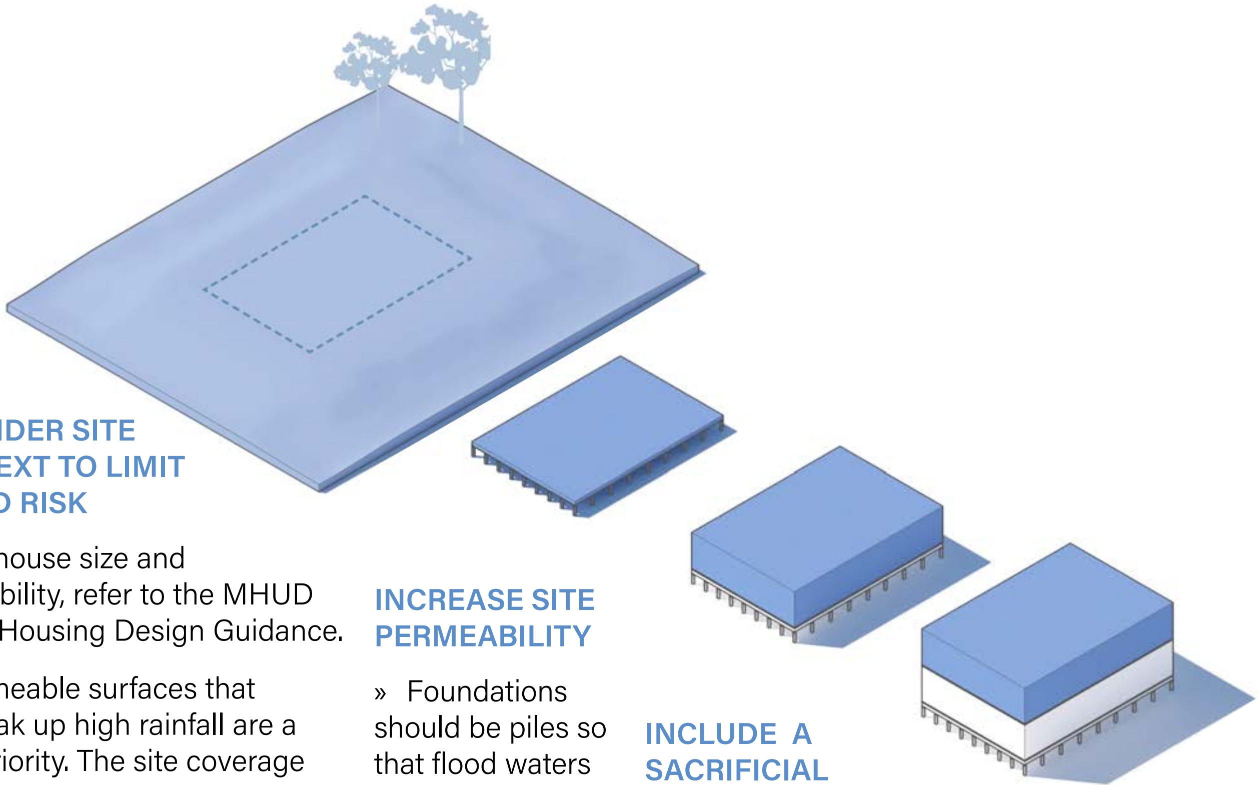
» Can people respond to the changing environment in the future without their house contributing to significant social or financial losses (can the house be transformed or moved)?

» Can the home be simultaneously flood resilient and reflect the community it is built for?

» Can the home be simultaneously flood resilient and accessible?

Design Principles

Informed by the preliminary research, the following are high-level design principles for flood resilient homes in Aotearoa.



CONSIDER SITE CONTEXT TO LIMIT FLOOD RISK

» For house size and affordability, refer to the MHUD Public Housing Design Guidance.

» Permeable surfaces that can soak up high rainfall are a high priority. The site coverage regulations in your local district plan are a minimum requirement.

» Orientation of building to predicted flood water direction.

» Landscaping such as swales, rain gardens and appropriate top soil to help with site drainage.

INCREASE SITE PERMEABILITY

» Foundations should be piles so that flood waters can permeate the ground.

» The foundation height must be above the predicted flood height according to your local district plan.

» Consider making the building movable or more easily dissassemblable.

INCLUDE A SACRIFICIAL GROUND FLOOR THAT IS BUILT TO FLOOD

» MHUD Public Housing Guidance recommends 2.4m - 3m stud height.

» Ground floor is built to flood with materials that can be dissassembled to help with drying post-flood.

CREATE A LIVEABLE SPACE IN A FLOOD EVENT VIA A FIRST STOREY

» Consider what living spaces your whānau need to have in a flood event and prioritise them on the first floor.

» Consider which rooms should be on the ground floor ("watery" spaces that are made to flood) and which ones go on the first floor (dry spaces).

» Hip, gable, simple monopitch and salt box rooves better direct water away from the house during high rainfall.

» Drainage systems such as guttering and drainpipes that can manage high quantities of water.

DIRECT WATER AWAY SAFELY

» An easily accessible balcony is recommended for emergency evacuations in a flood event.

PROVIDE EMERGENCY EXITS FOR EVACUATION

» Wheelchair accessible lift alongside stairs as per Lifemark standards or other credible accessibility standards.

» Accessible ramp, at minimum 1:12, 1.2 metres wide.

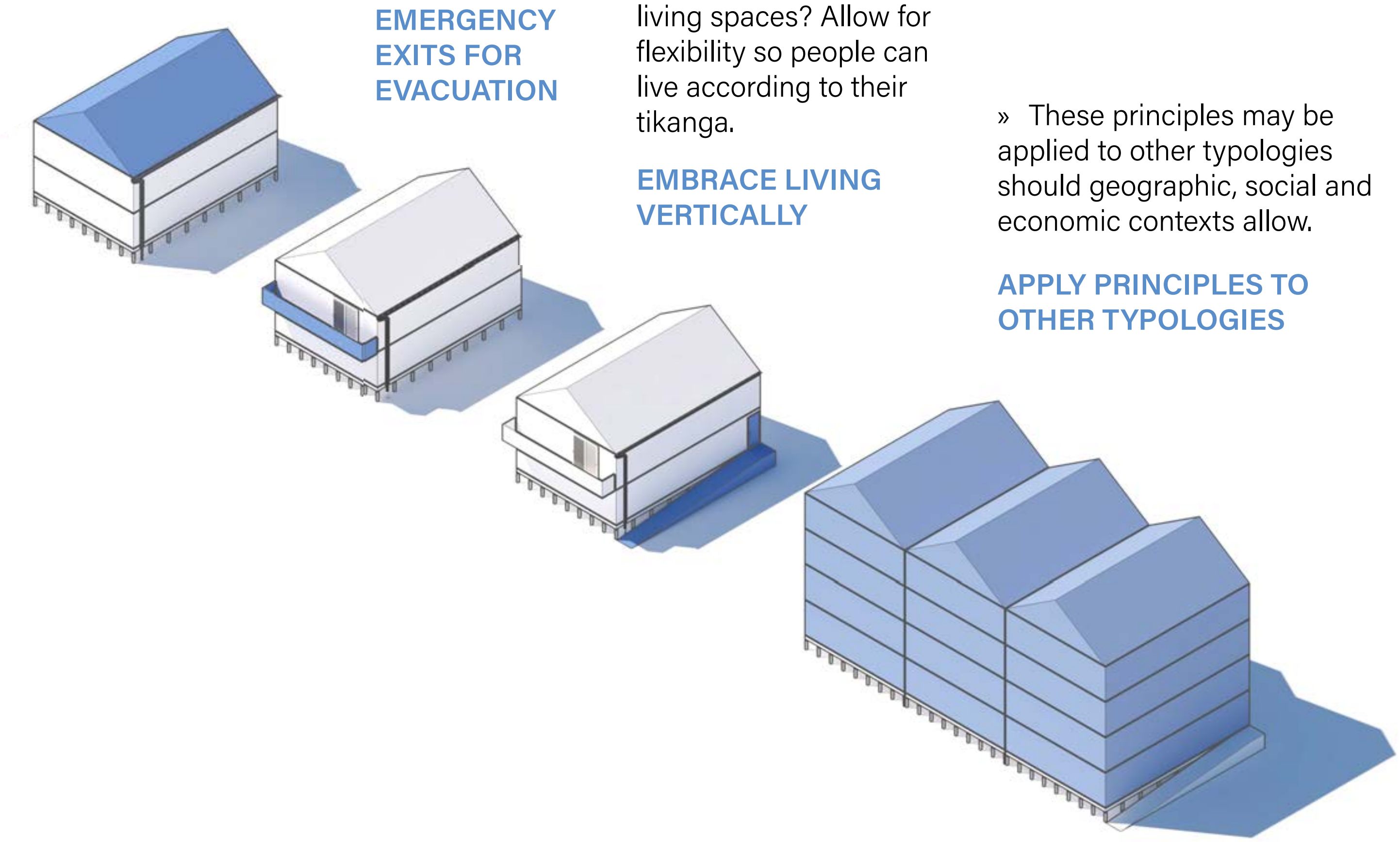
» Hallways and doorway widths as per Lifemark standards.

