

Hybrid Infill

The Search for an Affordable Housing Solution

Master Thesis Explanatory Document
Supervised by Kerry Francis & Dave Strachan

Maria Taylor
1224456

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Abstract

The provision of quality, affordable housing is vital for our communities and country. The current housing shortage, and lack of quality, affordable housing in Auckland provides the foundation for the relevant and significant inquiry. The intensification of land within the city boundaries through infill development, the implementation of prefabricated construction methods for improved construction efficiency and productivity, and the exploration of smaller, more efficiently designed dwellings; are three ways identified and examined as methods to increase the supply of quality, affordable housing.

The review and analysis of literature and precedent outlined the many benefits of prefabrication in the provision of quality, affordable housing, and it's greatest defeat in the limitations that are typically addressed through site-specific design. Recent literature has identified the hybrid, panel + module typology of prefabrication, largely unexplored in New Zealand, to have the greatest potential to incorporate responsive, site-specific design, for better architectural outcome, with the efficiencies that prefabrication has been proven to provide.

The development of the hybrid system for application to a unique infill, social housing programme, with diverse and wide-ranging site conditions, provides the constraints and requirements of the inquiry. The design process documented provides a model to the methods and considerations required in the development of a hybrid prefabricated system for quality, site specific, affordable, infill housing in Auckland.

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Finally to my friends and colleagues, thank you for your encouragement and for making the worst times still feel like good ones.

Authenticity

This Explanatory Document has been prepared by myself, Maria Taylor as partial fulfilment of the requirements of Unitec Master of Architecture (Professional) programme.

I declare that all work included in this document is my own, unless stated otherwise in accordance with Chicago Manual of Style (16th edition).

Maria Taylor Student # 1224456

Date: February 2014

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Architectural Question

Can the development of a hybrid prefabricated system for suburban infill offer a solution for affordable, high quality, site specific housing in Auckland?

Objectives

- Review and analyse current literature and research material surrounding the provision of affordable housing in Auckland, to identify methods to increase the supply of affordable housing without reducing quality.
- Survey, examine and critically analyse literature and precedent material surrounding prefabricated housing past, present and future, as a vehicle to increase design and construction affordability, efficiency, productivity, and quality.
- Develop and test the identified solutions on the Housing New Zealand *RightSize, New Two-bedroom Homes Initiative* by the design and development of a hybrid panel + module typology to incorporate site specific design with prefabrication techniques as a solution to affordable, infill, social housing.

Scope and Limitations

The Housing New Zealand *RightSize New Two-Bedroom Homes Project* provides an opportunity to test the hybrid typology of prefabricated housing. Constraints, requirements and limitations surrounding the inquiry are outlined in Chapter 5: Formulation of the Brief.

1.0 Background

The population of Auckland City is projected to grow by one million over the next 30 years.¹ The projected growth of Auckland and the vision to become the world's most livable city has spurred *'The Auckland Plan.'* The plan hopes to create a shared vision for Auckland to tackle issues of housing shortages, transport, job supply and opportunity, as well as environment protection and enhancement.

To implement this plan, the *Auckland Unitary Plan* has been developed to generate policies and rules to decide what will be built and where, in order to create a higher quality and more compact city whilst still providing rural activities and maintaining the marine environment.²

The projected overwhelming growth of the city has generated shortages in housing and land supply as well as issues around housing affordability. The co-convenor and housing spokesperson for the *Child Poverty Action Group* says, *"The lack of affordable housing is the single biggest social or economic issue facing Auckland."*³

1 "The Auckland Plan: An Overview," *Auckland Council*, 3, accessed January 24, 2014, http://www.aucklandcouncil.govt.nz/EN/newsevents/culture/OurAuckland/Documents/Auckland%20Plan_OurAuckland.pdf.

2 "The Auckland Plan," *Auckland Council*, accessed March 13, 2013, <http://www.aucklandcouncil.govt.nz/EN/plans/policies/projects/plans/strategies/theaucklandplan/Pages/theaucklandplan.aspx>.

3 "Bridging Auckland's Wealth Gap," *The New Zealand Herald*, accessed April 22, 2013, <http://www.nzherald.co.nz/news/print.cfm?objectid=10784783>.

1.1 Auckland Housing Shortage

Auckland Council released its *Housing Action Plan Stage 1* in December 2012. The report identifies a current shortfall of new dwellings of around 20,000 – 30,000 and a need of 13,000 new homes each year for the next 30 years. These figures were confirmed by a subsequent investigation by Government officials into housing affordability and residential land availability, resulting in the release of the *Housing Affordability: Residential Land Available in Auckland Report* in March 2013.

The report identifies that Auckland faces a housing crisis because of:

- A persistent under-supply of housing to meet demand
- A lack of housing choice
- Poor-quality, unhealthy and overcrowded housing
- Declining affordability and home ownership.⁴

There is no single solution, nor a single sector to address these issues, and urgent, large-scale, bold, multi-sector action is required to:

- Increase housing supply to meet demand
- Increase housing choice to meet diverse preferences and needs
- Increase the quality of existing and new housing
- Improve housing affordability
- Increase the supply of affordable housing.

The Unitary Plan makes provision for 400,000 additional homes in Auckland and is expected to become operative in 2016. In the interim period *The Auckland Housing Accord*⁵ has been established between the Council and the Government intended to result in increased housing supply and improved housing affordability in Auckland.

At present only 50 homes are completed each week, amounting to 2,600 a year – which is a fraction of the 13,000 homes the city is projected to need each year. *The Auckland Housing Accord* has been established to develop 39,000 new homes over the next 3 years achieved through both urban intensification and expansion of the current city boundaries. The three-year *Auckland Housing Accord* sets an additional target of 9,000 additional houses consented in the first year, 13,000 in the second and 17,000 in the third.

In summary,

- 400,000 new homes (in 30 years) through both urban infill and by building in rural areas
- 13,000 new homes the city needs each year
- At present only 2,600 new homes are being completed a year.

⁴ “The Auckland Plan.”

⁵ The Auckland Housing Accord between the Council and the Government is has been established to urgently support the increase of housing supply and improved housing affordability in Auckland in the interim period until the Auckland Unitary Plan becomes operative.

“It costs too much and takes too long to build a house in New Zealand”

Deputy Prime Minister Bill English, the Minister for Infrastructure

1.2 Affordable Housing

The 2013 Demographia International Housing Survey rated Auckland as “severely unaffordable.” The lack of quality affordable housing provided by the local market and the high natural population growth as well as high immigration in Auckland are core factors. The under-provision of affordable housing leading to overcrowding, decreased home ownership, and reduced socio-economic wellbeing for communities. Inevitably households are left with less discretionary income to spend on other goods and services, reducing living standards and increasing poverty rates. The problems identified are expected to be exasperated in the coming years.

Government research shows that new housing prices are impacted by;

- Land supply restrictions
- The provision of infrastructure
- Excessive building materials costs
- Low productivity in the construction sector
- Costs imposed by the delays in the regulatory process.

For many years, the supply of new housing in New Zealand has been disproportionately at the upper end of the market, while demand has increased at the lower end. In relation to this, houses are also increasing in size. The average new house in New Zealand is now larger than it’s American equivalent, and twice the size of those in many European countries.⁶ In 2010 the average size of a new house built in New Zealand was 205 square metres; in comparison to just 112 square metres 70 years prior. The average household size has however decreased, meaning that fewer people are living in larger homes.⁷

The recent publication *Homes People Can Afford: How to Improve Housing in New Zealand* identifies three major ways to reduce capital costs without reducing quality.

- Intensified use of available urban land and existing infrastructure,

Quote Kieran Campbell, “Auckland stays near top of unaffordable list,” *NZ Herald*, accessed July 2, 2013,

http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=10860649.

⁶ Joanne Black, “Home Stretch: The Price of Houses.” *NZ Listener*, February 11-17, 2012, 22.

⁷ Rau Hoskins, “‘Nano Whare’: Past meets future in a new model for Maori Housing.” In *Homes People Can Afford: How to Improve Housing in New Zealand*, ed. Sarah Bierre, Phillipa Howden Chapman and Lisa Early (Wellington: Steele Roberts Aotearoa, 2013), 110.

- eg. by shared or co-operative ownership models
- Smart integrated design that enables efficient use of smaller floor areas without compromising quality and functionality of indoor and outdoor living
 - Systems approach to building design, production and site assembly, including sourcing of materials at or close to the point of origin, leveraging of collective purchasing power, factory manufacture of building components, flat-pack delivery to site, and fast assembly process.⁸

Affordable, good quality housing, is vital for health, economic, environmental and social benefits essential for our communities and our country.



 Figs. 1.31 & 1.32 Affordable infill housing within the current city boundaries versus, housing & infrastructure development beyond the current city limits.

⁸ John Gray and Ross Whitcher, "Houses can be affordable *and* good" In *Homes People Can Afford: How to Improve Housing in New Zealand*, ed. Sarah Bierre, Phillipa Howden Chapman and Lisa Early (Wellington: Steele Roberts Aotearoa, 2013), 123.

“We can’t have Los Angeles type sprawl.”

Len Brown, Mayor of Auckland

1.3 Land Supply

In Auckland, the cost of land is high. Building cheap houses on expensive land is not economically viable; therefore the supply of affordable housing has suffered. Many experts claim that the solution is to expand city limits, while others argue that this is unsustainable. The provision of housing and in particular, affordable housing, is a complex issue. Solutions that confront single aspects of the issue (such as expanding city limits to access cheaper, unsettled land) are weak as they disregard wider conditions and effects.

The new housing target is proposed to be supplied inside Auckland’s current urban boundaries as well as outside to accommodate population growth through both *greenfield* and *brownfield* housing development. In March 2013 Auckland Council published a short analysis of metropolitan greenfields development,⁹ provided by Land Solutions Ltd. The report identified many issues regarding infrastructure provision to service greenfield land. Conclusions made from the report confirm that greenfield development is not a quick fix to Auckland’s housing supply challenge, and that concentration on brownfield development is appropriate for a number of practical and sustainable reasons. Socially, building on cheaper land beyond the current city limits creates higher operating costs for low-income households. Regional policies and strategies therefore seek to accommodate the majority of this growth within existing urban areas, via new concentrated and intensified developments. However, these policies and strategies are somewhat neglectful of the role that traditional suburban areas could play in accommodating housing supply through suburban infill and intensification projects that make better use of private and state owned land.

The main capital costs concerned with housing supply are in land and building. Making more intensive use of already settled urban/suburban land can reduce land and infrastructure costs, and provide a socially acceptable solution. This is achievable by co-locating dwellings on sections previously occupied by single houses, through compact housing design and footprint, and efficient use of external space adjacent to dwellings. In this circumstance introduced dwellings are located on serviced, or partially serviced sites with existing infrastructure within established communities. Whilst much focus is towards new housing developments and urban intensification, the focus of this research is towards intensified use of available suburban land and existing infrastructure in Auckland through infill.

⁹ Greenfield definition: Urban expansion in rural areas
Brownfield definition: Urban intensification.

1.4 Suburban Infill

“The single dwelling on a quarter-acre section is no longer an affordable model of housing and has not been for a long time. Instead we can take new approaches to provide more affordable houses and new ways of urban living that encourage the formation of a sense of community and a good quality of life.”¹⁰

At the heart of this issue is the Kiwi “quarter-acre dream.” This nostalgic idea of the ideal home, is a single-storey bungalow on a large suburban section, stereotypical in the 1950’s and 60’s and was propagated by British politician Austin Mitchell’s 1972 book, *The Half-Gallon Quarter-Acre Pavlova Paradise*.

Consequentially section sizes in Auckland are larger than other developing cities, density is lower and land is used improvidently. Although lifestyle and technology have changed drastically since the mid-twentieth century, many of us expect or assume the same living environment. How can these ‘luxurious’ sections with what could be described as ‘excess’ space be redeveloped to make better use of the land within our current city boundaries?

Although architecture is central to the discussion when creating housing, it is the leftover space and landscape that have also proved to be vital to our inherent culture and lifestyle. If we accept that the outer limits of the city cannot continue to expand we must adopt a collective and shared understanding of home and landscape rather than the isolation from each other that we currently seek, and that has been the norm.

¹⁰ Sarah Bierre, Phillipa Howden Chapman and Lisa Early, ed., *Homes People Can Afford: How to Improve Housing in New Zealand*, (Wellington: Steele Roberts Aotearoa, 2013), 127.

Where will the manpower come from to build 39,000 homes over three years in Auckland?

1.5 Skilled Workforce Shortage

The Christchurch rebuild, repair of leaky homes and the nationwide strengthening of buildings for earthquakes are all creating added pressure on the construction industry – on top of preparing Auckland for another million people.

It is estimated that the construction industry will need to increase in size by 300% to come close to achieving what has been announced. Meanwhile skilled tradesmen continue to leave New Zealand shores. Increasing building efficiency and training unskilled workers will be fundamental in providing good quality, affordable housing and achieving goals set by *The Housing Accord*.

“During times of skill shortages, mechanisation is able to increase the capacity of the construction sector, reduce the need for labourers and increase the skill base of firms, and provide a consistent, quality product to clients.”¹¹

Internationally, Economic Census data has shown that in all cases, off-site work is more labour efficient and capital intensive.¹² Using methods of prefabrication can assist in creating a greater production program and project management by skilled trade leadership leading a lower skilled workforce.

11 J.C. Burgess, N.R. Buckett and I.C. Page, *Study Report (SR 279): Prefabrication Impacts in the New Zealand Construction Industry*, SR 279, (BRANZ, 2013), 31. Accessed September 6, 2013. http://www.branz.co.nz/cms_show_download.php?id=2935644f1d-998595f3a2d8f5e8167dd08a42a179.

12 Paul Teicholz, *“Labour Productivity Declines in the Construction Industry: Causes and Remedies (Another Look),”* Department of Civil and Environmental Engineering Stanford University. Accessed May 12, 2013, http://www.aecbytes.com/viewpoint/2013/issue_67.html.

1.6 Productivity

Productivity is defined as “the rate at which a company produces goods or services, in relation to the amount of materials and number of employees needed.”¹³ A report from the New Zealand Productivity Commission has found that construction productivity in New Zealand is low. It states that one of the “key barriers to productivity growth, is the [New Zealand construction] industry’s ... low levels of innovation.”¹⁴ The report also found that the fastest way to reduce building cost is by reducing the time taken in production, not by focusing on costs themselves.¹⁵

Auckland is unusual for its prevalence of bespoke, stand-alone homes. In New Zealand sole traders are the most common-sized business in residential construction, who specialise in the one-off, rather than the mass-produced. Most firms build just one house a year, and only five built more than 100 homes.¹⁶

Innovation utilising prefabrication construction methods offers a vehicle for the increase in productivity. It is suggested that up to half of the time spent by the labour force in traditional on-site projects is spent on “wasteful activities,” as a result of delays around subcontractors, suppliers, weather, rework, injury and unscheduled breaks.¹⁷ It can therefore be assumed that there is huge potential to improve productivity by reducing wasted time, and consequently huge potential to improve productivity by implementing prefabrication construction methods given the proven associated time-savings.

Moving work inside has also proven to create a safer, more comfortable working environment and increases opportunity for a larger worker pool. Ergonomically designed workbenches can be installed improving conditions for workers over traditional building site.¹⁸

In late 2013 BRANZ released a study report: *Prefabrication Impacts in the New Zealand Construction Industry*, a case study is included to compare traditional construction to different methods of prefabrication of a three-bedroom house. Construction is expected to take 14 weeks using traditional construction compared to an expected 5 weeks for (hybrid) prefabricated construction.¹⁹ This is due to better scheduling, enhanced quality control, improved access to tools and facilities, a single site for trades, less travel time and easy site access.²⁰

Pamela Bell, Prefab NZ Chief Executive Officer believes that, “More emphasis is needed on factory conditions, rather than outdoor yards, to achieve potential benefits from prefabricated processes in terms of safety, efficiency and productivity.”

13 Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 19.

14 Ibid 35

15 Ibid 25

16 Black, “Home Stretch: The Price of Houses,” 24.

17 Colin Davies, *The Prefabricated Home* (London: Reaktion Books, 2005) 65.

18 Stephen Kieran and James Timberlake, *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*, (New York: McGraw-Hill, 2004), 123.

19 Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 25.

20 Ibid, 26.

2.0 Introduction

New Zealand has a very low proportion of public housing when compared to similar European welfare states.²¹ In New Zealand, government financial support for developing new social and affordable housing is provided to Housing New Zealand (HNZC), and community housing providers such as VisionWest and New Zealand Housing Foundation (NZHF) through the Social Housing Unit (SHU). There is a significant need for successful delivery of good quality affordable housing for the many households whose needs cannot be met by the private sector. A review of state housing in New Zealand by the Government, *Home and Housed?*, emphasised that the current stock is run-down and in the wrong place.²² The current portfolio of social housing in New Zealand is not meeting the demands of tenants.

21 Michael Baker, Jane Zhang & Philippa Howden-Chapman, "The health effects of social housing: The Social Housing Outcomes Worth Study." *In Homes People Can Afford: How to Improve Housing in New Zealand*, ed. Sarah Bierre, Philippa Howden-Chapman and Lisa Early (Wellington: Steele Roberts Aotearoa, 2013), 33.

22 Housing Shareholders' Advisory Group. *Home and Housed: A vision for social housing in New Zealand*, (Wellington: Department of Building and Housing, 2010).

2.1 Changing Demographic

The changing demographic of Housing New Zealand tenants has resulted in an excess supply of the conventional three-bedroom state house designed for the 'nuclear family.'

Demand has been identified for larger state homes for larger families especially Polynesian and Maori families in South Auckland that are currently experiencing overcrowding and the negative health and social outcomes associated.

Here, and internationally there is an increased demand in both private and public sectors for housing that caters for smaller households as we see average household sizes deplete as people live longer, have children later and prefer to live alone. Housing New Zealand has also recognised the increasing demand for two-bedroom dwellings to cater particularly for the elderly, single people with caregivers, couples with children, and solo parents. The Auckland Regional Policy Statement identifies this demographic change, *"The average household size is now below three persons. The number of single parent and one person households has increased rapidly in recent years."*²³

Furthermore an associated requirement for inter-generational family housing has also been identified. The current supply generally fails to cater for either extended family or associated smaller family units - including solo parents and elders that provide or require support from additional family members and often want to be near family.²⁴

23 "Auckland Regional Policy Statement: July 1999," accessed February 20, 2014. <http://www.aucklandcity.govt.nz/council/documents/regionalplans/aucklandcouncilregionalpolicystatement/ACRPS%20Policy.pdf>.

24 Hoskins, "Nano Whare: Past meets future in a new model for Maori Housing."109.

2.2 A Smaller Footprint

As discussed, the average house size in New Zealand has steadily increased since the 1970's, presently larger than it's counterpart in other developing cities. The most obvious way to reduce costs surrounding the provision of housing and subsequently land-costs is to produce a smaller footprint.²⁵ This has been recognised worldwide, the global trend of 'nano architecture,'²⁶ introduces a shift towards smaller, more efficiently designed dwellings. Cluster housing, and co-housing are also gaining momentum – where sites are developed together, facilities are shared, with individual units retained.²⁷

“The argument for building smaller and smarter houses is based on an acknowledgement of diminishing worldwide resources, higher embodied energy costs associated with larger houses and higher land costs and land shortage in urban areas.”²⁸

Compact homes take up less valuable land whilst presenting lower maintenance costs and energy consumption. Furthermore, as identified, there is a large requirement for smaller unit housing.

Well-designed spaces, with appropriate volume, light and openings, with higher quality finish are essential. A stronger connection to the outdoor environment is furthermore crucial to provide the ability to extend living spaces and relieve pressure on indoor environments. Minimising unnecessary circulation whilst employing modern space-saving technologies and smart and effective storage are also vital considerations.

25 Killick, *Owning a home an impossible dream*, 25.

26 Phyllis Richardson, *Nano House: Innovations for Small Dwellings* (London: Thames & Hudson, 2012).

27 Hoskins, “Nano Whare: Past meets future in a new model for Maori Housing.” 109.

28 Ibid 110.



Fig 2.3.1. Images from RightSize Expression of Interest (EOI) Document

2.3 RightSize

In reaction to *The Auckland Housing Accord* and current social housing shortfalls identified, Housing New Zealand launched a new programme in May 2013 aptly named *RightSize*. The aim to provide housing that better meets tenants requirements in relation to size, location and amenity whilst targeting state housing to people with the highest housing needs.

The initiative consists of two programmes; *The Home Extension Programme*, which converts three-bedroom homes to four- and five-bedroom homes; and *The New Two Bedroom Homes Project*, which delivers infill two-bedroom homes on large existing Housing New Zealand properties.

It is a requirement of the two programmes that a large portion of the construction is off-site thus minimising the construction activity on-site together with the associated disruptions and risk of that work to the tenants and neighbours. The programmes are targeting a maximum two weeks on-site construction period. Further to this, off-site or prefabrication construction techniques are suitable for this unique programme due to its large scale and high level of repetition.

Approximately \$377 million is required to provide up to 3,000 new state house bedrooms and 500 new two-bedroom homes in the next three years. The 500 new infill homes will contribute towards the target of 39,000 houses over three years announced in *The Auckland Housing Accord*. Although the first stage of the programme is exclusive to Auckland it will eventually be extended to other cities such as Wellington.

2.4 The New Two-Bedroom Homes Project

The New Two Bedroom Homes Project correlates with demographic change and responds to the shortage of supply and increasing demand for two-bedroom properties in New Zealand, specifically Auckland. The properties identified for development are to be larger individual residential sites owned by Housing New Zealand within the former Auckland City Districts of Waitakere, North Shore and Manukau. Typically these properties include an existing tenanted dwelling with rear yards capable of constructing a secondary Minor Household Unit (MHU) under current local District Plan requirements. Access to building site will predominantly be through a residential driveway.

A MHU is ancillary to and associated with the primary residential unit on the site, and has the ability to be developed without costly subdivision process and provision of (all) independent services and infrastructure. Currently the minor dwelling housing type is limited to a 65m² floor area restriction in Waitakere district plan requirements and 60m² in all other areas in the Auckland regions as well as other requirements summarised in Table 1, page 89.

As land cost and the provision of services and infrastructure are the significant parts of any residential development in Auckland, the possibility to deliver affordable housing is improved by the better utilisation of existing Housing New Zealand properties towards higher density in suburban areas. The increased supply of two-bedroom dwellings will also facilitate the local relocation of Housing New Zealand tenants currently in homes excessive to their requirements, in turn increasing availability of larger homes for families that need them.²⁹

The disadvantage of the programme is the negative effects and disruption on the existing tenants, who are expected to remain in occupation during the project works. To compensate for the loss of backyard and manage the strategy of retaining private internal and external living environments the existing property will be upgraded in parallel to the MHU infill construction. It is essential that additional effects of construction activity on-site are minimised so that the disruption and safety risk of that work to the tenants and neighbours is reduced.

The New Two-bedroom Homes Project presents an opportunity to test and explore the issues discussed in Chapter 1 & 2 surrounding the provision of affordable housing. The programme employs suburban infill in an approach that demands a reduced footprint. Increased productivity in the delivery of affordable housing can be achieved by the use of prefabricated construction methods. Off-site construction has also been identified as appropriate to the inquiry in order to minimise disruption to existing tenants and neighbouring properties.

²⁹ "Right Size," *Housing New Zealand Corporation*, Accessed September 12, 2013, <http://www.hnzc.co.nz/housing-development/right-size>.

3.0 Introduction

Prefabrication has been identified as a vehicle to increase labour efficiency and productivity, and consequently reduce building cost (increasing affordability of housing) by reducing the time taken in production. The pursuit of prefabricated housing in response to *The New Two-Bedroom Homes Programme* is further validated by the maximum two-week on-site construction period target and minimisation of safety risk and disturbance of the infill housing to existing tenants and neighbours.

The following chapter defines prefabrication (and identified typologies), it's pro's and con's in relation to the provision of quality affordable housing. A summarised history includes significant architectural figures and influence alongside local and international examples of interest and significance to the inquiry. A review of prefabricated housing today and its projected future leads to the final section, a closer look at the hybrid prefabrication typology relative to the nature of the inquiry.

Definition:

The term prefabrication (or “prefab”) is defined to be “any component constructed away from the site,”³⁰ and the term is often used interchangeably with the term “off-site construction.” Rather than a product, prefabrication is a system or process that describes a way of construction rather than an aesthetic outcome.³¹

Internationally prefabrication is being used to improve efficiency and productivity of construction, deliver higher quality buildings faster for reduced cost, reduce energy use and construction waste. In addition prefabrication helps to address health and-safety concerns on-site since a factory environment can be considerably safer than a construction site. Prefabrication also addresses issues of project delivery, allowing complex systems to be completed in the factory reducing specialist trades on-site. Recognised benefits include increased product precision, standardisation of components, decreased labour and construction cost for improved productivity and profitability, shorter assembly and on-site construction time, and improved quality control. Prefabricated building methods produce higher quality often “tighter” building envelope, increased durability and higher building performance. The modular approach and controlled environment often produces less waste and

increased recycling, and off-site construction reduces the impact of site

30 Pamela Bell, “Kiwi Prefab: Prefabricated Housing in New Zealand: An historical and contemporary overview with recommendations for the future” (Master’s thesis, Victoria University, 2009), 25.

31 Ibid, 31.



Fig. 3.0.1. Prefab offers more for less Chart, *Kiwi Prefab*.

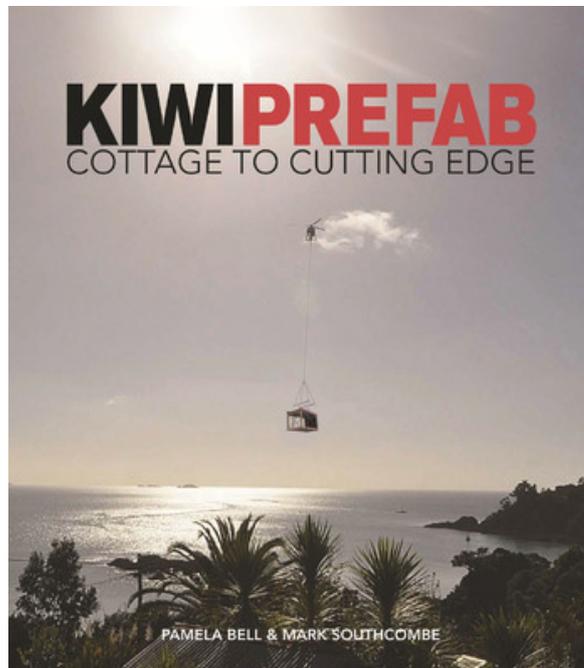


Fig. 3.0.2. *Kiwi Prefab*, 2012 publication, Pamela Bell & Mark Southcombe

construction work on neighbouring areas.

Although many people confuse prefabrication to be cheaper than traditional construction, more capital is required to invest in factory machinery and systems. True cost savings can only be achieved when scale and repetition are initiated, or cost savings due to shorter construction time are incurred, such as relocation costs. Time on site can occur simultaneously with the fabrication of parts off-site in factory conditions, the factory setting also reduces weather delays saving further time. Higher efficiency and productivity, less material waste and improved safety can be achieved through prefabrication, however these advantages are difficult to measure and dependent on the design, system, and construction procedures put in place. Because of increased testing and repetition, fewer defects are likely to occur when compared with traditional bespoke design. It is believed that increased quality is where prefabs greatest potential lies.³²

Despite the many advantages prefabrications greatest defeat is in the limitations that are typically addressed through site-specific design. Site-specific design often produces a better architectural outcome, responsive to site conditions such as temperature, solar orientation, privacy, views, predominant winds, ground conditions, contour, vegetation, materiality and history. In order to optimise solar orientation and passive solar design strategies for a higher performing dwelling, site-specific design must be incorporated. In New Zealand specifically, prefabrication has historically been not widely accepted, as bespoke design is prevalent and often demanded.

Prefabrication is gaining momentum in the New Zealand construction industry by the initiation of construction sector group, *PrefabNZ* who aim to double the uptake of prefabrication in New Zealand by 2020. Prefabricated housing has been identified as a key lesson and opportunity for the architecture profession, in an evolving industry where they are not hugely present.³³ Pamela Bell the Chief Executive Officer and founder is passionate about prefabrication and her 2009 Master of Architecture thesis *Kiwi Prefab: Prefabricated Housing in NZ*, gained industry attention and lead to the launch of *PrefabNZ*. Consequently in 2012, Pamela co-authored the book *Kiwi Prefab: Cottage to Cutting Edge* with Mark Southcombe (Victoria University). The book contextualises prefabricated housing in New Zealand, reviewing local and international history and contemporary and emerging prefab design. Misconceptions are abolished and suggestions are made for the future of prefabricated housing in New Zealand. The research is conclusive that further inquiry towards the uptake of prefabrication in New Zealand is appropriate for a number of reasons:

“Worldwide economic recession is forcing consolidation and efficiencies in the building industry, the government has identified prefabrication for starter homes, the international contemporary prefab movement is gaining momentum, and several new prefabricated housing products are entering the local market.”³⁴

32 Pamela Bell, “Primer: About Prefab Housing.” In *Kiwi Prefab: Cottage to Cutting Edge*, ed. Pamela Bell and Mark Southcombe (Auckland: Balasoglou Books, 2012), 38.

33 Davies, *The Prefabricated Home*, 206.

34 Bell, “Kiwi Prefab: Prefabricated Housing in New Zealand: An historical and contemporary overview with recommendations for the future,” 25.

3.1 Prefab Typologies

Five types of prefabricated housing have been identified by Bell, categorised according to the size of its part; component (stick and subassembly), panel (nonvolumetric), module (volumetric), hybrid (module+panel) and complete buildings (box-form). The different typologies reflect differences in methodology and the degree of completion in an offsite location. Bell's definitions have been adopted for this thesis, as listed below.³⁵

³⁵ Bell, "Primer: About Prefab Housing." 38.

Component
(stick and
sub-
assembly)



Component

Component-based prefabrication includes stick and sub-assembly prefabrication. Stick refers to lengths of timber or steel that are pre-cut, pre-sized or pre-shaped puzzle-type pieces brought to site. Sub-assemblies include windows and doors, fixtures and fittings, and structural members such as pre-nailed roof trusses and wall frames. The use of pre-nailed components has become an accepted part of the traditional construction process by the full range of home building companies in New Zealand. A common form of component-based construction is known as kitset housing.



Fig. 3.1.1. Pre-nailed roof trusses and wall frames ready for sub-assembly.

Panel (non-
volumetric)



Panel

Panelised, nonvolumetric or two-dimensional prefabrication comprises manufactured panels that are transported as a flat-pack. They can be classified as closed panels, complete with doors, windows, services, cladding or lining, or be open panels, made up of framing components. Some architects refer to closed panel systems as cartridges or cassettes.



Fig. 3.1.2. SIP wall panels assembled on-site, SGA & Studio19 Community Housing, 2012.



Fig. 3.1.3 Prefabricated modules combined on-site by Resolution 4 Architecture.



Fig. 3.1.4. Service module & floor cartridges lifted into scaffold structure, of Loblolly House, 2006, by Kieran Timberlake Architects.



Fig. 3.1.5. Onemana Bach by SGA & Studio19, lifted out for overnight delivery, 2010.

Module

Modular, sectional, volumetric or three-dimensional (3D) prefabrication refers to a 3D structural unit made away from and combined with other units or systems at site to create a whole dwelling. Prefab elements can be referred to as volumes, modules, or sections. By contrast cores and pods refer to non-structural volumetric units often used within conventional buildings. Modular units are manufactured in controlled conditions with a high degree of services, internal finishes and fit out installed in factory prior to transportation to site. This approach is particularly suited to highly serviced areas such as kitchens and bathrooms, which have a high added value, and cause disruption and delays on site.

Module
(volumetric)



Hybrid

Hybrid prefabrication is a term used for combinations of systems, such as hybrid module + panel or semivolumetric systems. These systems use a mixture of volumetric units for the highly serviced areas such as kitchens and bathrooms and construct the remainder of the building using panels or by another means. Hybrid prefab systems combine the benefits of two prefab construction systems, balancing efficiency with flexibility and consumer choice.

Hybrid
(module-plus-panel)

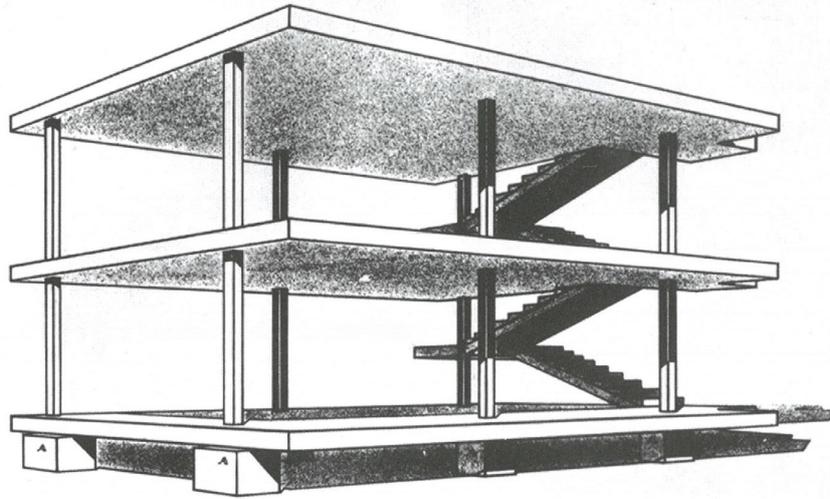


Complete Buildings

Box-form or complete buildings are commonly known as portable, relocatable or transportable dwellings in New Zealand. They are a type of volumetric prefab where entire buildings are constructed in a factory or yard and then moved by a heavy haulage vehicle to site where they are attached to permanent foundations. These buildings may or may not incorporate prefabricated components, and standardised framing and sheet elements.

Complete
buildings
(box-form)





MEMBRE-OSSATURE DE BETON ARMÉ
SOULÉE SANS FERRAGE
SUR DES POINTS D'APPUI FOURNIS A.

Fig. 3.2.1. *Maison Dom-ino* by Le Corbusier, patent drawing, 1914

“Architects have been fascinated by prefabrication for a long time.”

Rybczynski, “Prefab Fad”

3.2 History - Prefabricated Housing

The loose term of “prefabricated housing” is nothing “new” when you consider that pre-cut housing kit-sets were sent to New Zealand and Australia with migrants from the United Kingdom as early as 1833.³⁶ And that the forerunners of modern architecture such as Frank Lloyd Wright, Le Corbusier and Walter Gropius were campaigning a factory-like approach where our homes became “machines for living” since the early 20th century.

The technological advancements in the late 19th century increased the ability for products to be mass-produced consistently, meaning that architects could focus on design systems for building components. These components could be manufactured much more rapidly by machines rather than traditional hand labour, therefore speeding up the construction process.

It is at this time, the second industrial revolution, that prefabrication and mass production became widely acknowledged by architects, designers, engineers and entrepreneurs as a solution to producing housing faster, cheaper and to a high consistent quality.

The architectural culture of prefabrication was a core theme of modernist architectural discourse and experimentation, their campaign was to successfully marry architecture and industry and create an image of modern living whilst exploring the endless possibilities of innovative materials and techniques. The fascination with the automobile began with Henry Ford’s assembly line in 1907 and got our modern predecessors wishing for a similar design process of standardised parts and types to fabricate architecture on mass, affordable housing. Internationally prefabricated housing gained momentum - between 1908 and 1940, the American venture Sears Roebuck and Company sold over 100,000 timber balloon-frame kitset homes from their US mail-order housing catalogue.³⁷

Just two years after Ford launched his first assembly line, Gropius

³⁶ Pamela Bell, “Prefabs Past: A History of NZ prefabricated housing.” In *Kiwi Prefab: Cottage to Cutting Edge*, ed. Pamela Bell and Mark Southcombe (Auckland: Balasoglou Books, 2012), 44.

³⁷ *Ibid.*

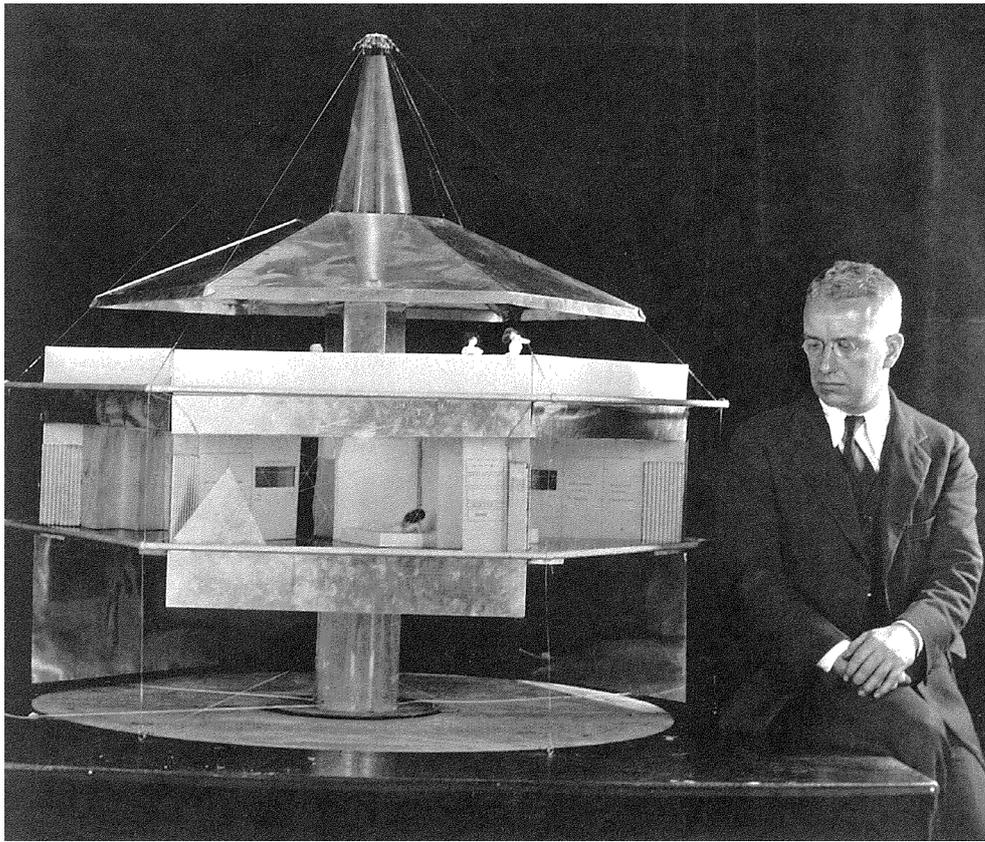


Fig. 3.2.2. R. Buckminster Fuller with model of the *Dymaxion House*, 1927



Fig. 3.2.3. Walter Gropius and Konrad Wachsmann inspecting prototype of *Packaged House / General Panel System*, Queens, New York 1946

proposed in 1909 to form a company for a “*General House Building Corporation on Artistically Unified Principals*,” which although implies his concern to preserve the role of an architect as artist, Gropius was just as concerned with the client or user, seen as the model of the prefabricated house replaces the direct relationship between architect and client to a relationship between architect and multiple end-users.³⁸

Frank Lloyd Wright and Le Corbusier then put their own theory into practice. Wrights ready cut series of American System-Built Houses were released with little market response, whilst Le Cobusiers Dom–ino 1914-15, building system (based on a standard structural unit) was a major influence on 20th Century architecture but failed to appeal and become a market success.

Many other attempts were made, some more successful than others, Richard Buckminster Fuller’s innovative Dymaxion House 1927, and then Wichita House 1944-46, were the first to address issues of sustainability – offering maximum space for minimum material use and cost. The aesthetic pursued openly celebrates their means of production, which was revolutionary at the time.³⁹ Buckminster Fuller was also responsible for some of the earliest service module designs, namely his one-piece Dymaxion bathroom which was originally clad in copper and then in fibreglass in Germany in the 1950’s. His innovative approach to design and theory being described as, “*provocative, future focused and ahead of mainstream consumer thought and acceptance.*”⁴⁰

A housing crisis in Germany during the 1920s developed an interest in mass produced housing from Aron Hirsch and Son, a global company in the copper and brass industry. They required a system and design for transportable insulated metal walls, developed by two architects, Friedrich Forster and Robert Kraft. A variety of houses were designed with exterior walls and roofs of copper, insulation by aluminium foil and asbestos building paper and timber framing with interior walls of ornamented pressed sheet metal. The entire system was devised of easily transportable elements that could be assembled on site within 24 hours. In 1932 Walter Gropius was hired to make improvements, claiming credit for several advances, including “*corrugated sheet-copper for the outer walls, aluminium instead of steel for the inner and a simpler corner joint and an altered appearance.*”⁴¹ In terms of aesthetics the houses were relatively unspectacular structures and although technologically advanced, were conservative in design.

Housing demand increased post World War II and prefabrication was seen as the answer, in America the all-steel Lustron Westchester house model was in full production. The first house produced in 1948 was named the “Westchester Two Bedroom,” which was approximately 95 square metres and consisted of a concrete foundation slab from which a skeletal steel frame was erected with trusses spanning the structure in a 1.2 metre module. All internal divisions were informed by the placement of prefabricated modular units that predominantly doubled as shelving, cabinetry, closets and vanities.⁴² The exterior was clad in 600mm square porcelain enameled steel panels, designed with durability and hygiene

38 Barry Bergdoll and Peter Christensen, *Home Delivery: Fabricating the Modern Dwelling*. (New York: MoMA, 2008), 17.

39 Ibid, 58.

40 Bell, “Prefabs Past: A History of NZ prefabricated housing.”⁴⁶

41 Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 62.

