PREFABRICATED FUTURES

Adaptable and productive construction methods
for New Zealand dwellings

Mitchell Holden

1841

Houses very simple. No sections
allotted. Lower part of Queen Street
a swamp. Cost of raupo whares £4;
of weatherboard cottages, £12.

FIGURE 1 - Typewritten note
found amongst
Roger Hay Archive

Prefabricated Futures:

Adaptable and productive construction
methods for New Zealand dwellings

by Mitchell Holden

A 120 - point thesis submitted to Victoria
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Finally, to my parents Blake and Diana, thank you for your never-ending encouragement, advice and delicious recipes. I can't thank you enough for always being there.

FIGURE 2 - Brooklyn House
1:100 concept
model

ABSTRACT

The traditional construction method of the New Zealand home has remained largely unchanged over the last century. These housing solutions that have supported our nation no longer suffice and the 'young home owner' is becoming a distant dream. New Zealand needs homes, and fast. Specialised trades create fragmentation in construction. This results in inefficient processes that divide the stages of constructing a home. What lacks in these instances is accessibility to design. Architects tend to focus on one-off, bespoke builds, whilst transportable home companies create generic, minimum spec designs. It can be argued that current prefabricated solutions are not complete, requiring sub-trades and work onsite that causes delays and construction related setbacks.

Investigation into a key historic precedent has driven this research. This demonstrates that attempts have been made to change the housing model in New Zealand with some success. The precedent aligns with past notions in considering core parts of the home as products. This can create efficiencies in construction. The current demand for housing provides the perfect opportunity to reboot the method in which we build.

This thesis questions how offsite panel assemblies can create a complete prefabricated housing product and improve construction efficiencies. This will still offer architectural choice.

BIM (Building Information Modelling) and parameter driven design are used as a vehicle to demonstrate how more efficient, more collaborative and more controlled design approaches can be developed in order to create a complete construction package.

Design-led research involving constant scale model testing and development led to my prefabricated wall panel design. Named the LapLock panel, I have developed a complete wall, floor and roof panel product system. Designed to be fully fabricated from structure to claddings and services in factory. This produces ruthless efficiencies onsite. The work utilises BIM in the form of Revit and takes advantage of parameter driven families to allow for fast manipulation and output of drawings for panels. A constant conversation between analogue and digital tools (in the form of physical scale models and Revit) strengthened the understandings of the limitations throughout the research.

This thesis offers a new way of considering how New Zealand builds homes. By introducing adaptable and efficient panels that are complete on arrival to site, the Laplock solution provides accessible architectural choice to clients. This future-proofs the construction of the New Zealand home.

FIGURE 3 - IBS prototype model
at 1:25

GLOSSARY

Assembly - component or end item comprising of a number of parts or subassemblies put together to perform a specific function, and capable of disassembly without destruction, parts can be customizable within their parameters

Cassettes – term used by Kieran Timberlake's expression of the house, similar to how a tape cassette has material inside: in this research usually a stressed skin floor panel with inbuilt services and insulation.

Hip Roof - a type of roof where all sides slope downwards to the walls, often at a gentle slope

IBS – Industrial Building Systems

Junction – where two (or more) components of a building meet, usually requiring detailing, ie. wall and floor junction

Modular – employing or involving a module or modules as the basis of design or construction.

Roof/Ceiling Diaphragm – Structural unit of roof and ceiling, complete with services and linings/claddings

Polyvalent – in the context of housing relates primarily to the interchangeability of activities between different rooms, derived from the context of multi-purpose hall or salle polyvalente, the kind of building that is to be found in every French village.

Prefab – prefabricated

PUR – rigid polyurethane insulation, highly effective lightweight insulation that has the ability to bond to most materials.

SIP – Structurally Insulated Panel

Skillion Roof – a mono-pitched roof, usually at an angle, generally where the ceiling and roofing run in parallel, with minimal/no ceiling space

Sticks and Fluff – timber framing and wool insulation

Volumetric- consisting of pre-built smaller modules offsite, then assembled on site, usually breaking a home up into a series of pieces

All Drawings are oriented North up unless stated otherwise

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Central Otago least affordable for housing

Regions > Central Otago

Central Otago has overtaken Auckland as New Zealand's least affordable area for housing.

The Massey Home Affordability Report compares house prices with wage levels and takes into account the cost of borrowing to discover where houses are most out of reach.

"Central Otago Lakes, including Queenstown now surpasses Auckland/Thames/Coromandel in the index as the most unaffordable region in New Zealand," the report said.

Auckland's median house price dropped by \$51,944 or 6.1 per cent in the last quarter, leaving median house prices to stand at \$800,000.

Central Otago Lakes, including Queenstown, now surpasses Auckland/Thames/Coromandel as the most unaffordable region in New Zealand, the Massey Home Affordability Report says.

Queenstown's housing shortage near 'crisis' point

CATHERINE HARRIS
Last updated 05:00, May 8 2017

Queenstown is a beautiful place with real growing pains.

There's no question Queenstown is on a roll.

The country's unprecedented tourism boom is generating more jobs in the picturesque town, drawing more workers.

At the same time, investors are swooping and a flood of people from other regions, notably high-priced Auckland, are moving there for the lifestyle.