» Tikanga implications of living vertically and tapu/noa relationships (these are hapū and iwi specific). For example, should bedrooms be below living spaces? Allow for flexibility so people can live according to their tikanga.

EMBRACE LIVING VERTICALLY

» These principles may be applied to other typologies should geographic, social and economic contexts allow.

APPLY PRINCIPLES TO OTHER TYPOLOGIES



Part 3

CASE STU

UDY

Analysis of commercially available timber CEC systems

Evaluation criteria

The evaluation criteria (right) are informed by the engagement and literature review, and the design principles.

The scenarios (page 66) will explore more in depth about structural and social implications of using the selected CEC system, including cost, feasibility, limitations and other factors which will be evaluated by CEC experts, architects and members of the community.

The following pages outline the evaluated CEC systems. Note that CEC systems are nuanced and this criteria was simplified due to the scope of this research.

Overall, all of the systems have potential to be used in the scenarios due to their circularity or their potential for flood-resilience. Preference was given to Aotearoa-based systems as they are more likely to address the New Zealand building code's requirements for seismic resilience.

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material?

Yes / No

Is the system movable in case of relocation?

Yes / No

Is the system assemblable and dissassemblable?

- for example, can elements of the system be replaced?

Yes / No

Is the system suitable for public housing in Aotearoa:

Yes / No

- Does it meet seismic requirements?
- Are there existing feasibility studies for it being used in Aotearoa?
- Can it be designed according to universal design principles?
- Can it support two-storey structures?

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly?

Yes / No

Can it be installed on piles?

- ie, not on a concrete slab

Yes / No

Does the system have potential to help speed up the process of drying post flood event:

- for example, removable linings that can enable better access to structure?

Yes / No

U-Build

United Kingdom

Fig.34. U-Build's Box House built in Bicester The home was created with future changes and extensions in mind.

U- Build is a self-build system. It simplifies construction with its modular and easily assembled boxes, allowing individuals to create customized spaces using only basic tools. Its circular economy approach is evident in its fully demountable and recyclable parts, minimal environmental impact, and the ability to adapt and relocate the structures as needed (U-Build, 2024). Key features include:

» All components of U-Build structures are designed to be fully recyclable, reducing waste and promoting material reuse at the end of their life cycle.

» The system's modular nature allows for easy disassembly and reassembly, facilitating the reuse of components and minimizing the need for new materials in future constructions.

» Many U-Build solutions eliminate the need for concrete foundations, allowing the structures to be relocated with minimal disruption to the ground.

» CNC files can be sent to CNC facilities in Aotearoa to be cut locally.

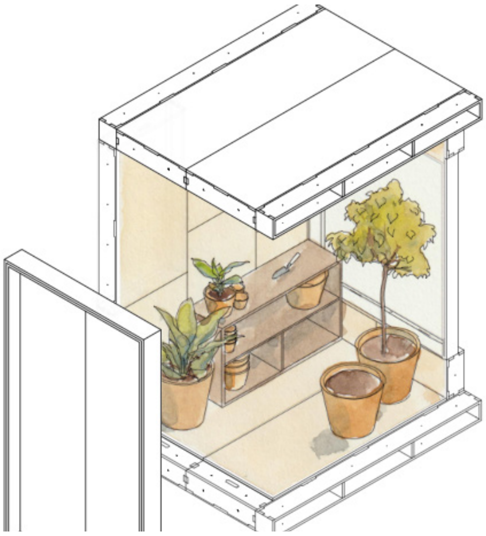


Fig.35. U-Build's modular bolt-together system.

Fig.36. U-Build's two-storey housing typology.

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material? [✓ Yes] / No

Is the system movable in case of relocation? [✓ Yes] / No

Is the system assemblable and dissassemblable? [✓ Yes] / No

- » for example, can elements of the system be replaced?

Is the system suitable for public housing in Aotearoa: Yes / [✓ No]

- » Does it meet seismic requirements?
- » Are there existing feasibility studies for it being used in Aotearoa?
- » Can it be designed according to universal design principles? ✓
- » Can it support two-storey structures? ✓

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly? [✓ Yes] / No

Can it be installed on piles? [✓ Yes] / No

- » ie, not on a concrete slab

Does the system have potential to help speed up the process of drying post flood event: [✓ Yes] / No

- » for example, removable linings that can enable better access to structure?

Easy Housing

Uganda

Fig.37. First Easy Housing three bedroom 50 sqm home on concrete piles.

Easy Housing create homes that integrate circular economy principles and enhance livelihoods and resilience (Easy Housing, n.d.) by:

» The structure is prefabricated in carpentry workshops, allowing for efficient assembly on-site. They use biobased materials like timber frames and natural insulation such as papyrus.

» Locally sourcing and using resilient supply chains.

» Architects collaborate with communities to tailor home designs to fit local needs and cultural contexts.

» Creating climate resilience by incorporating passive design principles like natural ventilation and elevated floors to withstand extreme weather.

» Brokering inclusive finance partnerships. Easy Housing collaborates with finance partners to make sustainable homeownership accessible.

Fig.38. Local builder's constructing Easy Housing,

Fig.39. Easy Housing build in progress.

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material? [✓ Yes] / No

Is the system movable in case of relocation? [✓ Yes] / No

Is the system assemblable and dissassemblable? [✓ Yes] / No

- for example, can elements of the system be replaced?

Is the system suitable for public housing in Aotearoa: Yes / [✓ No]

- Does it meet seismic requirements?
- Are there existing feasibility studies for it being used in Aotearoa?
- Can it be designed according to universal design principles? ✓
- Can it support two-storey structures?

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly? [✓ Yes] / No

Can it be installed on piles? [✓ Yes] / No

- ie, not on a concrete slab

Does the system have potential to help speed up the process of drying post flood event: [✓ Yes] / No

- for example, removable linings that can enable better access to structure?

XFrame

Aotearoa

Fig.40. XFrame' s Assembly Three Suite+ two-storey prototype.

XFrame is a circular economy construction system offering modular, demountable structures, designed to facilitate easy adaptation and reduce waste. The system's inherent lateral bracing allows lining materials to be clipped onto the structural frame, enabling effortless reconfiguration while minimizing environmental impact. This includes:

- Reversible fixing methods for wall linings and claddings, enabling easy updates and modifications without generating significant waste.
- Parts are precision-milled from engineered radiata pine plywood, ensuring efficient material use and minimising waste.
- The assembly process is designed to be efficient, using only common hand tools. Additionally, the system avoids the use of nails or glue, relying on precise connections and reversible fixing methods.
- Made from natural and rapidly renewable materials
- Engineered for geometric stability and scalability, XFrame's design ensures structural integrity and adaptability across various building sizes and configurations.