42 Ibid, 104.



Fig. 3.2.4. Case Study House No. 8 by Charles and Ray Eames 1945-1949



Fig.3.2.5. Exterior view of Case Study House No. 8 by Charles and Ray Eames, 1945 - 1949

in mind. The house was transported entirely flat-packed on a specially designed *Lustron* truck with assembly taking approximately 8 days. Its innovative material use and speed of assembly was revolutionary, it was also one of the first prefabricated houses that openly communicated its means of construction and an air of honesty and pride as an industrial product. The product met the market with much criticism because it was so obviously factory made and was described negatively with statements such as 'bathtub' and 'hot dog stand', the question was posed, "Do people really want to live in steel homes?"⁴³ At the same time in Germany, Packaged House (or General Panel System) devised by Walter Gropius and Konrad Wachsmann, generated a detailed panel plus three-way connector jointing system. Floors, walls and ceilings were all devised from the same panel type, limiting the number of parts and simplifying fabrication and delivery. It was however the larger scaled, standardised housing developments that scarred the reputation for modular prefabricated housing until the present.

The 1945 experiment initiated by John Entenza the editor of *Arts and Architecture Magazine*, in which major architects were commissioned to reconsider the modern dwelling in reaction to the poor quality of post World War II housing boom models produced by non-architects.⁴⁴ All were prefabricated to some degree and strove to introduce good design into good value on the American housing market. The most successful and innovative system, made entirely of off the shelf components was Case Study House No. 8 designed by Ray and Charles Eames to be their private residence. A home devised of two separate volumes – a living quarters and work studio demonstrates the possibilities of designing with a finite palette of prefabricated parts. Every element ordered by catalogue or purchased from an industrial manufacturer including its steel beam and truss structure and sidings of various materials and colours. The Eames attention in this case was focused on volumous space and questioned the price of space, the industrialisation of the industry and the properties of steel. The house was however not specifically designed for replication and because it was conceived as their own home it largely reflected their unique personalities and lifestyle rather than being a model from which the common modern American family could live.

In 1950 Jean Prouvé was commissioned to deliver fourteen single-family homes in the Parisian suburb Meudon. The houses were to be embedded as infill housing into an already built up suburban context rather than the normal undeveloped location typical of prefabricated housing developments (at the time). Each of the houses intended for low-income accommodation were erected as a steel portal frame (atop a masonry basement) to provide an exterior envelope from which cladding could be placed. Everything was designed to a 1m grid; no element was more than 4m long or weighed more than 100 kilograms. A series of nine modular panels with varying degrees of opacity, perforation, materiality and joinery elements could be chosen by the client, offering a degree of customisation that had not been seen before. The panels, insulated and clad on both sides, could simply slip into place, the perimeter frame also supporting the minimally pitched roof. On site construction boasted just three days.

Modular building reflected the 1960's view of society, imagining that everything could be broken down into functions, which could then be

⁴³ Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 104.

⁴⁴ Ibid 94



Fig. 3.2.6. Panelised state houses in the 1940's.

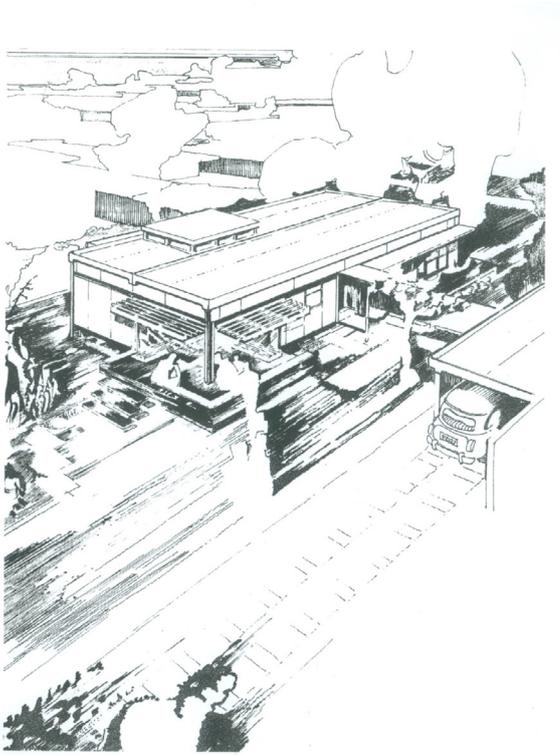


Fig. 3.2.7. IBS Double-wide prefab home.



Fig. 3.2.8. De Geest factor housing production, 1970's.

assembled into ready-made solutions. It is during these years and into the early 70's that schemes use terms such as *plug-ins*, *interlocking modules*, *living pods* and *living capsules*, influenced by the Japanese Metabolist movement and an emerging society of consumption. It is also at this time that the prefabricated megastructure appeared, utopian ideas of plug in cities and the revival of monocoque assemblies. Many of which resembling futuristic alien type structures, epitomised by the Finnish Futuro House by Matti Suuronen, literally a single flying-saucer shaped volume dropped in remote locations by helicopter. "New research into prefabricated housing was essentially thrown out with the modernist bathwater in the 1980's".⁴⁵

New Zealand

Meanwhile, in New Zealand the 20th century began with housing of a quaint cottage aesthetic devised of standard plans and kitsets of pre-cut and numbered components produced by New Zealand Railways Department. The first infamous State House was opened in Mirima, Wellington in 1937, utilising a standard range of house plans, construction details, window and door sizes and internal fittings, including baths, wash basins and cupboards. Larger contractors like Fletchers also supplied pre-cut framing and unlined wall panels, this combined with pattern-book designs and use of unskilled labour saw the state housing scheme of the 1930s and 1940s become one of the most successful public housing schemes in the world.⁴⁶ The applications developed here, roof trusses and open wall framing pre-engineered and pre-nailed away from site, with moisture barriers, insulation and exterior claddings applied at site are the core for traditional construction techniques used at present.⁴⁷

Parallel to international trends, a modular approach rose to popularity in the 1960's, IBS and Group Architects being the forerunners. In the 1970's IBS created the Xibis system, a combination of modules and panels which can be seen as one of the first examples of hybrid prefabrication design in New Zealand. Many others have risen to the task but only commercial players such as Lockwood Group, Keith Hay Homes and De Geest Construction, less architecturally motivated have endured.

Summary of Learnings

- **Negative response from the public to, the mass production of housing, untraditional forms and an aesthetic that openly expresses the homes means of production**
- **Use of basic structural unit and modular set-out**
- **Weight and size restriction to easily manage prefabricated components**
- **Speed of assembly**
- **Customisation through variation in wall panels**
- **Use of off-the-shelf components**
- **Maximum space for minimum cost – first to address sustainable issues**
- **Focus on volume of space rather than just floor area**
- **Service module design for isolation of services**
- **Innovative use of materials and technology**
- **Modular units for internal walls that double as shelving.**

⁴⁵ Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 24.

⁴⁶ Bell, "Prefabs Past: A History of NZ prefabricated housing."52.

⁴⁷ Ibid.

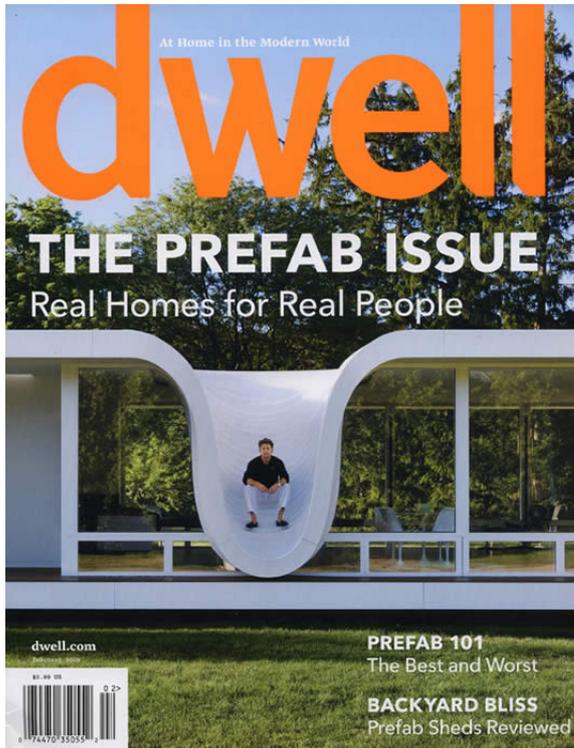


Fig. 3.3.1. Dwell Magazine, The annual Prefab Issue, Real Homes for Real People and Prefab Now.

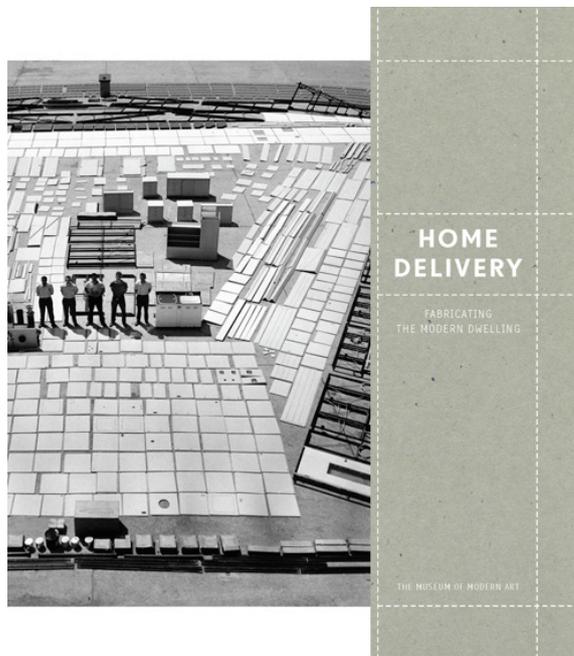


Fig. 3.3.2. Home Delivery: Fabricating the Modern Dwelling, Barry Bergdoll and Peter Christensen.



Fig. 3.3.3. MoMA Home Delivery Exhibition, 2008.

3.3. Prefabricated Housing Today

Internationally prefabrication has gained the level of attention that the industrial revolution brought to the public nine decades ago – resurfaced by a Green Modern Prefab movement. The resurgence in contemporary prefabricated housing is architecturally led with a sustainable agenda, attuned to rising house costs, changes in lifestyle aspiration and technological advancement. Media has assisted to promote the movement with popular magazines such as *Dwell*.

The 2008 exhibition *Home Delivery: Fabricating the Modern Dwelling* exhibition at the Museum of Modern Art (MoMA), New York organised by Barry Bergdoll and subsequent publication, amplified the renewed interest. The exhibition (and publication) provides an evaluation of the past, present and future of the prefabricated house to demonstrate its many ironies. *“Its commercial ubiquity on one hand and its failure as a utopian idea on the other; the fascination it has held for modernism’s leading protagonists; and the role it has played in determining relations between invention and production in modernity.”*⁴⁸

The diverse collection of material exhibited illustrates the prefabricated house not just as a mass-produced object of design but also as important explorations in the discussion of sustainability, affordability and design and construction innovation.⁴⁹ For architects, prefabricated homes hold a potential similar to that of prints for the artist,⁵⁰ as a vehicle to increase the availability and experience of architecture.

In Barry Bergdolls introduction to the publication *Home Delivery* he states *“the viability and affordability of factory-produced housing has long been proven as more and more modular units blend into the urban and suburban fabric,”* and asks the question, *“what might the next*

48 Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 7.

49 Ibid.

50 Ibid 24.

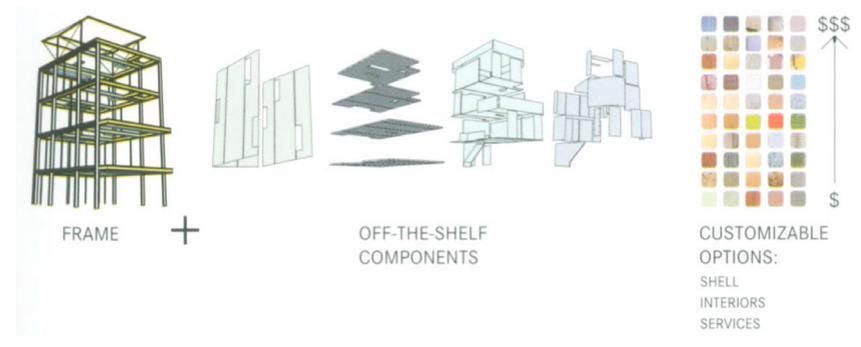


Fig. 3.3.5. Kieran Timberlake Associates, diagram describing process of mass customisation

generation look like?”⁵¹

For most of the 20th century, the theoretical and practical basis of efforts to realise prefabrication was repetitiveness.⁵² Mass production of architecture however was then, and remains now, prefabricated housings lack of appeal. The history of the prefabricated house has affected some to associate it with low quality attributes, “*light, flimsy, temporary and cheap.*”⁵³ In some cases the negative perceptions are justified, albeit an unwarranted generalisation. The association is also made to temporary and less-permanent outcomes, particularly for complete transportable dwellings that aesthetically appear as though they could be picked up and removed as easily as they arrived. Designs driven by transportation restrictions often produce non-traditional forms, such as modular outcomes or low flat roofs, which along with unconventional materials are not always accepted by the public.

Le Corbusier’s argument for revolution of the building culture lay in the factory production of once hand crafted objects such as clothes, shoes and household products, as well as in modern mobility – automobiles, planes and ocean liners. The frustration that other industries, far younger than construction and in some cases far more technical to produce, were far more advanced than the construction industry in terms of production. Eighty-five years on and the frustrations largely remain. They failed then but what has changed today?

*“Everything. Mass production was the ideal of the early twentieth century. Mass customisation is the recently emerged reality of the twenty-first century. We have always customised architecture to recognise differences. Customisation ran at cross purpose to the twentieth-century model of mass production. Mass customisation is a hybrid. It proposes new processes to build using automated production, but with the ability to differentiate each artefact from those that are fabricated before and after. The ability to differentiate, to distinguish architecture based upon site, use, and desire, is a prerequisite to success that has eluded our predecessors.”*⁵⁴

Kieran Timberlake Associates claim that the new age of mass customisation is the dawn of a new era for prefabrication – advanced from Le Corbusier, Gropius, and Washmann. The rapid development of digital production within both design and construction industries, and the development of 21st century ideals and possibilities of mass customisation have provided a radical new platform for prefabrication.

For architecture, new technology provides the opportunity to advance design towards fabrication and construction processes – a shift from consent documentation to highly detailed and precise ‘shop drawings’ for manufacture of parts. BIM technology presents the ability to easily manipulate and make changes to the manufacture of parts for mass-customisation, and communicate those changes rapidly. The prospect in pursuit of customised design for client preference, climate and site specific conditions as well as different manufacturing environments.⁵⁵

51 Ibid 9.

52 Kieran and Timberlake, *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*. 123.

53 Bell, “Primer: About Prefab Housing.” 40-41.

54 Kieran and Timberlake, *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*. XII.

55 Branko Kolarevic, *Architecture in the Digital Age: Design and Manufacturing* (New York and London: Taylor & Francis, 2003).

However, recent manifestos and academic applications with extreme focus on the digital leave a sickening feeling of doubt – are we falling down the same rabbit hole again? Form generated for forms sake,⁵⁶ spaces that are so flexible that they have no sense of space and envelopes with more technology than a spaceship are not a direction in which prefabrication's greatest potential has been identified – we have seen buildings that resemble spaceships and other machines many years prior, how can we learn from these past market repulsions and not commit the same design errors again. The designer, preoccupied by the process of design rather than the logic of construction will not solve pragmatic issues that take a project from concept to production – and as we know throughout history this is often prefabs greatest barrier.

The Future of Prefabricated Housing

The ability for a housing system to allow for differentiation and a site specific response, yet embrace the quality, economic, construction, productivity and sustainable efficiencies that prefabrication is proven to provide has greater prospect today than yesterday. Pamela Bell and other experts believe that it is within the hybrid typology that the greatest potential for mass customisation lies – though largely unexplored in New Zealand.

“New Zealand’s housing market is small and there is customer demand for differentiation. This indicates that an adaptable panel and service core design using off-the-shelf parts is a logical choice. The hybrid module + panel typology offers significant unexplored potential for New Zealand prefabrication.”⁵⁷

This typology makes sense for a number of reasons, the combination of modular and panelised existing technologies increases potential economic feasibility and combines the benefits of flat-pack and modular, appropriately customised to each specific project. Utilising this approach can make use of the advantages of prefabrication and reduce its limitations and general apprehension from society.

⁵⁶ Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 25.

⁵⁷ Bell, “Kiwi Prefab: Prefabricated Housing in New Zealand: An historical and contemporary overview with recommendations for the future,” 31.

3.4 Hybrid Prefabricated Housing

The hybrid typology has been identified as an area that requires further research, and indicates considerable potential for the future of prefabricated housing in New Zealand. The hybrid module + panel typology, or more accurately module + panel + site works, as it can also refer to the mix of the prefab systems with traditional construction on-site; is believed to achieve design variation and site-specific design most successfully, whilst still retaining the productivity, economic, higher quality and sustainable advantages of prefabrication.

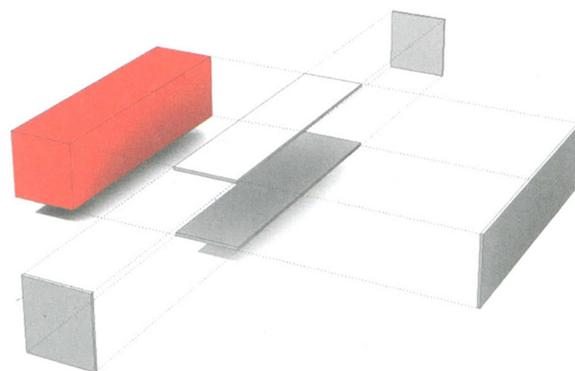
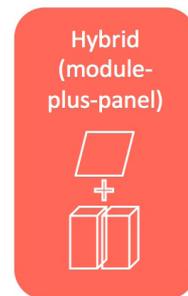


Fig. 3.4.1. System3, Diagram showing module + panel concept



PANELISED (non-volumetric) PREFAB

Panelised systems come in many forms and materials; they can be prefinished internally, externally or both, some with integrated structure, services and/or insulation, some with window and door elements pre-installed, delivered in various sizes and assembled using various jointing systems. The differing and adaptable characteristics of panelised systems result in differing on-site work requirements, flexibility and customisation.

Panelised systems combine the construction benefits of factory controlled conditions with the ability for elements to be stacked flat for efficient transportation to site. Therefore, transport restriction is less influential in driving the building form. Panels do however require more work for assembly on-site than modular units. International studies have shown that panelisation in comparison to on-site framing of walls can offer significant time and resource savings.⁵⁸

58 Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 37.

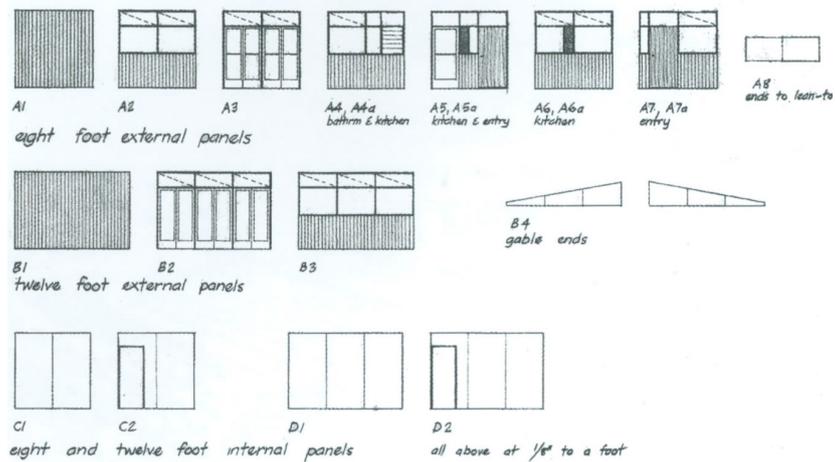


Fig. 3.4.2. Group Architects, wall components for 1952 panel system

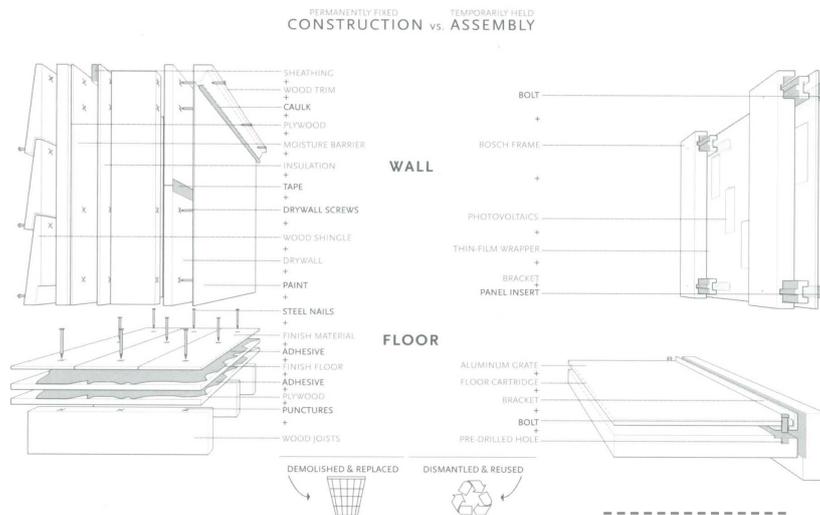


Fig. 3.4.3. Cellophane House, comparison of traditional construction to assembly of wall and floor panels

SERVICE MODULE (volumetric) PREFAB

The service module is a three-dimensional structural unit constructed off-site and transported to site where it is combined with panels to create a complete dwelling. The module integrates highly serviced areas, such as kitchens, bathrooms and laundries with fittings and internal finishes completed in controlled, factory conditions prior to transportation, reducing multiple and specialist trades on site. Numerous service modules can be produced in parallel generating greater efficiency. Often service modules are shrink wrapped and stored until they are required on-site using just-in-time delivery methods.

Module
(volumetric)



Fig. 3.4.4. Modules
manufactured in
Stanley Modular
Matamata factory



Fig. 3.4.5. Modules
stacked three high
at site in Auckland



Fig. 3.4.6. Modules
lifted into position
by crane on-site in
Auckland



TRADITIONAL CONSTRUCTION



HYBRID CONSTRUCTION

Reduced construction timeline: Construction/manufacturing of parts occurs quicker and simultaneously with site work.

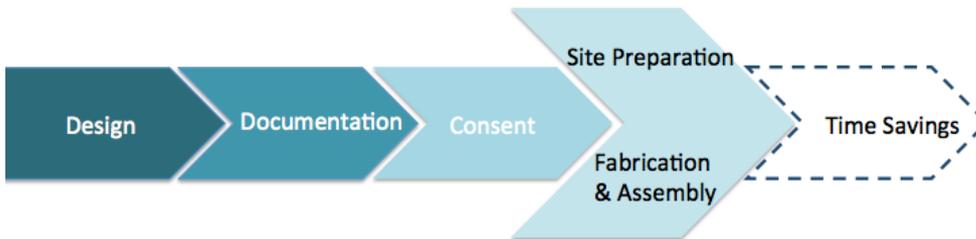


Fig. 3.4.7. Diagram depicting time savings in hybrid programme



Fig. 3.4.8. Image showing construction process of the *Meridian First Light House* by First Light Studio

The hybrid combination offers reduced construction timeline, minimised work on-site and therefore disruption. The smaller building components (in comparison to modular or complete building prefabrication) allow efficient transportation and delivery to sites with restricted access conditions of suburban infill. A hybrid approach offers more flexibility, customisation and site-specific design for social and sustainable requirements.

To date, there are few detailed or built examples of hybrid systems in New Zealand, although some concepts exist. The earliest examples of a hybrid system in New Zealand include the *All-Pine Prefab* house by Group Architects in 1953 (refer Case Study 04), and *Xibis* by IBS (Industrial Building Systems) two decades later. Whilst the *All-Pine Prefab* system combined a library of standardised interior and exterior panels with a standardised service module to produce eight plan variations, *Xibis* combined several ground floor modules with steeply pitched roof panels to create a second storey. Although modular prefabrication and panelised prefabrication have continued to be explored, the combination of the two has only begun to be investigated again in recent years. Although unbuilt, architects Herriot and Melhuish Architecture from Wellington entered their hybrid *Module 1.2* (refer Case Study 03) design into the *Department of Building and Housing 2008 Starter Home Design* competition. It consisted of a service module housing kitchen, bathroom and laundry set within wall and roof panels of Structurally Insulated Panels (SIP's).

The *First Light House* was designed and built by four Victoria University of Wellington architecture students as an entry into the biennial *United States Department of Energy Solar Decathlon* competition in 2010-2011. Among other entry requirements the house had to be assembled within the period of one week, which had a large impact on the approach to prefabrication and design.⁵⁹ Wall, floor and roof panels were prefabricated in separate locations and then assembled into six volumetric modules with internal finishes and fit out installed in factory prior to shipping from Wellington to Washington DC. The real design challenge then lay in the connection detail, and aesthetic treatment to conceal the joints between modules.

Since the success of the project, winning third prize overall, the team have refined the design of the original *First Light House* for the local commercial market. Among their criteria was to reconsider the construction system for the most efficient and affordable way to way to fabricate the home off-site.⁶⁰ Although a modular approach was the quickest and easiest way to construct the home for the specific competition, when applying the system to local (New Zealand) market requirements the designers admit that, "*Transporting fully finished modules also means moving a lot of air...which is expensive and inefficient.*"⁶¹ They begun by exploring panelised construction, which are easier to transport but take longer to build because of the increased panel connections on-site and the complex service connections between them. To get around this they have now adopted a hybrid approach, "*to utilise the best of both worlds*"⁶² Two pre-finished service modules now

59 Mark Southcombe, "Digitally Fabricated Futures." In *Kiwi Prefab: Cottage to Cutting Edge*, ed. Pamela Bell and Mark Southcombe (Auckland: Balasoglou Books, 2012), 122.

60 "Built at the Speed of Light Part 2," First Light Studio, accessed October 3, 2013, <http://firstlightstudio.co.nz/kiwi-prefab-blog-part-2>.

61 "Built at the Speed of Light Part 2."

62 Ibid

Fig. 3.4.9. Early exploded construction diagram showing how parts fit together like a jigsaw

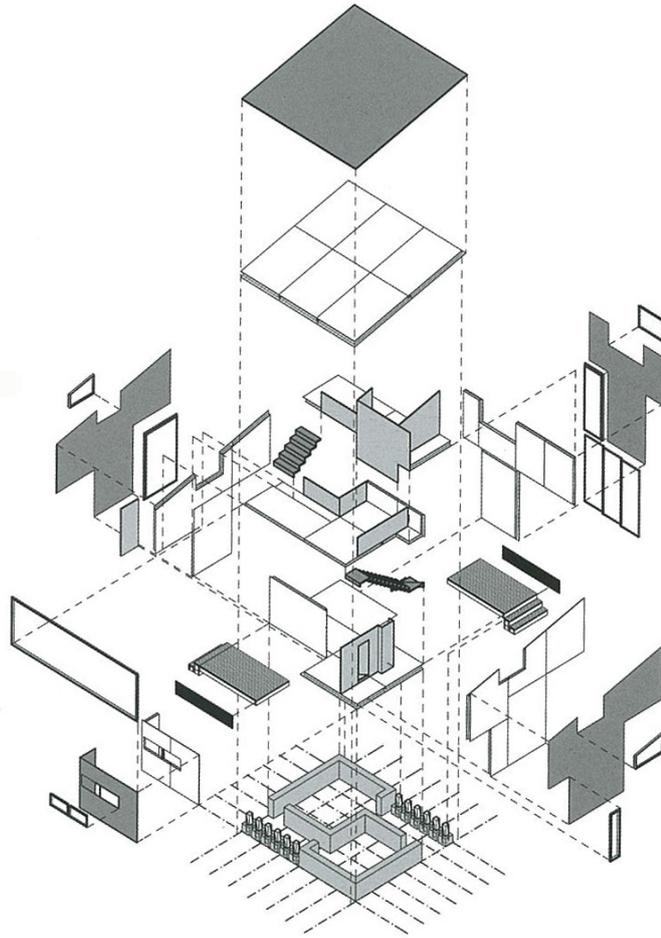


Fig. 3.4.10. Cellophane House repeated sequence of houses in urban context

run the south side of the house, whilst the rest of the house is assembled as prefabricated individual panels. “All the hard work is done prior to arriving on site and the final assembly is quick and easy.”⁶³

The *Jigsaw House* project is a conceptual exploration led by Victoria University Senior Lecturer in architecture Mark Southcombe and Associate Professor Andrew Charleson. The large jigsaw-like components are intended to minimise the number of parts and trades involved in the conception of a house, therefore delivering a faster and easier method of construction.⁶⁴ Wall, floor and roof panels interlock gaining structural stability from each other, and whilst a service module is not integrated, all services are pulled away from the panelised elements and expressed as a separate element to simplify construction.⁶⁵ Initially explored as plywood panels, which failed structurally, SIP's were then experimented with before arriving at a solution utilising digitally cut cross-laminated timber CLT as the primary building material. Assembly occurs using a light Hiab crane system. The CLT panels are reverred for their dimensional accuracy, sustainable and structural properties and ability to be customised using CNC technology. Although unresolved for commercial viability, the conceptual framework and use of CLT is similar to international hybrid precedent *System3* by Austrian architects Oskar Leo Kaufmann and Albert Ruf (**refer Case Study 01**) which employs a separate ‘skin’ producer to deal with issues around thermal envelope and external finishes.

Internationally, there are several other innovative design exemplars identified as hybrid module + panel design such as *Loblolly House* (**refer Case Study 02**), *LivingHomes* and *Cellophane House* by American architects Stephen Kieran and James Timberlake.

Stephen Kieran and James Timberlake explore the hybrid typology further in their book *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*, a provocative publication if not controversial. When these two describe building they do so with terms like *chunks* and *blocks* and integrated component assemblies (manufacturing revolution in car and plane manufacturing) and are pro hybrid assemblies and BIM technology.

During the course of this research BRANZ released the *2013 BRANZ Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, a comprehensive report accessing the impact of prefabricated building systems in the New Zealand Construction Industry. The intention in particular, to determine whether there are apparent differences in economic and environmental outcomes between prefabricated building methods and traditional construction. The report outlines the natural opportunities for next steps in the adoption of prefabrication, two of which point directly towards the hybrid typology.

- *Recognition of the benefits of prefabricating larger sections of buildings – ie. The extension of the successful model of pre-nailed wall frames and roof trusses into wall and roof panels*

63 Ibid

64 Southcombe, “Digitally Fabricated Futures.” 122.

65 “Kiwi Prefab: Jigsaw House,” *Kiwi Prefab: Cottage to Cutting Edge*, accessed on February 17, 2014, <http://www.kiwiprefab.co.nz/exhibition/3/item/28/>.



- *Integration of prefabricated module's.*⁶⁶

A case study of a prefabricated 120m² house compares three different approaches of prefabrication; transportable housing, panelised housing and hybrid modular housing, to traditional on-site build and made several conclusions.

Prefabrication of building elements in New Zealand provides;

- *Greater security in economic outcomes*
- *Greater opportunity for enhanced environmental sustainability than traditional construction.*⁶⁷

The case study concluded that the hybrid construction system offered the greatest efficiencies. Material and labour costs have the ability to be reduced through bulk procurement and higher efficiency of time. However sound processes and planning are required to maximise these benefits, and many of the benefits of prefabrication increase with scale and repetition. Therefore the full benefits of the hybrid system can only be gained when there are multiple units to construct.⁶⁸

The hybrid typology identified is explored as a possible solution to the problems identified surrounding Auckland housing supply and affordability, productivity, land supply and subsequently tested on the Housing New Zealand *New Two-Bedroom Homes* Project. A hybrid prefabrication approach is appropriate for a number of reasons outlined in the considerations imposed by Housing New Zealand specific to the project;

- **Minimise construction activity on-site**
- **Minimise disruptions and safety risk of that work to the tenants and neighbours**
- **Reduced construction timeline; target maximum two-weeks on-site construction period**
- **Deliver using large scale and high level of repetition**
- **Restricted access via residential driveway**
- **Response to specific site conditions surrounding privacy, outdoor space, parking and access and orientation**
- **Non institutional design outcomes**
- **Sustainability in terms of building performance, life-cycle costs and construction process**
- **Efficiency and economic saving using manufacturing style approach.**

The system to be tested

A standardised module to incorporate highly serviced areas, with remaining spaces flexibly arranged around the prefinished module/s with the use of panel systems (and on-site work) to allow greater transport freedom, design quality and site specific design.

⁶⁶ Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 41.

⁶⁷ *Ibid*, 2.

⁶⁸ Davies, 2005; Fawcett & Allison, 2005.

4.0 Methodolgy of Analysis

Precedent for hybrid typology housing system design were identified in the previous chapter. Each of the five following Case Studies are examined through literature, and analysed through drawing in both plan, to understand planning and component design relating to module set-out, and three-dimensionally to understand the components of the hybrid system and their assembly.

Case studies analysis in terms of;

- Size and footprint comparable to number of occupants
- Module set-out
- Cost (when available)
- Service module and panel component design and assembly
- Form
- Outdoor Space
- Circulation
- Separation achieved between public and private spaces
- Ability to, and methods of, customisation
- Sustainability and site specific design
- On-site / off-site balance of construction
- Transport and delivery
- Built-in furniture and storage integration.

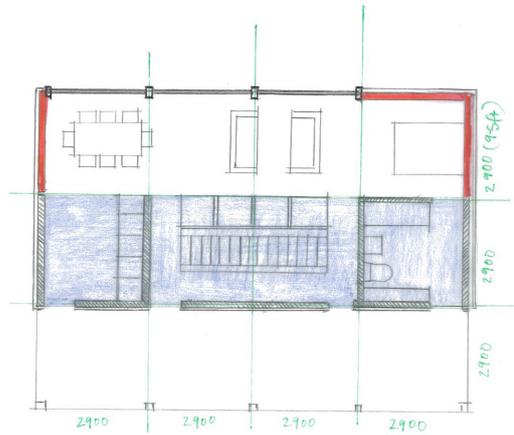


Fig. 4.1.1. System3, plan and module analysis

4.1 System3

System3 by Austrian architects Oskar Leo Kaufmann and Albert Ruf, is the result of their quest for a building system that delivers high quality design and finish at low cost. The fundamental system involves an open plan, one bedroom, single unit dwelling. A simple rectangular volume *of which the architects see as building blocks of which “greater communities” can be made.*⁶⁹

The dwelling consists of two space types, a “*servicing*” space and a “*naked*”⁷⁰ space. The servicing space, effectively the service module, provides all amenities and is distributed as a complete enclosed volume. The naked space then forms the panel portion of the hybrid method – floor slab, walls, windows, roof and optional “skins.” The panels enclose equal amount of ‘naked space’ as the ‘service space,’ to create two equally proportioned rectangular volumes side by side.

69 Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 10.

70 Ibid. 214.

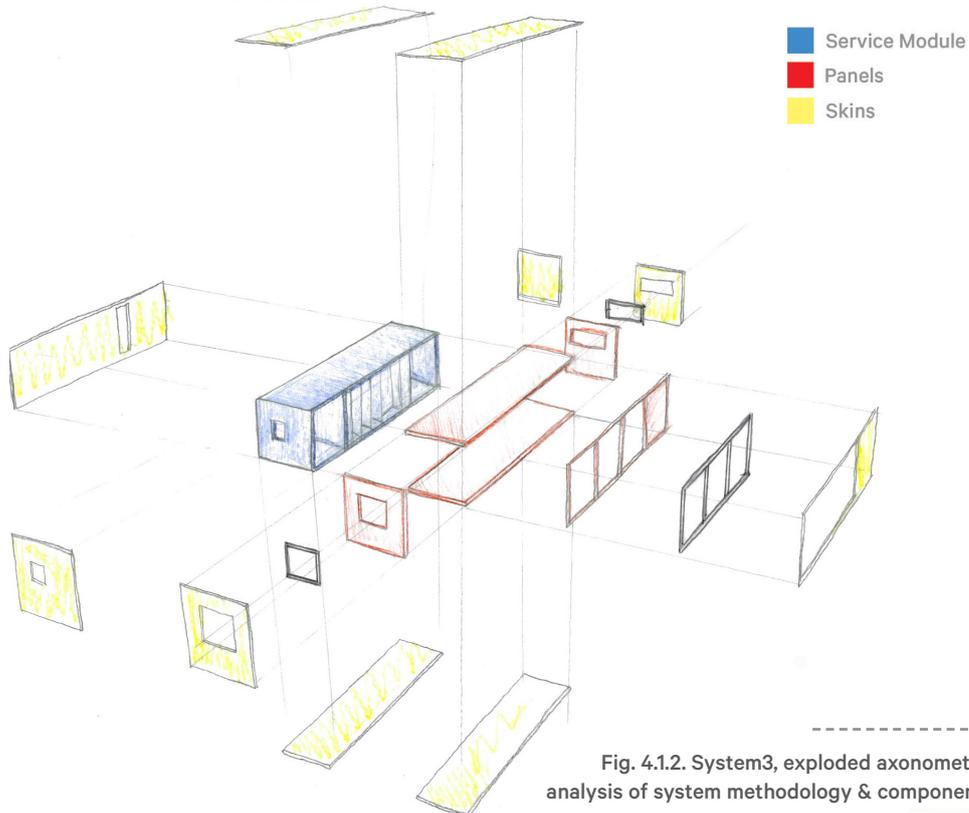


Fig. 4.1.2. System3, exploded axonometric analysis of system methodology & components

CASE STUDY 01 System3

ARCHITECTS Oskar Leo Kaufmann and Albert Ruf
KFN Systems - Austria

YEAR 2007 - 2008

LOCATION N/A - Prototype constructed for *MoMA Home Delivery Exhibition*, New York

SYSTEM Hybrid

size 5.8m x 11.6m

footprint 67.3m²

levels 1 (with the ability to be stacked)

no. of bedrooms 1

no. of people 1-2

m²/person 67.3m² / 33.7m²

cost \$130,000 USD = \$2380 NZD / m² once production system is fully operational

module 2.9m(9.5ft) - driven by the dimensions of a standard shipping container

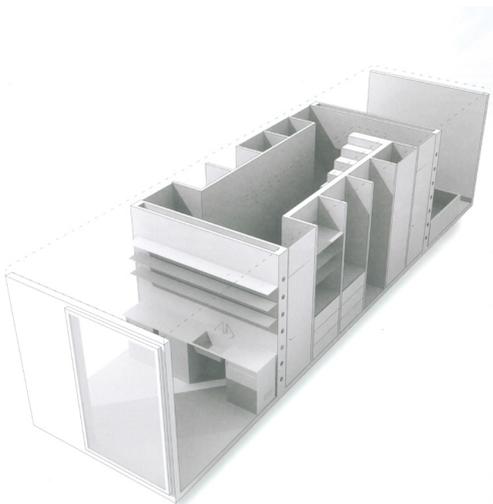


Fig. 4.1.3. System3, pre-finished service module

Fig. 4.1.4. System3, rendering depicting stacked units



service module The service module makes up half of the dwellings total area, includes kitchen, bathroom, electricity, Internet, laundry, heating, cooling, ventilation and vertical circulation (if required). All services are limited to the service module, lighting and electrical outlets included – additional lighting in adjacent space is to be provided by power extension cables to freestanding light sources.

panels The panels for floor, walls and roof are approximately 120mm (4.75”) thick of solid LVL. Apertures within the wall panels are CNC cut specific to site and climate conditions. Wall panels are distributed as a whole wall, roof, and floor, so panel junctions only occur in corners. Door and window elements are fabricated by a separate producer and delivered directly to site for assembly, as is the cladding, or ‘skin’, which is conceived to act as a jacket, ‘removable, changeable and washable,’ and includes thermal insulation, vapour barrier and waterproofing.⁷¹

form Simple rectangular volume with flat floor and roof planes to allow for vertical stacking.

outdoor space A third volume of equal space can be added to the other side of the service module, dependent on programme and site conditions. Larger openings from the dining space connect to outdoors if site conditions permit.

circulation Circulation is indirect and inefficiently connected, resulting in limited ‘held’ space within the unit. Entry to the dwelling is located at the back of the service module, from which you enter past the back of the kitchen and into the living dining area. The stair can be accessed directly from this point also.

⁷¹ Bergdoll and Christensen, *Home Delivery: Fabricating the Modern Dwelling*. 216.

privacy The open plan arrangement provides limited privacy and separation between public and private spaces. However the separation achieved between kitchen and bathroom is successful.

customisation The individual unit has the ability to be customised to local environments through use of local materials, appropriate openings, glazing, screening and cladding. The unit can be repeated to form multi-unit housing or raised off the ground on pilotis. The simple flat roof form allows the system to also stack vertically, twist and slide to produce many configurations at various scales.

sustainability and site specific design Placement on-site is to be positioned for appropriate solar orientation, with service module oriented north (northern hemisphere). The system is envisioned to accommodate local materials in given regions. Apertures in wall panels are conceived to integrate options between double and single glazing, as well as privacy, sun and mosquito screens.

site/factory balance The service module is completed by an independent producer in a designated factory. The floor, wall and roof panels are made by a separate producer. Yet another producer is used for prefabricated joinery elements, and another for the building 'skin.' All components are then delivered to the service module factory, where they are packaged together for transport to site and assembled.