SOCIETY

You think Auckland's housing crisis is bad? The Queenstown car crash will be worse

But this isn't Auckland. Economic inequality are writ large, as P...
...the worst aspect...
...the worst aspect...
...the worst aspect...

So what's the significance of the...
...the significance of the...
...the significance of the...

Auckland Council unveils how many affordable homes built

...the solution for the city's housing crisis has been...
...the solution for the city's housing crisis has been...
...the solution for the city's housing crisis has been...

The Mess We're In: Auckland's Housing Bubble from a Construction Sector Perspective.

Professor John E. Tookey,
Auckland University of Technology
May 2017

A report prepared for The Policy Observatory,
Auckland University of Technology

Queenstown's housing crisis the price of living in paradise? Up to 30 in one house

...the struggle for housing in Queenstown - but the struggle for housing in Queenstown - but the struggle for housing in Queenstown...

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BUSINESS

Neighbours up in arms over five homes on single Auckland section

13 May 2017 12:05pm

Neighbours are up in arms over a proposal to build five three-storey terraced homes on an Auckland section currently holding one house and a garage.

Pending council approval, the development would see the picturesque Mt Albert house bowed to make way for the cluster of new homes on the 607sq m section.

Christchurch's housing paradox – the downside of a building boom

MICHAEL WRIGHT
Last updated 10:17, March 3 2017

Avaara Green is one of a number of large-scale housing developments on the outskirts of Christchurch.

Christchurch's rental market is oversupplied and freshly built terraced houses are sitting empty and unsold in the suburbs. How did the city with the real estate market decimated by the earthquake get here?

Affordable housing hitch

By Vaughan Elder

News > Domestic

Dunedin Mayor Dave Cull has declined a request from local Māori and social agencies for the Dunedin City Council to lead a crisis meeting over a lack of affordable housing.

"We are seeing a trend of landlords ending and not renewing leases, which forces tenants into a rental market they often cannot afford."

How the Auckland housing crisis is hitting small and medium businesses

24 Apr, 2017 6:05am

If the housing market continues to run unchecked local businesses looking to recruit staff are going to find it increasingly harder.

SOCIETY

'These problems will not be fixed by the market'

By Bruce Plested | Guest writer
June 28, 2017

Mainfreight founder Bruce Plested has used the company's annual report to criticise the political response to the housing crisis, educational underachievement and the degradation of the environment. Here's an edited version of what he wrote.

Mainfreight's 39th year saw a record profit, up 17% on the previous year. As is the way with business and life, there are always challenges. On November 14th 2016, Wellington and the South Island were rocked by a 7.8 magnitude earthquake, centred on Kaikoura, resulting in two deaths and over 50 injured. At the time of writing, there have been 15,000 aftershocks. This earthquake cut the main road and rail links between Picton and Christchurch, leaving no rail options, and the only road link available through Spring Creek, on a road not designed to carry lots of trucks.

Labour promises 1000 affordable homes in Queenstown over 10 years

VERNON SMALL

Last updated 14:30, July 20 2017

Labour leader Andrew Little and finance spokesman Grant Robertson unveil Labour's fiscal plan including \$2 billion to fund its KiwiBuild policy.

Labour is pledging to build 1000 affordable houses in Queenstown over the next decade as part of its KiwiBuild policy to build and on-sell 100,000 homes over the next 10 years.

The houses would cost up to \$500,000, leader Andrew Little said.

"There will be good, modern starter homes, sold at cost to first home buyers. Three-bedroom homes in terraced housing will cost \$500,000 with smaller houses costing less. That will put home ownership back in the reach of young couples and vital workers like police and teachers who are being priced out of Queenstown," Little said in a statement.

Construction costs rising as peak approaches - RLB

CHRIS HUTCHING

Last updated 05:00, February 19 2017

Shortages of skilled labour are adding to construction costs in 2017.

New Zealand's wave of construction will peak next year, predicts construction and quantity surveyor consultancy, Rider Levett Bucknall.

Rising construction costs will continue to outstrip inflation as the New Zealand and Australian economies enjoy economic growth over the next two years.

RLB's Auckland director, Geoff Speck, said the residential market is fuelling growth.

The only way is up if Wellington wants to solve its housing crisis, says report

COLLETTE DEVLIN AND MATT STEWART

Last updated 19:57, May 24 2017

Wellington's housing density could change in suburban areas if the Housing Forum recommendations are adopted.

Wellington needs to grow up if it wants to solve its housing crisis, a report says.

At the heart of the problem is the lack of supply, and one way to solve it is raising height limits in the suburbs to match those in the city centre.

The advice comes from a recent Housing Forum, at which 70 stakeholders from the housing sector, community organisations and politicians came up with solutions to problems identified by the Mayor's Housing Task Force.

BUSINESS / ECONOMY

Are the wrong kind of houses being built in Auckland?

From Mike To Noon, 9:08 am on 15 May 2017

Share this: [Facebook](#) [Twitter](#) [Google+](#) [LinkedIn](#)

Too many of the wrong type of stand-alone, customised houses are being built in Auckland, a professor of construction says.

Professor Tookey said although it was politically challenging, people needed to be compelled or encouraged to sell their rental properties. Photo: 123RF

Tuesday, 27 June 2017

Housing pressures

By Guy Williams

Regions > Queenstown

Building and Construction Minister Dr Nick Smith says he cannot rule out the Government extending its special housing legislation when it expires in just over two years.