Fig.41. X-Frame Prototype Pod 1 with reusable shingle cladding.

Fig.42. Galloway 10 was XFrame's demonstration project showcasing the technology's potential to deliver high performance housing while utilising a local supply chain (XFrame, 2024).

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material? [✓ Yes] / No

Is the system movable in case of relocation? [✓ Yes] / No

Is the system assemblable and dissassemblable? [✓ Yes] / No

- » for example, can elements of the system be replaced?

Is the system suitable for public housing in Aotearoa: [✓ Yes] / No

- » Does it meet seismic requirements? ✓
- » Are there existing feasibility studies for it being used in Aotearoa? ✓
- » Can it be designed according to universal design principles? ✓
- » Can it support two-storey structures? ✓

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly? [✓ Yes] / No

Can it be installed on piles? [✓ Yes] / No

- » ie, not on a concrete slab

Does the system have potential to help speed up the process of drying post flood event: [✓ Yes] / No

- » for example, removable linings that can enable better access to structure?

WikiHouse

United Kingdom

Fig.43. WikiHouse's 2022 project in Ukraine, build to provide shelter for displaced families.

WikiHouse is an open source modular building system designed for easy design, manufacture, and assembly of high-performance structures. Its components are digitally fabricated for precision, making construction straightforward and efficient, while also supporting sustainable practices. Key features include:

» WikiHouse Skylark buildings are designed to be easily disassembled, allowing for the reuse or recycling of blocks rather than demolishing and disposing of them.

» The use of spruce plywood, which is not only durable but also carbon-negative, helps reduce the overall environmental impact by capturing and storing atmospheric carbon.

» Components are digitally fabricated to exact specifications, ensuring efficient use of materials and reducing waste during both the construction and disassembly processes.

Fig.44. On-site assembly of a WikiHouse.

Fig.45. Structural components of a WikiHouse.

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material? [✓ Yes] / No

Is the system movable in case of relocation? [✓ Yes] / No

Is the system assemblable and dissassemblable? [✓ Yes] / No

» for example, can elements of the system be replaced?

Is the system suitable for public housing in Aotearoa: Yes / [✓ No]

» Does it meet seismic requirements?

» Are there existing feasibility studies for it being used in Aotearoa?

» Can it be designed according to universal design principles? ✓

» Can it support two-storey structures? ✓

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly? [✓ Yes] / No

Can it be installed on piles? [✓ Yes] / No

» ie, not on a concrete slab

Does the system have potential to help speed up the process of drying post flood event: [✓ Yes] / No

» for example, removable linings that can enable better access to structure?

EasyBuild

Aotearoa

Fig.46. EasyBuild home built on elevated timber piles.

EasyBuild offers a modular construction system designed to deliver high-quality, cost-effective, and energy-efficient homes with a streamlined building process. Their approach emphasises speed, ease of construction, and reduced environmental impact by:

» Using a modular construction method which cuts build waste by two-thirds compared to conventional methods.

» The homes are designed to be highly energy-efficient, featuring superior insulation and airtightness.

» By sourcing raw materials locally, EasyBuild minimises transportation-related emissions and supports a more sustainable supply chain.

» The modular approach and pre-approved designs streamline the construction process, reducing the need for extensive on-site modifications.

» The building units can have elevated foundations and can be moved, but not easily dissassembled.

Fig.47. Construction of EasyBuild home using its modular framing system.

Fig.48. EasyBuild can be configured into two-storey buildings.

Evaluation Criteria

Can the system be produced from a local, sustainably sourced timber material? [✓ Yes] / No

Is the system movable in case of relocation? [✓ Yes] / No

Is the system assemblable and dissassemblable? Yes / [✓ No]

- for example, can elements of the system be replaced?

Is the system suitable for public housing in Aotearoa: [✓ Yes] / No

- Does it meet seismic requirements? ✓
- Are there existing feasibility studies for it being used in Aotearoa? ✓
- Can it be designed according to universal design principles? ✓
- Can it support two-storey structures? ✓

Does the system use fittings, fasteners, adhesives, sealants and other items that allow for disassembly? Yes / [✓ No]

Can it be installed on piles? [✓ Yes] / No

- ie, not on a concrete slab

Does the system have potential to help speed up the process of drying post flood event: Yes / [✓ No]

- for example, removable linings that can enable better access to structure?

Scenario Overview

The following are three design scenarios showing existing and new approaches to building a 12 person, 175m2, multigenerational home.

The purpose of scenarios is to show a spectrum of construction approaches to flood resilience.

These scenarios were used to prompt conversations with communities, architects and other experts so they can visually understand the choices side by side. The overarching purpose of educating people on alternatives to the construction systems we are most familiar with.

The scenarios are detailed in the following pages, alongside the opportunities and challenges that were highlighted in conversations with community members, architects and designers.

SCENARIO 1: TYPICAL APPROACH

» A typical way of building for permanance in Aotearoa. A concrete slab foundation with conventional timber post and beam walls and timber gable roof in accordance to NZS3604.

» The lower storey is not built to flood and is likely to experience damage and will need significant drying time periods.

» Concrete slabs, although efficient from a cost point of view, have detrimental impacts in urban settings due to decreasing ground permeability (the capacity of soil to absorb and transmit water) and can exacerbate flood effects.

» This common way of building is the most cost effective because it has standardised approaches and uptake by industry and community.

SCENARIO 2: BUNKER APPROACH

» A hybrid approach, addressing flood risk with a concrete lower storey that is build to flood.

» It has an XFrame circular economy construction upper storey and roof, which is assembled without glue or nails, and can be disassembled, moved and reused. The current cost of XFrame is approximately $180 per sqm (for the 140mm frame only, assembled.)

» The combination of concrete slab and lower storey may have benefits of withstanding flood water, but again, exacerbates the issues with permeability in an urban setting. Perhaps may differ in a rural setting.

SCENARIO 3: HYBRID CEC APPROACH

» An approach that centres circular economy construction methods. Build on piles to increase site permeability, with a portal frame substructure. It uses XFrame for structural walls, infill walls and the roof.

» Majority of the structure is designed for disassembly, with structural elements, insulation and linings that could be removed, replaced and dried unlike with conventional walls.

» The structure's capacity to be disassembled may also support relocation of homes.