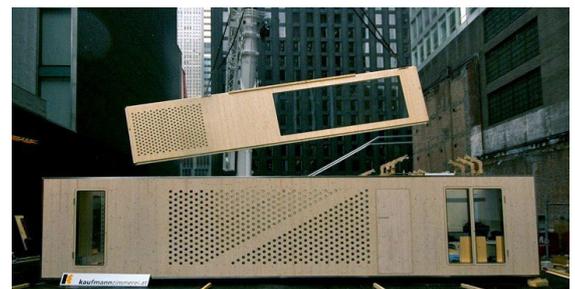
transport and delivery The volumetric service module, together with flat-packed panels, joinery and skins, are designed to fit within a standard container to be delivered as a complete building package. The architect makes customisable decisions and passes on to a 'planner' who delegates all duties for fabrication, delivery and assembly.

furniture All built in storage and furniture is contained within the service module, with all elements made of stainless steel. Shelving has the ability to be moved and altered by integration of a pegboard pattern in which fixings are made, allowing for customised storage solutions.



Fig. 4.1.5. System3 large-scale stacked assembly

Fig. 4.1.6. System3, installation view of assembly at MoMA



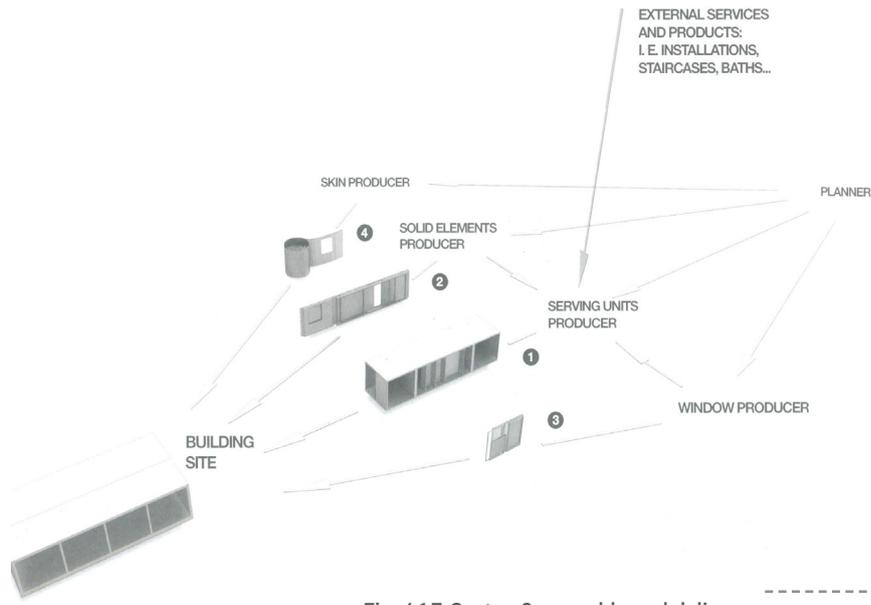


Fig. 4.1.7. System3 assembly and delivery programme diagram

The flat roofed form, although flexible in its ability to be stacked, is reminiscent of the early to mid 20th century prefabricated housing which was rejected by the market and still negatively associated with prefab housing today. The modernist form allows for limited sun control and passive design principals, which similarly create a sharp demarcation between the inside and out, with no sheltered intermediate space to link the two.

Optional outdoor space is presented as a bounded volume on the opposite side of the service module, and therefore, has limited connection to living spaces. The customisation of apertures, glazing types and screening is a successful approach and provides important specific site and climate customisation with minimum interference to the system via simple fabrication modification utilising CNC technology. The separation of the 'skin' as a separate component to the basic structural wall panel allows for flexibility and customisation, however presents a large amount of on-site work. Rather than delivering complete prefabricated panels to site, considerable on-site labour and time are required to install joinery, insulation, vapour barrier (building wrap), and cladding to arrive at a weather tight envelope.

Although doubt surrounds the viability of the many separate producers of components and amount of components for assembly on-site, the process of delivery and role of the 'planner' is strong. As is the ability for the complete building package, both volumetric and flat packed components, to be transported within the confines of a standard container.

Fig. 4.1.8. System3 interior of prototype looking from bedroom through to living and dining



Fig. 4.1.9. System3 interior of prototype showing prefinished stainless steel kitchen from dining



4.2 Loblolly House

Loblolly House by Stephen Kieran and James Timberlake is the consequential prototype following their book, *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*, which attempts to reframe the way we think about prefabrication. The hybrid system of off-site fabrication and on-site assembly employs both flat-pack and modular construction. Each element within the building is alleged to achieve a single function, grouping together several systems and elements into a prefabricated, ready to install component for assembly.



CASE STUDY 02 Loblolly House
 ARCHITECTS Kieran Timberlake Associates
 YEAR 2006
 LOCATION Chesapeake Bay, USA
 SYSTEM Hybrid

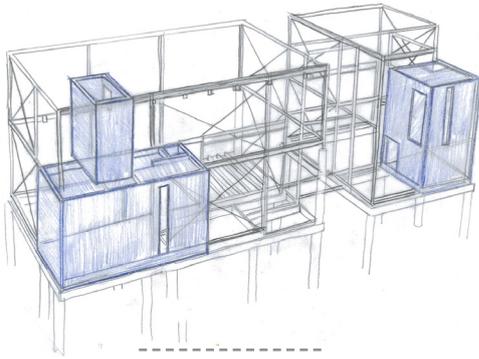


Fig. 4.2.2. Loblolly House service module analysis

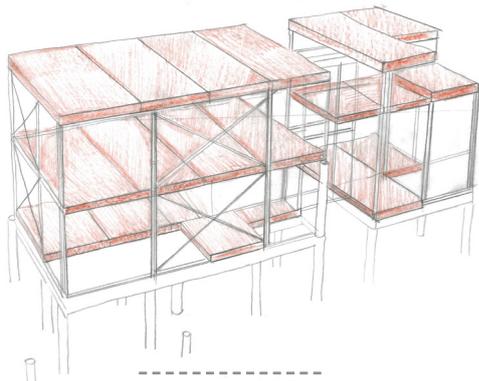


Fig. 4.2.3. Loblolly House floor cartridge analysis

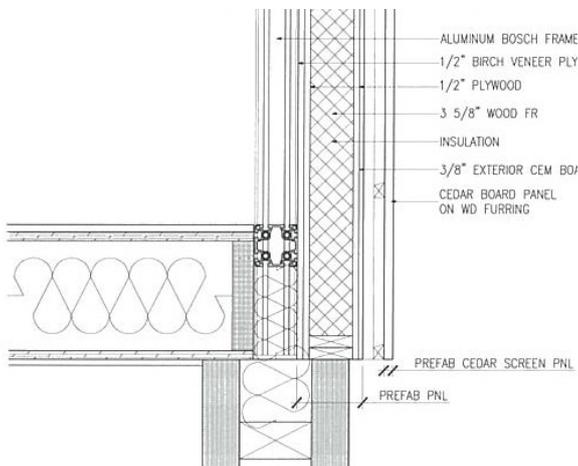


Fig. 4.2.4. Loblolly House wall & floor cartridge connection detail

footprint 204m²
 levels 2
 no. of bedroom 3
 no. of people 4-6
 m²/person 51m² / 36m²
 cost not available – although high budget is assumed
 module The module is driven by the structural bay, which varies between a 2.4m and 3m module, although all floor cartridges are 2.4m wide

service module The architects term it a 'block,' with the rationale that block implies an isolated insertion, whilst 'module' implies a strategy of expansion. Three system-intensive blocks are designed to minimise the shipment of air and incorporate bathrooms, storage and mechanical rooms.⁷² The service modules are described as the organs of the *Loblolly House* - and organise all incoming and outgoing utility connections which are embedded in the floor cartridge system. Unlike most service modules reviewed, the kitchen is not incorporated but treated as a *fixture*, prefabricated and delivered from a separate supplier.

panels The system utilises a frame structure, or as the architects describe, 'scaffold'. The system combines standard extruded anodised aluminium sections with a mixture of standard and bespoke connectors. Originally a commercial system, the architects saw merit in the systems rapid assembly, accuracy, availability and flexibility. The scaffold and its connectors act not only as the structure but connect panels (*cartridges*), service modules (*blocks*) and kitchen and stairs (*equipment*) to the frame with merely the aid of a wrench.

Panels are referred to as cartridges, the 'ideal term for an element based architecture.' The floor cartridge integrates timber LVL joists and services for distribution from blocks. Integrated radiant water heating, wastewater, ductwork for mechanical ventilation, and electrical conduits are pre-installed. The pre-insulated floor cartridges are lifted into place by a crane and inserted into the frame. Each panel is 2.4m wide and varies in length. The roof panel is essentially the same construction as the floor panel, however cladding treatment on-site differs.

72 Stephen Kieran and James Timberlake, *Loblolly House: Elements of a New Architecture*, (New York: Princeton Architectural Press, 2008), 103.

The wall cartridge consists of a timber structural frame between an inner shell of OSB and outer shell of cement board, providing a cavity that integrates vapour barrier and insulation. Prefabricated window elements, most of them full height, are integrated into the cartridges in factory conditions. The wall cartridges, which incorporate both stories, are craned into position in several large elements and bolted in place. Prefabricated cedar rain-screen panels are then attached to the house in segments, the *'overlapping cedar boards act as a filter for rain, wind and solar radiation.'*⁷³

form the dwelling is elevated from the ground on piles to *'metaphorically establish the house amid the trees.'*⁷⁴ The modernist pilotis approach creates an open passageway beneath, from which two rectangular forms sit, linked by a passageway or bridge. The flat roof with no eaves produces a modernist aesthetic with a multi-layered facade.

outdoor space The envelope of the building opens up to the surrounding landscape, by use of large sliding or bi-folding doors and operable west façade. Sheltered deck space is integrated with access from the master bedroom and circulation space on level one. There is no immediate physical connection to the ground plane.

circulation An exterior stair is accessed from ground level, flanking the entire east facade. Level two can be accessed by either continuing to ascend the exterior stair or via the internal spiral staircase.

privacy Each individual space within the dwelling is separated by building form, link-way or level change. The exclusion of the kitchen from the service module allows greater separation and privacy between living/kitchen/dining space and the bathrooms.

customisation The hybrid system of scaffold, cartridge, blocks and fixtures has merit in adaptation to other sites. However, unlike other reviewed hybrid designs the approach here is entirely bespoke in its outcome. The framework developed could be applied to different conditions with a great deal of review and specific design customisation.

sustainability and site specific design The design is site-specific, its disconnection from the ground plain intended to reduce the impact of the building on the coastal landscape and local wildlife. The exposed west elevation incorporates an adjustable façade to allow varying shifts of protection against wind, water and solar gain, to control internal environment. The system is designed with disassembly in mind, so that elements of the building can be removed, replaced, and recycled.

⁷³ Kieran and Timberlake, *Loblolly House: Elements of a New Architecture*. 95.

⁷⁴ *Ibid*, 57.

Fig. 4.2.5. Loblolly House wall panel analysis

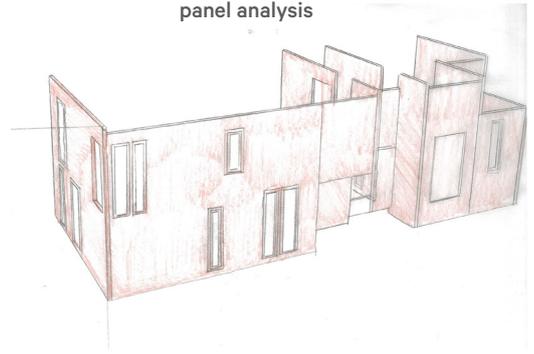
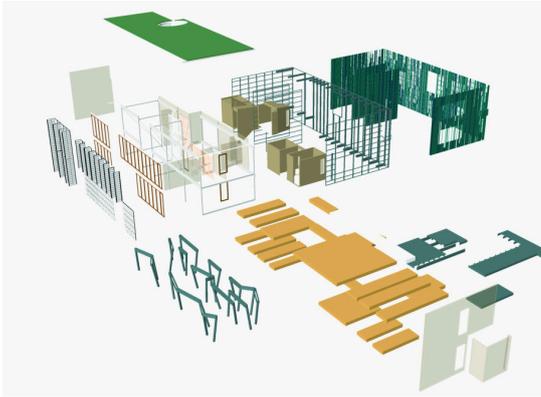


Fig. 4.2.6. Loblolly House Western adjustable façade

Fig. 4.2.7. Loblolly House cedar rain screen



Fig. 4.2.8. Loblolly House components for on-site assembly



site/factory balance Piles are traditionally driven on-site. The scaffold is pre-cut and pre-drilled, then assembled with speed and efficiency on-site. Prefabricated service blocks, cartridges, rain-screen panels, stair and kitchen units are lifted into place and secured on-site. Site finishing is intensive with no prefinished floor, wall or ceiling linings integrated into prefabricated components.

transport and delivery All prefabricated components are developed and refined within a virtual model for both fabrication and assembly strategy. Embedded information takes into account transport limitations and how the components are shipped. All major components are prefabricated off-site, and delivered flat-packed, other than service modules that are delivered volumetrically. Wall and floor cartridges, in comparably large sections, are craned into position.

Furniture Storage is generally integrated within service blocks. All other furniture are freestanding hand selected objects.

Loblolly House presents a highly bespoke and site-specific outcome utilising the benefits of prefabricated components for on-site assembly. The objective, not to provide a housing prototype that could be produced on mass but a re-evaluation of the way we build houses and how the use of the hybrid typology can produce better outcomes. Therefore direct learning for the purposes of the inquiry is more to do with the way of building and thinking developed. The high budget and technological complexity is not directly relevant, however the theoretical framework of the system has potential.

The development of the cartridge is convincing in terms of the grouping together of numerous elements into a prefabricated component for efficient site assembly. However the cartridge design employed do not incorporate prefinished internal linings, which increases on-site labour and time, and reduces accuracy and efficiency. The incorporation of prefabricated cedar rain-, wind- and sun-screen panels has aesthetic and functional merit, however extra expense is involved in essentially cladding the building twice.

The segregation of the kitchen from the service modules allows greater design flexibility and smaller more intensive volumes for transport. The modern kitchen, with less service requirements and modular cabinetry descent is logically prefabricated and delivered independently.

Subsequent to *Loblolly*, the firm went on to develop the system for the general housing market. A collaborative relationship was formed with *LivingHomes*, a developer of 'housing products' based in Santa Monica, to develop both single- and multi-family homes. The commercial system employs cartridges for roofs, floors, exterior walls and interior partitions, which are prefabricated with integrated structure. The two-storey wall cartridges act as balloon-framed elements, which attach to the base of the floor cartridge. The abandonment of the scaffold in place of structurally integrated panels suggests that the frame is excessive, costly or unnecessary in the commercial model.

4.3 Module 1.2

Module 1.2 by Wellington architects Herriot and Melhuish (HMA) was designed as an entry in the *Department of Building and Housing 2008 Starter Home Design Competition*. HMA engaged a hybrid, service module + panel approach, which in this case explores structurally insulated panel (SIP) technology. The design made the final shortlist, however remains unbuilt.

Simplicity of form is combined with a modernist aesthetic to deliver a high performing home that utilises a combination of engineered timber construction and innovative building technology. The long and slim service module is positioned on the south side of the house; the remaining space is apportioned between private and public zones. The proportions of the service module allow the unit to incorporate both zones of the house, the kitchen adjoining to the public zone to the west, and bathroom and laundry in the private zone to the east. Although the design is for a 109m² three-bedroom home, the system includes conceptual plan variations for one-(75m²), two-(93m²) and four-bedroom (122m²) homes.

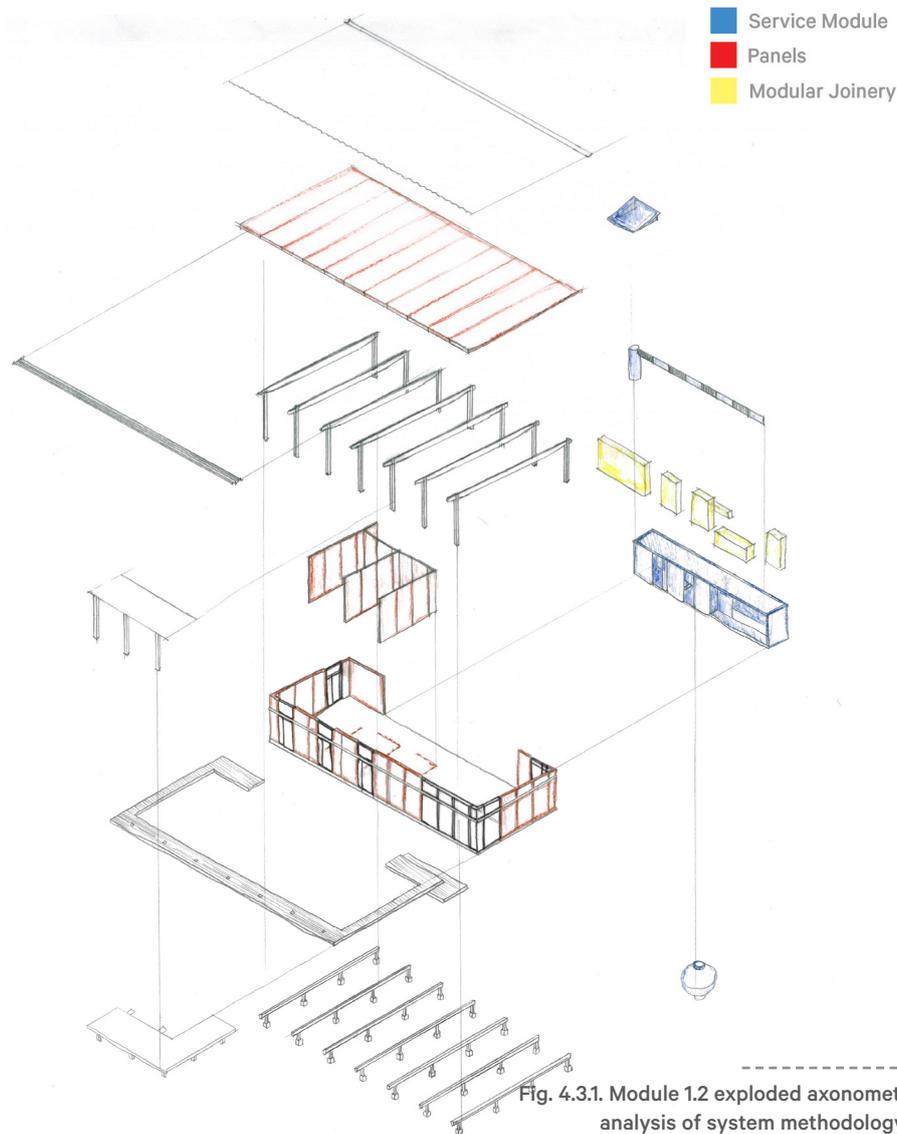


Fig. 4.3.1. Module 1.2 exploded axonometric analysis of system methodology & components

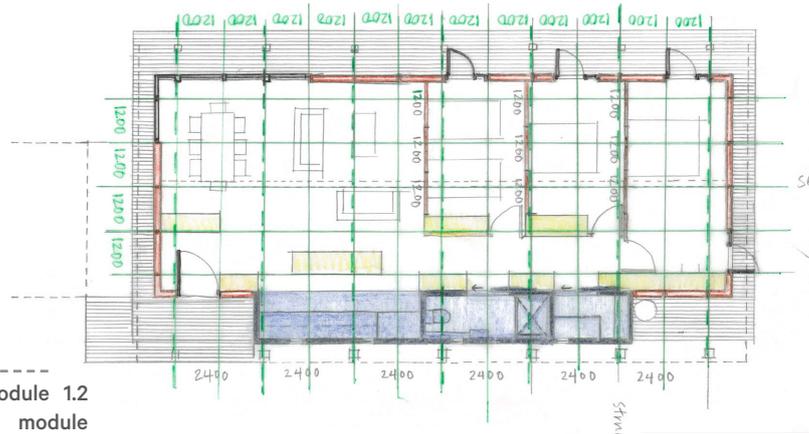


Fig. 4.3.2. Module 1.2 planning and module analysis

CASE STUDY 03 Module 1.2
ARCHITECTS Herriot and Melhuish Architecture, Wellington
YEAR 2010
LOCATION UNBUILT
SYSTEM Hybrid

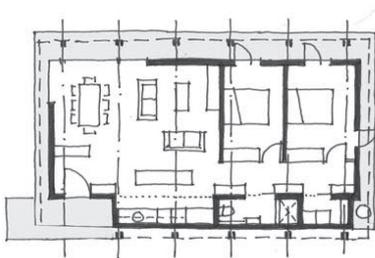


Fig. 4.3.3. Module 1.2 two-bedroom adaptation of plan

size 109m² (with 39m² deck)
 footprint 109m² (two-bedroom option 93m²)
 levels 1
 no. of bedrooms 3 (2)
 no. of people 3-6 (2-4)
 m²/person 36.3 m² - 18.2 m² (two-bedroom option 46.5m² - 23.25m²)
 cost \$148,954 (\$1392/ m²)
 module 1.2m (with 2.4m structural bay for LVL portal frame)

service module The service module (1.8m by 9.6m ,17.28m²) encapsulates kitchen, bathroom and laundry. Its position within the plan allows it to be plugged on to the side of the building, delivered and installed in parallel with the floor cartridges. Electrical and data services are distributed to the rest of the house through a concentrated central underfloor service duct, which reduces issues surrounding the incorporation of services into SIP panels and allows the internal wall panels to be removed, added or re-configured. The timber-framed unit is pre-finished both internally and externally with all appliances, fixtures and fittings installed.

panels The structure of the house is expressed independently from the building envelope, essentially a LVL portal frame with 2.4m structural bays, inset 600mm from building edge. The engineered lumber achieves large spans with less material.

Wall panels are 1.2m wide SIP's consisting of a 145mm rigid foam insulation core (R.3.6) with clear-finished 9mm plywood internally and painted exterior grade 12mm plywood externally. Internal 1.2m wall panels are also prefabricated off-site using timber framing

and clear-finished 9mm plywood. Window and door elements are supplied by a separate manufacturer and delivered directly to site for installation.

The roof consists of SIP's of the same construction, however to achieve higher thermal performance in the roof the panels have a 165mm thick insulation core, achieving R5.0. Although this system achieves a prefinished ceiling lining, roof cladding is constructed on-site.

Floor construction is ultimately on-site, utilising clear-finished particleboard on timber joists, although bearers are LVL, which are dimensionally truer with higher structural performance. On flat sites, there is the option for a traditional concrete pad foundation or concrete raft for those with poor ground conditions.

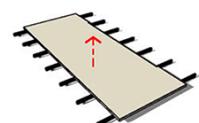
form Simple rectangular plan with modern aesthetic and monopitch roof pitched to north. The service module is expressed as an independent unit.

outdoor space A continuous 1.2m wide deck runs the north elevation and can be accessed from the living area via large sliding openings. The deck can also be accessed from each of the three bedrooms. A battened sunshade runs the northern façade to filter light, additional clip on sunshades are optional.

circulation Entry to the dwelling is via a small back porch to the south-west, a transitional entry space is defined by a storage wall before entering into the larger living/dining space. A central corridor essentially divides the service module and living/dining/sleeping spaces, resulting in a direct and efficient circulation path.

privacy Privacy between private and public zones of the house is well managed, although the close proximity of the kitchen and bathroom is undesirable. There are however, no direct sight lines and built in furniture acts as an additional buffer.

customisation The standardised portal frame allows the floor-area of the house to extend in 2.4m modules, fundamentally allowing the same standard planning arrangement and service module to extend from a one-bedroom solution to a four-bedroom solution. The isolated structure also allows the non-load bearing internal partitions to be organised as per individual user requirements. Options to upgrade to different exterior claddings, floor coverings, bathroom fittings and glazing are presented, as well as the option for extra decking area, sunshades, and prefinished storage units and joinery.



RAISED PLATFORM

sustainability and site specific design Engineered timber construction makes efficient use of wood, an inherently sustainable product with plentiful availability in New Zealand. The thermal performance achieved by SIP technology reduces thermal bridging to create a thermal envelope that exceeds New Zealand code requirements. Eave design and placement of openings ensures solar gain in the winter months and adequate shading in high summer sun conditions. Natural ventilation is controlled via operable glass louvres and window openings. Sustainable features such as solar panels, rainwater collection and grey water system are also options that can be easily integrated at an extra cost. Site specific design is limited to foundation type and outdoor space design, such as decks, steps and balustrades.

transport and delivery The prefabricated service module is delivered and craned into position adjacent to (on-site) remaining building platform. Services are connected and pre-cut LVL portal frame erected. SIP panels are delivered pre-cut and flat-packed directly to site. Building is enclosed, and clad before internal fit out occurs using prefabricated modular wall panels and joinery items.

on-site/off-site balance The system combines prefabricated elements with on-site foundations to produce an efficient construction process. Although the SIP roof panels produce a prefabricated ceiling lining, they are essentially then traditionally clad, with building paper, battens and metal profile roofing, increasing on-site work in comparison to prefabricated roof panels. The basic system essentially produces a prefabricated four-in-one wall, external pre-painted cladding, partial structure, insulation and internal lining. Joints between panels are then covered with a timber batten.

furniture Prefinished, built-in storage units are integrated into the design to make efficient use of space and reduce the need for moveable furniture. Units are constructed from prefinished MDF, with upgrade option to timber veneer plywood.



Fig. 4.3.4. Module 1.2 exterior view

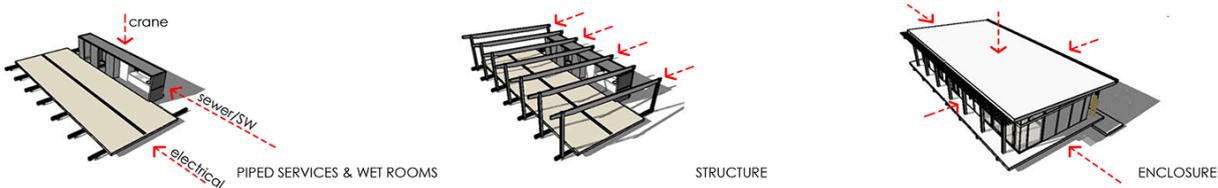


Fig. 4.3.5. Module 1.2 on-site assembly diagram

Although the *Module 1.2* system can be customised to adjust area, add or subtract bedrooms, the design of the service module restrains the building form to adapt proportionately specific to particular site conditions. The concept plan for a two-bedroom version is comparably large at 93m², perhaps driven again by the proportions of space devised by the standardised service module design.

Although separation between public and private zones is generally appropriate, the bathroom and kitchen are in close proximity, it may be more suitable to distance them further by moving the laundry to the central position. The laundry size although suitable for a three or four-bedroom home, is excessive for a two-bedroom home and would be better integrated into a hallway or bathroom for space economy.

In conditions such as high wind zones that require a cavity, or when cladding is upgraded to cedar weatherboard (or other cavity construction cladding type) the system becomes inefficient because the house is essentially clad twofold, and work on-site is increased. The roof is similarly inefficient, although it integrates both a portal frame, and SIP roof panel, the system demands that it is then traditionally wrapped in building paper, battened and clad on-site.

Whilst the affordable design shows technological foresight and innovation, much of the design relies on technology that at the time, and still currently in 2014 is not available. Timber SIP panels manufactured in New Zealand utilise OSB rather than plywood, which does not provide a weather-tight external surface. The substitution of OSB to ply is valid as it also provides a robust internal lining with a superior aesthetic. However, because fixing is usually concealed with secondary lining, the solution is presented to cover joints and fixing with a batten for both wall and ceiling surfaces, an unconvincing aesthetic outcome.

The *Module 1.2* system also demands an exterior grade of LVL, which the competition entry suggests, "*are currently in development and close to market.*" Again, four years later, the technology is still not available, it is assumed that it is predominantly for these reasons that the entry did not make it to the finalists and that a prototype remains unbuilt.

4.4 All-Pine Prefab

The *All-Pine Prefab* house by Group Architects is the prototype of a building system in partnership with *New Zealand Forest Products* to promote New Zealand grown timber. The Groups philosophy already incorporated modular planning and efficient material use, so prefabrication was a natural evolution.

The system comprised of eight plan variations for one-, two-, and three-bedroom homes using a variety of panels and standard service module. The prototype with rectangular plan and flat projecting roof was erected in 10 days for the *Auckland Birthday Carnival* at Western Springs.⁷⁵

⁷⁵ Brenda Vale, "Prefabricated Houses." In *Group Architects: Towards a New Zealand Architecture*, ed. Julia Gatley (Auckland: Auckland University Press, 2010),83.

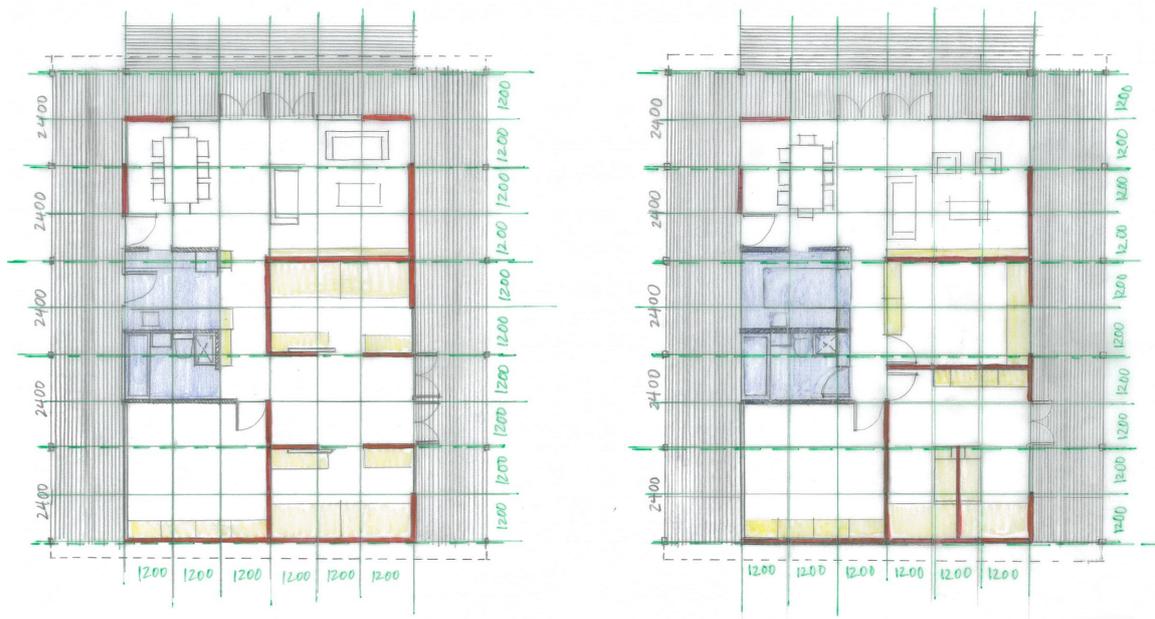


Fig. 4.4.1. All-Pine Prefab module and planning analysis

CASE STUDY 04 All-Pine Prefab
 ARCHITECT Group Architects
 LOCATION Western Springs, Auckland
 (10 day exhibition period)
 YEAR 1953
 SYSTEM Hybrid

size 12m x 7.2m = 86.4m²
 footprint 86.4m²
 levels 1
 no. of people 4 - 6
 m²/person 21.6m² – 14.4m²
 cost not available
 module 1.2m

service module The adjacent bathroom and kitchen (with incorporated laundry) are designed to be prefabricated as a standard module (2.4m x 3.7m, 8.88m²) ‘to keep all the plumbing in one place’ across eight plan variations.⁷⁶ All plumbing is integrated into the dividing wall between the kitchen and bathroom. The service module design and placement within the planning arrangement generates an enclosed kitchen form.

panels The external and internal walls follow a 1.2m module producing combinations of 2.4m and 3.6m panels. The library of panels provides the ability to configure eight plan alternatives using varied combinations, each with a different arrangement of solid wall and glazing. The wall panels are combined on site with traditional suspended timber floor construction using standard (2.4m x 1.2m) pine sheets.

form Rectangular form with roof projecting on three sides, originally flat, it was replaced with a gable roof after it was damaged in a fire in 1960.

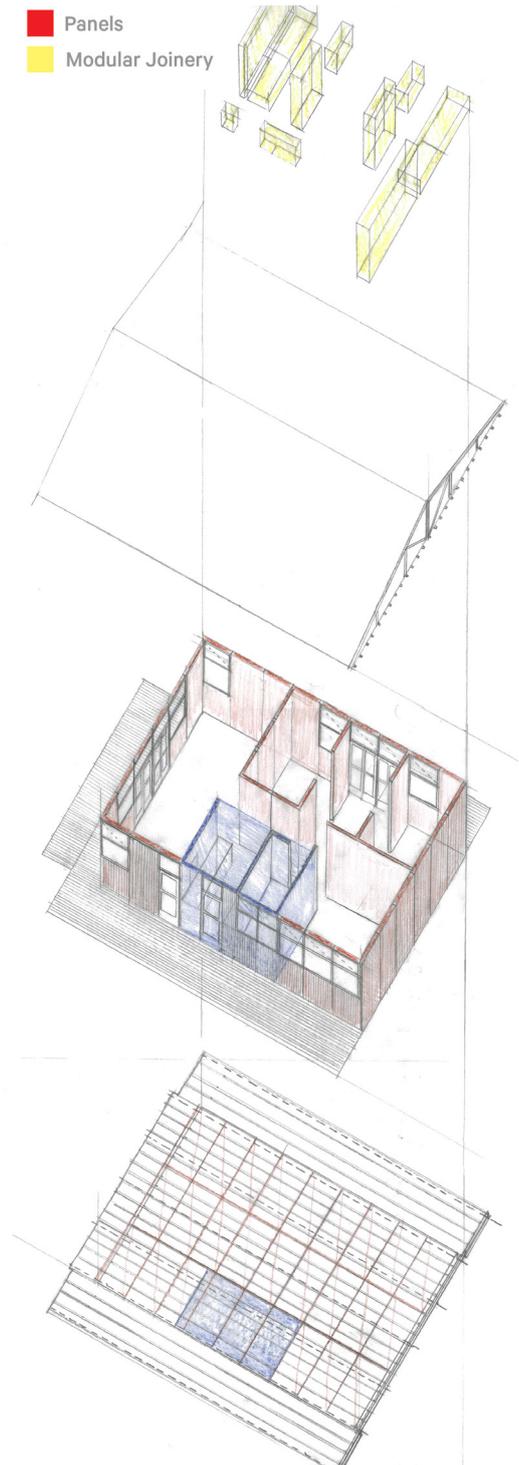
outdoor space A covered deck accessed from bedrooms and living areas wraps the west, north and east sides of the dwelling.

circulation A direct and central circulation path defines public and private zones without disruption. Entry is direct and informal into the dining area, with larger openings to outdoor space from living area.

privacy Public and private space are separated appropriately. Kitchen and bathroom are adjacent, as the kitchen is conceived as an enclosed volume the arrangement is socially comfortable.

customisation The system offered eight different plan variations utilising the same library of panels.

Fig. 4.4.2. All-Pine Prefab exploded axonometric analysis of system methodology & components



⁷⁶ Vale, “Prefabricated Houses.”83.

sustainability and site specific design The dwelling is positioned on-site for appropriate solar orientation. The design incorporates projecting eaves for sun-control, full-length windows for solar gain, and no south openings for internal temperature comfort.

furniture Built-in furniture is incorporated in the Groups well-renowned and celebrated manner. This approach derived from *gesamtkunstwerk*, meaning the total work of art, which was celebrated by modern architects interested in all aspects of design and originated in the Arts and Craft movement.⁷⁷ Bookshelves, sideboards, storage, children’s desks, window seats and built in beds, the furniture transcends the simple design, makes efficient use of space and completes the scheme.

⁷⁷ Julia Gatley, “Who was Who in the Group?” In *Group Architects: Towards a New Zealand Architecture*, ed. Julia Gatley, (Auckland: Auckland University Press, 2010), 15.



Fig. 4.4.3. All-Pine Prefab
at the 1953 Auckland
Birthday Carnival

There is limited material available around the further eight plan variations conceived, and is therefore difficult to assess the systems potential for customisation and site specific design. All wall panels are equal height to allow re-configuration of components for different plan variations, it can be assumed that this why the prototype originally incorporated a flat roof as gable ends complicate panel design and re-configuration. The flat roof form required by the limitations of the prefabricated system goes against the Groups philosophy to respond to New Zealand climate and vernacular architecture.

The orientation of outdoor spaces, on all three sides, suggests a response sustained by generous section sizes of the time, with no demand or requirement to respond to the conditions of higher density. The integration of built-in furniture and study space is successful and makes efficient use of space for family use in an affordable solution.

4.5 Studio 19 Community Housing

Studio 19 Community Housing is a development of a four-bedroom dwelling and two-bedroom minor dwelling for Waitakere based social housing provider, VisionWest Community Trust. The collaboration, which Dave Strachan, of Strachan Group Architects (SGA) runs annually with sixteen third year architecture students, is an effort to provide architecture at low cost utilising innovative prefabricated construction methods.

The two homes were essentially constructed utilising predominantly prefabricated panelised components, prefinished off-site and then delivered to site in three volumes (complete building and modular typologies). On-site work was limited to site works and the entry link between sleeping and living modules of the four-bedroom dwelling.

The two-bedroom minor dwelling is of specific relevance to the enquiry because of the parallel District Plan constraints and programme. Although the system is not essentially hybrid, the investigation of panel technology is also appropriate.



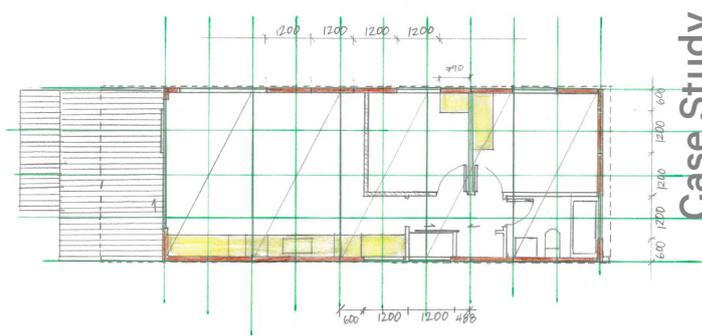


Fig. 4.4.1. Studio 19 Community Housing plan and module analysis

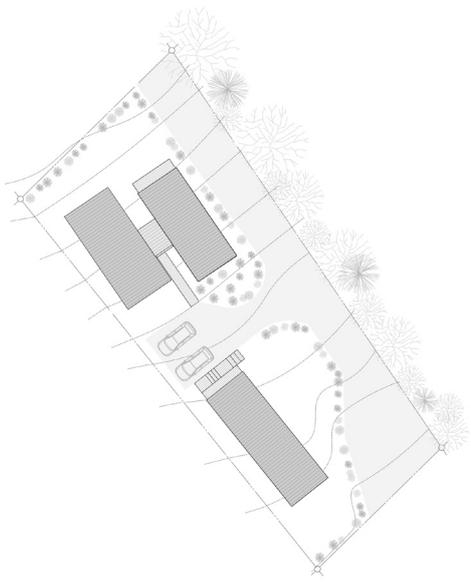


Fig. 4.5.2. Studio 19 Community Housing site plan



Fig. 4.5.3. Studio 19 Community Housing exterior

CASE STUDY 05 Studio 19 Community Housing specifically the two-bedroom minor dwelling
ARCHITECT SGA in collaboration with sixteen third year Unitec School of Architecture Students and VisionWest Community Trust
YEAR 2012
LOCATION Henderson, Auckland
SYSTEM Panelised, modular, complete transportable

size 4.8m X 12m = 57.6m²
 footprint 57.6 m²
 levels 1
 no. of bedrooms 2
 no. of people 1 - 3
 m²/person 57.6m² – 19.2m²
 cost \$85,000 NZD (\$1480/ m²)
 module 1.2m (600mm occasionally), roof has an independent module of 1.0m

service module No service module
panels Three types of panel/cartridge technology contribute to the primary building envelope. The 2.4m wide modular floor cartridge system from *Flexus* presents a transportable thermal mass solution delivered directly to site in six modules from an individual supplier. The system integrates *Posi-STRUT* (290mm-340mm deep) trusses in place of traditional joists to provide large clear spans, with a 30mm topping slab of *Flexus*; a fibre-reinforced engineered cementitious composite (ECC) with the structural integrity of reinforced concrete and reduced weight. Following delivery underfloor polystyrene insulation is fitted between the floor trusses, before 7mm plywood to complete transportable floor cartridge system.

Wall construction utilises SIP panels (EPS core sandwiched between 12mm OSB) which are pre-cut to size, with door and window openings removed. The panels are connected with timber framed bottom plate and studs. With sufficient installation experience, the SIP's are erected much faster than traditional timber framing. The system achieves a high performing building envelope with minimised thermal bridging

(achieving R3.0). The layout respects a 1.2m module to the external framing line, with most wall panels and window openings respecting the module grid or 600mm half module. Joinery is delivered by a separate manufacturer and installed on-site. Internal walls and linings are constructed traditionally on-site, as are exterior wall claddings, plywood with textural battening and profiled metal on the south walls only. Both cladding types require building wrap and cavity construction.