Dr Smith told the *Otago Daily Times* the issue would have to be addressed next year.

"The appropriate thing would be that whoever is in government in 2018 would reassess progress, consult with key councils like Queenstown's, and make a decision as to whether further provision was required."

The district's rapid growth meant the council had to identify new areas for residential development, and he was "very supportive" of the Queenstown Lakes District Council's proposal to apply the special housing mechanism to the Ladies Mile.

Last week the council decided to seek public feedback on including the Ladies Mile as "category 2" land in its special housing policy.

If it approves the move at its August meeting, it would open the way for new housing in an area widely regarded as Queenstown's rural gateway.

Dr Smith said if the council did not create additional areas, housing pressures on families and workers would only get worse.

Dr Nick Smith

\$1,403

Minimum Fortnightly Repayments

Loan: \$550,000

House Price: \$ 650,000

Deposit: \$ 100,000

Loan Term: 30 Years 0 Months

Interest: 5.29 % p.a.

Payment Frequency: Fortnightly

Bryce Pearce

@Brycepearce

Follow

If \$650k is affordable and affordable is defined as repayments being no more than 30% of income, how many are earning \$2333 per week?

8:01 AM - 4 Jul 2017

28 43

INTRODUCTION

1.1 - Situation

By 2031, New Zealand will be short 115,000 homes and over the next 30 years, Auckland alone will need 400,000 homes (Prefab NZ 2015). A typical 120m² traditional house build, using traditional timber framing ('sticks and fluff') takes approximately 14 -16 weeks, with a myriad of problems that can occur during this time, particularly weather related. Compared to this, in the same test, a prefabricated panelised house took half the time of only 7 weeks (Burgess, Buckett, and Page 2013). Using prefabrication, Fletcher Construction using have now built a house in just one day (Newshub 2017). It is apparent the New Zealand media depicts a housing crisis to its audience, as Fig. 4 demonstrates, but what is lacking is the same attention towards a solution such as prefabrication.

On a positive note, Concision, a Christchurch based construction company, have worked alongside Mike Greer Homes and are producing homes in their factory. They are creating prefabricated walls, roofs and floors, combining them into modules. They currently estimate their ability to be around 1000 houses a year (Concision 2014).

Recently, the new Labour government announced a plan to provide New Zealand with 100,000 new houses over the next 10 years. That's 10,000 built homes a year. To place these numbers and Concision's work into context, the country needs 10 factories like Concision to create this supply. Considering traditional construction takes twice as long, it can be seen that prefabricated building components are crucial for New Zealand's housing development plans (Burgess, Buckett, and Page 2013).

FIGURE 4 - Collage of New Zealand media reflection on housing (left)

FIGURE 5 - Concision panel factory in Christchurch, NZ (above top)

FIGURE 6 - Concision walls being installed onsite (above bottom)

New Zealand's Housing Shortfall

New Zealand's Building Industry

32,700

Self-Employed
63.80 %

13,800

1-5 Employees
26.89 %

3,700

6-19 Employees
7.29 %

900

20-100 Employees
1.78 %

80

100+ Employees
0.16 %

Cost of Building in New Zealand

27 % Materials
18 % Labour
45 % Land
10 % Other (profit, plant and fees)

All data from BRANZ E626 2014

New Zealand's Current Construction Methods

Component

Panel

Volume

Hybrid
(Pod + panel)

Complete
building

10yrs 90 %
5yrs 60 %
Now 33 %

10yrs 30 %
5yrs 15 %
Now 5 %

10yrs 20 %
5yrs 10 %
Now 2 %

10yrs 10 %
5yrs 5 %
Now 1 %

10yrs 20 %
5yrs 10 %
Now 2 %

A series of research polls undertaken at the beginning of 2017 highlighted over 1000 people's understanding of *the Most Important Problems Facing New Zealand*. Housing is seen as a key issue for many New Zealanders, almost doubling in percent over the last year (Roy Morgan Research 2017).

Currently, the author believes the key issue with prefabrication is the lack of architectural design quality of the panels and joins. Additionally, we must consider the level at which we design an element. Root level design will influence the entire architecture of the home. After all, advocates and experts for mass customisation encourage the design to occur at the root level of a product (Kieran and Timberlake 2003).

A contrast exists between the traditional construction method of a one-off bespoke build and the in-factory prefabrication of housing components. Could this root level design at factory production level remove the lack of engagement an architect has throughout the lifecycle of a project? In doing so this could prevent the continuous need for documentation of bespoke designs (Hays Recruiting 2016).

FIGURE 7 - Prefab NZ 5 Year impact report findings from 2010 to 2015

Typifies living conditions and habits

ROOM PLANNING SYSTEM

Panel System
IBS joining methods

ADAPTABLE HOUSING ASSEMBLY

MORE DESIGN
MORE PEOPLE
FOR LESS

Reducing designers workload

EFFICIENCY ON SITE
PANEL AS A PRODUCT

RESEARCH QUESTION:

How can innovations in offsite panel assemblies improve efficiencies, whilst retaining architectural choice, in New Zealand housing?