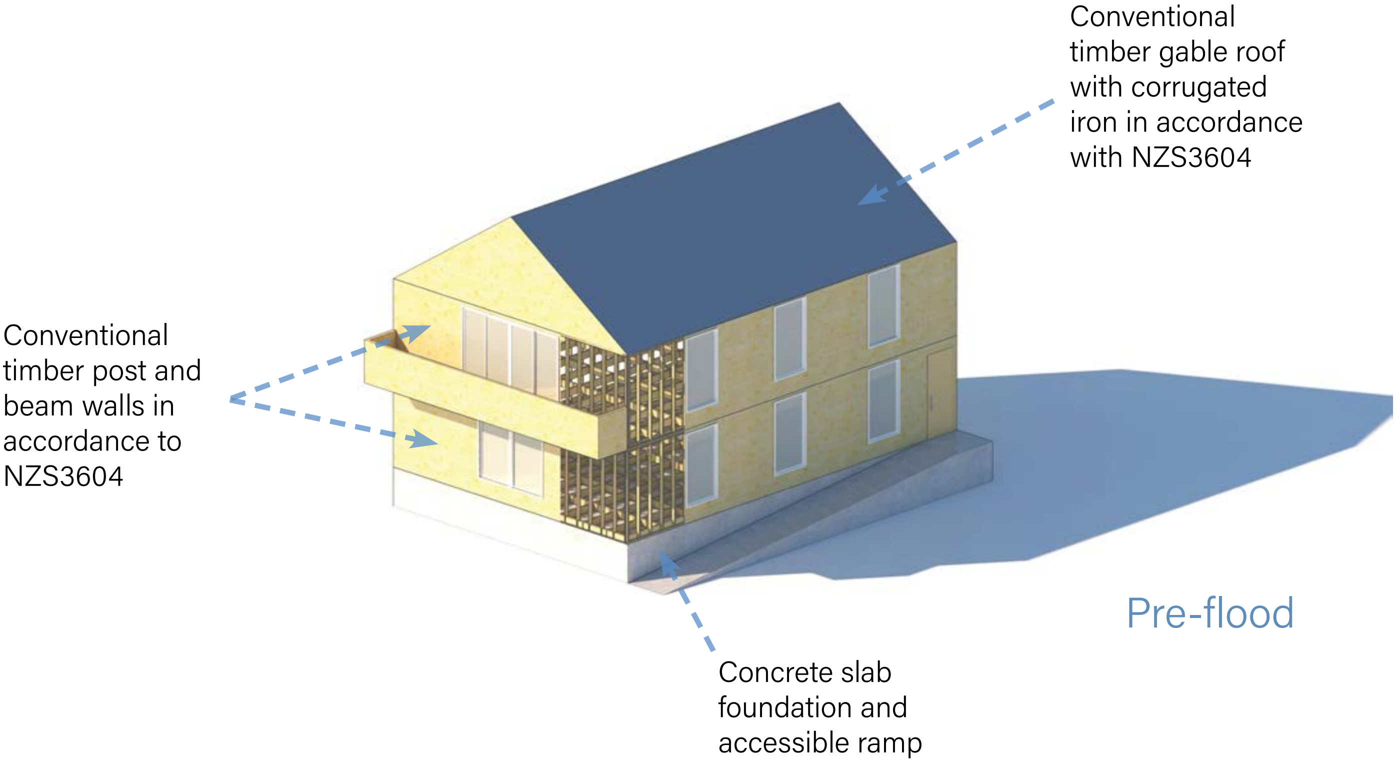
SCENARIO 1

SCENARIO 2

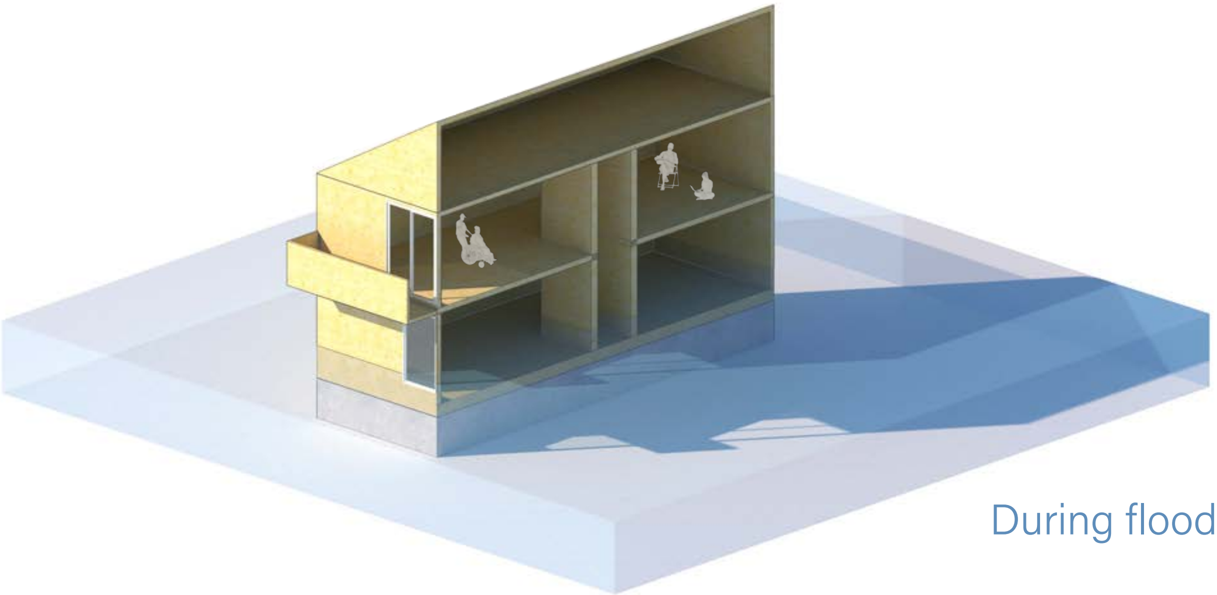
SCENARIO 3

Scenario 1

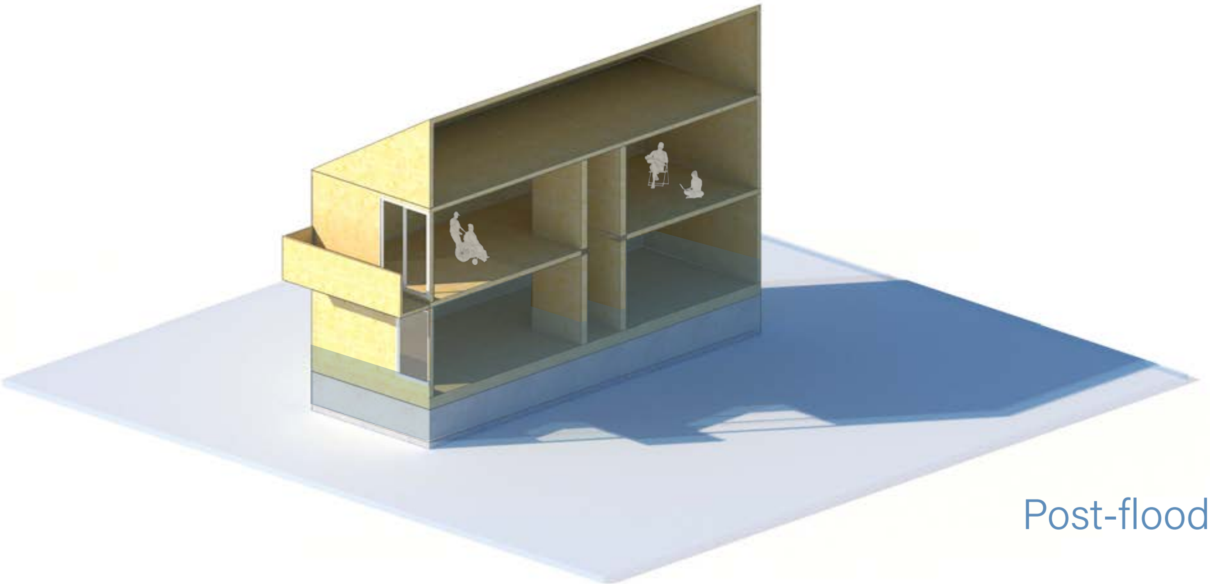
Typical Approach



Pre-flood



During flood



Post-flood

Opportunities

» Cheapest and easiest solution – it is a familiar way of building

» Smaller adjustments can be made to make it more flood-resilient - what are the ways we can adopt flood resilience in small ways?