Roof panels are metal SIP's, essentially a 150mm Polyphen insulation core bonded between 0.59mm profiled roofing and a prefinished steel ceiling panel sheet. The 1.0m wide panels are pre-cut and delivered directly to site, where they are lifted mechanically and manoeuvred into position manually. The panels interlock and are fixed efficiently, achieving complete roof structure, insulation, cladding, and ceiling lining within a matter of hours. The SIP roof panel delivers excellent thermal performance (achieving R4.45).

form Building form is simple and rectangular with monopitch roof falling to north, incorporating an expressed gutter that pairs as a sunshade. The roof is expressed as a folded element, as it wraps around the south wall, which is clad in the same metal profile cladding. The form is extruded to the north-west to provide sheltered outdoor living and entry.

outdoor space A triple slider opens up the north-west elevation, essentially extending the living to sheltered outdoor space.

circulation The large sliding opening acts as a single entry and exit point to the dwelling. Circulation from entry point is in one direct line, incorporating kitchen circulation, before progressing to an efficient hallway in the private end of the house.

privacy Planning is divided into private and public zones, a door delineates the threshold. Although the bathroom is separated from the public kitchen and living area, the sight line from the entry position to the bathroom is direct.

sustainability and site specific design The dwellings are positioned with a north-east bias, designed appropriately for solar gain with limited south openings and appropriate eave design. The use of SIP technology creates a high performing thermal envelope, the continuous insulation core enables reduced thermal breaks, with R-values twice that required by code. Full height openings enable solar access to thermal mass incorporated in the floor cartridges to reduce running costs for users.

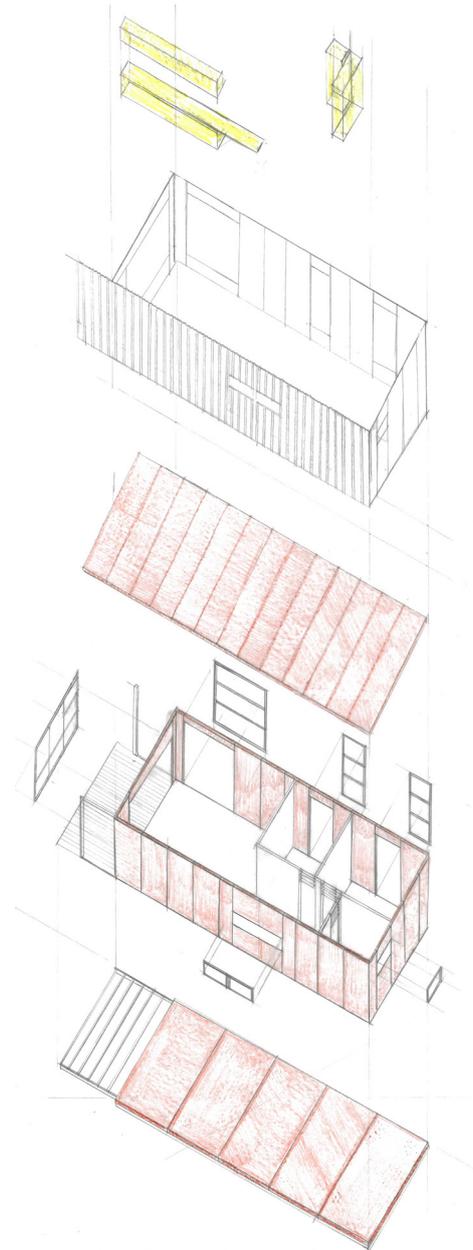


 Fig. 4.5.4. Studio 19
 Community Housing exploded
 axonometric analysis of
 system methodology &
 components

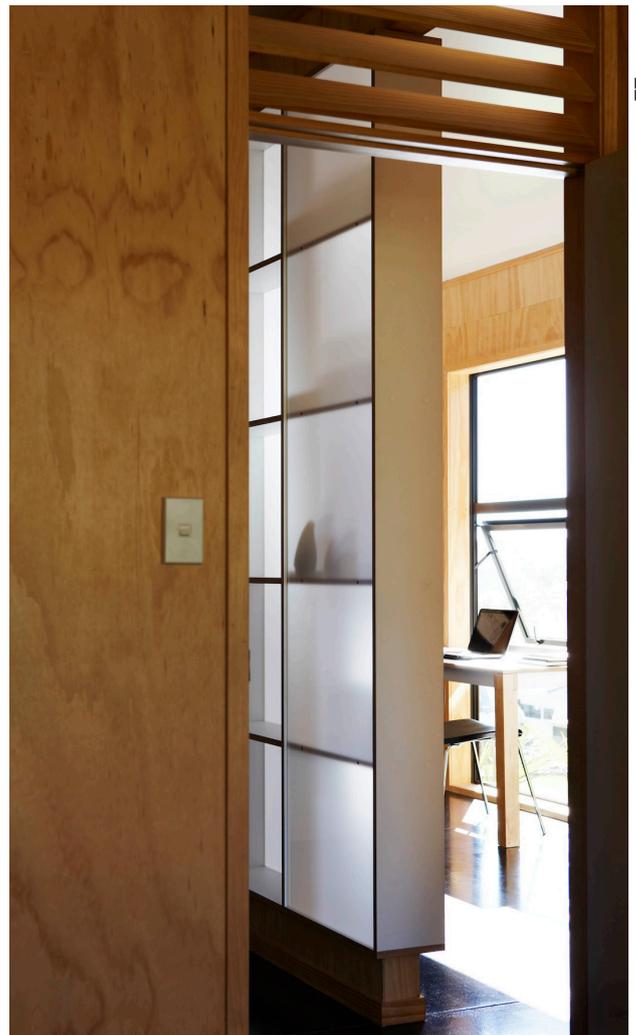
site/off-site balance The Studio 19 programme required the dwellings to be built off-site and transported as prefinished volumetric modules. The primary building envelope is panelised and supplied by three separate commercial suppliers, achieving efficient assembly. However from this point the build is ultimately traditional, albeit various features such as modular use of standard sheet sizes, prefinished modular kitchen and storage units.

delivery Floor cartridges and both variety of SIP's are delivered flat-packed and assembled on temporary foundations. Joinery is delivered and installed from a separate supplier. External and internal finishing is completed off-site before the dwelling is transported as a complete volumes to site in Henderson.

customisation Building form and design is restricted by dimensional limitations when transporting prefinished modules volumetrically.

built in furniture CNC cut kitchen cabinetry and storage units are finished off-site and delivered in modules. Both dwellings incorporate a built in desk area to encourage education in the home.

Fig. 4.5.5. Studio 19 Community Housing Interior built-in study, bench seat and cabinetry



The *Studio 19 Community Housing* minor dwelling follows a 1.2m module for efficient material use and construction. The modular *Flexus* floor system achieves a durable and robust flooring solution with thermal mass properties in a transportable prefabricated component. The system however, is no longer available and problems in the assembly process occurred due to issues with product precision and structural sagging.

The incorporation of full height glazing into the 1.2m module is successful in providing solar access to the thermal mass floor and creating light-filled spaces in the compressed footprint. Circulation is direct, combined with efficient planning and CNC cut built-in furniture and cabinetry to make effective use of space within the 57m² dwelling.

Although the SIP wall panels provide a high performing thermal envelope, they require both external cladding and internal lining to be completed traditionally. The roof panels however provide an efficient solution combining a high performing insulation core, with both external and internal pre-finished skins.

Materials are durable, robust, and low maintenance with low toxicity finishes appropriate to social housing requirements.

The open linked site relationship achieves a sense of shared ownership and community. Rather than turning their backs on each other, or putting up fences, private and public spaces are well placed to provide natural surveillance so that the occupants can see the comings and goings on the property.

Fig. 4.5.6. Studio 19 Community Housing interior of living space



4.6 Summary of Learnings

- Use of 1.2m module set-out for efficient material use and construction
- Utilisation of engineered timber products, LVL, CLT and OSB (see glossary)
- Development of transportable thermal mass
- Integration of window and door elements into wall panels in off-site factory conditions to reduce on-site assembly components
- The integration of external cladding to wall panel rather than separate production, or traditional on-site application, of cladding to reduce external and on-site work significantly
- Integration of prefabricated sun-, rain, privacy- screens (panels) for site specific customisation
- Use of metal SIP roof for externally supplied roofing solution, to provide prefinished exterior and interior skin, high thermal performance and rapid assembly
- Use of a cartridge approach to panels, grouping together numerous elements into a prefabricated component for efficient on-site assembly.
- Panel design with cavity construction to allow for alternative cladding types
- Customisation utilising CNC technology
- Large sliding/bi-folding doors for extension of living to outdoor space
- The exclusion of the kitchen from the service module to, allow greater design flexibility and variation, minimise the shipment of air, and achieve greater separation between bathroom and kitchen functions
- Avoid direct lines of sight from living space to bathroom
- Integration of modular built-in furniture and storage units as an additional buffer between public and private zones and for efficient use of space
- Use of ply for internal lining to achieve a robust, low maintenance, durable and low toxicity finish appropriate for social housing
- Create open-linked site relationships for sense of community.

“There is not one correct application of prefabrication; it is an approach developed for a unique client, brief, site and context, much like custom architecture.”

Alistair Gibbs, Off-site Fabrication.

PART TWO

5.0 Formulation of the Brief

5.1 Programme

The architectural programme is to investigate the hybrid typology of prefabricated housing in response to *The New Two Bedroom Home Project* initiated by Housing New Zealand (HNZC). The scheme plans 500 infill two-bedroom minor household units (MHU) for use as social housing on existing HNZC properties with three-bedroom homes (typically) in suburban Auckland.

The design inquiry responds to the diverse site conditions whilst providing high quality and a high quantity of affordable infill social housing. The speed of construction and minimisation of disturbance to existing tenants are vital considerations.

5.2 Constraints

- Existing dwelling cannot be moved on the site or relocated, as it will cause disruption to tenants
- Council and District Plan requirements surrounding the development a Minor Housing Unit (MHU) - 60-65m² maximum footprint
- Budget is approached as affordable, aligned with existing cost expectations for the provision of affordable housing in New Zealand and HNZC
- For economic and availability reasons, transport is required to be possible at any time of the day on all standard roads without pilot vehicles
- The addresses of sites supplied by HNZC for the research project cannot be exposed to protect the interests of the existing tenants.

5.3 Housing New Zealand RightSize Objectives

- The completed house or house extension should be fit for purpose, sustainable and able to be integrated into the community
- To improve the utility and enhance the existing HNZN owned housing assets. To implement with speed and at scale to meet the housing demands of Housing New Zealand tenants
- A low total Cost of Ownership including implementation, average unit costs and costs per square metre, maintenance periods/durability and replacement
- The creation of value and yield uplift of the portfolio
- Minimisation of disruption to existing tenants, who are expected to remain in occupation during the project works
- The creation of an efficient and effective end-to-end repeatable process that sustains continuous improvement
- The creation of synergies with other programmes within HNZN
- To create housing supply that can be used for tenants that are temporarily displaced by this or other projects.¹

Documents prepared by HNZN to provide standards and guidelines for designers have been reviewed and integrated into the design requirements when appropriate, standards and guidelines that are challenged are outlined. The most recent *Housing New Zealand Corporation Property Quality Standards for New Builds, Low and Medium Density Housing Projects*, forms the basis of inquiry and the guidelines specific to Maori and Pacific are also taken into account.

¹ "RightSize Expression of Interest." *Housing New Zealand*, 2013. 13.

5.4 User requirements

	Single (+55 and under 55)
	Couple (+55 and under 55)
	Single/couple and one infant
	Single/couple and one child
	Single/couple and one youth (over 10)

The design of the two-bedroom dwellings should meet the requirements of these user groups. The provision of adequate and safe play and learning areas with good indoor/outdoor connections are vital for improved social and health outcomes and also to minimise internal damage to the dwellings. Almost 25% of applicants on the current waiting list are over 55.² It is essential that the design addresses the needs of this tenant group such as accessibility.³

Housing New Zealand recommends that two children families, especially with infants, are excluded from the candidate tenant profile for the programme because of the potential spread of diseases in this age group.⁴ Singles or couples with two children (under 10) will be considered, as well as singles or couples with one infant and one child.

The delivery of bedrooms that allow for a double bed or two single bed configuration is essential to provide flexible sleeping arrangements among the different user groups identified.

² "RightSIZE Modular Pilot Programme Housing Requirements Analysis," *Housing New Zealand*, 2013. 5.

³ (Current wait list 2013) vs. (10 year forecast demand Sourced from 2013 CAP plan)

Henderson/Westgate	394	174
New Lynn/Avondale	194	136
Mangere/Otahuhu	145	576
Manurewa	83	271
Otara/Papatoetoe	101	239
Papakura/Franklin	15	79

⁴ NZ Epidemiological studies show that children under five are particularly vulnerable to the spread of infectious diseases (notably, rheumatic fever, meningitis, septicaemia, bronchiolitis, tuberculosis, pandemic influenza). Maori and pacific island families are most highly represented in these statistics.

5.5 Social (Design) Requirements

Typical social design requirements are amplified by the compressed footprint requirement, as are the material and design requirements surrounding damage to units by anti-social behaviour.

- Cater for user requirements at different stages of life or with various temporary or permanent disabilities (accessibility)
- Preserve privacy and achieve cultural sensitivity between public and private, living and sleeping zones by avoiding direct entry and visual connection between the two
- Separation between bathroom (toilet) and food preparation and eating (kitchen/dining)
- Visual and physical connection between living area and outdoor area to relieve indoor pressure and extend living space
- Reduce health issues associated with poor housing outcomes (refer sustainable requirements)
- Warm, dry, well ventilated, healthy homes (refer sustainable requirements)
- Durable, robust, hardwearing materials
- High sense and quality of space in internal and external environments to compensate for compressed footprint
- Bedrooms to allow for both a double bed or two singles bed configurations
- Safe areas of play for children
- Integrated study space away from bedroom
- Smart integration of storage and built-in furniture to maximise the use of space
- Safe with natural surveillance.

5.6 System & Construction Requirements

- Standardised prefabricated service module for volumetric transportation
- Prefabricated panels for floor, walls and roof for flat-pack transportation
- Ability for customisation to a variety of site-specific conditions
- Non-institutional outcome with the ability for individualisation
- Optimal use of materials to avoid waste for sustainable, economic advantage as well as increased productivity and efficiency
- Utilise off-the-shelf products where possible available locally with short lead times
- Low maintenance and durable claddings, linings and finishes
- Take advantage of economy of scale
- Minimise wet trades (particularly on-site)
- Interchangeable/adjustable configurations
- Assembly two-weeks on-site maximum.

5.7 Sustainable Requirements

- Passive solar design and orientation
- Thermal envelope above code standard
- Transportable thermal mass
- No south openings or limited to non-habitable space⁵
- Passive ventilation (especially kitchens and bathrooms and sleeping spaces)
- Maximise exposure to the sun, ensuring maximum solar gain and natural warmth in winter
- Minimise prevailing wind
- Orientation of the building to allow for optimal north facing glazing
- Maximise outdoor living to the north
- Protection of glazing (particularly west facing) to prevent overheating in the summer
- Abundant natural daylight
- Utilise sustainable materials with durable, low maintenance and low-toxicity qualities
- Energy efficient to achieve lower operating costs for users.

5 Habitable space: a space used for activities normally associated with domestic living, but excludes any bathroom, laundry, water-closet, pantry, walk-in wardrobe, corridor, hallway, lobby, clothes-drying room, or other space of a specialised nature occupied neither frequently nor for extended periods. <http://www.legislation.govt.nz/regulation/public/1992/0150/latest/DLM162576.html> Building Act 2004

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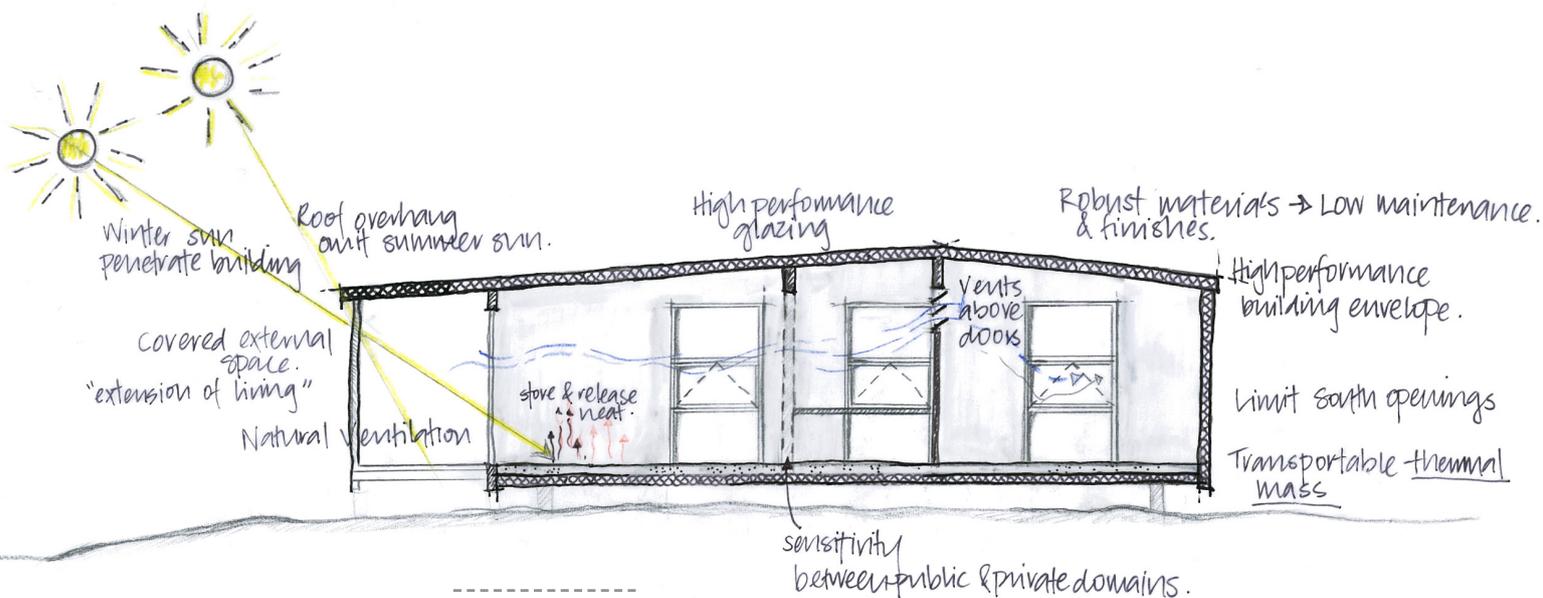


Fig. 5.7.1. Sketch outlining sustainable design requirements

5.8 District Plan Requirements

Council requirements relating to the development of a MHU differ across the current independent District Plans of Auckland. An attempt has been made to review and rationalise one set of requirements across the Auckland region, for both the basis of the inquiry and as we move forward with the Unitary Plan, summarised in Table 1.

Although 65m² is the maximum footprint area in Waitakere, all other District Plans in the Auckland area require 60m². Inquest to Auckland City Council suggests that in moving forward with the Unitary Plan, all areas will require the 60m² maximum footprint; therefore, for this inquiry the 60m² limitation is adopted across all sites to standardise and simplify design and construction.

Additionally open space requirements vary across the three districts reviewed. Manukau accept a 24m² total area with a reduced 4m diameter circle, whilst North Shore City requires 40m² and Waitakere 50m² both with a 6m diameter circle equal to that of the major dwelling requirement. Adopting the Manukau requirements for this project means that all minor units have a reduced private open space requirement to reflect the smaller floor area in relation to the existing major dwelling. Size does not itself make space usable, rather its quality does.

Requirement	GENERAL REQUIREMENTS	VARIATION		
		Waitakere	Manukau	North Shore City
Site Area	Minimum 600m² (net)			
Footprint	60m² maximum	65m ²		
Height	5m - must be of a single level design to reduce visual presence of the unit	8.0 m possible		
Private Space Existing Dwelling	80m² total (can be in two areas) - containing a 6m² diameter circle Minimum dimension 3m Average slope not greater than 1:4	25m ² / bedroom		
Private Open Space MHU	24m² - containing 4m diameter circle Minimum dimension 3m Average slope not greater than 1:4 Open decks, steps, ramps less than 15m ² are permitted within the open space	50m ² - containing a 6m diameter circle		40m ² - containing a 6m diameter circle
Vehicle access	2.5m carriageway, 3m street opening			
Parking	Two on-site existing dwelling One on-site minor dwelling In practical location for the MHU			
Side Yards	1.2m			
Openings	Windows of any habitable rooms located no less than 1.2m from a site boundary or existing major dwelling			

Table 1. Summary of District Plan Requirements for MHU Development



Fig. 6.0.1. Wider Auckland context



Fig. 6.0.2. Proximity of site location from Auckland CBD

6.0 Site Analysis

For the basis of this research Housing New Zealand (HNZC) supplied twenty randomly selected sites identified for *The RightSize New Two-bedroom Homes Programme* across proposed areas for development in Auckland. The location of each site is within a 16km radius of Auckland Central Business District (CBD). All sites provided are typical suburban sections with a single detached three-bedroom dwelling.

Property area ranges from 604m² to 999m² with an average of 692m². Some properties are in close proximity to each other or on the same street, however none of which are adjacent with common boundary.

The identified sites for HNZC development and subsequently the research project were first explored diagrammatically in terms of:

- **Existing building location**
- **Solar Orientation**
- **Secondary buildings requiring removal**
- **Topography**
- **Privacy**
- **Access and existing driveway**
- **Vegetation**
- **Proximity and location of neighbours.**

Key for following site analysis diagrams:

-  Access, existing driveway
-  Secondary building requiring removal
-  Existing building location

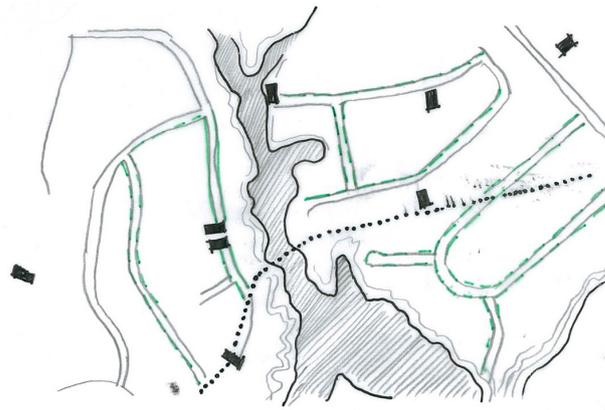


Fig. 6.0.3. Example of proximity of site location to each other

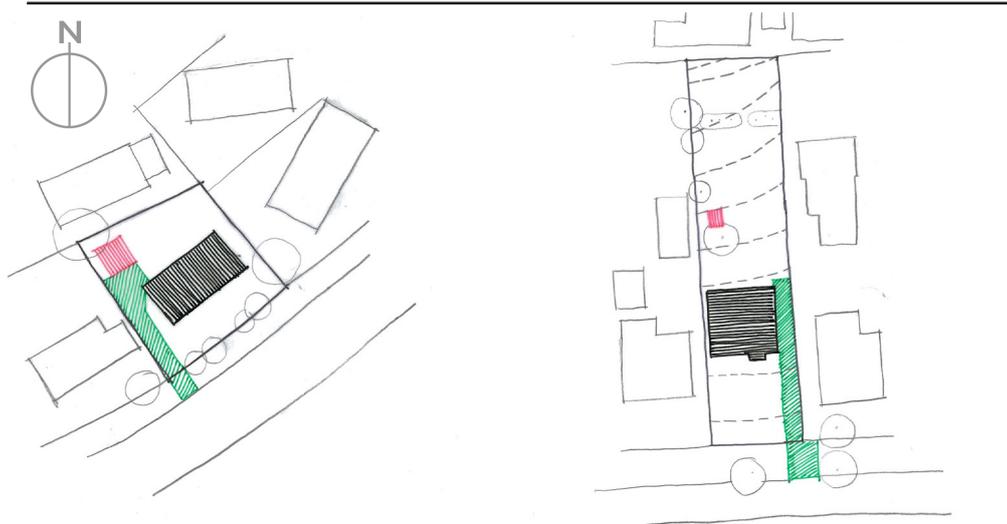


Fig. 6.0.4. Proportional diversity: wide and shallow, long and thin.

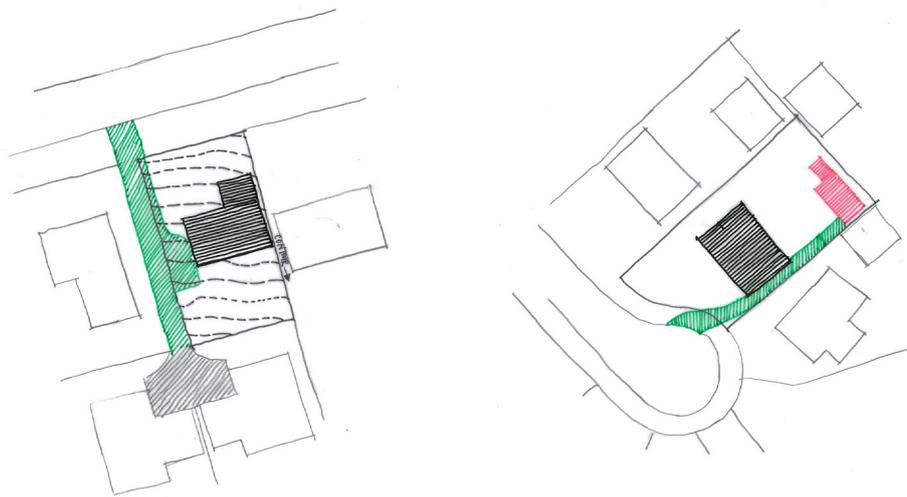


Fig. 6.0.5. Topography diversity: steeply contoured, flat.



Fig. 6.0.6. Existing house angled to site boundaries in comparison to existing house parallel to site boundaries. Driveway access pinched by building footprint, driveway access clear of building footprint.

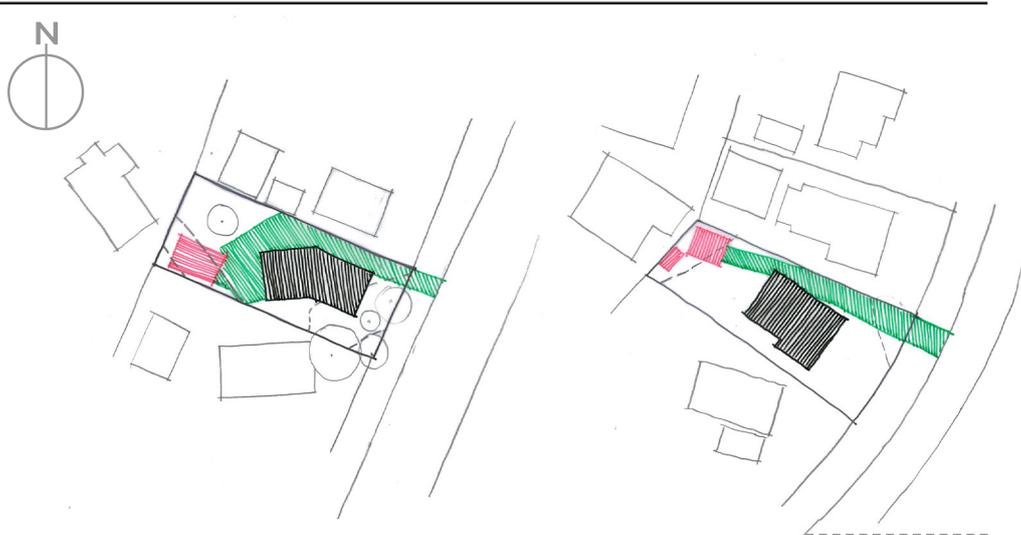


Fig. 6.0.7. Abnormal shaped building, normal shaped site, normal shaped building, abnormal shaped site.

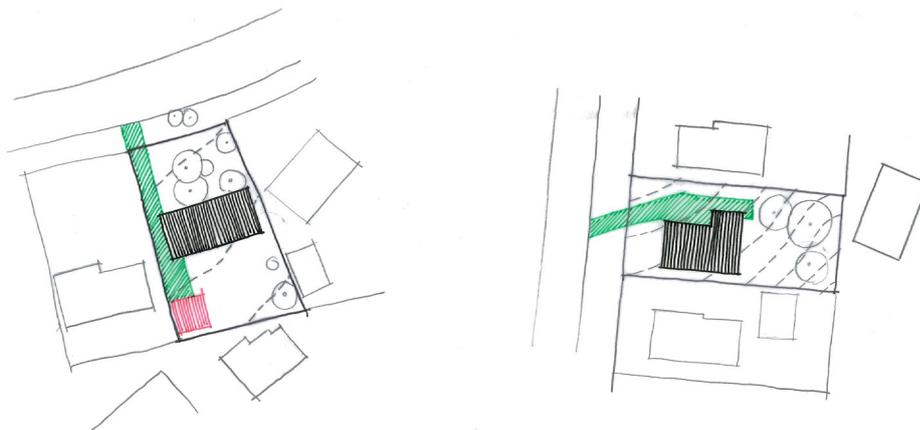


Fig. 6.0.8. Existing secondary building requiring removal, existing trees requiring removal.



Fig. 6.0.9. Diversity such as rear yard size and existing vegetation even though sites are in close proximity and have similar orientation.



 Fig. 6.0.10. Corner site with open access, sandwiched site with existing garaging blocking entry.

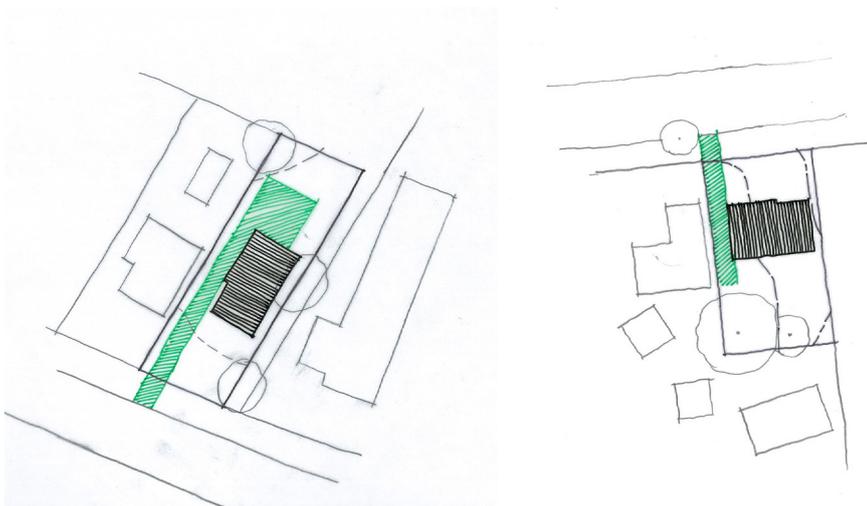


 Fig. 6.0.11. Variation in entry orientation: south, north.

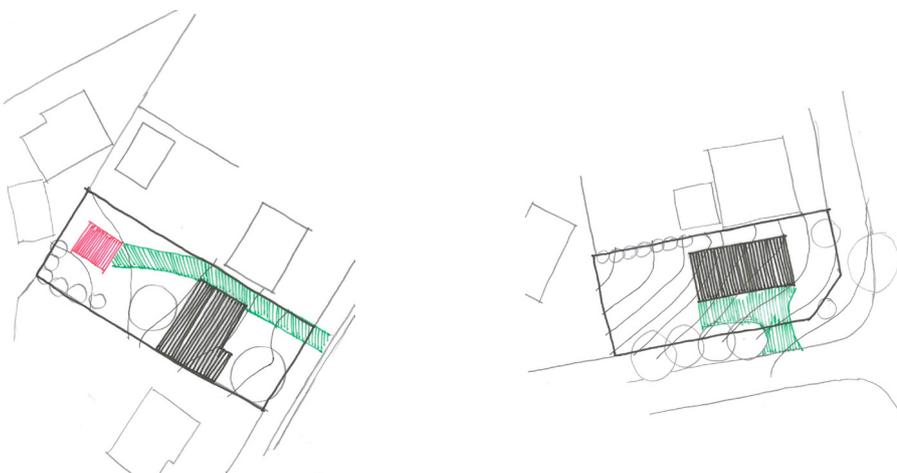


 Fig. 6.0.12. Access diversity: Corner site with open access, compressed access with existing garaging blocking entry.

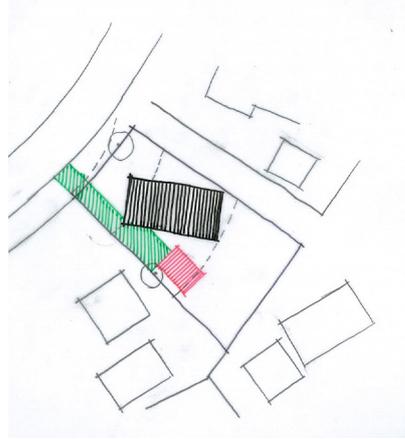
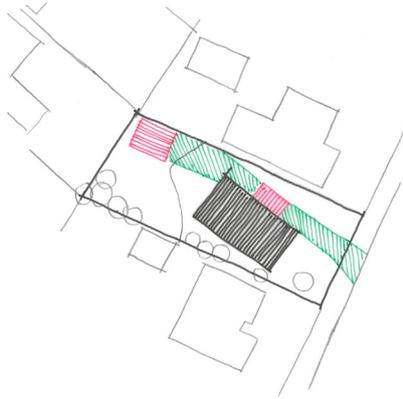


Fig. 6.0.13. Proportional and dimensional diversity of rear yard and relation to construction access.

6.1 Critical Appraisal

Further to the variety in site area, initial site analysis drew attention to the vast diversity amongst the sites, in terms of proportion, solar orientation, contour, size and location of existing house and access. The diverse nature of the existing house was unpredicted, not only in terms of size and proportion but also age, condition, construction and aesthetics such as form and materiality.

The initial statement from HNZN, *“As the existing houses are typically on the front portion of the section, the new houses will be generally built on the rear portion of the land. Access will predominantly be through a residential driveway,”*⁶ is in most cases only partially correct. The position of the existing dwelling is often more central on the site than the statement suggests. However when the provision of access is considered it is the rear yard of the site that is, in all cases, larger and better suited for the location of the new minor dwelling. The centralised location of existing dwellings is problematic for the programme and does not make good use of the state owned land. Access in most cases is down the side of the existing house, with corner sites an exception. In most cases, the side with greatest accessibility or width, is the same side as the existing driveway. Access width varies from 2.8m to over 6m. Topography ranges from completely flat to steeply contoured. Many existing tenants will suffer the loss of secondary buildings. Smaller buildings such as garden sheds will be relocated, but detached single and double garages will be removed or demolished. The loss of storage and extra sheltered space is problematic to the success of the programme.

Initial site analysis has identified the requirement for diversity and customisation in regard to the unique and wide-ranging site conditions. Differences in building form and proportional footprint is evident, given the diversity of sites and compact site area for the new minor dwelling to be assembled. The diverse community and aesthetics of existing buildings also requires aesthetic customisation in terms of cladding and form in response to site specific qualities.

⁶ *“RightSize: Expression of Interest,”* HNZN 2013, 12.

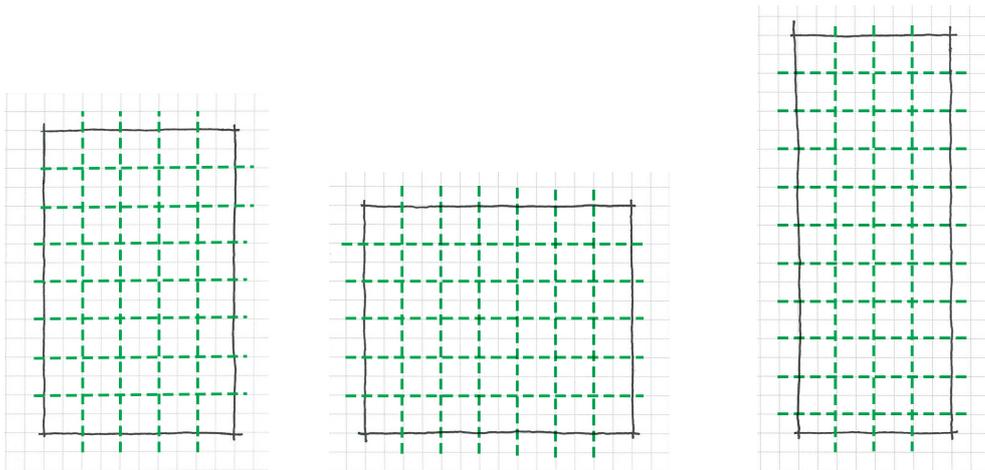


Fig. 7.1.1. 12m module floor area and footprint exercise



Fig. 7.1.2. Site application of footprint form to site

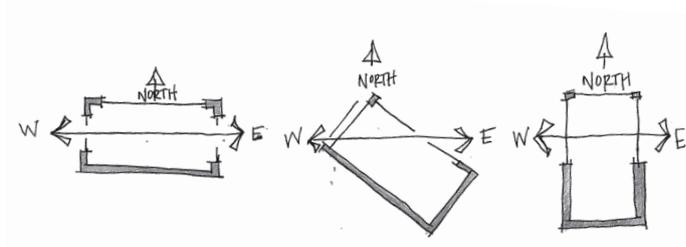


Fig. 7.1.3. North variation explored

7.0 Preliminary Design

With constraints and brief defined, conclusions made from precedent studies and initial site analysis, planning is first approached by using the 1.2m module grid set-out to generate different proportioned forms equal to (or below) the 60m² maximum footprint.

7.1 Floor Area & Footprint

MHU 1	6.0 x 9.6 = 57.6m² 6.0 x 10.8 = 64.8m ² - Possible for Waitakere sites
MHU 2	7.2 x 7.2 = 51.84 m ² – Area produced too small for two-bedroom dwelling 7.2 x 7.8 = 56.16m ² – Half module is required to produce an area closer to the 60m ² limitation 7.2 x 8.4 = 60.48m² - Can this be rounded down to 60m ² ?
MHU 3	4.8 x 12 = 57.6m ² 4.8 x 12.6 = 60.48m² Half module is required, can this be rounded down to 60m ² ?

From this exercise the dilemma of the module is amplified due to the size restriction of MHU District Plan requirements. Space is precious and therefore cannot be forsaken entirely for the purpose of the 1.2m module. For this reason a 600mm half module is accepted, with the belief that standard materials can be cut once and used elsewhere within the same dwelling or programme.

The question is raised, is the area able to be rounded down to the nearest square metre? In terms of prefabrication and efficiency it does not make sense to cut sheets down (increasing labour and construction waste) for the sake of less than half a square metre. At present, Auckland City Council does not have a straightforward answer to this question and the decision is to the discretion of the individual processing the Resource or Building Consent.

The exercise produced three forms of which appeared to work on all twenty sites (fig. 7.1.1 & fig. 7.1.2.).

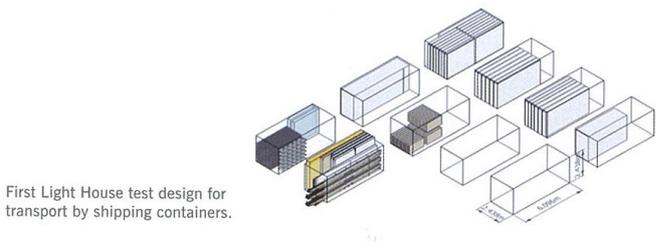
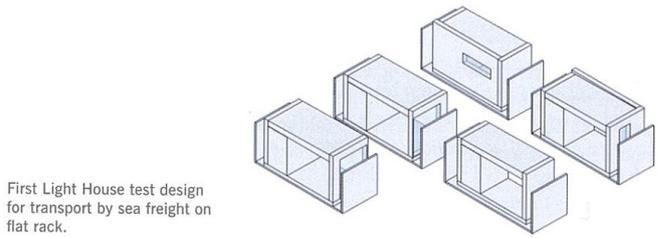
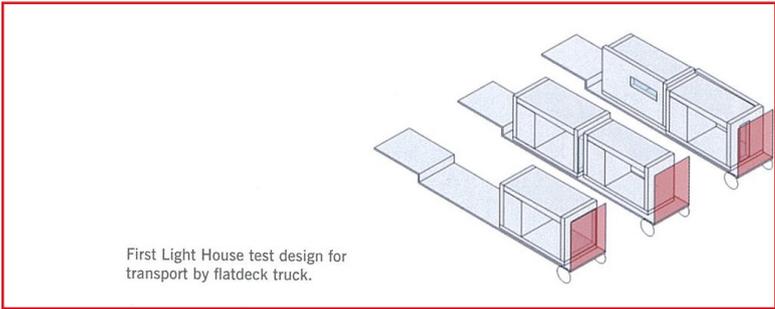


Fig. 7.2.1. Transportation types explored in the *First Light House* - in this application the flatdeck truck approach is viable

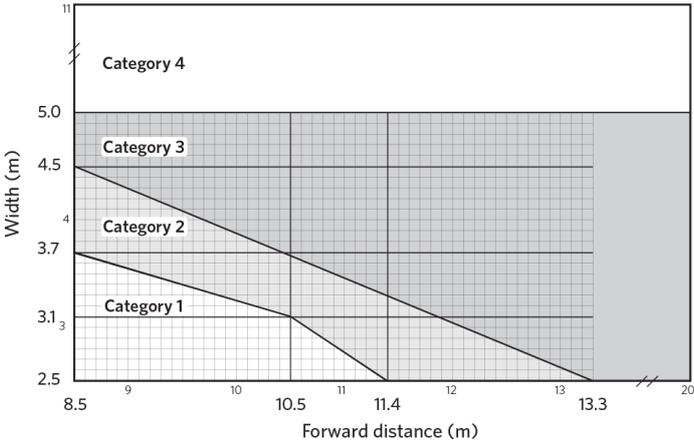


Fig. 7.2.2. Determining (transport) Category, based on width and forward distance

7.2 Transportation Requirements

Site analysis confirmed that sites for minor dwelling development are accessed via a residential driveway to the rear of the site in all cases. Access for the majority of sites surveyed is very narrow and restricted, limiting the feasible size for machinery, trucks and lifting equipment required for delivery and assembly.