FIGURE 8 - Thesis research aims and areas diagrammed by the author

1.2 - Scope, Aims + Objectives

This thesis aims to utilise design-led research as a means to produce a final design, as opposed to developing a design from research. With a project that negotiates a field with such a large scope and level of specific professional input, a clear and defined framework for this thesis has been outlined.

In essence, the research delves into three key areas: the modularity of the house, the adaptability and efficiency of a wall, floor or ceiling panel, and the detail design of these elements.

In narrowing the focus for this thesis, New Zealand's critical housing issues create a motivator for change. The notion of revisiting the housing model in New Zealand has been discussed on a multitude of platforms (Gray and Witcher 2013), (Church 2016), (Housing Shareholders Advisory Group 2010). Yet nothing to date has critically shaken the construction industry and therefore the housing market. Current housing-volume builders continue to build in the traditional timber-framed way.

FIGURE 9 - Panel vs. Modular sketch diagram

The market, as outlined by John Tookey in his report *The Mess We are in...* particularly influences affordability. Unfortunately, in the scope of this thesis, affordability in relation to market price is something that cannot be changed by a designer. The focus of this research aims initially at the improvement of the wall as a product. It then explores how this could then manifest toward a floor and ceiling component that could come to influence the new residential builds in New Zealand. It also acknowledges that the same dwelling in Auckland is substantially more expensive than the same home in Wanganui (Tookey 2017). Crucially, it is the efficiency and the adaptability that is the focus of the research, particularly in relation to onsite construction.

A significant portion of this thesis reports on design testing of modular solutions and their successes and failures. The detailing of the author's LapLock system largely ignored calculations and strength testing, but looked to meet standard NZS3604 and building code requirements, such as cladding overlaps, lintel sizes and the like.

From the outset, the design seeks to create a more holistic method of construction that can be applied to multiple building scenarios. Through the major design phase, it tests whether a panelised wall system can create a form of quality architecture.

1.3 - Research Methodology

The research method focused primarily on taking elements of existing solutions, applying improvements from other case studies, and then testing the design via a series of New Zealand contexts. Initially, design tests derived from earlier projects by the author took place. An integral part of this research was the use of scale modelling to test theories, dimensions and ideas of the author and the case studies. This placed existing 'hunches' on the table, helping to identify limitations and successes. The research method relies on a discourse between the testing of the modularity of a space, and a modular panel format. These are tested side by side to allow learnings from one to influence the other. It follows a digital and analogue conversation between scale model testing and BIM modelling in Revit.

The research takes a macro to micro approach, rather than the opposite. It takes a wider holistic understanding of the needs of a house and briefly defines these to influence a panel design. It puts them to the test in three site studies in order to understand the limitations. The limitations are then improved, informing the detail design phase. This ultimately creates the product the author has termed the 'LapLock' panel.

Whilst a literature review is contained mainly in Chapter 3, other literature sources and case studies have been spread throughout the thesis and are referred to when and where necessary. A constant critical reflection, and a conversation with the initial case studies throughout the thesis formed a stronger argument for design decisions and changes.

FIGURE 10 - Research Methodology outline

02

BACKGROUND

This chapter outlines the construction related build-up to New Zealand's housing problem, the attempts to change housing models and the downfalls that traditional building methods have.

FIGURE 11 - Lustron Factory
prefabricated home laid
out before assembly,
Chicago

2.1 - The Building Method and its Issues

New Zealand has a tradition of timber-framed building. Although the dream for many European settlers in the 1860's and 70's was a New Zealand built from masonry, timber was light, easy to construct and offered great flexibility (Isaacs 2010). New Zealand has long had seismic issues that preclude against the use of brick, stone and even poorly reinforced concrete. These quickly succumb to the movement of the earth, whilst timber framing survives (Isaacs 2010).

The essence of timber framing is the use of a large number of small sections of timber elements, with low structural capacity distributing the applied load in conjunction with "non-structural" elements such as linings and claddings (Shelton and Beattie 2011). Load bearing vertical members such as studs are continuous, while horizontal dwangs are cut in between the studs. NZS3604 was developed in the 1970's to standardise our building methods on timber framing. Apart from significant reviews made in 1991, 1999, 2011, methods of building have not changed since in any significant form for the last century (Shelton and Beattie 2011).

Of a particular significance to this research is the subject of permanence in the method we deliver our dwellings. Currently, areas in Christchurch have an overstock of houses firmly rooted to their foundations in a time where more houses are needed in places like Queenstown and Dunedin (Wright 2017). Could this be seen as wasted opportunity? If possible, could these walls, floors and ceilings/roofs be removed from this excess housing in Christchurch to a new location?

In this research, the question of permanence can have a direct influence on the notion of adaptability. Adaptability also needs to consider reusable characteristics. In the context of a 90x45mm stud, whilst it is adaptable to multiple situations in housing as a piece of timber, its lifespan is cut at the time it is fixed into a wall system. Stepping up a scale, the same studs then create a typical wall with exterior/interior claddings. Once fixed to a concrete floor slab, the reuse value of this entire wall section diminishes further. With construction and demolition waste contributing to over 50% of New Zealand's landfill waste, the adaptability of a new wall product or system that minimises this percentage is critical and thus is a parameter of this research (Inglis 2007).