Challenges

» Often underestimate flood provisions like foundation height; expensive flood modeling required to account for risks

» Material toxicity from glues, insulation, and adhesives impacts waterways

» Limited salvage/recycling options post-flood; NZ lacks strong construction recycling systems

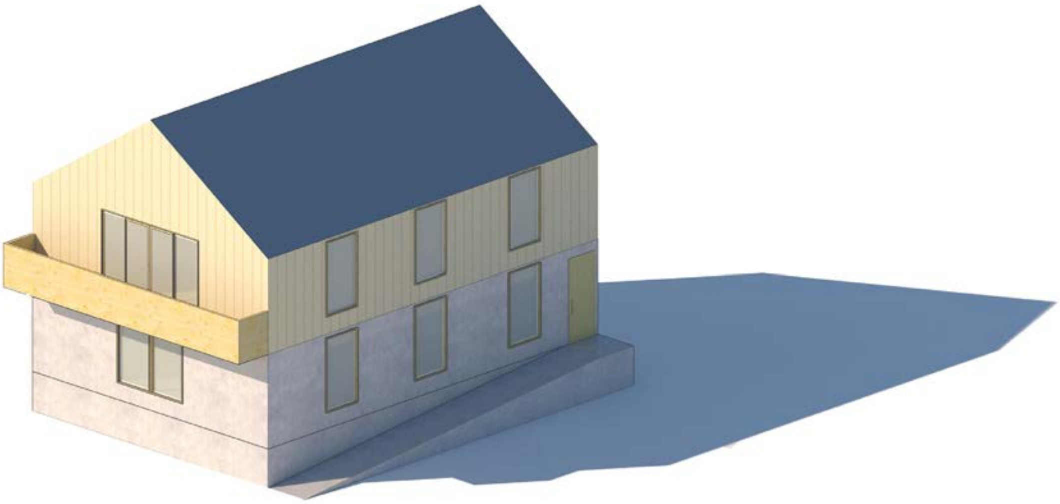
» Long drying times post-flood, delaying recovery

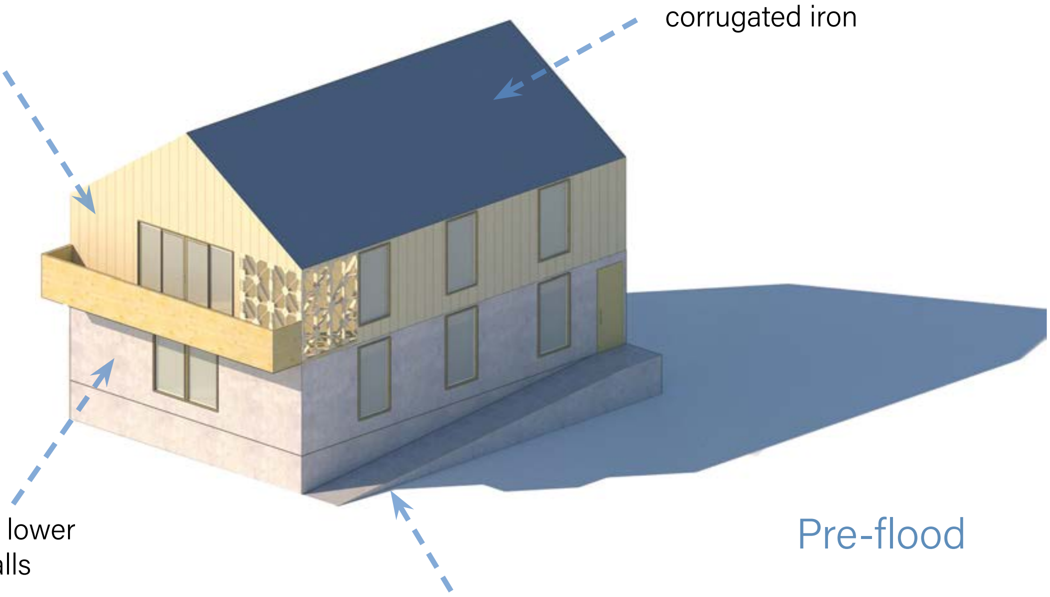
» Built for permanence, making relocation challenging

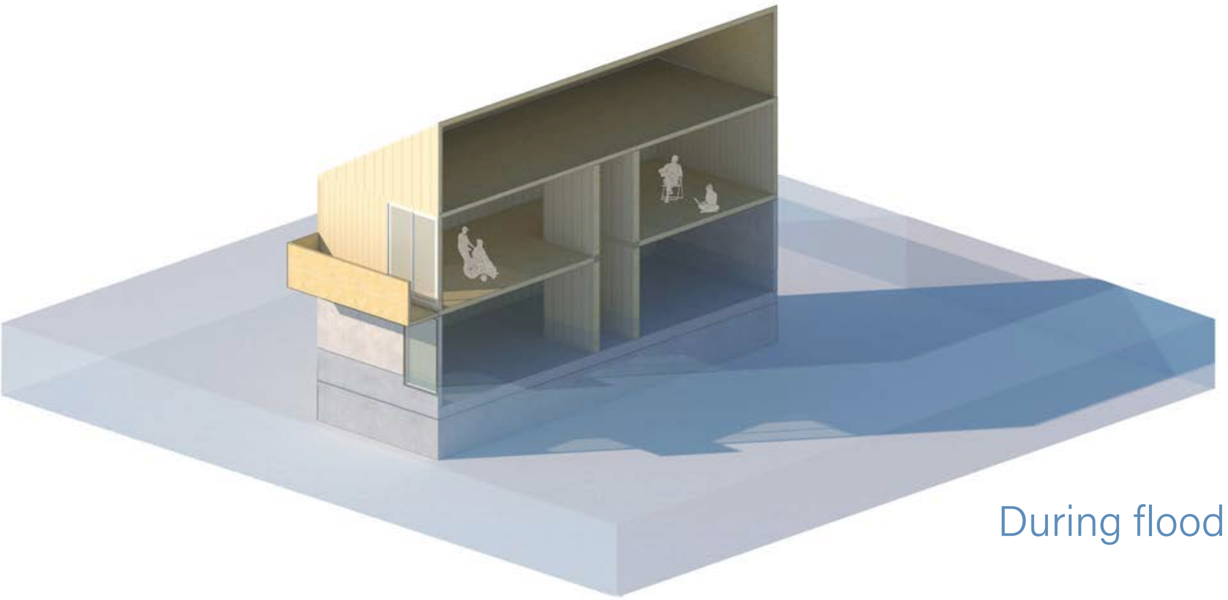
» Does not meet some of the Base Principles established in this research