The large scale and access restrictions of the programme require a transport, delivery and assembly solution with the ability to operate at all times of the day, with plentiful availability. The developed transport solution should not require pilot vehicles for economic feasibility (less resources and cost) and minimal disruption to other road users, neighbours and existing tenants. Because the programme will be built and transported locally, international transport considerations are not required.

Given these considerations transport and assembly has been approached to utilise standard Hiab (truck mounted crane) and manual lifting. Consideration of panel and service module dimension, rigidity, manageability and weight are explored in terms of local transport requirements and restrictions.

The graph (fig. 7.2.2.) is based on the categories defined by *NZ Transport Agency for Overdimension Vehicles and Loads*.¹ To warrant daytime transport and delivery and ensure that pilot vehicles are not required, the dimensions of components must comply with the restrictions of Category 1 Loads.

CATEGORY 1 LOADS

- Maximum width 3.7m
- Maximum forward length 11.4m.

Width and forward distance are only two of the requirements of Category 1 loads, the following limitations and requirements also apply. A Category 1 vehicle or load also requires,

- Front overhang up to maximum 7.0m
- Rear overhang up to maximum 7.0m.

¹ "Overdimension Vehicles and Loads, Factsheet 53 June 2013," NZ Transport Agency, accessed July 13, 2013, <http://www.nzta.govt.nz/resources/factsheets/53/docs/53-overdimension.pdf>.



Fig. 7.2.3. Overall maximum height for standard Hiab transport.

- “Oversize” sign required if width is greater than 3.1m
- No pilot required for wide loads that are less than 3.1m.²

Note: Pilot is required for loads that are over 3.1m and travel in excess of 40km/h

The requirement for use of standard Hiab truck is grounded on availability in the Auckland area and economic feasibility.

- Standard truck deck length 9.0m
- Standard truck deck width 2.4m
- Standard truck deck 1.0m high from ground level.³

Panels are flat-packed either laid flat on the truck deck and stacked, or stood on edge using an A-frame or “toast-rack.” The foot of the A-frame structure adds an additional 200mm to deck height.⁴

To comply with *NZ Transport Agency* requirements (and allow motorway travel) the overall max height of load is 4.5m for standard bridge clearance. This means that anything with a combined height over 4.25m will need to travel an over-dimensional route (main routes) “*potentially adding extra costs.*”⁵

Therefore panels must have a maximum dimension of **3.25m** in one direction and **8.5m** in the other direction.

The reach of the crane varies between 9m - 28m depending on the size and position of the mounted crane on the truck, with front mounted Hiab achieving the highest lift capability between 1,500kg and 14,000kg at minimum reach; and between 750 to 1,300kg at full reach.⁶ The weight restrictions will influence the size and consequent weight of panels and service pod. The access to site and plan orientation will also be influenced, specifically the position of service module in relation to access way.

2 If night travel is required, the following requirements apply.

- Must have a revolving amber lamp on truck roof
- Must use reflective panels at load extremities
- No pilot required if load is less than 3.1m
- Pilot is required if load width excess 3.1m and the “oversize” load is travelling in excess of 40km/h
- Consideration must also be given to compliance of lighting rules delineating the load, see clause 6.7m mass and dimension rule.

“*Overdimension Vehicles and Loads, Factsheet 53 June 2013.*”

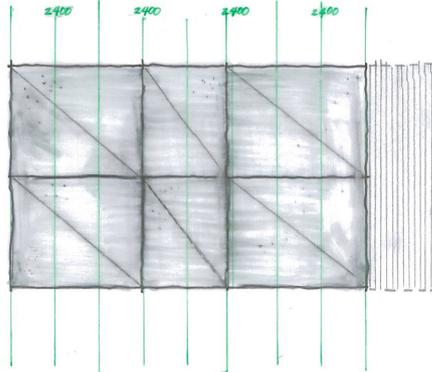
3 Jim Speck (Hiab Transport Ltd), email message to the author, March 27, 2013.

4 Ibid.

5 Ibid.

6 “Hiab Trucks,” *Hiab Transport Ltd*, accessed March 24, 2013. <http://www.hiabtransport.co.nz/hiab-trucks>.

Floor cartridge set-out
1.2m module



Planning, wall panel and opening
placement in relation to module set-out
1.2m module



SIP roof panel set-out
1.0m module

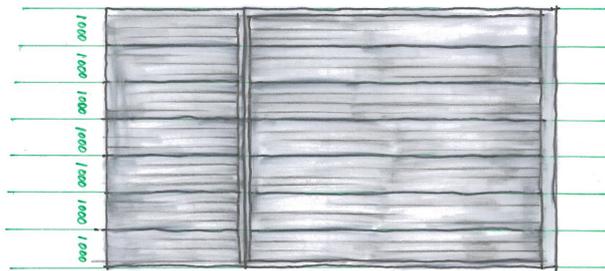


Fig. 7.3.1. Concept plans MHU 1
1:200

7.3 Planning

Planning is explored to contain defined levels of privacy within a compact footprint. Space is arranged into private space (bathrooms and bedrooms), intermediate space (circulation/separation) and public space (living, kitchen, dining and outdoor living space). All doors are 810mm wide and hallways 1025mm for wheelchair access.

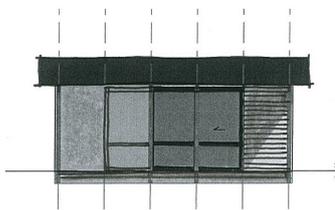
The 1.2 module is manipulated between the 600mm half module to tolerate interior walls and glazing/openings within the module grid. Generally debate surrounds the module driver, whether to let the internal or external dimension determine the set-out.¹ Considering the requirement for transportable floor cartridges, the wall to floor junction detail (see page 119, fig. 8.5.9.) and internal materiality, the internal dimension dominates and is used to set-out the module grid.

General floor area is typically calculated to the exterior of the floor plate, which in traditional timber framed buildings is to the external framing line, excluding cladding.² This is as per industry standard. As the internal dimension is now driving the module set-out the calculations for footprint are recalculated to encapsulate dimension to the external framing line (add 90mm timber framing).

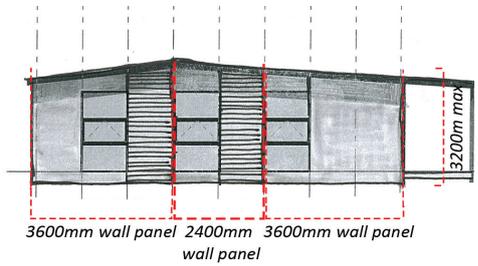
MHU 1	6.18 x 9.78 = 60.44m² 6.0 x 10.8 = 64.8m ² - Possible for Waitakere sites
MHU 2	7.38 x 7.38 = 54.46 m ² – Area produced too small for two-bedroom dwelling 7.38 x 7.98 = 58.89m² – Half module is required to produce an area closer to the 60m ² limitation 7.38 x 8.58 = 63.32m ² - Possible for Waitakere sites
MHU 3	4.98 x 12.18 = 60.65m² 4.98 x 12.78 = 63.64m ² - Possible for Waitakere sites

¹ Earl Rutherford, (Director, MOTM Architects Ltd), interview by author, May 20, 2013.

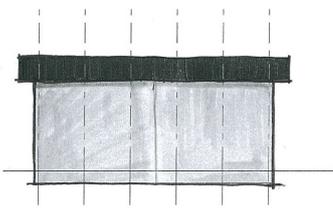
² Dave Strachan (Director, SGA Ltd), letter, November 26, 2013.



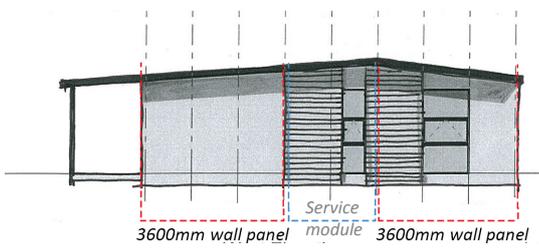
North Elevation 1:200



East Elevation 1:200

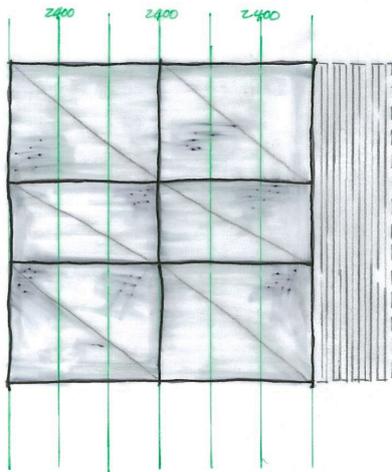


South Elevation 1:200



West Elevation 1:200

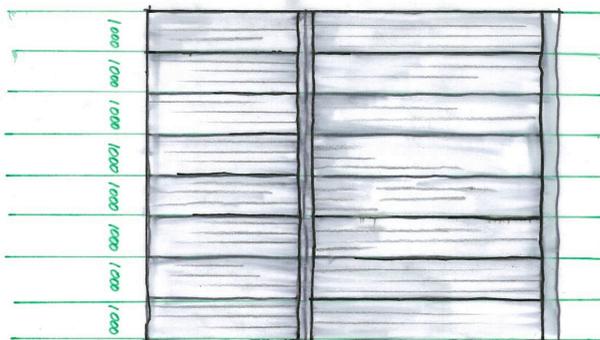
Fig. 7.3.2. Concept elevational diagrams of MHU1 panel dimensions.



Floor cartridge set-out
1.2m module



Planning, wall panel and opening
placement in relation to module set-out
1.2m module



SIP roof panel set-out
1.0m module

Fig. 7.3.3. Concept plans MHU 2
1:200

Floor cartridges follow the 1.2m module, the set-out is driven by the location and dimension of the service module. This process further divides the bedroom and living floor cartridges to simplify construction.

Internal planning is driven by the 1.2 module (and occasionally 600mm module). The placement and dimension of all window and door elements corresponds to the module also. An effort has been made to standardise openings to two window types only and one door. The large sliding opening acts as the front door whilst providing the ability to further open to extend the living space outdoors.

Paths of circulation have been kept direct and minimal. An effort has been made to direct movement through living spaces to create uninterrupted 'held' space within the open-plan arrangement. Bedrooms and bathrooms are entered from circulation space rather than directly from living spaces to preserve privacy and form separation between private and public zones of the dwelling.

Roof eaves are integrated to compensate for the variance between dominant 1.2 module and 1.0m SIP roof panel and provide adequate sun shading. The roof form is driven by the 5.0m clear-spanning capability of the roof SIP which roof extends over front deck to form a sheltered outdoor living space and entrance.

7.4 Critical Appraisal

The planning exercise explores the fundamental elements of the hybrid system for the application of this research project. The exercise revealed that modular set-out sometimes works inefficiently in regards to planning and subsequently floor area dimension. Often spaces formed are larger than what is required in order to respect the module, for example it is much easier to make a bathroom too big than too small. The constraints of this enquiry in relation to maximum floor area do not allow for this possibility, which is problematic to the success of the project.

A single standardised service module was attempted across all three floor plan types. The design exercise concluded that the objective is unfeasible given the limitations imposed, again, by the module set-out and maximum floor area. Ideally there would only be one variation of the service module. However, parallel construction and a limitation of service module alternatives throughout the programme of 500 infill dwellings is acceptable given the economies of scale and constraints defined.

To increase the added value of the service module it should ideally include not just the bathroom, but the laundry and hot water cylinder also, which all three MHU alternatives are not currently achieving. The third plan type, MHU 3, was the most problematic form to incorporate service module and subsequently a rationalised approach to the regularity of floor cartridge set-out.

Evaluation of the window elements exposed that a kitchen window should be integrated for natural surveillance purposes and increased natural light. The bathroom window could be substituted for a high horizontal window, standardised for use in the kitchen to avoid increasing the amount of window types. The deck space shown is too narrow, and the fixed pane of the sliding door element must be placed suitably to allow for comfortable habitation of the covered outdoor space.

8.0 Delivery & Development of Components

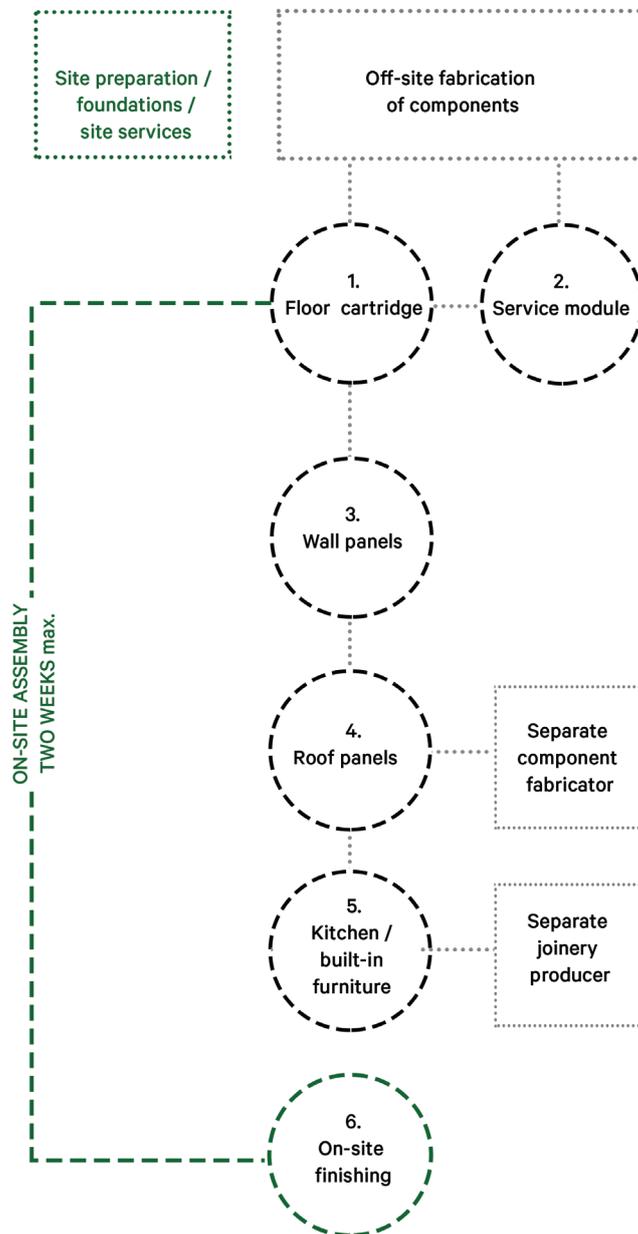


Fig. 8.1.1. Diagram outlining assembly programme.

8.1 Assembly

Timeframe Requirements

- Can be closed in within two days
- Two weeks on-site construction time.

Individual sites are to be reviewed in terms of site access and topography at developed design stage. The various elements of the dwelling can then be customised to individual site requirements, in terms of assembly as well as site-specific design. The construction and assembly programme is then orchestrated to ensure components are only delivered to the site when needed, streamlining assembly using just-in-time delivery methods.¹ (refer fig. 8.1.2.).

*Stanley Modular believe that, "It is in the methodology of delivery that the largest cost savings are achievable."*²

8.2 Timber Construction

Timber has a long history in prefabrication, beginning with the Norwegians and Swedes, technical innovation has recently propelled it from being perceived as a traditional building material to cutting-edge construction and utilised in innovative prefabricated systems. For the approach of this research timber construction has been explored for a number of relevant reasons. Timber construction typifies building in New Zealand. Tried and trusted, traditional timber framed construction is widely understood and recognised in the existing housing industry. Inherently sustainable, wood is renewable and grown locally in New Zealand and performs as a carbon sink.

Engineered wood or LVL (laminated veneer lumber) is better suited than sawn timber for structural analysis, precision manufacture off-site, and easy erection. Made in factory-controlled conditions LVL's are comparably stronger, straighter and more uniform and because of their composite nature, are less likely to warp, shrink or twist. LVLs also enable large spans and centres with less material, compared to traditional construction, meaning more design flexibility and reduced weight for transport and assembly. The multiple layering process creates higher efficiency in material use.

Cross-laminated timber developed initially in Europe as an engineered wood product, ideal for systemised prefabricated construction. The large panel sizes, range of thicknesses and two way spanning capacity brought to the market a methodology to factory-build entire floor, wall and roof components, easily flat-packed to site for rapid assembly.

¹ Angela Eglinton, "Hybrid best of both worlds," Build (138) Magazine, October/November, 2013, 88-89.

² Gary Caulfield, (former Business Management Developer, Stanley Group), interview with the author May 21, 2013.

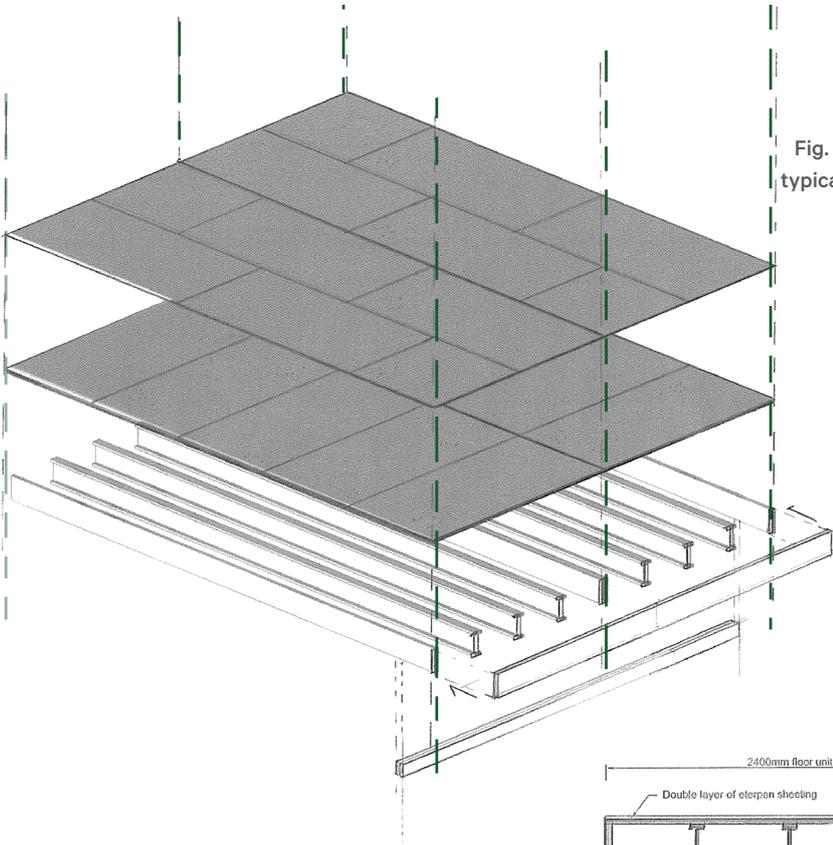


Fig. 8.3.1. Exploded axonometric of typical thermal mass floor cartridge

15mm pre-sanded fibre cement sheet, glued and pre-finished

20mm fibre cement sheet, screw fixed

36mm LVL boundary joist

Double bearer 2 x 140x45mm

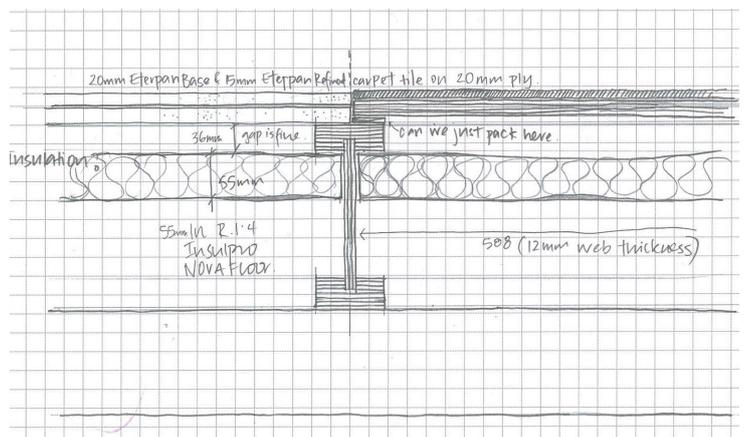
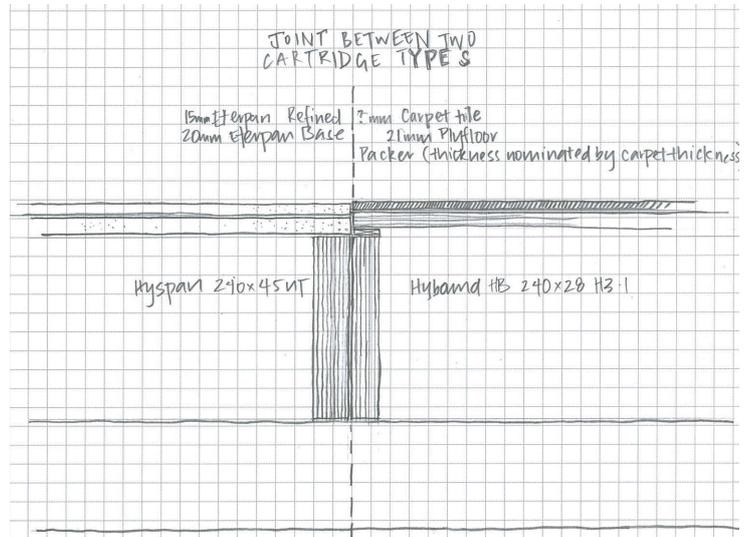
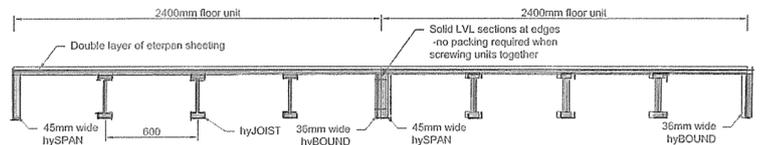


Fig. 8.3.2. Detail sketches showing joint between thermal mass floor cartridge and ply with carpet cartridge in bedrooms.

8.3 Floor Cartridge

Requirements

- Thermal mass
- 2.4m module.

Prefabricated housing solutions typically have little thermal capacity due to transport limitations such as weight and strength. Greater thermal mass has been identified as a requirement for more sustainable, higher performing homes in New Zealand.¹ The *Studio 19 Community Housing* precedent incorporates *Flexus Modular Flooring* cartridges as a solution to transportable thermal mass, while the precedent study outlined structural, precision and finishing issues - the notion of providing a transportable flooring solution which incorporates a light weight topping slab for thermal mass is strong.

The exclusion of wet trades in the factory process and on-site is desirable.² The exploration begins with research of alternative materials with embedded thermal mass quality. Ordinary concrete has a density of 2400kg/m³, whilst lightweight composite concrete is usually around 1750-2100kg/m³.³ Medium - high density fibre-cement has recognised thermal mass properties and is available in standard sheet sizes, in various thicknesses and finishes. Fibre-cement (depending on supplier) comparatively has a lower density than standard concrete, approximately 1350kg/m³,⁴ but includes the benefits of reduced weight for transport and minimises the need for wet-trades on-site.

Floor structure is explored to incorporate engineered timber products from *Carter Holt Harvey*, manufactured and sustainably grown in New Zealand. The *hyJOIST* consists of structural LVL flanges and a structural plywood web and offers many benefits for prefabrication of floor cartridges in comparison to conventional timber joists. The *hyJOIST* is lightweight with high structural strength and spanning capability, dimensional precision and provides easier installation of services within the floor space.⁵ The perimeter of floor cartridges, or boundary joists use a combination of *hySPAN* and *hyBOUND* solid LVL for fixing requirements and higher strength for wall to floor detail. The system achieves 600mm joist centres to correspond with the 1.2m module, (refer fig. 8.3.1.).

The floor cartridges subsequently relate to internal layout; kitchen, dining, living, circulation spaces and service modules consist of a 20mm *PBS Eterpan Base* sheet, which is fixed to the floor structure (running across the joist direction), and a secondary 'finishing' 15mm sheet of *PBS Eterpan Refined* which is glued to the base sheet in the opposite direction (covering base sheet joints) with no requirement for additional (exposed) fixings. *Eterpan Refined* is pre-sanded and ideal for expressed joint applications and exposed finish. The cartridges are then prefinished

1 Sarah Bierre, Phillipa Howden Chapman and Lisa Early, *Homes People Can Afford: How to Improve Housing in New Zealand*, (Wellington: Steele Roberts Aotearoa, 2013), 129.

2 Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 33.

3 "Frequently Asked Questions," *Flexus Bendable Concrete*, accessed 18 February 2014, <http://www.flexus.co.nz/flexus-frequently-asked-questions/>.

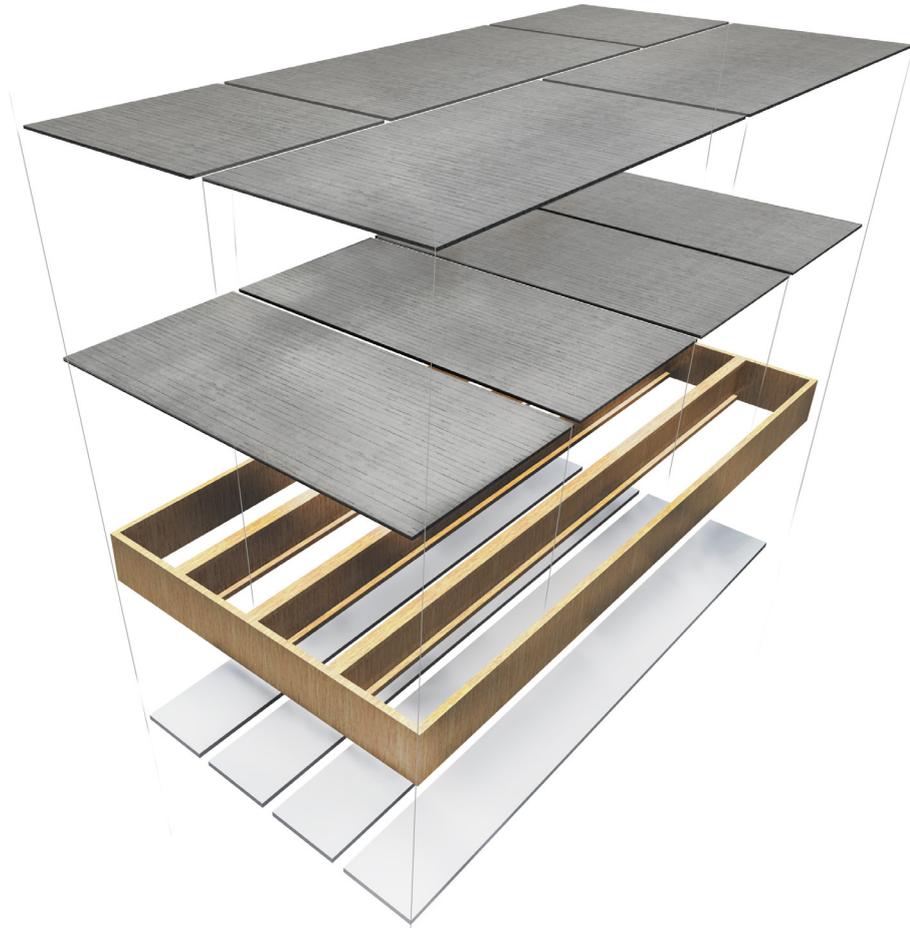
4 Nick Blase (Technical Manager, PBS Distributors), email message to the author, March 7, 2013.

5 The 12mm web thickness allows services to be integrated into floor cartridges simply without compromising the structural integrity of the member.

with polyurethane (two-coats off-site, and one coat on site), achieving a finished floor surface that is durable, water resistant and does not require extra floor coverings in bathrooms and kitchens. HNZN requires carpet in bedrooms, so for economy the floor cartridges corresponding to bedrooms utilise standard 20mm plywood sheets finished with carpet tiles that are of industrial quality and durability and can be replaced individually as required (refer fig. 8.3.2.).

This innovative alternative offers the possibility to reduce tenants energy consumption and achieve a comfortable internal environment. The thermal mass is left exposed and finished to store and release solar heat into the dwelling. The full height windows in this case are essential for solar penetration to the thermal mass.

Fig. 8.3.3. Exploded axonometric of floor panel configuration



8.4 Service Module

Precedent analysis concluded that greater design variation is achieved when the kitchen is excluded from the service module. The added value of incorporating the kitchen was outweighed by the inflexibility in design and planning restriction. The service module in this design exercise is approached as a volumetric unit containing an accessible bathroom, laundry, hot water cylinder, electrical switchboard and storage. The construction process begins with floor cartridge with prefinished fibre cement flooring, timber wall frames are then prefabricated and lifted into position and fixed, a drop-in ceiling braces the structure. A single horizontal window is installed, exterior walls are pre-clad and all fixtures and fittings and installed in factory controlled conditions. Specialist trades work efficiently on numerous modules in parallel, completing the majority of waterproofing, painting, plumbing and electrical services off-site.

Internal finishes are completed off-site right down to the installation of internal doors and toilet roll holder. The outer-faces of internal walls are lined on-site so that services can be fed from the module. The service module is shrink wrapped and delivered to site in unison with floor cartridges from which the wall panels are lifted and fixed.

The design incorporates an accessible wet area shower for the future proofing of user requirements. Bathrooms are seen as high-risk areas in HNZN properties.¹ A stainless steel shower tray, fibre cement flooring and plywood internal lining are durable and robust finishes in response to the perceived risk of damage.

¹ Karin Cunningham (National Commercial Manager, *Plumbing World*), interview with author July 4, 2013.

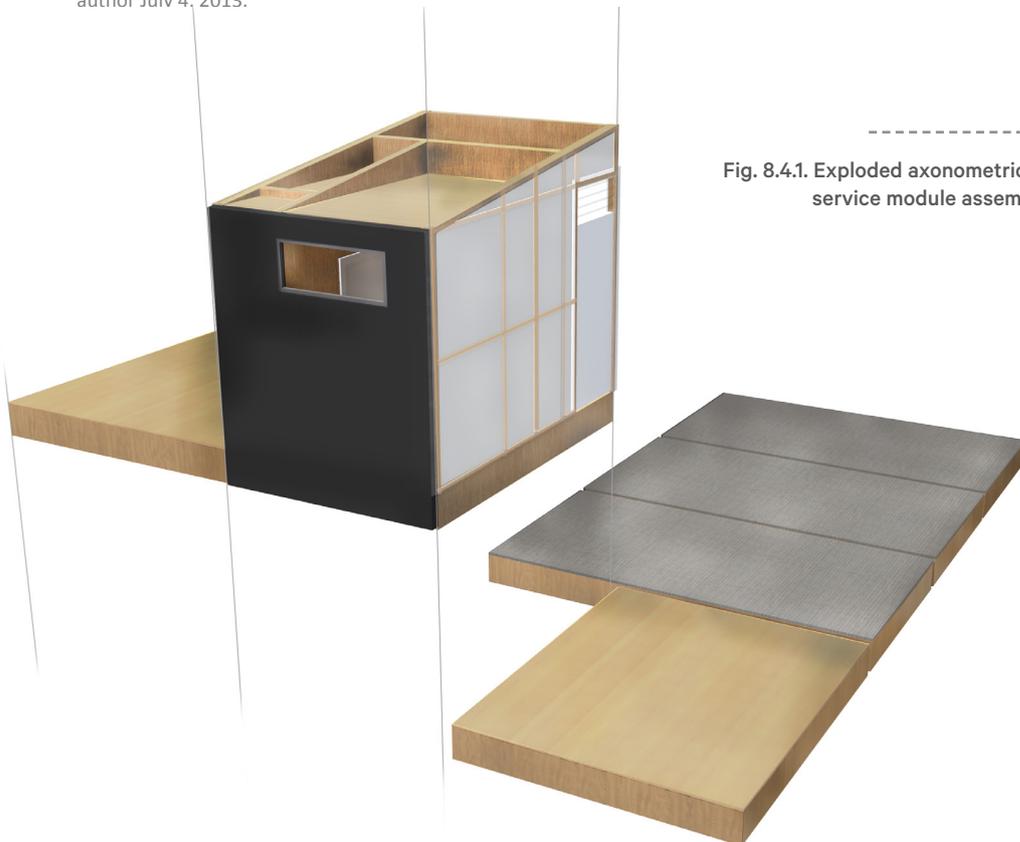


Fig. 8.4.1. Exploded axonometric of service module assembly

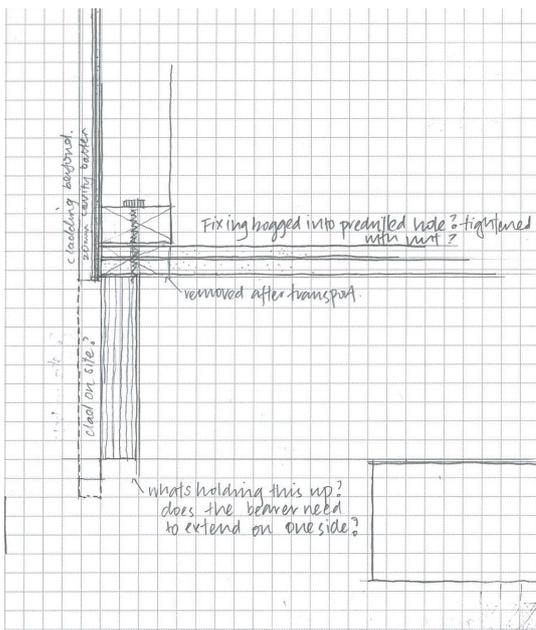


Fig. 8.5.1. Initial detail sketch of wall panel to floor cartridge connection: cladding below floor level to be done on-site.

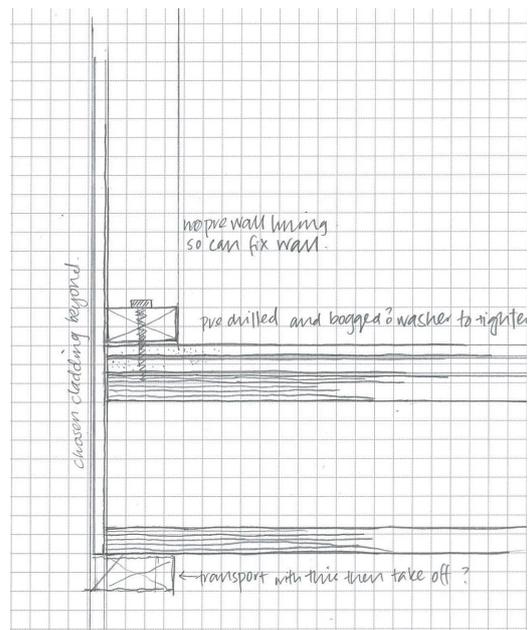


Fig. 8.5.2. Initial detail sketch of wall panel to floor cartridge connection: cladding integrated below floor level.

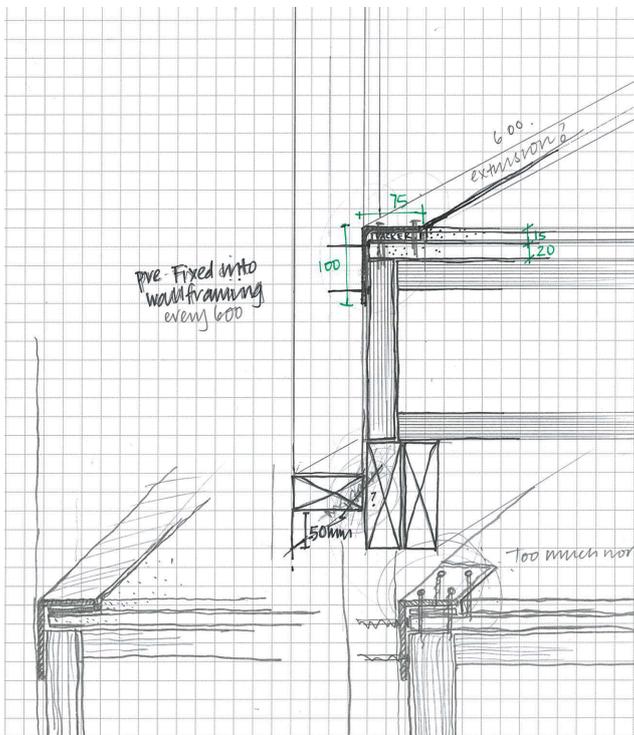


Fig. 8.5.3. Initial detail sketches of wall panel to floor cartridge connection: wall panel hanging off floor cartridge with steel angle extrusion.

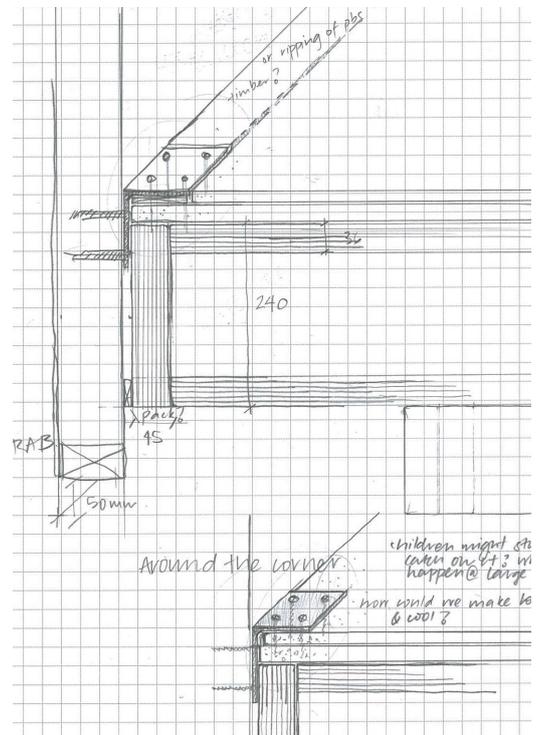


Fig. 8.5.4. Initial detail sketch of wall panel to floor cartridge connection: wall panel hanging off floor cartridge with steel angle bracket for economy.

8.5 Wall to Floor Detail Development

Precedent study findings indicate that wall panel systems with incorporated external cladding can significantly reduce work (and therefore time) on-site. External work on-site has higher impact to existing tenants and neighbours; therefore wall panel design is approached with the aim to prioritise the incorporation of external finishing.

When integrating external cladding the pre-installation of window and door elements is viable, yet does increase panel weight and reduces structural rigidity. However the incorporation of these elements into the wall panels means that all fixing, seals and flashings can be done efficiently in factory conditions, again reducing work on-site, specialist contractors and deliveries to site. The requirement for full height windows for access to thermal mass has further design influence as structural stability is reduced at the base of the wall panel where it becomes “floppy.”¹

In traditional construction wall framing generally rests on top of the floor structure, and cladding is required to extend minimum 50mm below the joist or lowest part of timber floor framing.² To avoid having to complete cladding below floor level on-site, and to allow for customisation of cladding and use of sheet materials, a wall to floor junction detail is explored to “hang” off the side of floor panels. This approach was utilised in the *Catholic Schools Expansion Programme* across nine sites in the lower North Island and the Tuwharetoa Marae ablution blocks, both collaborations by Assembly Architects, Dunning Thornton Consulting Engineers, MOTM Architects and Stanley Group Modular.³

The increased panel depth below floor level also provides additional structural stability to allow for large openings, flush with floor level to increase light and connection to the outside whilst allowing the natural warmth of the sun to heat the thermal mass in floor. The solution also provides an improved thermal envelope as insulation continues below the floor level.

The design process involved the exploration of several ideas surrounding the connection detail before arriving at (see fig. 8.5.9.), screw fixed from the boundary joist into a double bottom plate.

¹ Earl Rutherford, (Director, MOTM Architects), interview by Author, May 20, 2013.

² E2 External Moisture, effective 24 December, 2012, 9.1.3 Bottom of cladding, Table 18.

³ Justin Wright, Assembly Architects Presentation (Engineering Lecture Theatre, Auckland University, July 24, 2013).