New Zealand is very competent at building with traditional timber framing: it is our most popular method with over 90% of residential dwellings using timber frame in 2015 (Rosevear and Curtis 2013). Our stick and fluff houses have been the foundation of the housing supply since the uptake of the colonial cottage (Bell and Southcombe 2012). Yet the seasonal, outdoor and onsite constraints of traditional building often exacerbate construction times and create delays. As an example, five out of seven projects on New Zealand's Grand Designs had significant delays and weather problems onsite. One of the fastest ways to reduce building costs is by reducing the time taken in production, not focussing on costs. In 2008, only a quarter of New Zealand KPI survey projects were on time (Caldwell 2008).

The typical process for building a house in

FIGURE 12 - Comparisons within the New Zealand construction and design industry by author

New Zealand sees the roofing placed on after the wall framing is erected. A milestone in building, the roof shout, indicates the framing and flooring is now sheltered from downpour. This usually happens after numerous weeks of site preparation, pouring or constructing the slab and then the framing of the walls and the roof. The downside to this method is that weather is allowed to access these elements that become internal and integral parts of the building structure. Materials dry out, but it is better prevented in the first place.

FIGURE 13 - Sketch by author showing ideal construction path using preclad and prelined wall, roof and floor panels

2.2 - The Wall as a Product

Architects that are active in the mass customisation construction industry have begun to look at and analyse the way in which we build in comparison to the product industry. Henry Ford's one size fits all method no longer makes for a successful product, project or service. Ford's method was essentially providing a cheap product to a large pool of potential customers. This was made possible by repetitive assembly items, and the limited choices of the product (Kieran and Timberlake 2003).

"You can have any colour so long as it is black." Henry Ford

Ford restricted choice in order to maximise on standardisation. With the *any colour so long as it is black* attitude, reduced variability in colour down to zero. Ruthless efficiencies in the factory, and the invention of the assembly line method, helped lower the price further. This in turn brought the price of the Model T Ford down from \$850 to \$300. The Model T was available for 20 years, essentially unchanged, except for a lower price each year. Economies of scale achieved the massive discount on price.

In this century we desire choice, expression, individuality, and the ability to change our minds at the last minute. The new client mandate for choice has already taken over the commercial product industry. Nike, Dell, and the clothing and automobile industries have all instigated changes. They offer real time, lower cost and better-quality items in their companies to meet the mandates of the customer. In the same way, a certain amount of economy of scale can also be found in house-building, with numerous volume-builders standardising on a select few designs. With the advent of mass customisation, things today can be different. By offering a large choice of assemblies, via an increase in smaller parts that are customisable, these companies can tailor customised options to the right market (Kieran and Timberlake 2003).

FIGURE 14 - Ford Model T factory line

03

CONTEXT

This chapter aims to briefly outline a theoretical framework, from historic ideas, that would align with change in New Zealand's construction industry. It draws from theorist Buckminster Fuller, and uses his passion and reasoning for changing the housing model as a vehicle for the design experiments.

FIGURE 15 - Buckminster Fuller's Wichita House prototype, which never met the designers satisfaction

3.1 - Positioning

You apparently cannot standardise. The word "standard" refers to the symbol, a standard bearer who typifies the group ideal. By "ideal" I mean the latest, sensational refinement towards truth along any one direction, along any one line. The standard then, being the group ideal, is an abstract. You cannot freeze up standards. (Fuller, 1929, p87)

Buckminster Fuller challenged the early 20th Century housing models through comparing the processes to that of the industrial revolution. Aeroplanes and automobile manufacturing developments were often the key focus of his addresses. In particular, the observation that throughout the levels of design, these machines always came to a final design, where only limited parts or assemblies could be changed (Krausse, Fuller, and Applewhite 2001).

Fuller advocated that the construction system needed to progress to the advancements the automobile industry had made, particularly in the movements that Henry Ford created. Of particular note, Fuller's lengthy discourse on the manufacturing of a car provided comparison with the manner current architecture is created. He outlined the particular notion that the "one thing we have to have the most and the major expenditure we have in life is housing" (Krausse, Fuller, and Applewhite 2001, p87).

In opening Fuller's address to the Architectural League in New York, Harvey W. Corbett proclaimed to the audience:

Do you realize that every time an ordinary house is built and set on the ground and fastened to it, there is not only no replacement value but that, if that thing is abandoned, it costs money to take it down? Every cent that is expended in the house is ended there. Nothing comes out of it (Corbett, 1929, p84).

FIGURE 16 - Dymaxion House, third test model, late summer 1929

04

CASE STUDIES

In beginning design-led research, a number of case studies were examined in order to outline the first design stage.

The case studies will cover projects personally undertaken, as well as examples from New Zealand and afar. These case studies have been chosen for particular strengths, such as their modular method or unique detailing, and are critically evaluated to outline the weaknesses and their relevance to this research.

FIGURE 17 - SARC 455 project -
Modular Housing Units for
Mount Victoria, Wellington

BEDROOMS

BATHROOMS

3 MODULES (3 FULL LINE SPACES) 3000 SQ. FT.	3.5 MODULES 3500 SQ. FT.	4 MODULES (4 FULL LINE SPACES) 4000 SQ. FT.

4.1 - Modern Modular

Location: North Carolina, USA

Prefabrication Level: Modular – traditional construction

Architect/Designer: RES4

Phase: 1 year design, 2 months site prep, 3 months on site

Size: 190m²

Perhaps the most developed and thoroughly researched method of designed modular architecture, RES4's Modern Modular outlines a typological bible of work derived from a simple scalar system.