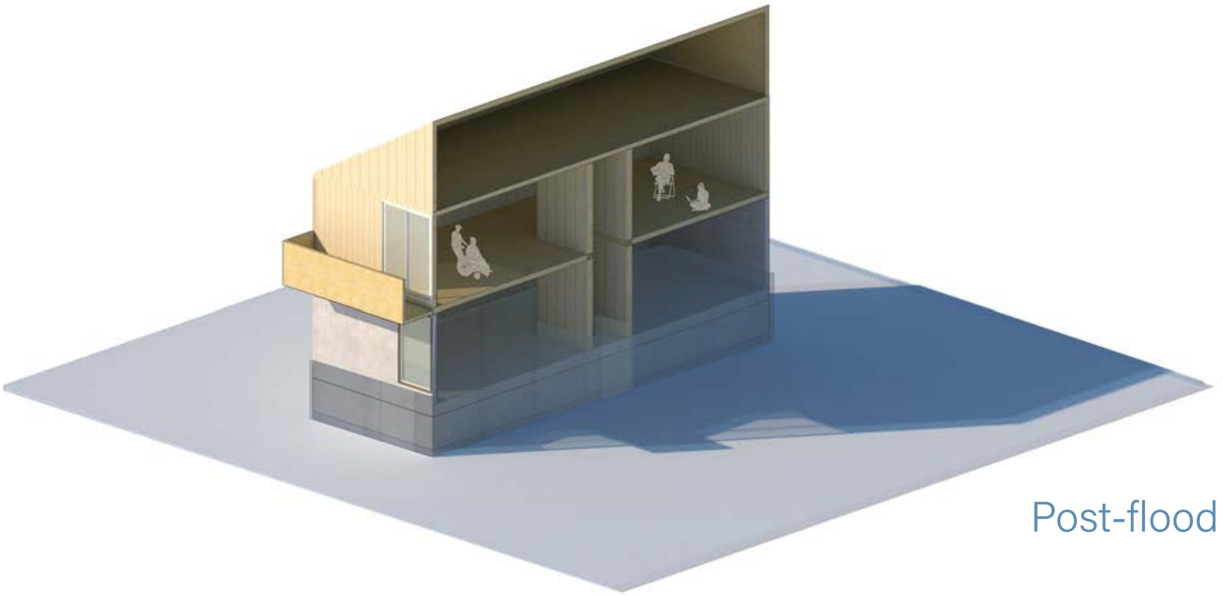
Scenario 2

Bunker Approach









Opportunities

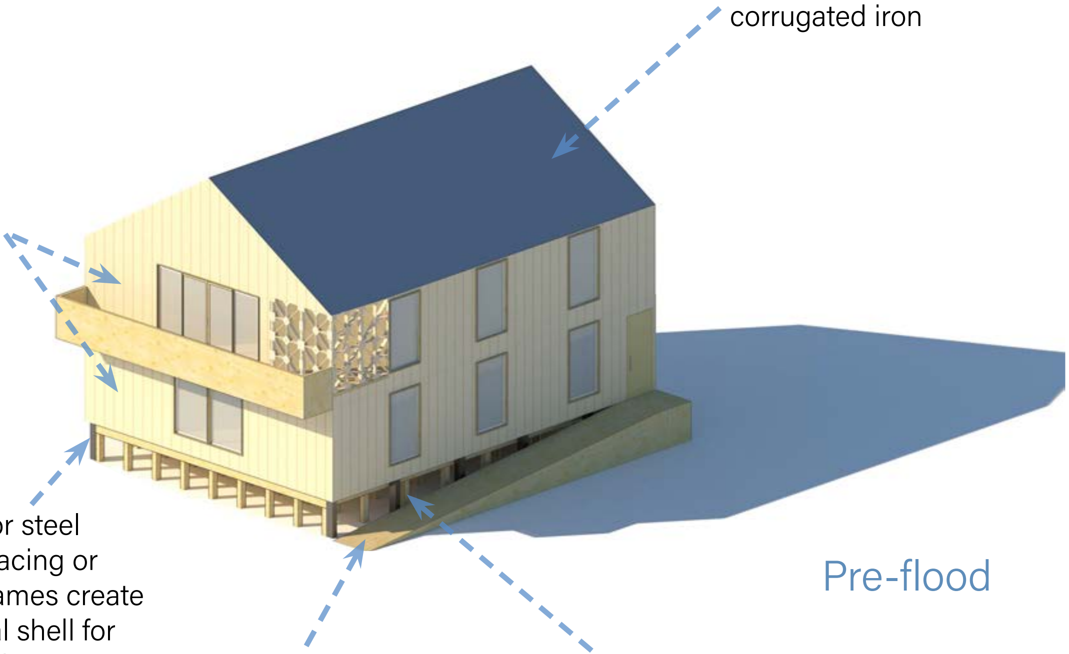
- “Made to flood” concrete bunker could be great solution during flood event in a rural setting
- A hybrid approach which gives people security on the lower storey and options to relocate upper storey

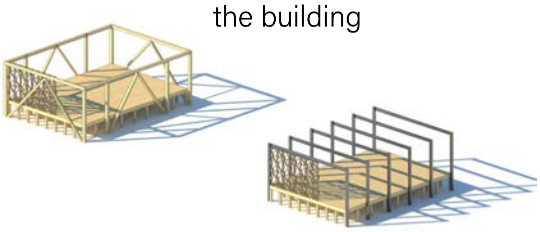
Challenges

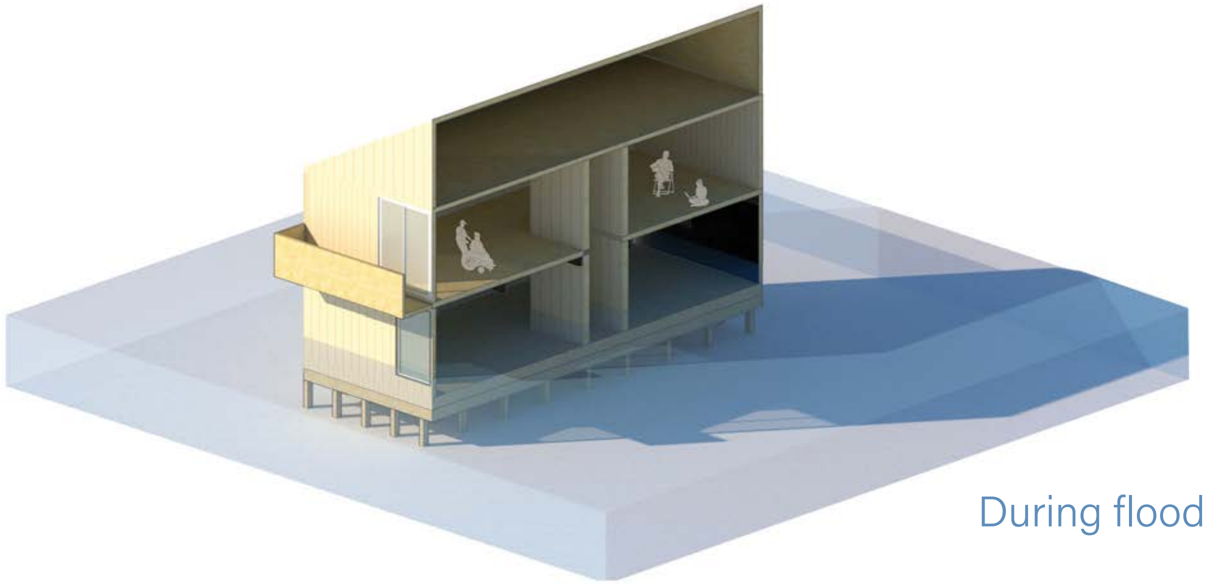
- Concrete slab and bunker lower storey still has permeability issues, which could cause issues in a densifying urban setting
- Lower storey built for permanence, making relocation challenging
- Does not meet some of the Design Principles established in this research

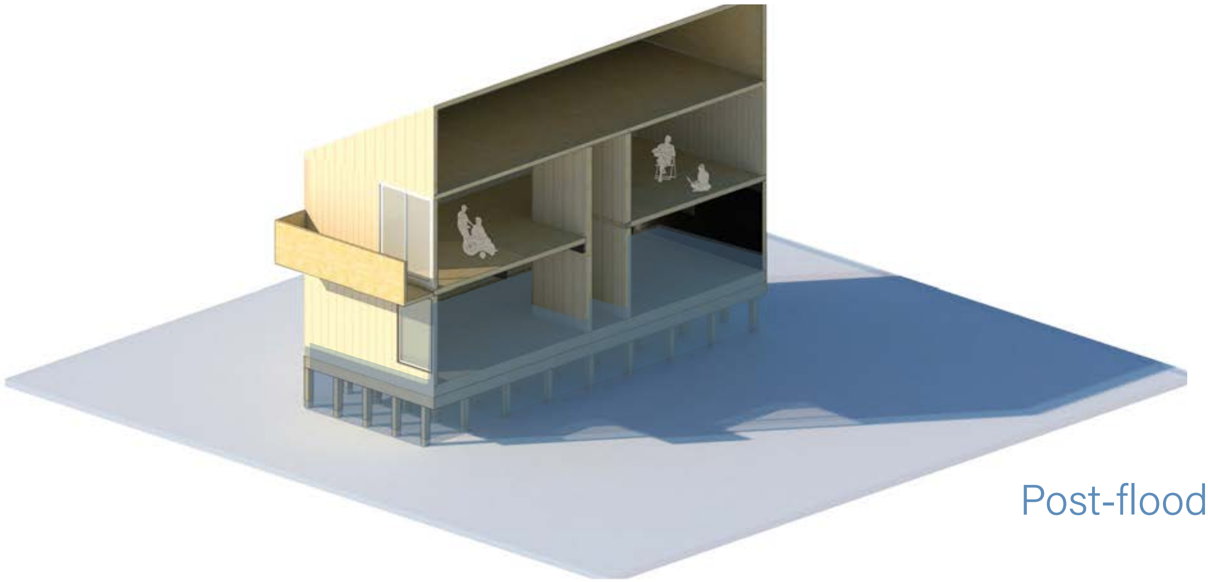
Scenario 3

Hybrid CEC Approach









Opportunities

- Stackable typologies can increase density. Can they use repeatable or varied designs?
- Protect both belongings and people
- Higher upfront costs might be justified by the typology's lifecycle
- No nails or adhesives, reducing environmental impact
- A braced exoskeleton allows the design to evolve
- Movable structures maintain familiarity with one's home
- Removable wall linings could improve drying times
- Standardisation supports quick builds for developers
- Site interventions can redirect water and debris. What other ways can the site protect homes from flooding?