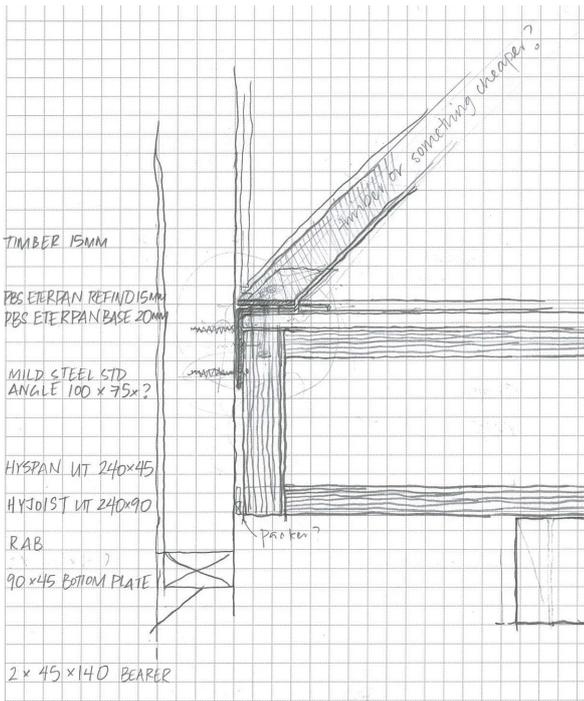


Fig. 8.5.5. Initial detail sketch of wall panel to floor carriage connection: wall panel fixed to steel angle bracket at the top of floor carriage, steel angle bracket concealed.

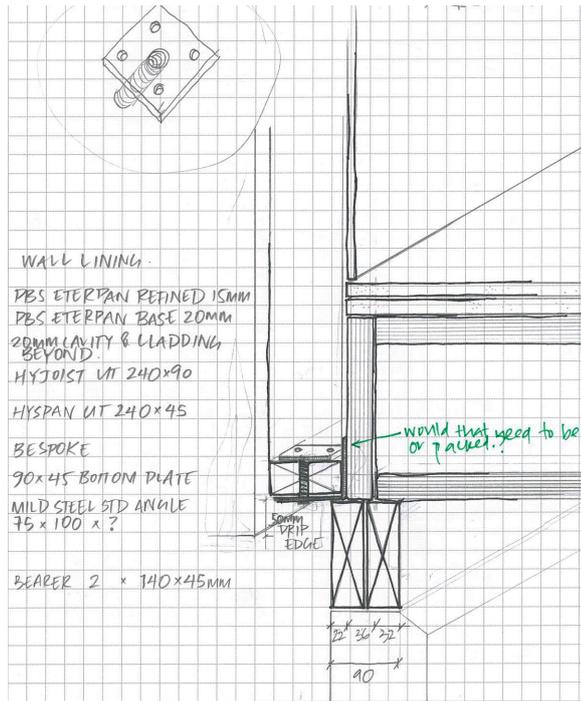


Fig. 8.5.6. Initial detail sketches of wall panel to floor carriage connection: wall panel fixed to boundary joist and leveraged off bearer with steel angle bracket.

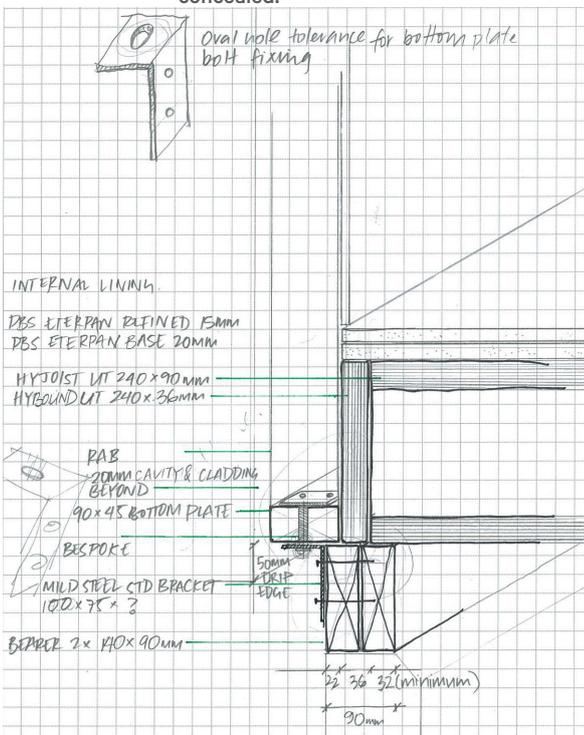


Fig. 8.5.7. Initial detail sketch of wall panel to floor carriage connection: wall panel fixed to bearers with steel angle bracket.

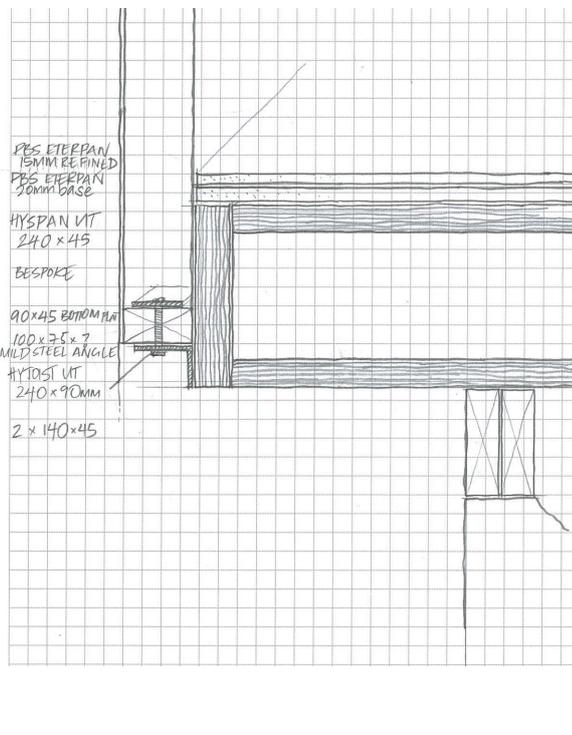


Fig. 8.5.8. Initial detail sketch of wall panel to floor carriage connection: wall panel fixed to boundary joist with steel angle bracket (with bearers set back).

Fig. 8.5.9. Detail Model 1:1
Wall panel to floor cartridge detail:
the final solution, boundary joist is
screw fixed into double bottom plate.



Wall panel to
floor cartridge
connection



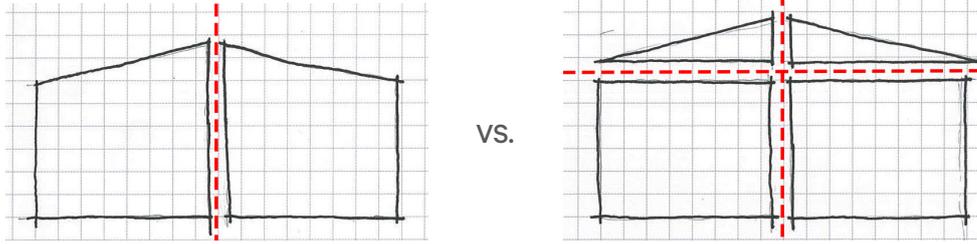


Fig. 8.6.1. Approach to panel design : Vertical joint only vs. Vertical and secondary horizontal joint

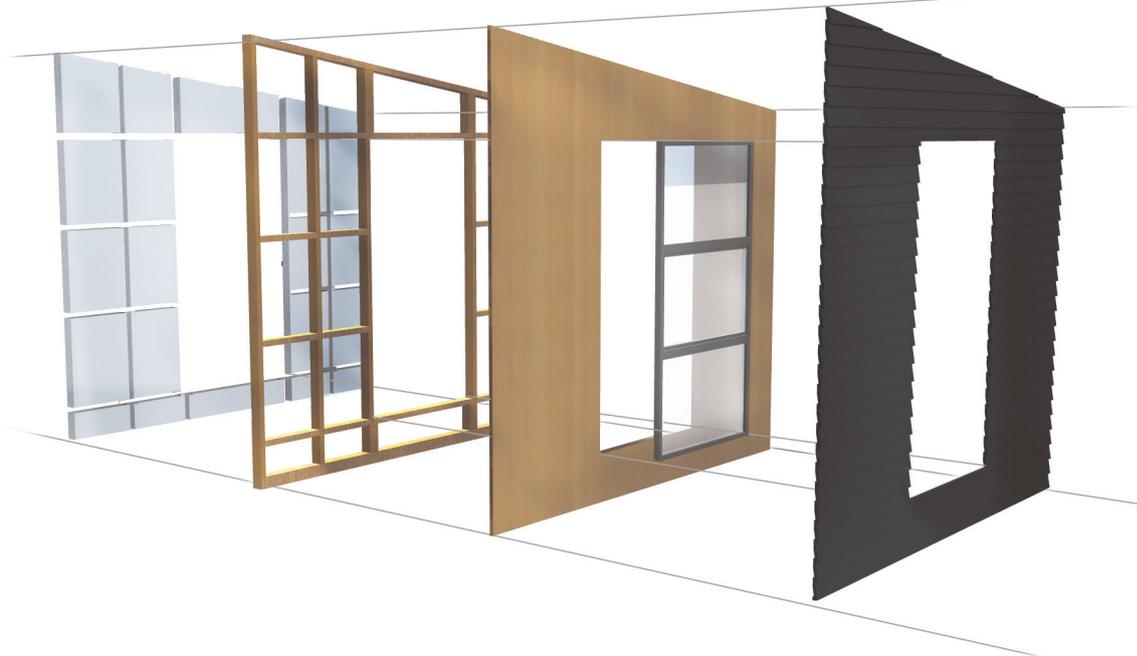


Fig. 8.6.2. Exploded axonometric of wall panel configuration

8.6 Wall Panels

Panel joints are limited to a vertical junction. In many precedents reviewed panels are equal height (and not raking) to increase flexibility throughout the system. This approach requires either a flat roof (an identified weakness in prefabricated housing), or a secondary horizontal joint to a secondary triangular panel from which the roof is formed. The later solution also requires a truss structure and flat internal ceiling for bracing. In the approach taken here, rather than putting 'hats' on the dwellings it seems aesthetically stronger to reduce the panel joint to one vertical joint and incorporate an exposed raked ceiling, increasing ceiling height, volume and sense of space with the dwelling. The approach also simplifies on-site assembly (and consequently reduces time frame) in that there are less components and therefore junctions (see fig. 8.6.1.).

The downfalls of this approach however is that the panel 'library' is increased because of differences in panel height and angle in relation to roof pitch and form. However the structure remains essentially the same, independent of what side of the panel you are cladding the framing remains the same.

The wall panel consists of a timber 90mm frame;¹ 7mm plywood rigid air barrier (RAB), which is code compliant as part of a cavity system, structurally stiff for transport and allows sealant to manage connections between panels;² aluminium joinery with double glazing; and essentially any cladding system that is direct-fixed or requires cavity construction. Medium density insulation is cut and fit prior to transport to site and taped in place. The 9mm plywood internal lining is installed on-site so that electrical services can be integrated and pre-lining inspection can occur on-site.³ The ply is finished with non-toxic water-based finish. Internal walls are prefabricated utilising 70mm⁴ timber framing and clad on one side. It is recommended that insulation for sound purposes is installed given the small footprint. The material is robust and resilient reducing risk of damage and the ongoing costs of maintenance and repair. Plywood does not require any wet trades (stopping) this combined with bracing qualities results in a construction type excellent for transport. Aesthetically timber contributes to warmth and character of a home.

As panels are required to be transported, materials used, for example the use rigid air barrier (RAB), the amount and placement of structure and fixings are somewhat increased to compensate this requirement. There is some material redundancy where double stud occurs at panel joints. This is one reason for the increased quality, durability and longevity of prefabricated construction outcomes in comparison to traditional on-site builds.⁵ Other attributing factors include reduced defects, protection from weather (rain) during construction and greater quality control procedures in the factory.

1 An approach utilising LVL studs was explored for increased structural stability and dimensional precision, however the added structural benefit was outweighed by the additional cost.

2 As building wrap requires lapping at joints prior to the fixing of external cladding.

3 Holes for horizontal electrical wiring are pre-drilled in 400mm centres for speed and ease on-site.

4 or 90mm framing above 3.0m height.

5 Burgess, Buckett and Page, *Study Report: Prefabrication Impacts in the New Zealand Construction Industry*, (BRANZ SR 279:2013) 33.

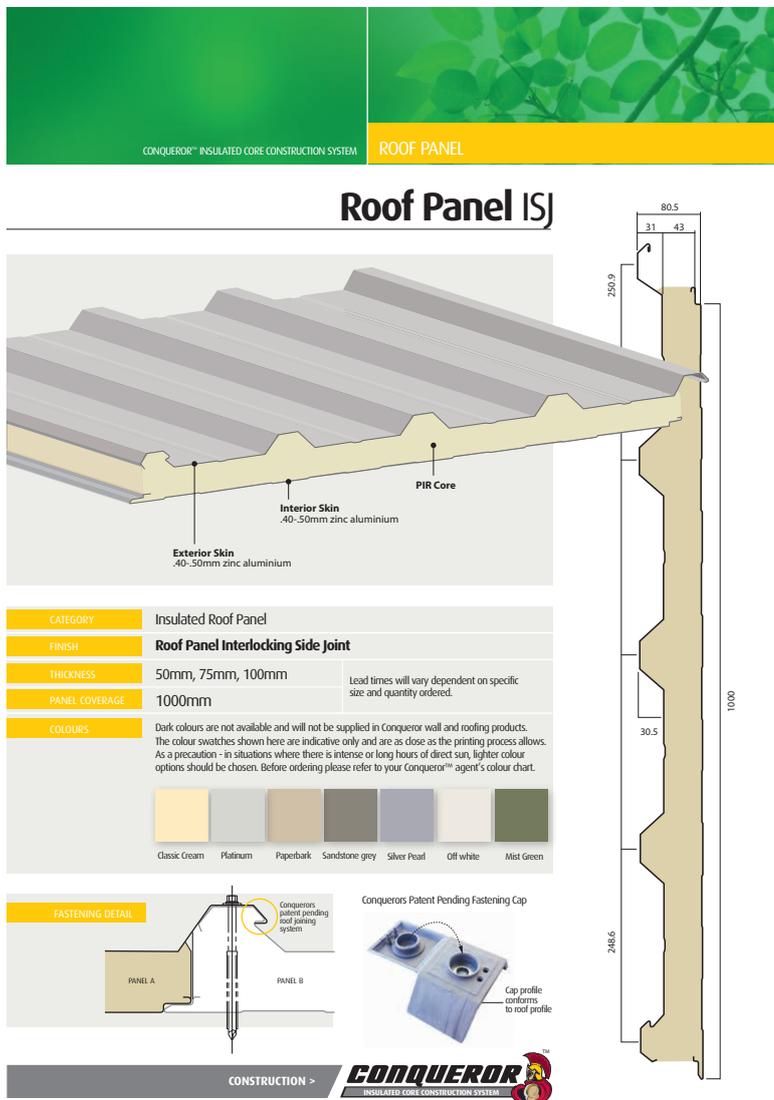


Fig. 8.7.1. Metal SIP panel specification from Conqueror

Window and Doors

All openings have been standardised and limited to three types only in order to save costs gained by an increased level of production. The units also follow a 600mm-1.2m dimensional module. Joinery height is at 2.2m, which, combined with floor-level openings, promotes a feeling of openness, lightness and sense of increased volume.

Bedroom windows are limited to one large opening only, for cost efficiency (one opening is more cost efficient than two) and to better occupy and furnish spaces (ability to accommodate double or two single bed configurations). A fixed passive sash vent in all windows ensures a controlled amount of fresh air supply at all times (without the jeopardising security). Operable louvres above all internal doors then aid cross ventilation – to encourage internal and external cross- ventilation within the dwelling, resulting in a healthier internal environment at all times.

8.7 Roof Panels

In *Studio19 Community Housing* precedent study outlined the utilisation of metal structurally insulated panels (SIP's). A commercially supplied (off-the-shelf) product, delivered directly to site when required in manageable panels with prefinished internal and external skins. *Conquerer* is a new metal SIP supplier in New Zealand, the first in the country to utilise a polyisocyanurate (PIR) insulation core.¹ The PIR core boasts higher R-value (100mm achieves R-5) and greater thermal performance, fire rating and reduced environmental impact when compared with other SIP core solutions manufactured locally.²

At the scale of the research project, panels are mechanically lifted onto the roof on delivery and manually positioned and connected quickly and efficiently with a single-fix modular construction technique that does not require specialist tools. The high spanning capability, 5.0m, reduces structural and framing requirements. The result is a low maintenance and robust internal and external finish complete and weather-tight within a matter of hours. The accelerated construction reduces site time up to 50%.³

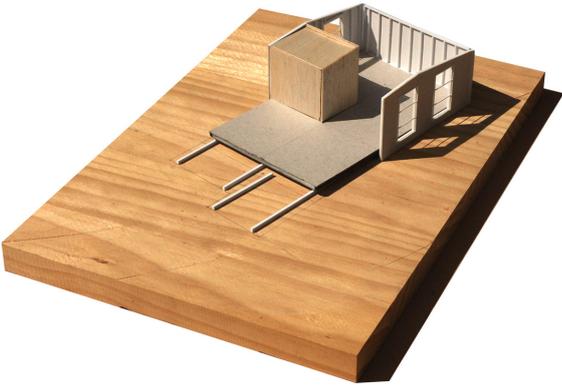
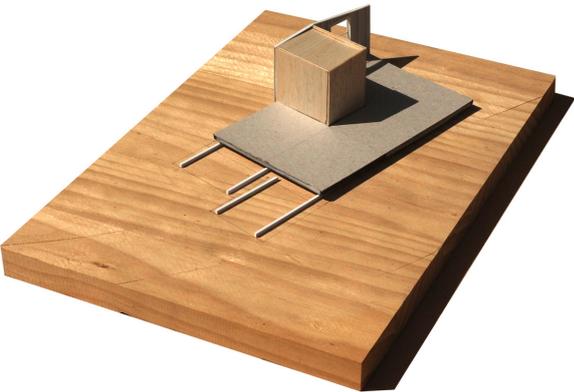
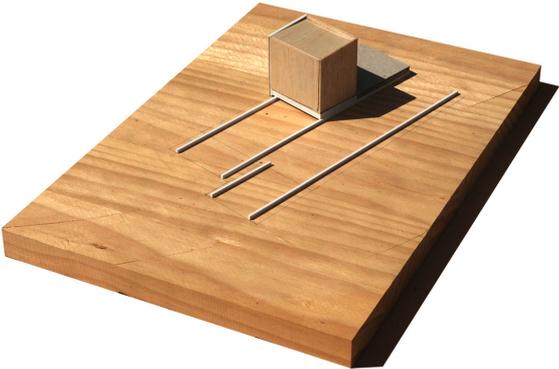
The roof is pre-manufactured and available in a 1.0m panel, therefore the roof module is 1.0m and length is cut to order. The transition from the 1.2m and 1m module is dealt with by use of overhangs, gutters and flashings.

Aesthetically the panel achieves a thin expressed roof sandwich and allows increased internal volume. Issues with service integration is dealt with by using wall lighting and trapeze pendants in the dining/living area.

1 The Conqueror Roof Panel ISJ consists of a 0.5mm profiled zinc aluminium exterior skin bonded to a 100mm polyisocyanurate (PIR) insulation core, with a 0.5mm zinc aluminium interior skin bonded to the underside.

2 "Construction Advantages," *Conquerer*, accessed February 18, 2014. <http://www.conquerorpanel.co.nz/construction-advantages/>.

3 Ibid.



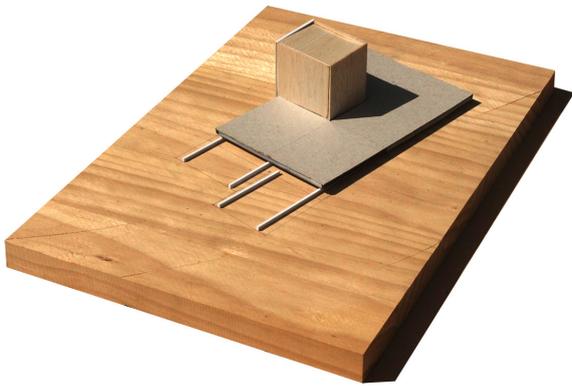


Fig. 8.1.2. Component and assembly process on-site Physical model 1:50

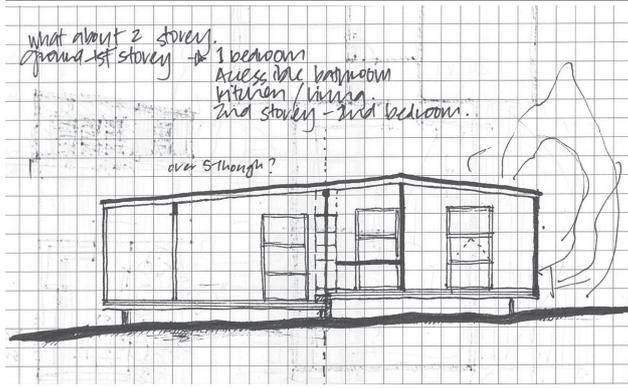


Fig. 8.9.1. Floor Break : Response to contour

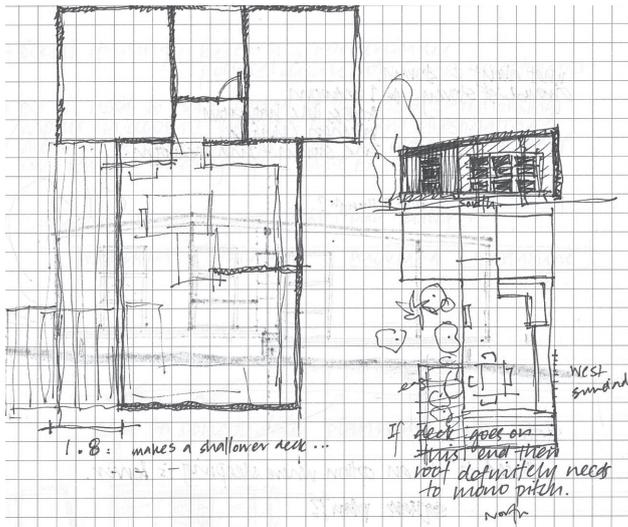


Fig. 8.9.2. 'T' Plan: Response to orientation, private space and further variation of form

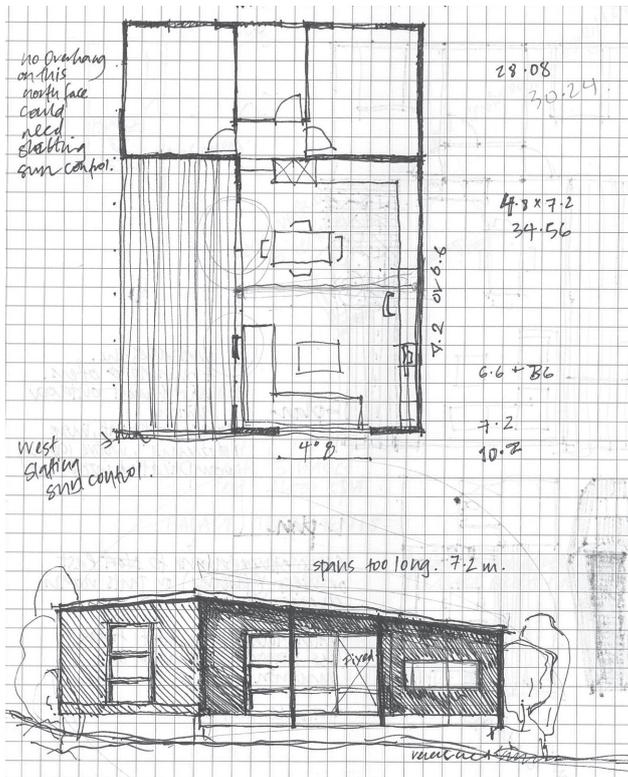


Fig. 8.9.3. 'L' Plan: Response to orientation, private space and further variation of form

8.9 Critical Appraisal

Further response to the diversity of site conditions identified is required to achieve site-specific design. The MHU forms are further evaluated and manipulated alongside the twenty allocated sites examined in the research project.

Response to Contour

The possibility is explored to incorporate a step in floor plate to respond to topography conditions (see fig. 8.9.1 & fig.8.9.4). The two-step floor drop responds to the landscape, an acknowledged downfall of the 1940's state housing programme. It also assists to create further spatial separation between sleeping and living zones of the compressed floor area, a method used by Group Architects in their First and Second Houses.¹

Although the break assists assembly in terms of height and volume concerning roof form, the increased height of wall panels at this junction stretches panel limitations. Consequently assembly of components is further complicated and accessibility is reduced.

Response to Orientation, Form and Private Outdoor Space

The plans are then manipulated to move beyond the rectangular form, in response to site-specific conditions such as orientation and private outdoor space requirements. The 'T' plan is first explored which is a direct manipulation of the MHU 2 plan (see fig. 8.9.2.). The variation achieves further site-specific application in terms of orientation, however generates increased wall panel components, two additional external corner junctions and two additional internal junctions; generating waste and complicating assembly greatly. Hence the variation is not developed further.

The 'L' plan however is superior to the 'T' plan because it achieves a simpler roof form and requires only one additional external corner junction and one additional internal junction. The plan can be flipped to give favour to east or west orientation, or placed directly north depending on other site-specific conditions (see fig. 8.9.3.). The roof form does however exceed the 5.0m SIP roof panel clear-spanning capability over the living area, therefore an exposed LVL beam is integrated. Because the form is a direct manipulation of the MHU 2 plan, there is repetition in floor cartridges, wall panels and service module. Aesthetically the form creates interesting façade depth and a private, sheltered and held outdoor space.

¹ Julia Gately, *Long Live the Modern: New Zealand's New Architecture 1904-1984* (Auckland: Auckland University Press, 2008), 57.

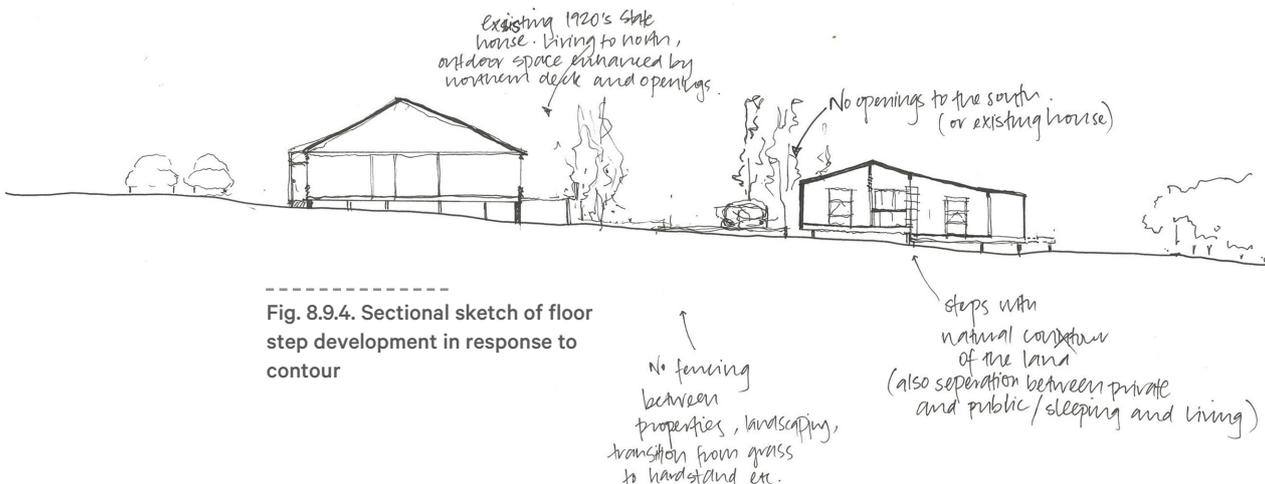


Fig. 8.9.4. Sectional sketch of floor step development in response to contour

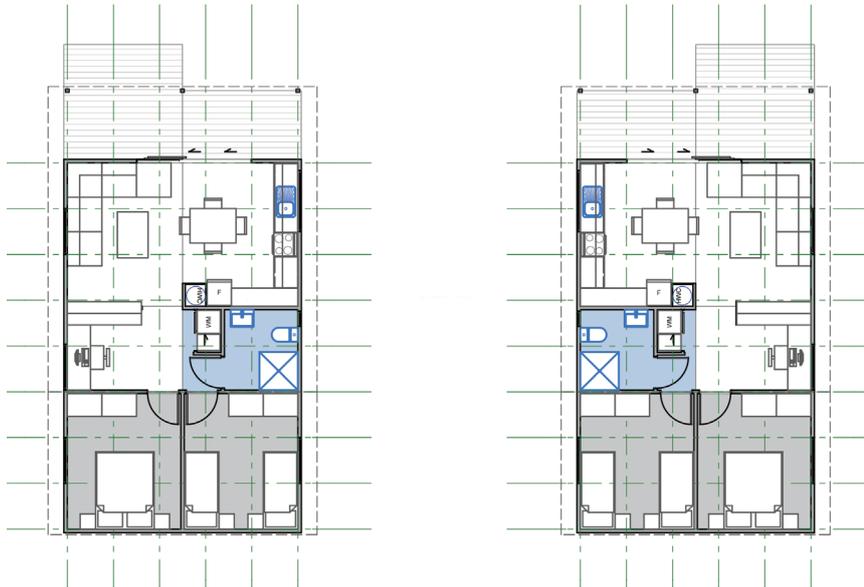


Fig. 8.9.5. MHU 1 and flipped version
1:200



Fig. 8.9.6. MHU 2 and flipped version
1:200

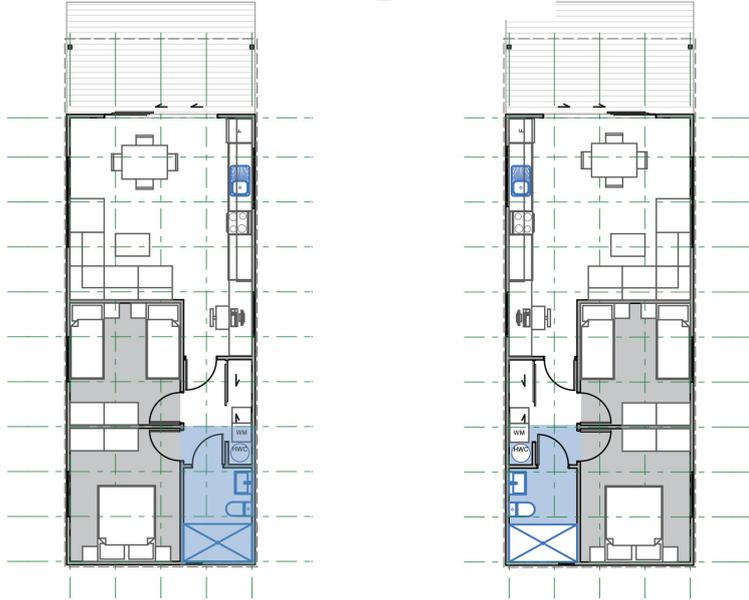


Fig. 8.9.7. MHU 3 and flipped version
1:200

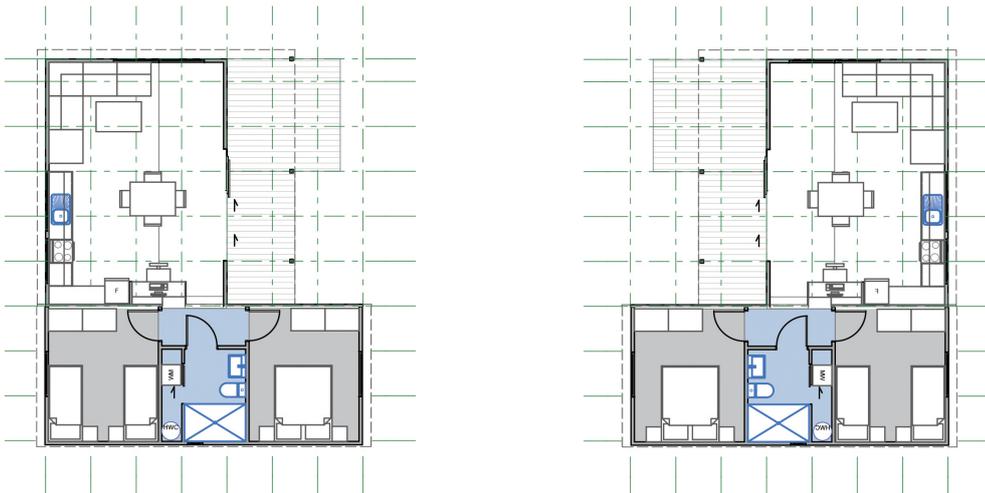
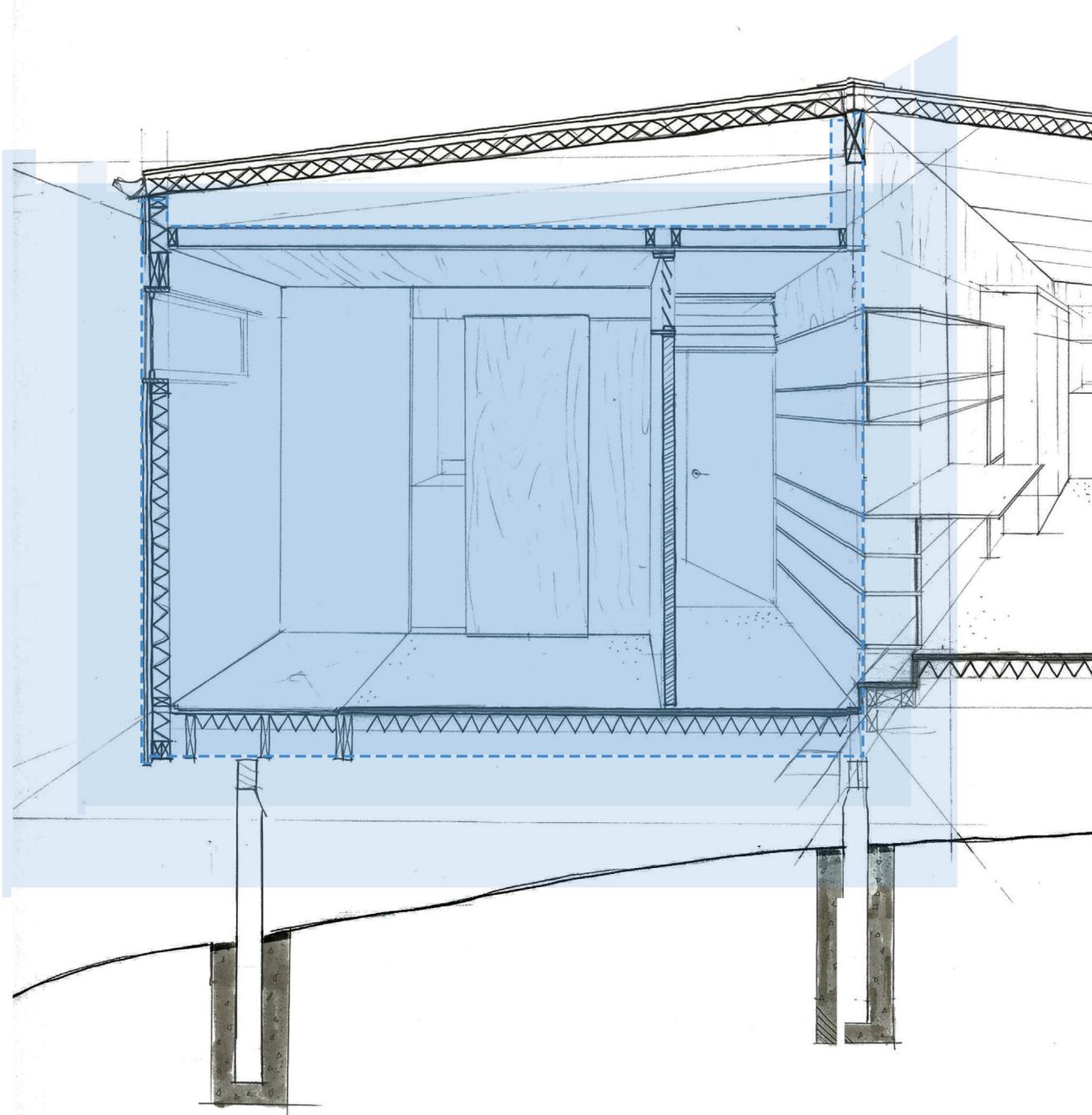


Fig. 8.9.8. MHU 4 and flipped version
1:200



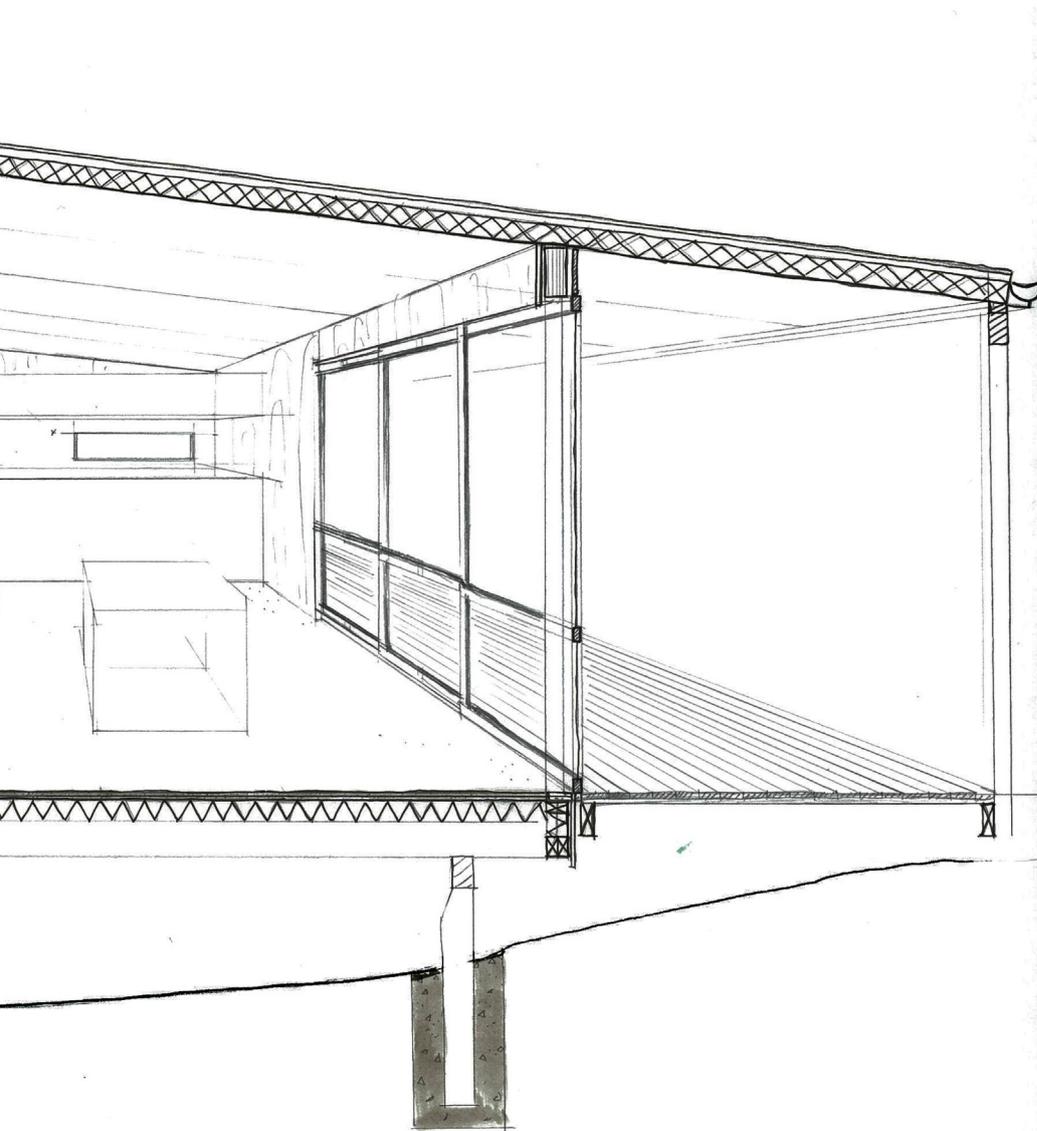


Fig. 8.9.9. Section MHU 2 describing floor break,
furniture wall and service module

9.0 Site Application

In order to test and further develop the design response, comprehensive site application and analysis is required. Five of the reviewed sites are selected, each with contrasting conditions and varying characteristics.

The site application method is required to;

- Test against existing house and site conditions whilst addressing the site requirements all at once
- Test the adaptability of the system in relation to real site conditions
- Test design methodology
- Review massing on-site.

9.1 Site Design Requirements

- Review existing house layout, locating public and private spaces in order to engage with existing site conditions
- Retain privacy and quality of outdoor space for existing dwelling (with north orientation)
- Privacy for neighbouring properties
- Private outdoor space for MHU (with north orientation)
- Safe access to outdoor living spaces
- Allow for outdoor cooking and food prep under cover
- Connection and relationship between the existing house and MHU, shared space
- Orientation to the sun
- Parking
- Access and ingress
- Natural surveillance
- Accessibility during construction/assembly period.