Their work derives from the identification of a market gap, one that is of particular relevance in New Zealand's residential housing portfolio. RES4 identified that as architects if they could design a relatively affordable domestic space, they might be able to tap into the country's emerging and broadening design consciousness (Tanney, Luntz, and Arieff 2013). Similarly, this parallels with New Zealand's hunger for well-designed modern and affordable homes.

The blueprint designed by RES4 outlines typical spaces that can be grouped and accommodated in the house. The design works through multiple scales to produce a myriad of final forms the home can take.

FIGURE 18 - RES4 Modern Modular housing layout types and methods (top left, above)

FIGURE 19 - RES4 Dwell Home factory and onsite construction (bottom left)

Differences in architectural qualities are apparent in the American influenced design, with obviously larger floor plates with a significant amount of circulation space to allow the modules to work and connect.

The formal gestures created by the architect blur into one typical form, no matter the amount of variations. The modules create a rectilinear, box oriented home. This poses the question as to whether the architectural expression begins at the root of the module grid. In this sense, a greater emphasis is placed upon the materials used to provide differentiation.

A further critical observation is the continued use of traditional construction methods inside the factory. The design utilises a factory to provide economic and timeline benefits. The modules could be improved with panelised construction in the factory. This could avoid the typical construction notion of focusing on existing commercial methods of residential prefabrication (Tanney, Luntz, and Arieff 2013).

The nature of the American home also nullifies much of RES4's work on a comparative basis to New Zealand. Whilst modular and efficient, the majority of their work sits well above typical house size for New Zealand. A 2-bedroom modular prefab home is 198m² and a 6-bedroom home 423m² (RES4 2013). By comparison, in New Zealand a two bedroom home would typically be sized between 70 – 100m² (Genius Homes 2017).

The Dwell Home was RES4's competition winning house. In a client driven challenge, run by Dwell Magazine, 16 architects were invited to design an innovative prefabricated house for \$200,000. Res4 was chosen as the winner. Often whilst the innovation of construction occurs, other traditional methods don't keep up. The build only took one month to be closed-in completely. This was thanks to the modularisation of the main exterior shell. Yet it was the interior assemblies such as joinery that slowed the process down (Tanney, Luntz, and Arieff 2013). The roof module was able to be installed on Day 2 of onsite construction thereby dramatically reducing any opportunity for weather related incidents causing delays or the need to re-work (Aarieff 2009).

FIGURE 20 - RES4 Three Pines Home, 2 Bedrooms, 3 Bathrooms - 200m²

4.2 - Industrialised Building Systems

Location: Auckland, New Zealand

Prefabrication Level: Panelised

Architect/Designer: The late Roger Hay and the late Ivan Juriss

The Industrialised Building System was developed by Keith Clark, a Palmerston North property developer, alongside architects Roger Hay and Ivan Juriss. The team saw an opportunity in New Zealand's need for housing. This was to create a similar system to that of the American post war modular housing movement (Bell and Southcombe 2012). In doing so, they strived for a better housing model, that could adapt and expand as the requirements for the house changed.

The Xibis was the first house to roll off the IBS assembly line. The panelised housing system, assembled in crane-able modules, and then trucked to site, looked initially to be the future of New Zealand housing. Of particular interest to this research was the development of a room module system and an accompanying 'block game' model (Bell and Southcombe 2012). This would allow the designers and the client to physically plan their building for the site at the very first interaction.

FIGURE 21 - IBS 'Weekend House' build in the Avondale Factory (top left)

FIGURE 22 - IBS Prototype House concept image (below left)

FIGURE 23 - IBS Block game demonstrating the possible layouts of the module (above)

Leaving behind a legacy of enduring success such as the one-piece fiberglass shower, Hay and Juriss developed multiple systems that allowed them to create the modular forms (Bell and Southcombe 2012). Wall construction consisted of a three-layer stressed skin sandwich panel system with its own specialised jointing system. Hay patented a cellular floor sandwich panel under the name Ribsel (Hay 1972). The units were assembled and trucked to site in lots of 10 or more.

The panel systems utilised a 1200mm and 800mm wall panel, combined with 200mm corner post. The wall lengths could then fit within the 2400mm, 3600mm, 4800mm module and so forth. This case study has become the focus of this research, and the historic system could be upgraded as a modern-day solution.

FIGURE 24 - The IBS Xibis house hand crafted model from the Xibis brochure (top)

FIGURE 25 - Stages of expansion of the IBS home allowing the addition of rooms (bottom)

Alongside the wall panels, the IBS research division developed a stressed skin floor. This was made from a timber framed grid, and then laminated with a 9mm strand board either side. The Ribsel was revolutionary in the 1970's, able to span up to 7.2m and was significantly lighter than other floor systems (Industrialised Building Systems Limited 1972).

NOTE: Every module length of wall has a 200 mm corner panel each end, and must contain one 800 mm panel* - at any point - all other panels are 1200 mm or divisions of 1200 (2x600, or 1x400 + 1x800) - or larger sizes in increments of 400, 600 or 800 mm* (or two 400 mm panels).