Challenges

- Where do disassembled materials dry, and how are they stored?
- Opt for steel, timber may swell or delaminate, reducing reliability
- How does it align with existing standards, like plumbing?
- What are the upfront costs and long-term benefits?
- New systems have obstacles with having enough data to accurately provide costs / rates. You need projects/historic costing data to provide better pricing and scale
- Factory assembly is currently expensive due to manual labor but could become more cost-efficient with higher volumes.
- Installation costs are variable and depend on the context, which makes it hard to have "average" costing
- Although the upfront costs may be high (approx. $180 sqm (140mm frame only, assembled), there is potential for cost efficiencies with increased volume and reduced onsite construction time

Conclusion

Key findings

This research critically examined circular economy construction (CEC) systems for flood-resilient housing in Aotearoa, developing a framework of design principles. It explored industry and community perspectives across three distinct scenarios, revealing a complex landscape of opportunities, challenges, and innovative thinking. The study uncovered the complex interplay between technological innovation, social needs, and environmental challenges.

The research emerged from a fundamental question: How can timber circular economy construction systems support structural resilience in public housing and the social resilience of communities? This inquiry led to a nuanced exploration of housing design that extends beyond traditional construction methodologies, emphasising adaptability, sustainability, and community-centered approaches.

Key findings include:

Many houses are at risk of severe damage from flooding in Te Awa Kairangi ki Tai, and around Aotearoa.

Flood-resilient housing design must balance structural resilience, social needs, and environmental responsiveness. Flood resilience comes from a holistic approach across all urban scales. The permeability of our urban environment has a large impact on how our homes can cope with floodwater. Concrete slabs are a popular foundation system in Aotearoa, however they can exacerbate flood damage due to the lack of ground permeability.

Structurally resilient homes do not necessarily equate to community perceptions of safety and social resilience in a flood event.

The clean-up and drying time of houses after a flood event can severely impact community resilience.

Timber CEC systems can enable housing that can be modified, relocated, and reconfigured. They represent a paradigm shift from conventional construction, focusing on adaptive, responsive housing that protects both physical infrastructure and social well-being in changing environmental conditions. These systems provide innovative structural solutions including:

» Modular construction

» Easy disassembly

» Simplified connection details which allow for modular removal and drying

» Multi-storey design capabilities

» Using materials that are less toxic or harmful to the environment

CEC systems can support social resilience by:

» Facilitating quick recovery after flood events

» Allowing housing transformations, and potentially relocation, without significant financial loss

» Sharing some alignments with te ao Māori approaches to whenua and community

Interpretation of results

The research revealed that flood-resilient housing requires a multifaceted approach, integrating:

- Structural resilience (physical adaptability and durability)
- Social resilience (community needs, cultural considerations, and the ability to prepare for floods)
- Environmental responsiveness (site-specific adaptations and ecological considerations)

The literature highlights a global shift from traditional flood prevention to more adaptive, resilience-based housing approaches. This research explores this transition, demonstrating how circular economy construction systems can:

- Respond to local contexts and align in parts with mātauranga Māori
- Integrate international best practices
- Develop innovative construction methods

The research corroborates existing literature's identification of key challenges in implementing innovative housing solutions:

- Higher upfront costs
- Lack of understanding of alternative systems
- Complex information deterring adoption
- Need for pilot projects to demonstrate value

Scenario analysis

Scenario 1: Typical apporach

Research participants recognised this as the most familiar path, valuing its immediate cost-effectiveness and ease of implementation. However, critical limitations emerged, including:

» Insufficient flood provisions

» Environmental concerns about material toxicity

» Limited post-disaster recovery capabilities

» Challenges in material salvage and recycling

Scenario 2: Bunker apporach

The hybrid concept of a concrete lower storey with relocatable elements demonstrated research participants' desire for security. However, significant challenges remained, particularly around urban applicability and the permanency of infrastructure.

Scenario 3: Hybrid Circular Economy Construction Approach

Research participants viewed this as the most forward-looking solution, emphasising:

» Potential for increased housing density that support flood resilience

» Enhanced design flexibility

» Reduced environmental impact

» Improved post-flood recovery capabilitie

» being lifted off the ground for protection from various threats such as flooding.

Implications

The research uncovered critical insights about CEC systems:

- Flood-resilient housing is not a universal solution but a context-specific approach
- Circular economy principles can support both structural and social resilience
- Innovative design can balance safety, adaptability, and cultural considerations
- Economic complexity: while innovative approaches may have higher upfront costs, long-term benefits and lifecycle considerations are crucial.

Limitations

Key limitations include:

- Emerging nature of Circular Economy Construction systems meant that the research was constantly evolving and there were significant gaps in existing literature. This was particularly true for accurate cost and performance modelling
- Context-specific nature of flood resilience solutions meant that design principles remained at a high level to be able to apply broadly.
- Expert Availability: Challenges in securing meetings and sustained interest from experts and community members
- Contextual Influences: Broader political and societal events such as the election of a new government shaped participants' priorities.
- Time as a Limiting Factor for collaborations: The pervasiveness of time poverty among potential collaborators and participants.
- Lack of community insights and voice
- Scope had to be narrowed down because on the level of complexity of the research
- The research was evolving constantly
- Affordability: is a key conversation, but it would have been good to have more time to explore this deeper because it is so critical, particularly challenging how we think of affordability when we compare homes that are built for permanence vs homes that are built for adaptive reuse

Future research

Future investigations should prioritise:

- Further engaging with Wāiwhetū hapu and local CHPs about innovative housing solutions
- Creating Aotearoa-specific frameworks for assessing flood-resilient housing
- Developing comprehensive cost-benefit analyses of CEC systems
- Piloting adaptive housing designs, with detailed costing, and technical validation studies for CEC systems
- Investigating flood resilience in different typologies, including papakāinga and higher density.
- Collaborating further with industry professionals, including those with significant knowledge of te ao Māori
- Expanding research to include urban scales and detail scales for a holistic study

Conclusion

This research demonstrates that flood-resilient housing requires a holistic, adaptive approach. By integrating technological innovation, environmental sustainability, and cultural sensitivity, we can develop housing solutions that protect both physical infrastructure and community well-being.

APPENDIC

CES

Appendix 1: References

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Appendix 2: List of Figures

Fig.1. Overlapping research lenses.

Fig.2. Map of Te Awa Kairangi ki Tai, showing 1 metre sea-level rise, AEP modelled flood hazards and general locations of public housing developments available online. Note that although %AEPs are forecast for 100 and 440 year annual recurrence interval, extreme weather events are becoming increasingly more frequent.

» Data accessible at:
https://www.urbanplus.co.nz/
https://letstalk.kaingaora.govt.nz/lower-hutt/wairarapa-map_copy3#/

Fig.3. Positioning the research.

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Fig.7. Volunteers help clear Main Street of debris after floodwaters subsided in Highland Falls, New York.

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» Te Kura Whare Project Team. (n.d.). Te Kura Whare [Photograph]. Accessible at https://living-future.org/case-studies/te-kura-whare/

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» Te Kura Whare Project Team. (n.d.). Te Kura Whare Site [Photograph]. Accessible at https://living-future.org/case-studies/te-kura-whare/

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Fig.14. A house on stilts in Kuttanad area of Alappuzha district of Kerala.

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Fig.15. Strategies for structurally resilient housing in flood-prone areas.

Fig.16. Para Kore Waste Hierarchy.

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Fig.20. Finch's linear material consumption model, showing how prevalent waste is in Aotearoa's linear building industry.