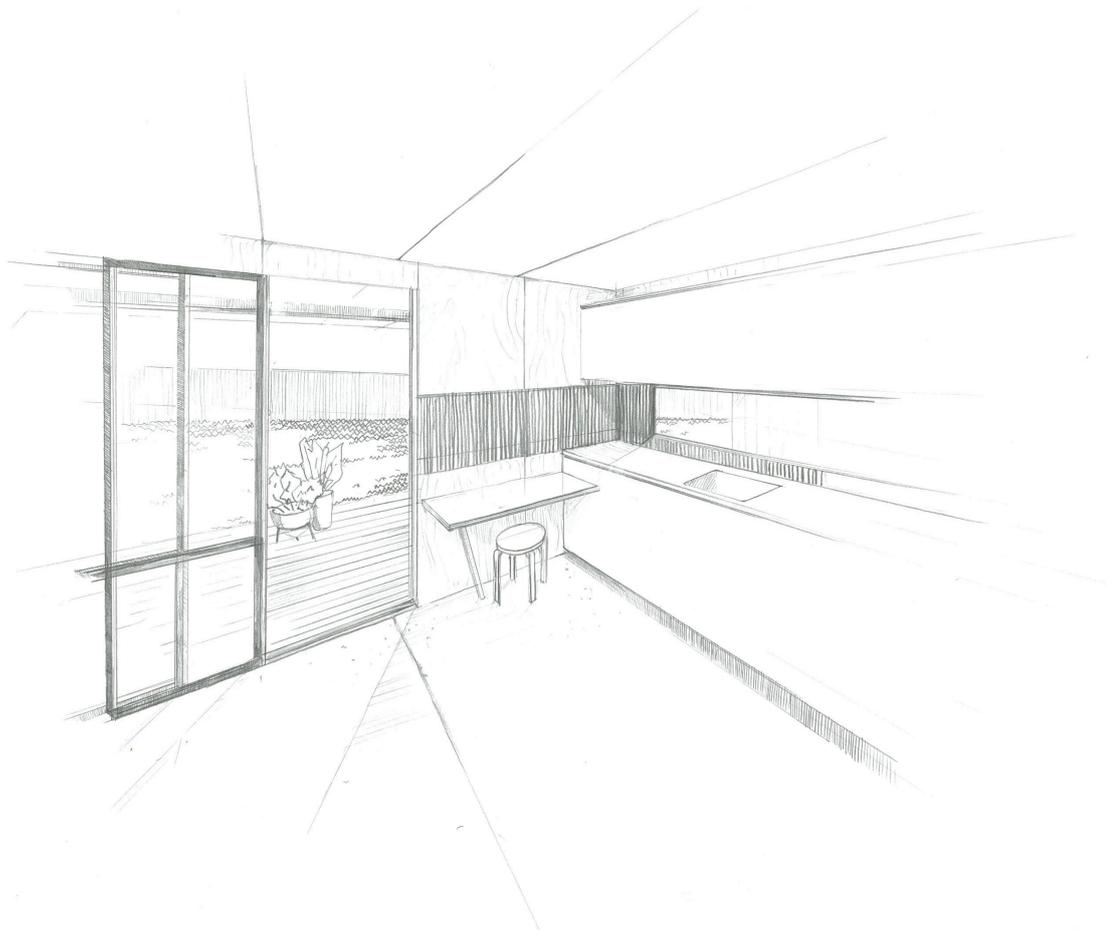


Fig. 9.3.1. Interior sketch depicting
natural surveillance from kitchen
window to entry approach

9.2 Mass-customisation

Manipulation to site-specific conditions:

- Selection of one of the four alternative MHU types, and their flipped versions for site-specific solar orientation, privacy and maximum use of available space
- Step in floor plate for inaccessible steeply contoured sites
- Integrated glazing and private outdoor space screening for sun, privacy and shelter
- Wall cladding in response to context
- Selection of wall panel type and location of glazing (if required).

9.3 Housing New Zealand Access Requirements

- The front path and entry should be overlooked from inside the house
- The path to the front entry door itself should be clearly visible from the street
- Progression through the house should be from public (living) to private (bathrooms, bedrooms)
- There must be weather protection to front doors (a porch) for rain and wind
- Retain good light to the entry
- Access should be level where possible
- It should not be possible to look from the street directly in the windows of a dwelling.



Fig. 9.4.2. MHU 1 Plan
1:100

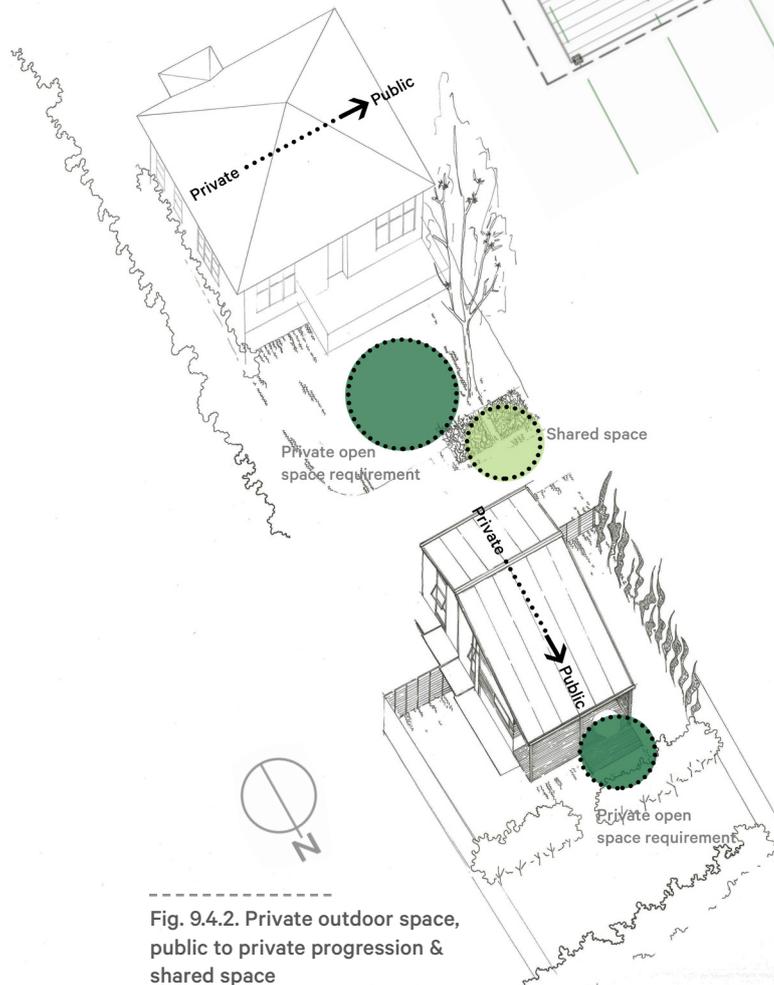


Fig. 9.4.2. Private outdoor space,
public to private progression &
shared space

9.4 Site Application 1

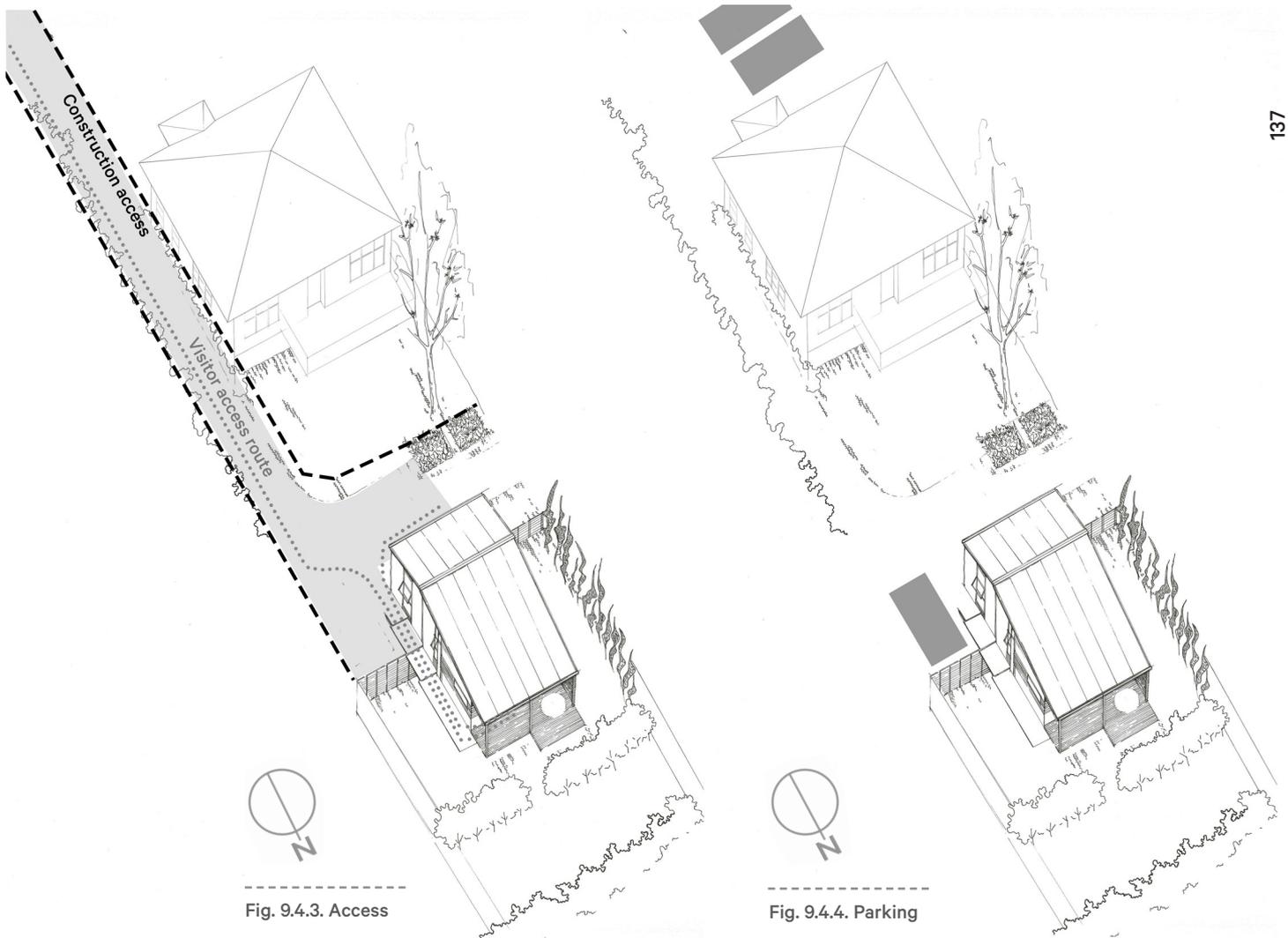
North orientation

Integrated screening for sun, shelter and privacy from neighbouring property

Natural surveillance from kitchen window to entry path route

Response to contour, two step floor break

No south openings creating higher thermal envelope and privacy between existing dwelling and proposed MHU.



9.5 Site Application 2



Fig. 9.5.1. MHU 4 flipped Plan 1:100

North-west orientation

The 'L' plan provides better proportioned and more private outdoor space for the MHU.

Kitchen window provides natural surveillance of visitor approach down driveway without impinging on the existing dwellings private space

Location of bedroom window to shared space and existing dwelling parking area is not ideal, appropriate privacy screening is to be integrated.

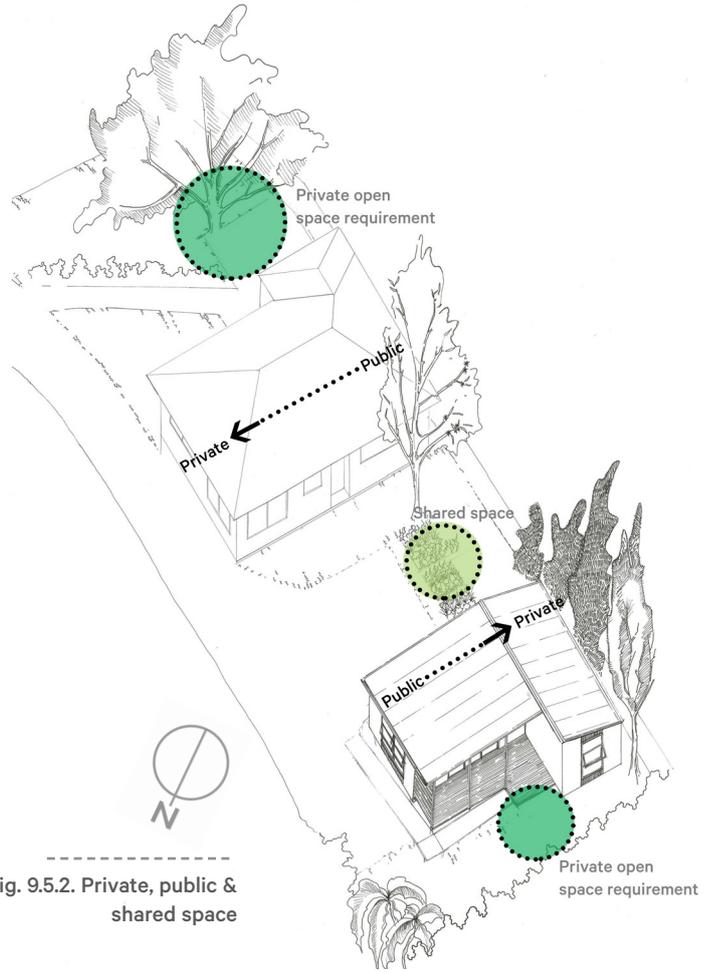


Fig. 9.5.2. Private, public & shared space

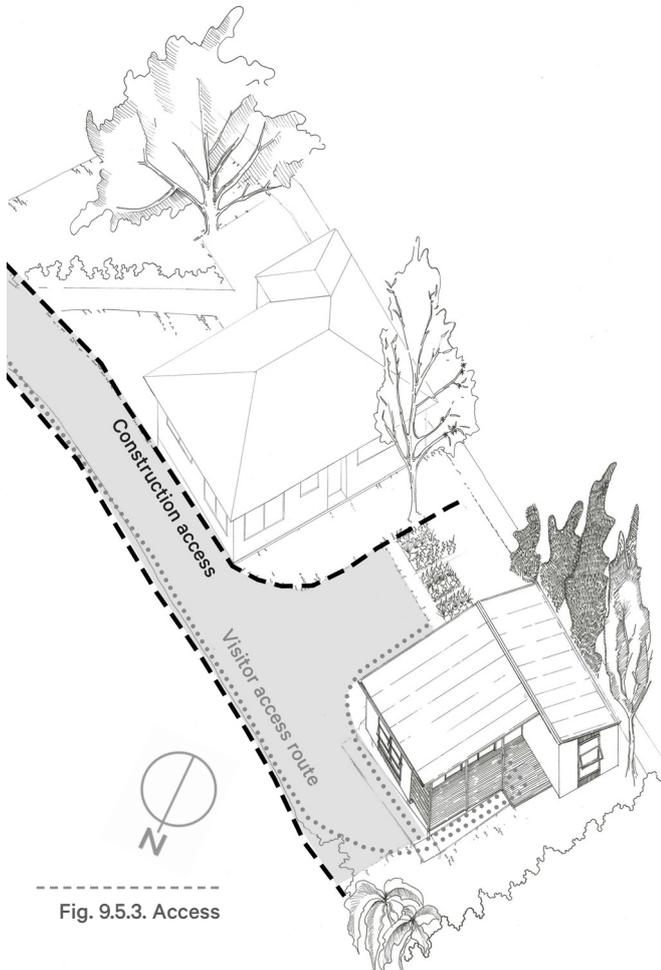


Fig. 9.5.3. Access

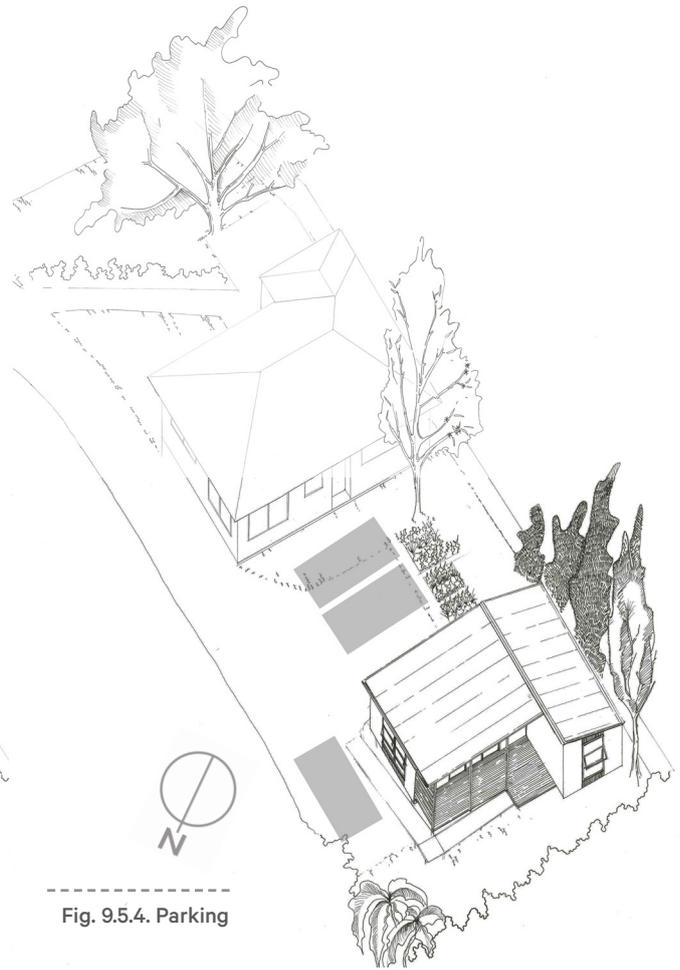


Fig. 9.5.4. Parking

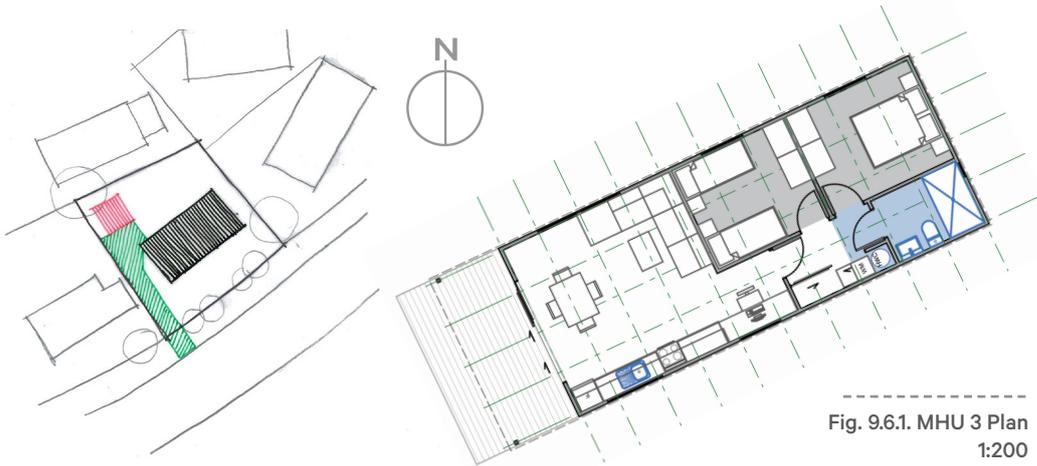


Fig. 9.6.1. MHU 3 Plan
1:200

9.6 Site Application 3

On application to site it is discovered that the intended MHU 3 is unable to meet the site design requirements defined by the inquiry. The rear yard of the property is compact and awkwardly proportioned, and consequently outdoor private space requirements for both the existing dwelling and proposed two-bedroom infill, and an appropriate relationship between the two can not be successfully achieved. A two-storied MHU 5 has been developed in response to these issues. The exploration of stacking is appropriate to the context as there are several two-storey dwellings in the immediate context.

Early site analysis and footprint application found that the site investigated in this exercise is the only one of the twenty sites surveyed to require the MHU 3 plan type. Consequently further development of MHU 3 is not required.

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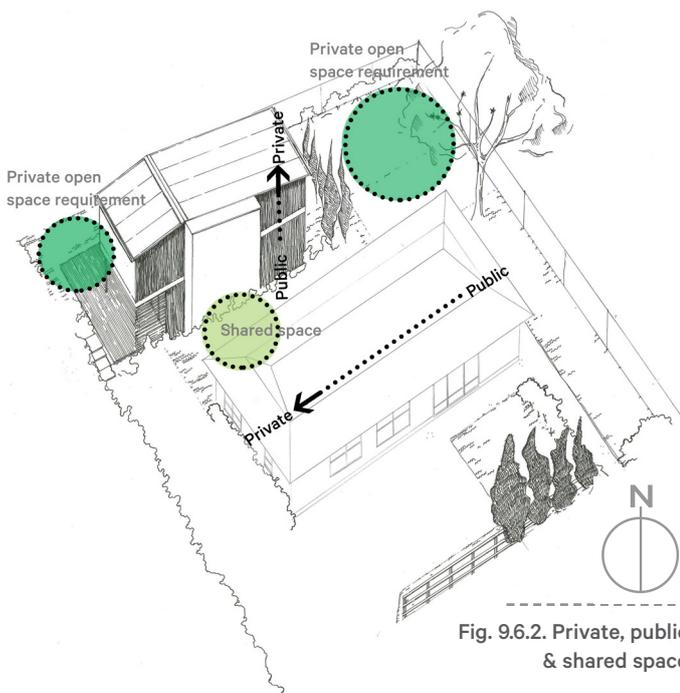


Fig. 9.6.2. Private, public
& shared space

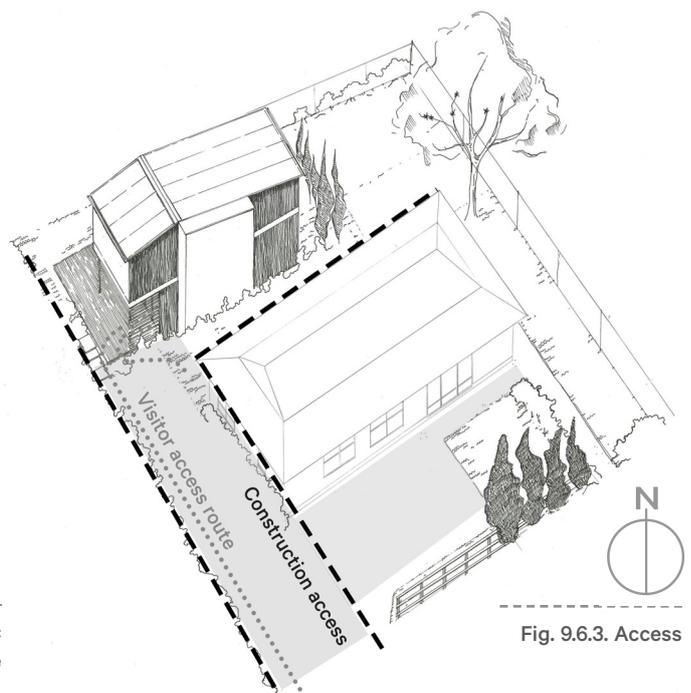
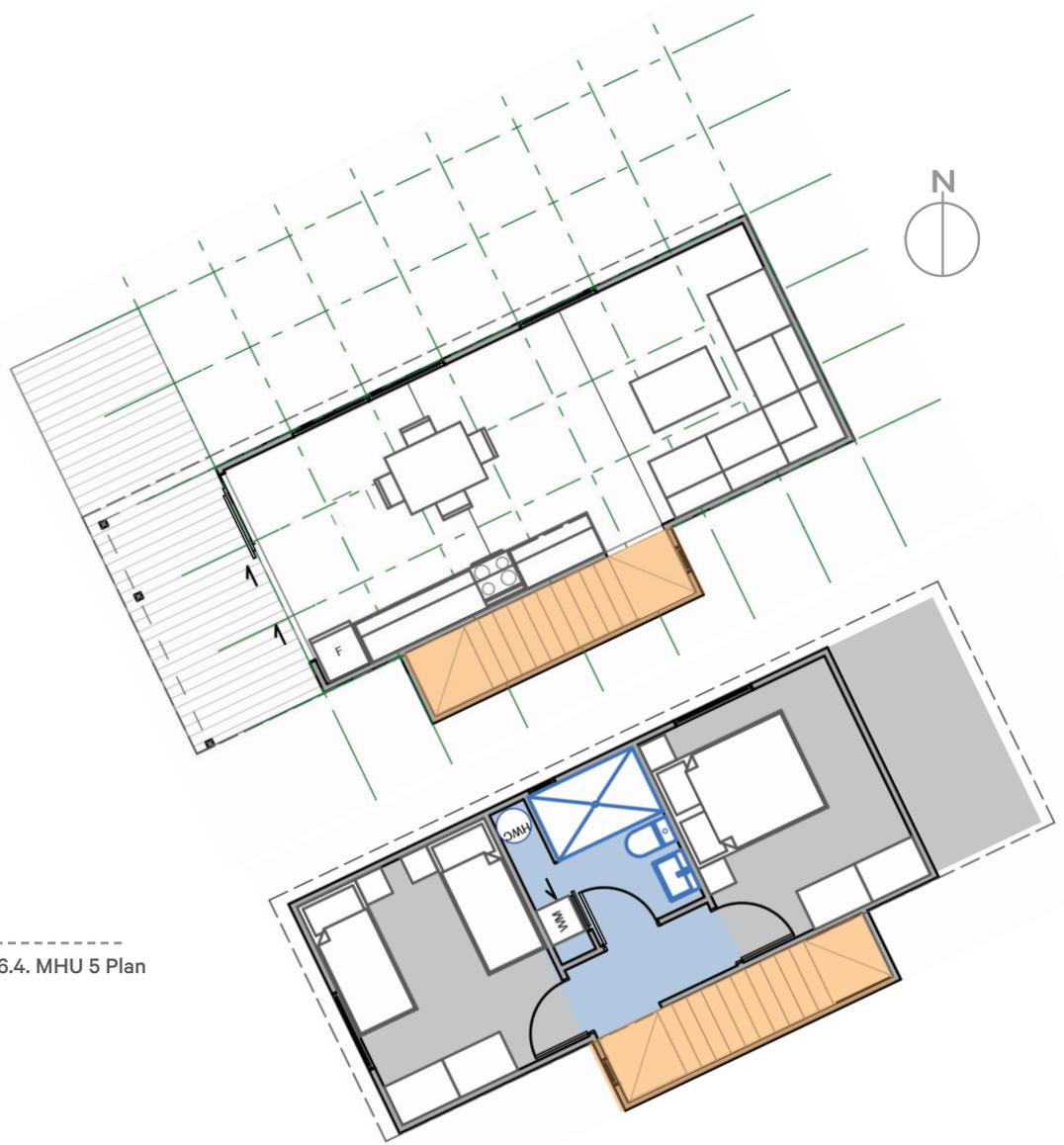


Fig. 9.6.3. Access

 Fig. 9.6.4. MHU 5 Plan
 1:100



North-west orientation

Remove east glazing to avoid overlooking neighbours private outdoor space

No south glazing requirement provides no natural surveillance of access and ingress approach

Integrated screening for sun, shelter and privacy from neighbouring property

No turning possible for car manoeuvring

Top storey slides to provide overhangs/covered outdoor space.

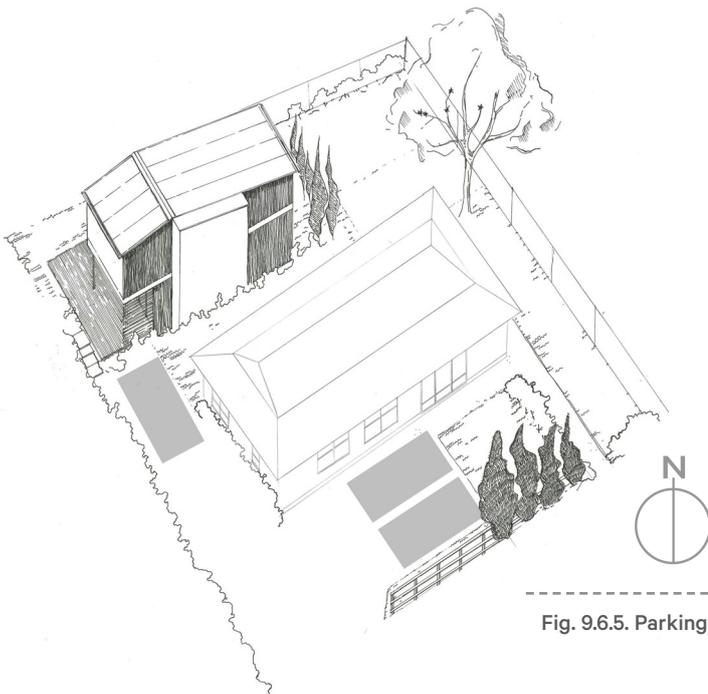


 Fig. 9.6.5. Parking

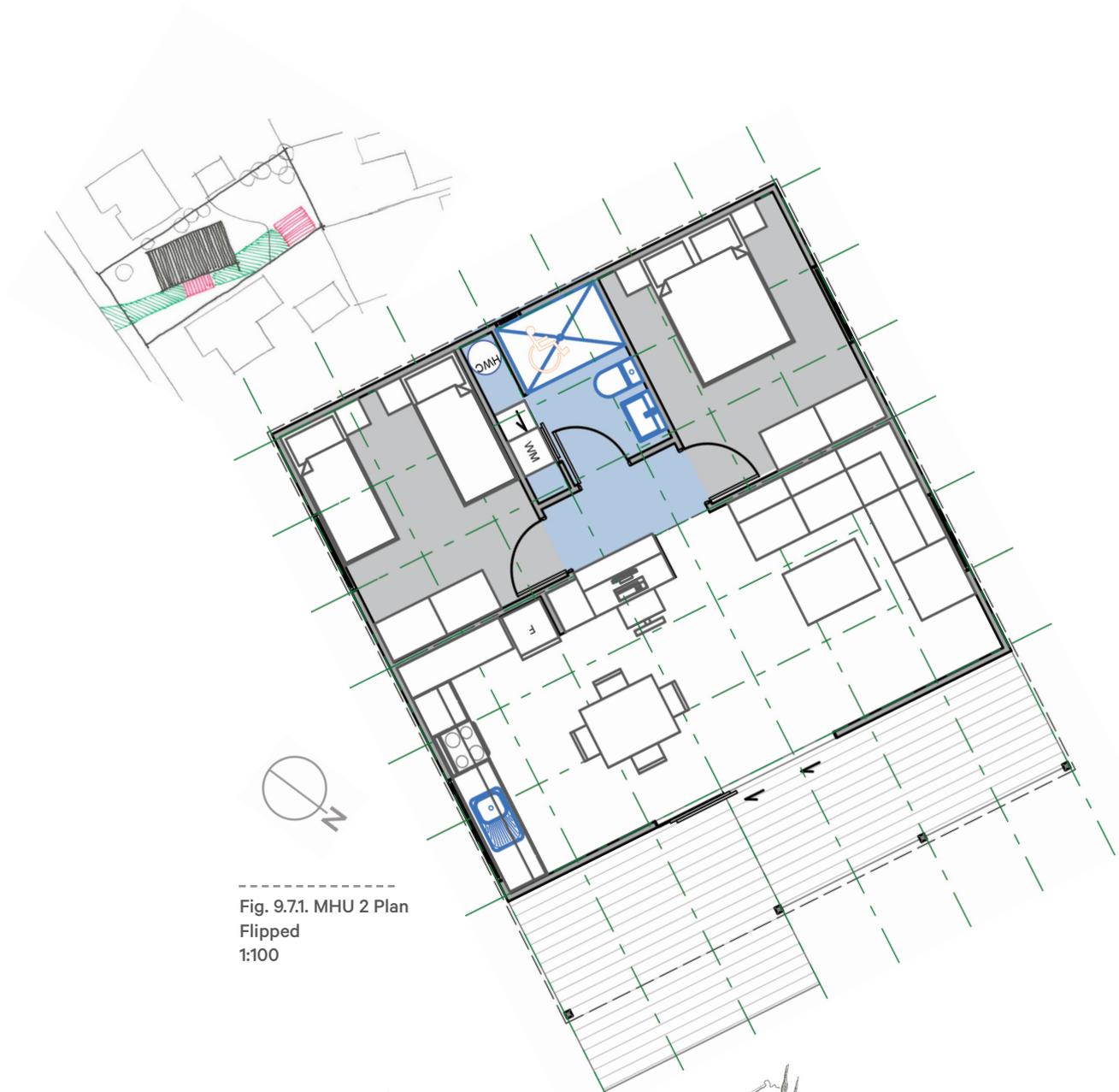


Fig. 9.7.1. MHU 2 Plan Flipped 1:100

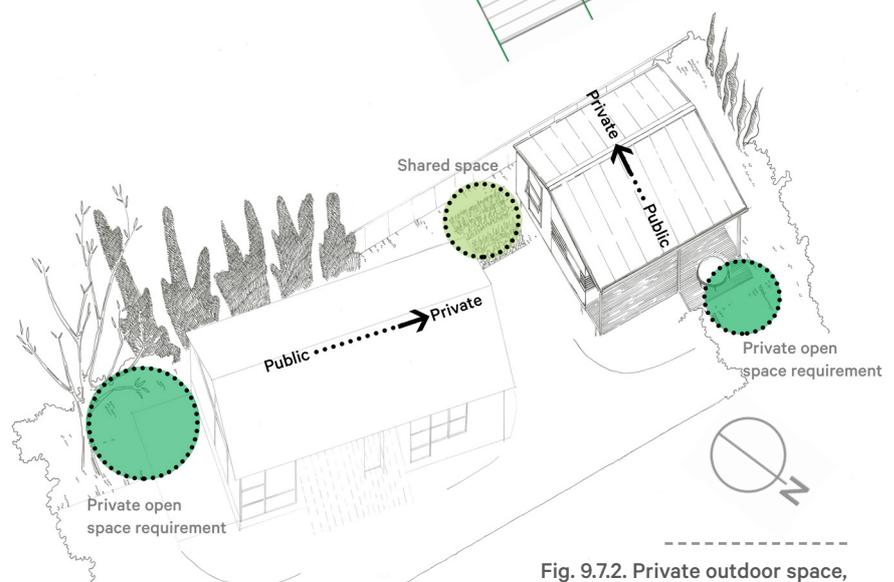


Fig. 9.7.2. Private outdoor space, public & private progression & shared space

9.7 Site Application 4

North-east orientation

Integrated west screening for sun, shelter and privacy from neighbouring property

Kitchen window provides natural surveillance of access and ingress approach

Location of bedroom window to shared space and existing dwelling parking area is not ideal, appropriate privacy screening is to be integrated

Enhanced eastern outdoor private space for existing dwelling to compensate loss of back yard and integration of cars.

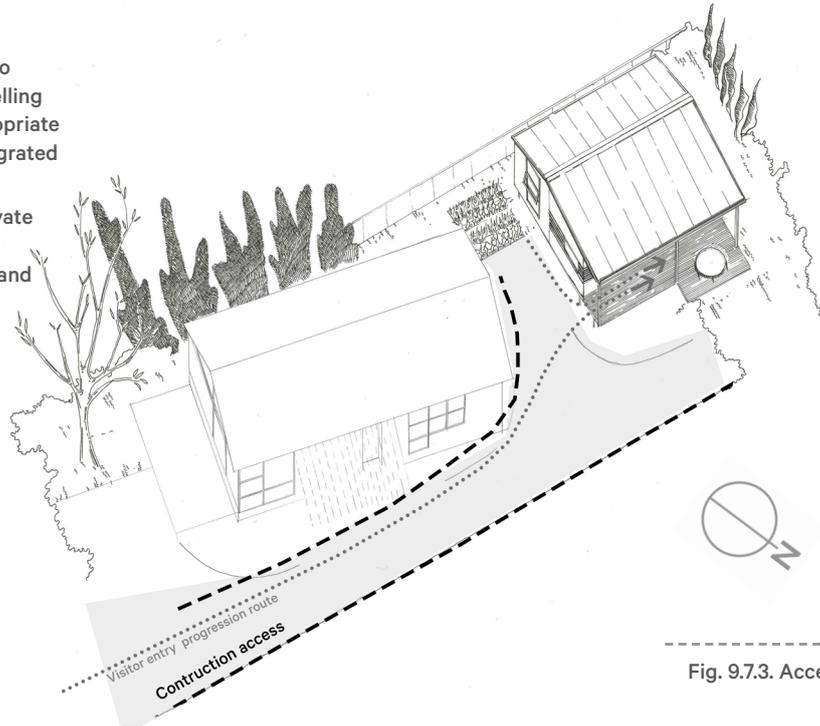


Fig. 9.7.3. Access

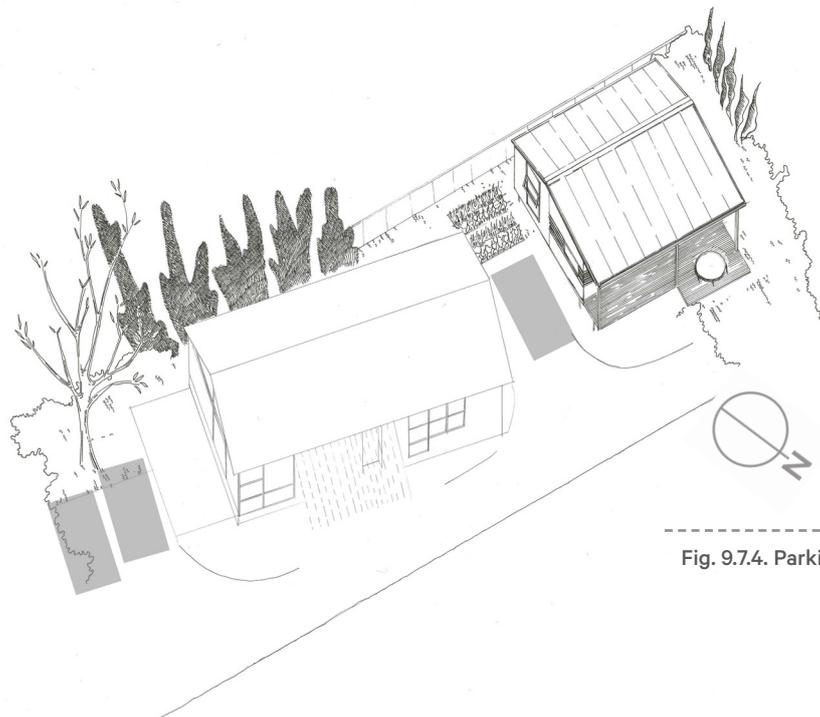


Fig. 9.7.4. Parking



Fig. 9.8.1. MHU 2 Plan
1:100

9.8 Site Application 5

North-east orientation

Integrated screening for sun, shelter and privacy from neighbouring property

Kitchen window provides natural surveillance of access and ingress approach

Steep topography is not appropriate for accessible housing, response to landscape two step floor break

Proximity and access to the MHU from the car is not ideal

Enhanced eastern ground level outdoor private space for existing dwelling to compensate loss of back yard

Increased time frame requirement for site preparation due to the steep contour and increased foundation requirement.



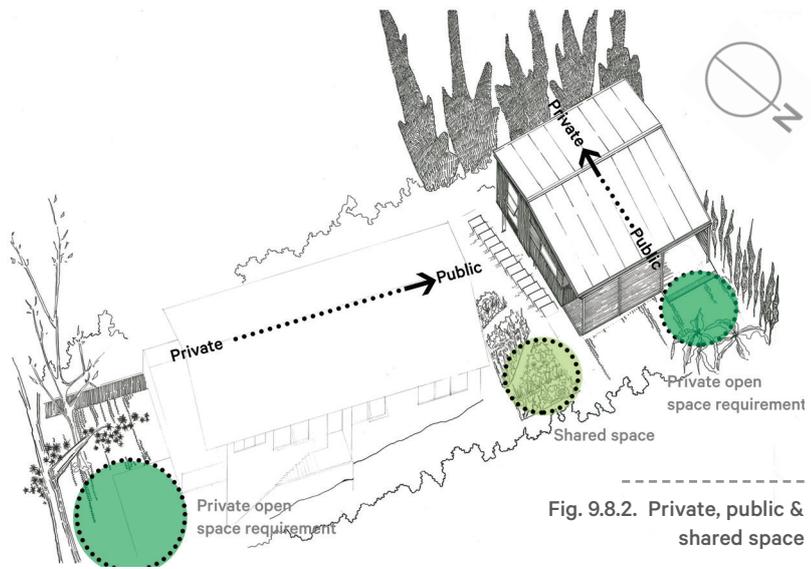


Fig. 9.8.2. Private, public & shared space

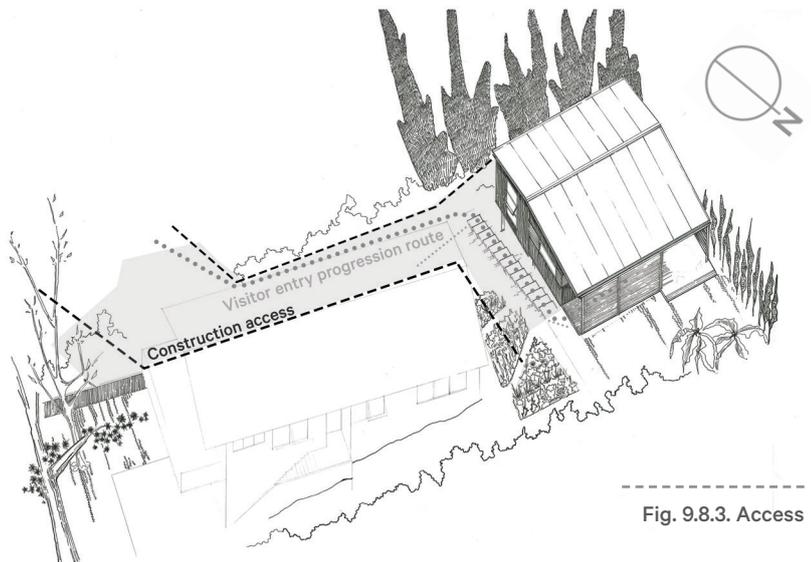


Fig. 9.8.3. Access

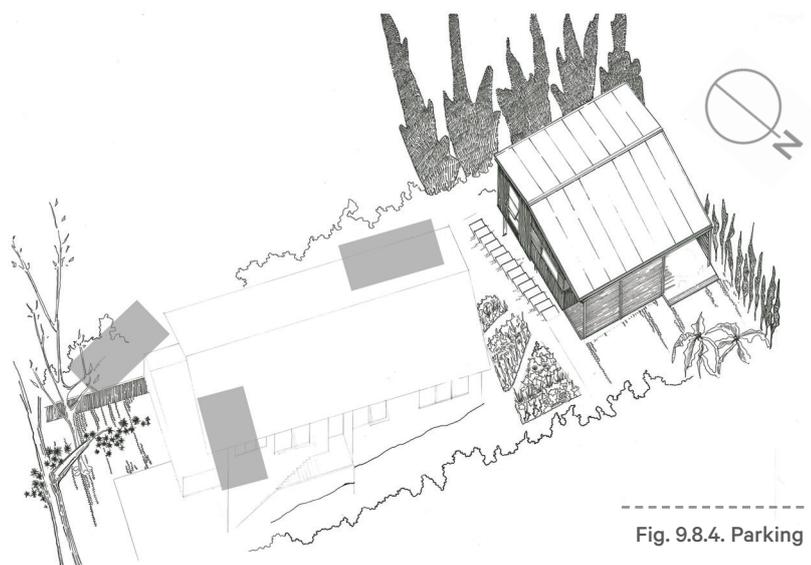


Fig. 9.8.4. Parking

9.9 Critical Appraisal

The application of the MHU designs to a variety of existing site conditions was a valuable exercise in terms of testing the the hybrid system developed to identify successes and failures of the system that require further development.