FIGURE 26 - Roger Hay's outline of the modular system, note the red floor plate lines are off-centred to the wall panel dimensions

4.3 - NZSIP

Location: Cromwell, New Zealand
Prefabrication Level: SIP Panel
Architect/Designer: NZSIP (in-house)
Phase: wall product solution
Size: 2750 mm x 1200 mm

Located in the Central Otago town of Cromwell is one of New Zealand's few Structural Insulated Panel (SIP) manufacturers. NZSIP offers innovative construction method in using SIPs, which are an ideal building product for the harsh climate in Central Otago. Although this isn't a complete building, at the detail level, NZSIP have looked to provide innovation within assembly by focusing on the wall as a product.

FIGURE 27 - NZSIP factory in Cromwell, New Zealand

Nelson Pine
Nelson Pine
Nelson Pine

Nelson Pine
Nelson Pine
Nelson Pine

PAA

Whilst not new technology, NZSIP had the initiative to pre-wrap the panels with Solitex Extasana, and include a camlock aligning bracket cast into the panel. This removes any human error in erecting the panels. The factory had issues with the transportation process of the panels, with third parties often ripping and damaging the Solitex Extasana, which would then not pass inspection. When queried if NZSIP would ever consider an entire pre-clad system, the difficulties in multiple material processes under one roof were cited.

In the current factory, having textiles, carpentry, chemical bonding process and combustible plastic materials has proven difficult. Adding another process such as cladding and services could be difficult and require a significantly larger factory (Maund 2017).

The panels use PUR foam core with 10 or 13mm OSB. They come in three thickness, 115mm (R 4.5) or 165mm (R 7) floor, wall and roof panels and 215mm (R 9.4) roof panels. Walls up to 1220mm and 3m high are available, with roof and floors up to 1220mm and 3.6m long.

As a detail case study, NZSIP provides insight into the difficulties of innovation. Currently, they produce more standard dimension SIPs than the innovative camlock, pre-wrapped SIPs.

FIGURE 28 - NZSIP wall and roof panel join with LVL 8 top plate (left)

FIGURE 29 - NZSIP cam lock used for locating panels (non structural)

4.4 - Connection

Location: Wellington, New Zealand
Prefabrication Level: Modules – traditional construction
Architect/Designer: Author
Phase: unbuilt
Size: 5m x 4m modules

The motivations for this thesis came from a project undertaken in a 4th year elective paper, SARC 455 House and Home. The conceptual challenge to re-imagine the home evoked critical perspectives on the processes that occur in the typical New Zealand dwelling. It also dealt with the uniquely dimensioned sites of Mount Victoria in Wellington, some of which were only 6m wide yet 30m long.

The project, Connection, conceptually separated six of the basic processes - gathering, sleeping, cooking, eating, washing, and working. This is in alignment with Bernard Leupen's common activities across most cultures, outlined in *Housing Design: A Manual* (Leupen and Moijj 2011). It proposed that each of these modules could be purchased by the home owner and the flexibility of the design meant arrangement of the units provided endless options. The units then were 'capped' with window or door modules. The design particularly suited the narrow sites of Mount Victoria, where access and constraints required a craned module option.

FIGURE 30 - Module layout options available for the Connection design (top left)

FIGURE 31 - Mt. Victoria streetscape view of Connection model (bottom left)

FIGURE 32 - Connection interior showing mezzanine level (top)

FIGURE 33 - Existing Mt. Victoria housing typologies (bottom)

This 2016 student project was further developed in 2017 to allow it to be used as a vehicle to test the limitations of a whole module, and explore the construction options at an early phase. Early design testing was crucial in order to highlight the limitations of modular designs. The method of how the modules connected together was further examined and a sliding lap system was chosen. This is outlined in Chapter 5.

This project began to test the notion of the adaptable home. What was proven in the later stages of the project was its inability to adapt well. The modules could only connect in one direction to allow the egress spaces to connect and therefore lacked the ability to adapt to a different site. One client therefore could not choose to mirror the kitchen module for a different view or sunlight access as the module was not symmetrical.

FIGURE 34 - Author sketch demonstrating the inability to mirror modules due to asymmetric design

05

MODULAR EXPLORATION

This design exploration chapter addresses the issues and complexities in creating a system that holistically respects the needs of dwelling, whilst creating efficiencies through prefabricated design. This chapter's focus is on outlining and analysing modular methods and constraints, in particular the key precedent of IBS. This section centres around research into design and then tests notions on modularity.

FIGURE 35 - 1:100 Scale room module test, inspired by traditional gable forms

PANEL

MODULAR

5.1 - Module Size

The IBS panel system became a key precedent for the modular method research. Hay and Juriss designed the system to fit within a 1200mm module (2400mm, 3600mm, 4800mm and so on) floor plate. This module offered the greatest flexibility whilst still retaining a set amount of parts. Hay advocated for the 400mm module, as opposed to the 300mm module. He was opposed to the 600mm panel for not providing enough fine tuning of sizes, stating that it is the “hallmark of poor design to take a basic module (ours – IBS – being 1200mm) and just cut it in two” (Hay 1972). The 400mm module suited the optimum dimensions of typical rooms as well.

Therefore, the panel sizes (in mm) obtainable are:

400 ; 800 ; 1200 ; 1600 ; 2000 ; 2400 ; etc in 400mm increments.