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» Rickard, P. (2023). A self-contained home is shifted onto a section at Te Karaka in Tairāwhiti. Fifteen of the relocatable pods are being delivered to the region this month for people affected by Cyclone Gabrielle [Photograph]. Accessible at https://www.rnz.co.nz/news/national/487584/stoked-relocatable-homes-arrive-for-some-tairawhiti-cyclone-victims

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» St George, D. (2024). The GIB Lounge in the exhibition hall [Photograph]. Auckland, New Zealand. https://www.nzia.co.nz/explore/in-situ-nzia-conference/in-situ-2024/#

Fig.31. The first of the pre-fabricated cottages, built by the Department of Housing Construction (which has evolved into Kāinga Ora) in Naenae Lane, near Military Road, Lower Hutt. Evening Post. (1943).

» Evening Post. (1943). The first of the pre-fabricated cottages, built by, the State Housing Department in Naenae Lane, near Military Road, Lower Hutt. Alexander Turnbull Library, Wellington, New Zealand. Accessible at https://natlib.govt.nz/records/19592746

Fig.32. A view of the Te Awa Kairangi Hutt River estuary with Rimutaka Range in the background. Smith, W., M. (1853).

» Smith, W., M. (1853). A wet day. July, 1853. [Painting]. Ref: A-034-012. Alexander Turnbull Library, Wellington, New Zealand. Accessible at https://natlib.govt.nz/records/22683419

Fig.33. An endangered construction technique called ‘mīmiro,’ where timber portals use interlocking compression joints, instead of bolting parts together. EQC. (n.d.).

» EQC. (n.d.). The timber portals use interlocking compression joints, instead of bolting parts together [Photograph]. Auckland, New Zealand. Accessible at https://www.auckland.ac.nz/en/news/2023/04/26/endangered-maori-construction-methods-passes-seismic-testing.html

Fig.34. U-Build's Box House built in Bicester The home was created with future changes and extnesions in mind.

» U-Build. (n.d.). Box House: As seen on Grand Designs [Photograph]. Accessible at https://u-build.org/projects/u-build-box-house/

Fig.35. U-Build's modular bolt-together system.

» U-Build. (n.d.). Unnamed U-Build system [Diagram]. Accessible https://u-build.org/

Fig.36. U-Build's two-storey housing typology.

» U-Build. (n.d.). Unnamed U-Build system 2 [Diagram]. https://u-build.org/

Fig.37. First Easy Housing three bedroom 50 sqm home on concrete piles.

» Easy Housing. (n.d.). *First Easy Housing three bedroom built for a private client just outside Kampala* [Photograph]. Accessible at https://www.easyhousing.org/projects

Fig.38. Local builder's constructing Easy Housing,

» Easy Housing. (n.d.). *Unnamed Easy Housing solution* [Photograph]. Accessible at https://www.easyhousing.org/solution

Fig.39. Easy Housing build in progress.

» Easy Housing. (n.d.). *First Easy Housing three bedroom built for a private client just outside Kampala* [Photograph]. Accessible at https://www.easyhousing.org/projects

Fig.40. XFrame' s Assembly Three Suite+ two-storey prototype.

» XFrame. (n.d.). *Assembly Three* [Photograph]. Accessible at https://xframe.com.au/xframe-system/case-studies

Fig.41. X-Frame Prototype Pod 1 with reusable shingle cladding.

» XFrame. (n.d.). *X-Frame Prototype Pod 1 with reusable shingle cladding and roof slope* [Photograph]. Accessible at https://kiwinet.org.nz/News/XFrame_for_waste_free_buildings_commercialisation_boost

Fig.42. Galloway 10 was XFrame's demonstration project showcasing the technology’s potential to deliver high performance housing while utilising a local supply chain (XFrame, 2024).

» XFrame. (n.d.). *Galloway 10* [Photograph]. Accessible at https://xframe.com.au/xframe-system/case-studies

Fig.43. WikiHouse's 2022 project in Ukraine, build to provide shelter for displaced families.

» WikiHouse. (2022). *The Shelter 1* [Photograph]. Accessible at https://www.wikihouse.cc/featured-projects/the-shelter

Fig.44. On-site assembly of a WikiHouse.

» WikiHouse. (2022). *The Shelter 2* [Photograph]. Accessible at https://www.wikihouse.cc/featured-projects/the-shelter

Fig.45. Structural components of a WikiHouse.

» WikiHouse. (2022). *The Shelter 4* [Photograph]. Accessible at https://www.wikihouse.cc/featured-projects/the-shelter

Fig.46. EasyBuild home built on elevated timber piles.

» EasyBuild. (n.d.). *CLIENT CASE STUDY EasyBuild DIY Extraordinaire! 1* [Photograph]. Accessible at https://easybuild.co.nz/who-we-are/case-study-secondary-dwelling-lower-hutt-diy/

Fig.47. Construction of EasyBuild home using its modular framing system.

» EasyBuild. (n.d.). *CLIENT CASE STUDY EasyBuild DIY Extraordinaire! 4* [Photograph]. Accessible at https://easybuild.co.nz/who-we-are/case-study-secondary-dwelling-lower-hutt-diy/

Fig.48. EasyBuild can be configured into two-storey buildings.

» EasyBuild. (n.d.). *Kingsford* [Diagram]. Accessible at https://easybuild.co.nz/our-designs/kingsford/

Appendix 3: Interviewee Bios

Ihaia Puketapu (Te Āti Awa)

Ihaia Puketapu is a community leader and kaiwhakairo (carver) actively involved in initiatives supporting the Te Āti Awa iwi and the next generation of young people. With a Bachelor of Arts specialising in Māori, Commerce, and Resource Management, he combines his expertise in resource management with his passion for preserving and promoting Māori culture and heritage. Ihaia is from Waiwhetū, Te Awa Kairangi ki Tai,

Marko den Breems

Marko den Breems is the Director of Architecture at Kāinga Ora, where he has been instrumental in establishing a Design Panel to streamline the procurement process for new public housing and urban development projects. His leadership focuses on integrating sustainability, innovation, and social outcomes into the design and construction of homes and communities across New Zealand. Marko's work at Kāinga Ora also includes supporting research initiatives like the F. Gordon Wilson Fellowship.

Kay Saville-Smith

Dr. Kay Saville-Smith is the Director of the Centre for Research, Evaluation and Social Assessment (CRESA), where she has led extensive research into housing markets, sustainable housing, and community development since 1994. Her work at CRESA focuses on applied social research and evaluation, particularly in housing policy and the residential building industry. Kay's contributions include leading public good science programs and advising on housing and urban development at the ministerial level.

Julia Mandell

Julia Mandell is the Design Director at Wilson Associates, where she leads innovative architectural projects with a focus on equity and sustainability. With over 20 years of experience in the field, Julia has contributed to various high-profile designs and has been an advocate for inclusive practices in architecture. She is also the granddaughter of F. Gordon Wilson.

Ged Finch

Ged Finch is the Director and founder of XFrame, an innovative circular economy building system designed to minimize construction waste through reusable framing solutions. With a PhD in Architecture from Victoria University of Wellington, Ged has been pivotal in advancing XFrame's structural and assembly features since 2017. His commitment to sustainability and innovation aims to significantly reduce the environmental impact of the construction industry.

Luke Ransfield (Ngāti Tukorehe, Ngāti Tu)

Luke Ransfield is responsible for projects and automation at XFrame, leveraging his background in digital design and fabrication developed through architectural studies at Victoria University of Wellington. He has contributed to research projects involving robotic-controlled 3D ceramic printing and automated VR training for large organizations using 3D scanning. At XFrame, Luke focuses on strategic project delivery and the development of internal project workflows.

Kristina Orr

Kristina Orr is an architectural designer at BCN Architects, where she applies her expertise in sustainable design to various projects. She has conducted significant research into temporary emergency housing, focusing on creating quick-to-assemble, sustainable solutions for disaster relief. Kristina's innovative approach aims to improve the efficiency and effectiveness of emergency housing, ensuring better outcomes for displaced communities.

THIRD STUDIO

F. Gordon Wilson Fellowship for Public Housing 2023

Te Kāhui Whaihanga
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