The MHU hybrid system generally achieves good solar orientation and provision of private outdoor space requirements. Although the loss of back yard is problematic for the existing tenants, District Plan private space requirements can be met in all cases. Issues with MHU bedroom windows in close proximity to shared space and existing house parking area were identified, appropriate planting and privacy screening is required to mitigate the concern. Otherwise the visual and acoustic privacy achieved between the occupancies is generally good whilst reinforcing community with open and linked site relationships.

Access requirements are difficult to meet in that the compact footprint does not allow for a traditional single 'front door' due to the increased circulation that a second entry point requires. In most cases the visitor entry route can be overlooked from the kitchen window, before arriving at the slider. The problem is more that the front door in all cases is not visible upon ingress to the dwelling. Further development is required to develop landscaping and building form to guide the visitor around to the entry point - perhaps by use of colour or difference in cladding. However a wide main entry is important in Pacific cultures for formal occasions such as death in the family, when the coffin is carried through the front door.¹

The integration of parking and car manoeuvring requirements requires the use of a great deal of valuable space on site. If the site was to be developed, removed from existing dwelling limitations it is probable that these requirements could be better designed and incorporated as to not dominate the site design.

The exercise, Site Application 3 revealed the limitations of of MHU 3 and a two-storey alternative was explored. In this variation a stair module and CLT mid-floor components are integrated to the assembly system. Increased floor area due to vertical circulation makes it unfeasible to fit with the maximum floor area requirement, so for this exercise the stair module has been excluded from the calculation. The two-storey option also breaches the District Plan 5m maximum height requirement. However the stacked version uses less land, requires less foundations and roof area and creates greater social and living outcomes for both properties.

1 Pacific Housing Guide, 8



10.0 Site Intervention - Final Presentation

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Fig. 10.0.1 Site Application 3 (9.7)
MHU 4 flipped Site Plan



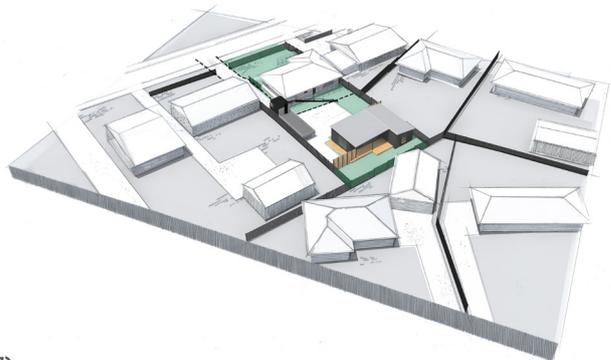
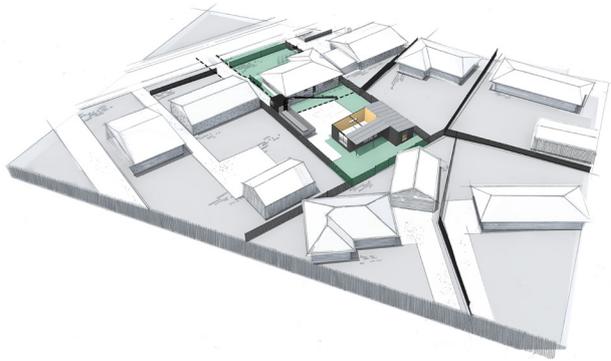
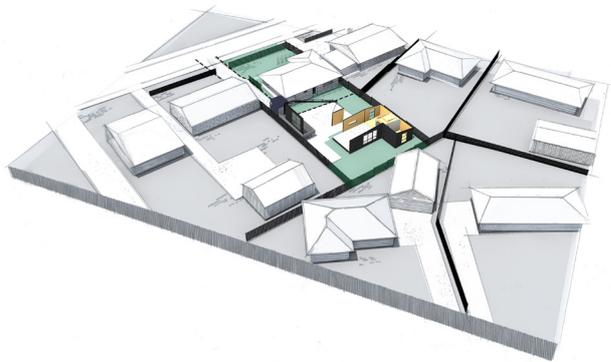
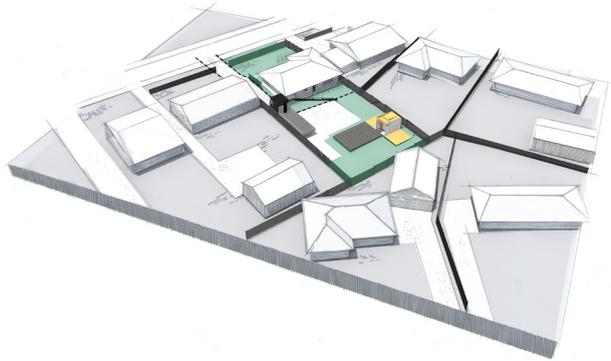


Fig. 10.0.2 Site Application 3 (9.7)
On-site assembly of components

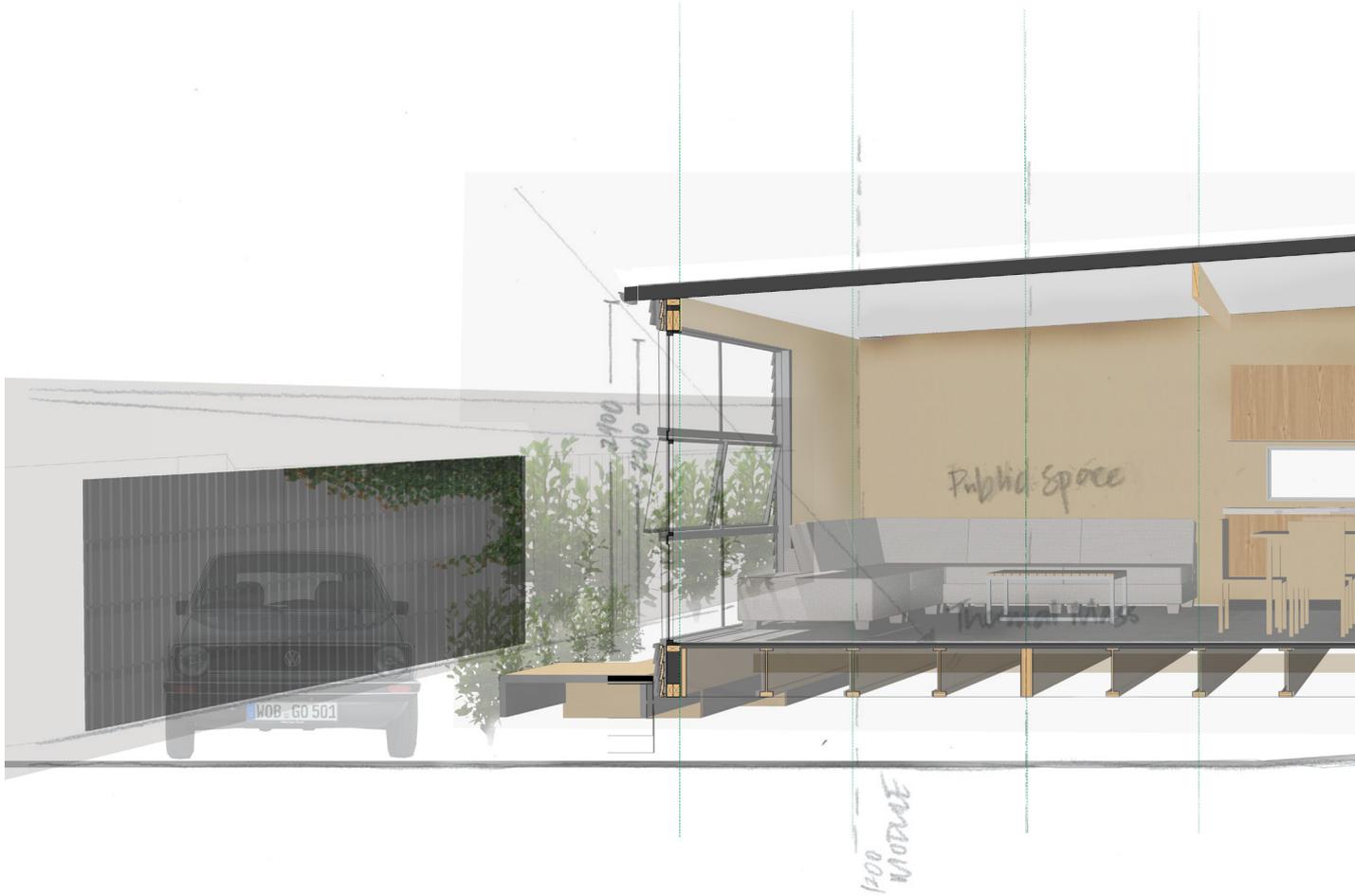




Fig. 10.0.3 Site Application 3 (9.7)
Section through public & private space



Fig. 10.0.4. Site Application 3 (9.7)
Approach from the street - existing dwelling private outdoor space



Fig. 10.0.5. Site Application 3 (9.7)
Ingress & entry to MHU



Fig. 10.0.6. Site Application 3 (9.7)
Living Space - Natural surveillance



Fig. 10.0.7. Site Application 3 (9.7)
Connection to covered outdoor space



Fig. 10.0.8. Site Application 3 (9.7)
MHU private outdoor space



Fig. 10.0.9. Site Application 3 (9.7)
Shared space

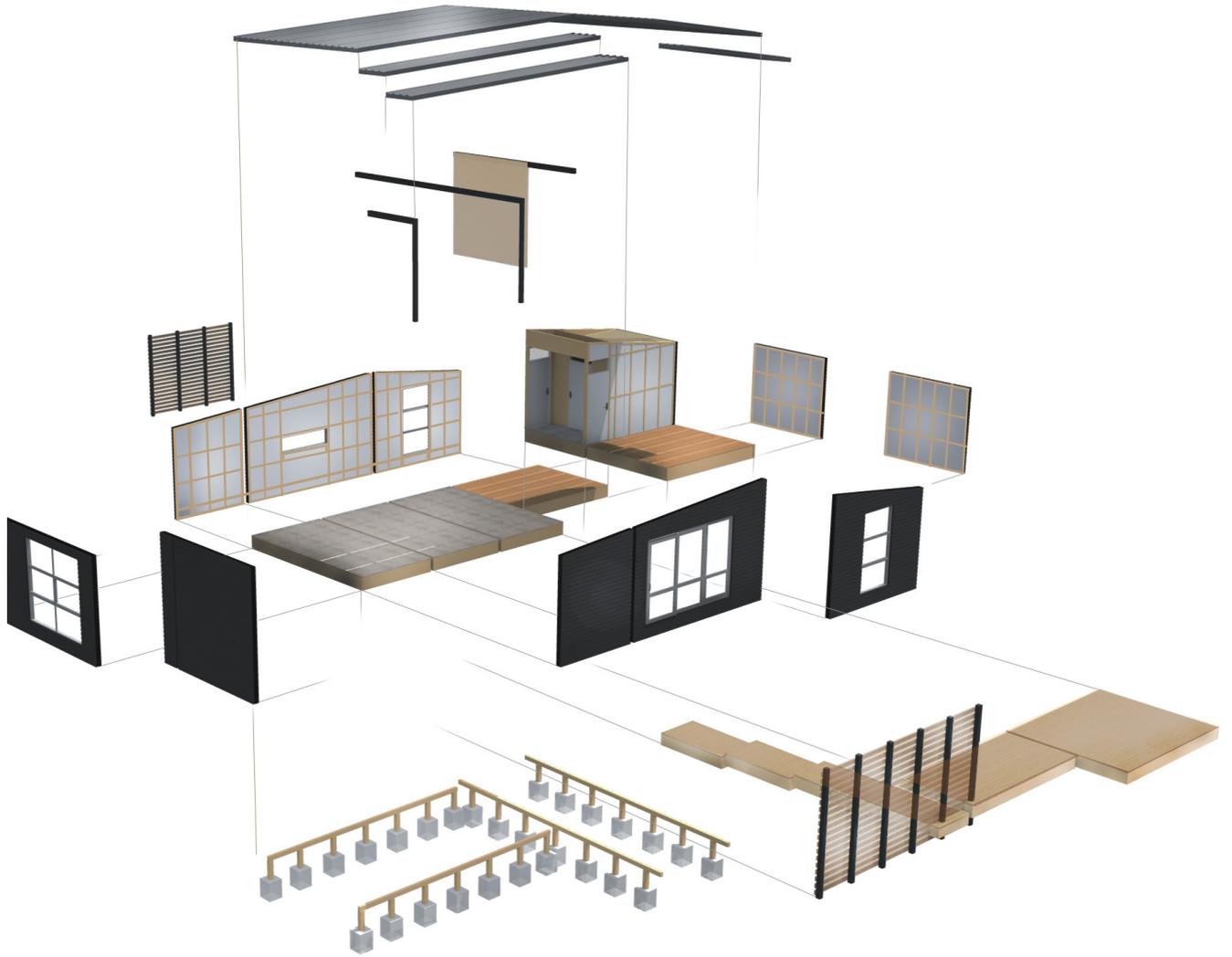


Fig. 10.0.10. Site Application 3 (9.7)
Exploded axonometric of system components

Part One - Summary

The comparatively low proportion of public housing in New Zealand presents a significant requirement for good quality affordable housing for the many households whose needs cannot be met by the private sector. The current portfolio of social housing in Auckland is not meeting the demands of tenants in terms of size and location.

Three major ways have been identified to increase the provision, affordability of housing without reducing quality:

- The intensification of land (and existing infrastructure) within the current city through infill development
- Increased construction productivity and efficiency by the implementation of prefabrication construction methods
- Smaller, more efficiently designed dwellings.

The decline in average household size in New Zealand has consequently generated an increased demand for two-bedroom dwellings, to cater for smaller households, particularly the elderly, single people, with caregiver, couples with children and solo parents. Housing New Zealand acknowledged this demand with the launch of *The RightSize Projects* in 2013. One of two initiatives, *The New Two Bedroom Homes Project*, will deliver 500 infill two-bedroom homes on large existing Housing New Zealand properties to better utilise state owned land. *The New Two-bedroom Homes Project* presented an opportunity to test and explore the methods identified for the supply of quality affordable housing.

Prefabrication has been acknowledged as a vehicle to improve efficiency and productivity to deliver higher quality buildings faster for reduced cost, with reduced energy use and construction waste. The pursuit of prefabricated housing in response to *The New Two-Bedroom Homes Project* is further validated by the maximum two-week on-site construction period target and minimisation of safety risk and disturbance of the infill housing to existing tenants and neighbours.

Despite prefabrications many advantages, historically prefabricated housing solutions have often failed due to the production of non-traditional forms and the design limitations typically addressed through client and site specific design. However, advancement in technology has provided the opportunity to pursue mass-customisation of prefabricated housing rather than the past failures of mass-production. The hybrid, panel + module typology of prefabricated housing has been identified as having the greatest potential for mass-customisation to provide responsive, site specific design, yet with the ability to embrace the efficiencies that prefabrication has been proven to provide.

In response to these conclusions the hybrid prefabrication typology formed the basis of the inquiry for a solution to the problems identified surrounding the supply of affordable in Auckland, and subsequently tested on *The New Two-Bedroom Homes Project*.

Part Two - Conclusions

Site analysis confirmed the requirement for site specific design given the unique and wide ranging site conditions surveyed. The requirement for differences in building form, proportional footprint, solar orientation, and response to contour and context were identified and applied to the development of the hybrid component design.

Initial planning found that efficient utilisation of the material and construction efficiencies of the 1.2m module identified would be better utilised if the MHU maximum floor area requirement allowed tolerance between 60m² and 65m² (the later, currently the maximum requirement in Waitakere). The proposal to raise the maximum floor area requirement to 65m² across all areas of Auckland, moving forward with the *Unitary Plan*, would also ensure an accepted infill housing solution without compromising functionality and quality of space.

The approach to the development of prefabricated components was to produce an appropriate balance between an efficient and affordable standardised system and the crucial prerequisite for quality, sustainable, site specific design. Preliminary design concluded that the initial requirement for one standardised service module was unachievable within both the constraints of the inquiry, and the requirement for variation in building form and proportion. The compromise was made to produce three adaptations across the service module design to ensure both a successful prefabricated system and a quality design outcome. Wall panels similarly were approached to reduce panel joints to one vertical joint to ensure a better architectural outcome and more efficient assembly process, despite an increased panel library. Given the volume and economies of scale of *The New Two-bedroom Homes Project* these decisions were justified.

The development of the floor cartridge system was successful in meeting the transportable thermal mass requirement to lesson the need for wet-trades to achieve limited on-site works and disruption to existing tenants. The modular system achieves efficient material use and a robust and low maintenance pre-finished floor surface. The floor cartridge to wall junction (allowing external cladding and integration of window and door elements) further assists to reduce on-site works to fulfil the target two-week on-site timeframe. The assembly of floor cartridges, service module, wall panels and SIP roof panels are expected to achieve a weather tight envelope within 1-3 days depending on access and the selected MHU design variation.

All bedrooms within the system developed allow for both double and two single bed configurations, allowing flexibility to the different user groups identified. The provision and connection to sheltered outdoor space and the integration of a built-in study provides safe play and learning areas for children. The accessible bathroom design of service modules to future-proof for accessible requirements was a direct response to the large percentage of applicants over 55 on the current waiting list. However, the design development of a two-step floor break alternative in response to contour reduces accessibility. The sites with this option applied however, have challenging access and would not be suited for tenants requiring wheelchair access.

On application to site the design variations and customisable options developed generally performed well in relation to solar orientation, the existing dwelling and the provision of council requirements such as private outdoor space. Although open-linked site relationships and natural surveillance were achieved the exclusion of a traditional front door requires further development to further define paths of ingress. The conditions of Site Application 3 required the exploration of a two-storey alternative to provide social design and outdoor space requirements. As we move forward towards higher density and suburban intensification further detailed development of the hybrid system to achieve multiple storey dwellings is valid, and it is recommended that the 5m maximum height council requirement is reassessed.

Site analysis informed that the existing dwelling was, in many cases, centred on the site. It is suggested that the constraint imposed by HNZC, that, the existing dwelling cannot be moved on the site relocated, as it will cause disruption to the tenants, is reassessed on a case-by-case basis. Many of the existing dwelling types examined were of timber suspended floor construction, with the ability for relocation. The programme objective, to achieve better utilisation of HNZC owned land, would be better met if the existing house was either relocated on-site to provide better separation and relationship to the MHU or relocated off-site to make way for higher density multi-unit housing.

Further Research

Additional to the development of the hybrid system to generate multiple storey dwellings, the further development and research in relation to other housing types and programme requirements is necessary. The design and construction of multi-unit housing requires the development of a firewall and acoustic panel to achieve higher density affordable housing solutions.

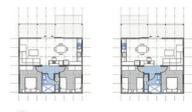
Furthermore the requirement to minimise disruption to existing tenants and a target of two-week on-site construction, ruled out the ability to utilise a slab on grade foundation on flat sites. The further development of a panel to slab on grade connection alternative is valid for application of the hybrid system to other programmatic circumstances in search of an affordable infill housing solution.

The research and design process documented can be used as a model or guide to the methods and considerations required in the development of a hybrid prefabricated system for affordable infill housing in Auckland. Furthermore the system developed has the ability to be applied to privately owned MHU development and adapted to other affordable housing solutions.

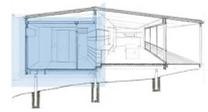
Hybrid Infill An Affordable Housing Solution



Unit 1 plan 100'



Unit 2 plan 100'



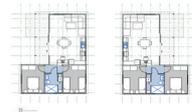
Proposed for residential development 100'



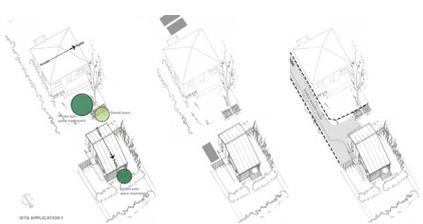
Unit 3 plan 100'



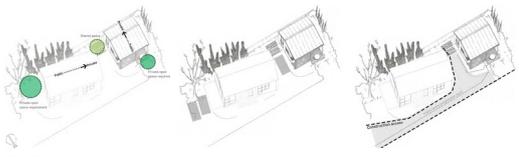
Unit 4 plan 100'



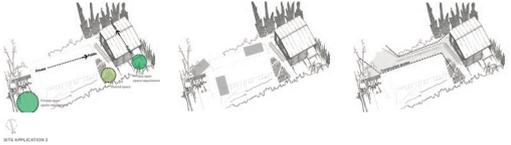
Unit 5 plan 100'



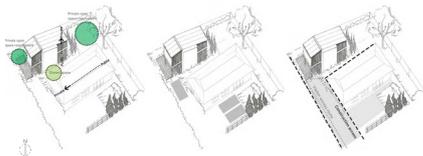
Site Application 1



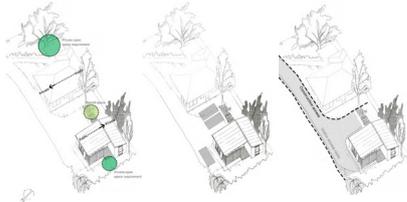
Site Application 2



Site Application 3



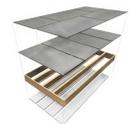
Site Application 4



Site Application 5



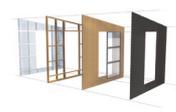
Site Application
Unit 1 plan 100'



Unit 1 plan 100'



Unit 2 plan 100'



Unit 3 plan 100'



Approach from the street - existing existing private outdoor space



Driveway



Connection to external outdoor space



2022 private and street space



Dining space - related to residence



Street view



ON SITE ASSEMBLY OF COMPONENTS



EXPLODED AXONOMETRIC OF SYSTEM COMPONENTS



Section through public and private space 120

Private

...to the existing element
...material availability

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- Fig. 3.0.1. Prefab offers more for less chart.
Reproduced from: Kiwi Prefab: Cottage to Cutting Edge. Auckland: Balasoglou Books, 2012, page 38.
- Fig. 3.0.2 Kiwi Prefab, 2012 publication, Pamela Bell & Mark Southcombe.
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- Fig. 3.1.1.1. Pre-nailed roof trusses and wall frames ready for sub-assembly
Reproduced from: "Prefab Roadmap: A way forward for Prefabrication in New Zealand (2013-2018)" PrefabNZ, page 7.
- Fig. 3.1.2. SIP wall panels assembled on-site, SGA & Studio19 Community Housing, 2012.
Supplied by: SGA Ltd, 2013.
- Fig. 3.1.3 Prefabricated modules combined on-site by Resolution 4 Architecture.
Reproduced from: Resolution: 4 Architecture. <http://re4a.com/projects/house-on-sunset-ridge/>. Accessed 10/07/13.
- Fig. 3.1.4. Service module & floor cartridges lifted into scaffold structure, of Loblolly House, 2006, by Kieran Timberlake Architects.
Reproduced from: Loblolly House: Elements of a New Architecture, New York: Princeton Architectural Press, 2008, page 107.
- Fig. 3.1.5. Onemana Bach by SGA & Studio19, lifted out for overnight delivery, 2010.
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- Fig. 3.2.1. Maison Dom-ino by Le Corbusier, patent drawing, 1914.
Reproduced from: Home Delivery: Fabricating the Modern Dwelling. New York: The Museum of Modern Art (MoMA), 2008, page 53.
- Fig. 3.2.2. R. Buckminster Fuller with model of the Dymaxion House, 1927.
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- Fig. 3.2.3. Walter Gropius and Konrad Wachsmann inspecting prototype of Packaged House / General Panel System, Queens, New York 1946.
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- Fig. 3.2.4. Case Study House No. 8 by Charles and Ray Eames 1945-1949.
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- Fig.3.2.5. Exterior view of Case Study House No. 8 by Charles and Ray Eames, 1945 – 1949.
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- Fig. 3.2.6. Panelised state houses in the 1940's.
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- Fig. 3.2.7. IBS Double-wide prefab home.
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- Fig. 3.2.8. De Geest factor housing production, 1970's.
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- Fig. 3.3.1. Dwell Magazine, The annual Prefab Issue, Real Homes for Real People and Prefab Now.
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- Fig. 3.3.2. Home Delivery: Fabricating the Modern Dwelling, Barry Bergdoll and Peter Christensen.
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- Fig. 3.3.3. MoMA Home Delivery Exhibition, 2008.
Reproduced from: <http://www.treehugger.com/sustainable-product-design/witold-rybczynski-visits-momas-home-delivery-exhibition.html>, accessed 24/01/2014.
- Fig. 3.3.5. Kieran Timberlake Associates, diagram describing process of mass customization.
Reproduced from: Loblolly House: Elements of a New Architecture, New York: Princeton Architectural Press, 2008, page 153.
- Fig. 3.4.1. System3, Diagram showing module + panel concept.
Reproduced from: Home Delivery: Fabricating the Modern Dwelling. New York: The Museum of Modern Art (MoMA), 2008, page 214.
- Fig. 3.4.2. Group Architects, wall components for 1952 panel system.
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- Fig. 3.4.3. Cellophane House, comparison of traditional construction to assembly of wall and floor panels.
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- Fig. 3.4.4. Modules manufactured in Stanley Modular Matamata factory.

- Reproduced from: Kiwi Prefab: Cottage to Cutting Edge. Auckland: Balasoglou Books, 2012, page 80.
- Fig. 3.4.5. Modules stacked three high at site in Auckland. 80 Kiwi Prefab.
Reproduced from: Kiwi Prefab: Cottage to Cutting Edge. Auckland: Balasoglou Books, 2012, page 80.
- Fig. 3.4.6. Modules lifted into position by crane on site in Auckland.
Reproduced from: "Prefab Roadmap: A way forward for Prefabrication in New Zealand (2013-2018)" PrefabNZ, page 3.
- Fig. 3.4.7. Diagram depicting time savings in hybrid programme.
- Fig. 3.4.8. Image showing construction process of the Meridian First Light House by First Light Studio.
Reproduced from: <http://firstlightstudio.co.nz/overview/built-for-speedy-2/>, accessed 12/12/2013.
- Fig. 3.4.9. Early exploded construction diagram showing how parts fit together like a jigsaw.
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- Fig. 3.4.10. Cellophane House repeated sequence of houses in urban context.
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- Fig. 4.1.1. System3, plan and module analysis.
- Fig. 4.1.2. System3, exploded axonometric analysis of system methodology & components.
- Fig. 4.1.3. System3, pre-finished service module.
Reproduced from: Home Delivery: Fabricating the Modern Dwelling. New York: The Museum of Modern Art (MoMA), 2008, page 219.
- Fig. 4.1.4. System3, rendering depicting stacked units. Reproduced from: Home Delivery: Fabricating the Modern Dwelling. New York: The Museum of Modern Art (MoMA), 2008, page 217.
- Fig. 4.1.5. System3 large-scale stacked assembly.
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- Fig. 4.1.6. System3, installation view of assembly at MoMA .
Reproduced from: <http://www.wallpaper.com/gallery/architecture/prefabricated-architecture-nyc/17050477/10548>, accessed 02/02/2014.
- Fig. 4.1.8. System3 assembly and delivery programme diagram.
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- Fig. 4.1.8. System3 interior of prototype looking from through to living and dining
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- Fig. 4.2.2. Loblolly House service module analysis.
- Fig. 4.2.3. Loblolly House floor cartridge analysis.
- Fig. 4.2.4. Loblolly House wall & floor cartridge connection detail.
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- Fig. 4.2.5. Loblolly House wall panel analysis
- Fig. 4.2.6. Loblolly House Western adjustable façade.
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- Fig. 4.2.7. Loblolly House cedar rain screen
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- Fig. 4.2.8. Loblolly House components for on-site assembly.
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- Fig. 4.3.1. Module 1.2, exploded axonometric analysis of system methodology & components.
- Fig. 4.3.2. Module 1.2 planning and module analysis.
- Fig. 4.3.3. Module 1.2 two-bedroom adaptation of plan.
Supplied by: HMA, 09/04/2013.
- Fig. 4.3.4. Module 1.2 exterior view.
Supplied by: HMA, 09/04/2013.
- Fig. 4.3.5. Module 1.2 on-site assembly diagram.
Supplied by: HMA, 09/04/2013.
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- Fig. 4.4.3. All-Pine Prefab at the 1953 Auckland Birthday Carnival.
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- Fig. 4.4.1. Studio 19 Community Housing plan and module analysis.

- Fig. 4.5.2. Studio 19 Community Housing site plan.
Supplied by SGA, 2013.
- Fig. 4.5.3. Studio 19 Community Housing exterior.
Supplied by SGA, 2013. Photography by Jackie Meiring.
- Fig. 4.5.4. Studio 19 Community Housing exploded axonometric analysis of system methodology & components.
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- Fig. 6.0.2. Proximity of site location from Auckland CBD.
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- Fig. 6.0.4. Proportional diversity: wide and shallow, long and thin.
- Fig. 6.0.5. Topography diversity: steeply contoured, flat.
- Fig. 6.0.6. Existing house angled to site boundaries in comparison to existing house parallel to site boundaries. Driveway access pinched by building footprint, driveway access clear of building footprint.
- Fig. 6.0.7. Abnormal shaped building, normal shaped site, normal shaped building, abnormal shaped site.
- Fig. 6.0.8. Existing secondary building requiring removal, existing trees requiring removal.
- Fig. 6.0.9. Diversity such as rear yard size and existing vegetation even though sites are in close proximity and have similar orientation.
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- Fig. 7.1.2. Site application of footprint form to site.
- Fig. 7.1.3. North variation explored.
- Fig. 7.2.1. Transportation types explored in the First Light House - in this application the flat-deck truck approach is viable.
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- Fig. 7.2.2. Determining (transport) Category, based on width and forward distance
Reproduced from: <http://www.nzta.govt.nz/resources/factsheets/53/docs/53-overdimension.pdf>.
"Overdimension Vehicles and Loads, Factsheet 53 June 2013," NZ Transport Agency, accessed 13/07/2013.
- Fig. 7.2.3. Overall maximum height for standard Hiab transport.
- Fig. 7.3.1. Concept plans MHU 1, 1:200.
- Fig. 7.3.3. Concept elevational diagrams of MHU1 panel dimensions.
- Fig. 7.3.3. Concept plans MHU 2, 1:200.
- Fig. 7.3.4. Concept plans MHU 3, 1:200.
- Fig. 8.1.1. Diagram outlining assembly programme.
- Fig. 8.3.1. Exploded axonometric of typical thermal mass floor cartridge.
- Fig. 8.3.2. Detail sketches showing joint between thermal mass floor cartridge and ply with carpet cartridge in bedrooms.
- Fig. 8.3.3. Exploded axonometric of floor panel configuration
- Fig. 8.4.1. Exploded axonometric of service module assembly
- Fig. 8.5.1. Initial detail sketch of wall panel to floor cartridge connection: cladding below floor level to be done on-site.
- Fig. 8.5.2. Initial detail sketch of wall panel to floor cartridge connection: cladding integrated below floor level.
- Fig. 8.5.3. Initial detail sketches of wall panel to floor cartridge connection: wall panel hanging off floor cartridge with steel angle extrusion.
- Fig. 8.5.4. Initial detail sketch of wall panel to floor cartridge connection: wall panel hanging off floor cartridge with steel angle bracket for economy.
- Fig. 8.5.5. Initial detail sketch of wall panel to floor cartridge connection: wall panel fixed to steel angle bracket at the top of floor cartridge, steel angle bracket concealed.
- Fig. 8.5.6. Initial detail sketches of wall panel to floor cartridge connection: wall panel fixed to boundary joist and leveraged off bearer with steel angle bracket.
- Fig. 8.5.7. Initial detail sketch of wall panel to floor cartridge connection: wall panel fixed to bearers with steel angle bracket.
- Fig. 8.5.8. Initial detail sketch of wall panel to floor cartridge connection: wall panel fixed to boundary joist with steel angle bracket (with bearers set back).
- Fig. 8.5.9. Detail Model 1:1, Wall panel to floor cartridge detail: the final solution consists of a large bolt fixing from boundary joist into double bottom plate.
- Fig. 8.6.1. Approach to panel design : Vertical joint only vs. Vertical and secondary

horizontal joint.

Fig. 8.6.2. Exploded axonometric of wall panel configuration.

Fig. 8.7.1. Metal SIP panel specification from Conquerer
Reproduced from: <http://www.conquerorpanel.co.nz/wp-content/uploads/roof-panel.pdf>, accessed 02/12/13.

Fig. 8.9.1. Floor Break : Response to contour.

Fig. 8.9.2. 'T' Plan: Response to orientation, private space and further variation of form.

Fig. 8.9.3. 'L' Plan: Response to orientation, private space and further variation of form.

Fig. 8.9.4. Sectional sketch of floor step development in response to contour.

Fig. 8.9.5. MHU 1 and flipped version, 1:200.

Fig. 8.9.6. MHU 2 and flipped version, 1:200.

Fig. 8.9.7. MHU 3 and flipped version, 1:200.

Fig. 8.9.8. MHU 4 and flipped version, 1:200.

Fig. 8.9.9. Section MHU 2 describing floor break, furniture wall and service module.

Fig. 9.3.1. Interior sketch depicting natural surveillance from kitchen window to entry approach.

Site Application 1

Fig. 9.4.2. MHU 1 Plan, 1:100.

Fig. 9.4.2. Private outdoor space, public to private progression & shared space.

Fig. 9.4.3. Access.

Fig. 9.4.4. Parking.

Site Application 2

Fig. 9.5.1 MHU 4 flipped Plan, 1:100.

Fig. 9.5.2. Private, public & shared space.

Fig. 9.5.3. Access.

Fig. 9.5.4. Parking.

Site Application 3

Fig. 9.6.1. MHU 3 Plan, 1:200.

Fig. 9.6.2. Private, public & shared space.

Fig. 9.6.3. Access.

Fig. 9.6.4. MHU 5 Plan, 1:100.

Fig. 9.6.5. Parking.

Site Application 4

Fig. 9.7.1. MHU 2 Plan Flipped, 1:100.

Fig. 9.7.2. Private outdoor space, public and private progression, shared space.

Fig. 9.7.3. Access.

Fig. 9.7.4. Parking.

Site Application 5

Fig. 9.8.1. MHU 2 Plan, 1:100.

Fig. 9.8.2. Private, public & shared space.

Fig. 9.8.3. Access.

Fig. 9.8.4. Parking.

Fig. 10.0.1. Site Application 3 (9.7) MHU 4 flipped Site Plan.

Fig. 10.0.2. Site Application 3 (9.7) Assembly of components on-site.

Fig. 10.0.3. Site Application 3 (9.7) Section through public & Private Space.

Fig. 10.0.4. Approach from the street - existing dwelling private outdoor space.

Fig. 10.0.5. Ingress and entry to MHU.

Fig. 10.0.6. Living space - natural surveillance.

Fig. 10.0.7. Connection to outdoor private living space.

Fig. 10.0.8. MHU outdoor private outdoor space.

Fig. 10.0.9. Shared sapce

Fig. 10.0.10. Exploded axonometric of system components.

Fig. 10.0.11. Final presentation layout.

Balloon-frame

A wooden building frame composed of machine-sawed scantlings fastened with nails, having studs rising the full height of the frame with the joists nailed to the studs and supported by sills or by ribbons let into the studs.

Brownfield

Urban intensification.

Building information modelling (BIM)

BIM is the wider set of integrated software tools of which digital drawing is just one tool. Elements embedded in a three-dimensional digital model are assigned values which can be independently accessed and cross-referenced to produce useful data during the construction coordination process.

Cartridge

A prefabricated subassembly that groups elements to be easily installed in or removed.

Complete buildings or complete building prefabrication

These are units that enclose usable space and actually form part of the completed building or structure (units may or may not incorporate modular coordinated dimensions). This includes the traditional transportable housing industry.

Component or component-based prefabrication

Components are relatively small scale items that are invariably assembled offsite, such as light fittings, windows, and door furniture. It includes structural members (trusses and frames), fittings, fixtures, and joinery that is cut, sized or shaped away from the site for assembly on site. A complete set of components is commonly referred to as a kit, kit-of-parts, or kitset.

Computer assisted design (CAD)

Computer software that enables designs to be drawn, rendered, rotated and checked in three-dimensions.

Computer numerically controlled (CNC)

Cutting or machining technology that is controlled by computer programming. It is the interface between computer software and manufacturing hardware which enables designs to be directly translated from digital to physical means without manual interference. The manufacturing sectors use this technology widely, whereas the construction industry generally uses the software to produce drawings, but not physical products. CNC machinery is usually programmed with CAD software.

Cross laminated timber (CLT)

CLT is a timber panel produced by gluing layers of solid timber continuous boards together, with subsequent layers rotated 90 degrees to create a 'giant plywood' that can be used for a variety of applications, including roofs, walls and floors.

Greenfield

Urban expansion in rural areas.

Green modern prefab

The term 'green modern prefab' refers to prefabricated housing that is architect-designed, has neo-Modernist design aesthetics and exhibits sustainable technologies or features.

Hybrid-based or hybridised prefabrication

Hybrid-based prefabrication is also referred to as semi-volumetric prefabrication. It consists of a mixture of volumetric or modular units and non-volumetric or panelised units (module plus panel). It may also include component and site-built elements.

Laminated Veneer Lumber (LVL)

LVL is an engineered wood product that consists of thin layers of wood (veneer) glued and pressed together, to form a strong and uniform building material.

Mass-customisation

This is the use of digital technology and CAD-CAM interfaces to produce individual custom designs from standard manufacturing technologies.

Module-based or modular prefabrication

These are units that enclose usable space and are then installed within or onto a building or structure. They are typically fully finished internally, such as toilet/bathroom pods or plant-rooms. Structural units are rooms or large parts of the building referred to as modules, volumes or sections. Non-structural units are used inside conventional buildings or modules, usually to contain utilities, and are referred to as cores or pods.

Off-site

Offsite is a term used to describe the spectrum of applications where buildings, structures or parts are manufactured and assembled remote from the building site prior to installation in their final position. In other words, moving operations that are traditionally completed onsite to a manufacturing environment.

Oriented strand-board (OSB)

Oriented strand board is an engineered wood particle board formed by layering strands of wood in specific orientations.

Panel-based or panelised prefabrication

These are planar units that do not enclose usable space, such as panel systems and cladding panels. They may include windows, doors or integrated services, and are either open-framing or closed-in with clad and/or lining. They are transported to site as flat-packs.

Prefab or prefabricated

This widely refers to materials or combinations of materials prepared away from the construction site for assembly at the final site, and ranging from components, panels, modules, hybrid and complete buildings.

Pre-nailed

This refers to complex components of materials that are cut, sized or shaped and joined together using nail-plate technology. Nail-plate technology comprises engineering software, computer-controlled cutting machinery, and steel plate fasteners. It is a technique commonly used for roof trusses and wall framing in traditional housing construction.

Structurally insulated panels (SIPs)

Panels are typically made using expanded polystyrene (EPS), or polyisocyanurate rigid foam insulation sandwiched between two structural skins of oriented strand board (OSB). SIPs are used as building panels for floors, walls and roofs in residential and commercial buildings.

Standardised

Standardised housing utilises components, methods or processes in which there is regularity, repetition and a background of successful practice. Standardisation is useful to gain efficiencies in prefabrication, but it does not infer standardised product or system outcomes.

Transportable housing

Housing that is transportable includes any house that is purposely built in order to be moved to another location. In New Zealand, this includes yard- and factory-built housing which is supplied by a number of businesses.