The floorplate (to exterior edge) sizes obtainable (in mm) are:

1200 ; 2400 ; 3600 ; 4800 ; 6000 ; 7200 ; etc in 1200mm increments.

So why a 1200mm module? Apart from fitting to typical room sizes, the module size has material usage benefits. The standard widths of sheets of plywood, GIB and other claddings are 1200mm and compared to a 900mm (based off 300mm) module, the material efficiency is higher for bracing sheets. This in turn reduces wastage. A 1200mm module allows for more appropriate window structure, allowing enough spacing for jambs and studs to support a window.

Other modules systems have struggled with the 1200mm and therefore the 2400mm due to constraints like the internal dimensions of a container for shipping (Nuttall 2012). In the instance of this research, factory manufacturing and vehicle transport negates these issues.

FIGURE 36 - Panel v.s Module design conversation sketch

FIGURE 37 - Modular panel method diagram inspired from IBS research (bottom)

5.2 - Module Concept

Considering at what point the assemblies are combined to create the dwelling is vital. For example, the panel can leave the factory, such as NZSIP and be assembled onsite. Inversely, a volumetric module can be produced completely in a factory, like the Modern Modular, and then brought to site for assembly. Each of these solutions have their advantages, but the individual panel has the capability to be more adaptable and more transportable.

The same panel has the ability to be applied to numerous sites and building designs, whereas a prefabricated volumetric model has a limited application and lacks futureproofing. An advantage of a complete volumetric module though is that no onsite exterior finishing is required. A panel requires protection during transportation. Corners and materials can get damaged easily. A problem NZSIP identified with shipping their panels prewrapped in Solitex Extasana was that multiple panels get ripped and damaged every day (Maund 2017).

Transport becomes a critical restraint in the forming and sizing of a modular method. Limitations for road transport via flatbed truck in New Zealand are set out as follows in the *Land Transport Rule: Vehicle Dimensions and Mass 2016*.

Width: 2550mm
Height: 4300mm
Length: 13-22m (varies by vehicle)

Other module concepts use a series of components to create the structure to support the building, then infill the walls with panels (Kieran and Timberlake 2008) (London and Anderson 2008). By having individual panels that are self-bracing and structural, like IBS, the amount of parts and assemblies required were reduced. Additionally, the choices associated with this were further reduced, creating a simpler and more efficient system.

5.3 - Module Construction

The IBS system relied upon two key components: the stressed skin sandwich wall panels and Ribsel stressed skin floors and skillion roof panels (outlined in Chapter 4). These pieces were assembled in the factory into volumetric modules that would then be placed onto a custom built low loader to go to site (Hay 1972). The panels used steel plates on the 4 corners of each panel, connected with a bolt into the floor and ceiling diaphragm. When IBS came to its demise, considerable issues still existed with junctions.

The IBS panel-to-panel join was not sufficiently sealed, allowing noise and air transmission between the panels. Their research shows the testing of an extra clip-on plate that covers the vertical join between two panels, creating a seal. This was dropped in favour of a continuous gasket seal (overlap) at panel edges. The clip-on plate creates an extra part for assembly, increasing the potential for installation error and increasing complexity. Test 1 in section 5.5 demonstrates investigation of the overlap seal in a rudimentary design test.

IBS developed the ceiling Ribsel panel (same as the floor panel) as the main roof structure. Roof articulation was then applied on top of this structure in an auxiliary manner, consisting of a parapet roof with falls moulded from fiberglass and filled with polyurethane foam insulation. This method would not be sufficient to meet current building codes. As the key precedent, the IBS roof/ceiling system does not offer significant advancements or innovation compared with current roofing systems, nor was it aesthetically pleasing by today's standards.

Pre-clad panels would negate the need for any scaffolding to the exterior of the building, a common need in residential projects. This has risen in cost since new rigorous safety enforcement (Page 2008). This means builders themselves can no longer do scaffolding in-house. They now need to contract a trained and licensed company, adding significant expense. Not requiring any exterior work to be done once the dwelling assembly is complete would be highly efficient, and a much safer method of building.

5.4 - Module Corners

The IBS system relies upon a corner panel module to set out the structure. The panel is critical to the arrangement of the modularity of the dwelling, as it sets the starting point for each direction. It provides the initial structure upon assembly. In essence, the IBS system acts as a structural component, such as the Loblolly aluminium scaffold (Chapter 9). The key difference is that the corner panel is constructed in the same manner and material as the rest of the wall panels, simplifying the assembly and process.

FIGURE 38 - Hay's sketch figuring out the optimum panel dimension in relation to golden ratio (top)

FIGURE 39 - Excerpt from IBS patent showing wall and corner panels (bottom left)

FIGURE 40 - Hay's sketch showing the need for revision of panel joins due to noise transmission

THE DESIGN

This chapter details the first version and intentions of a modular method, developed from the learnings in the previous chapters. This begins the design iterations toward the LapLock panel up to this point, and a case study analysis and author initiated design testing has taken place. The aim of the preliminary design phase was twofold – to further test a modular room building method consistent with New Zealand, and to outline design parameters to continue into further design phases. This part of the research aimed to critically compare the adaptability of a set modular home versus a panelised home, and the limitations that each method would have.

The blueprint for this framework is parameter driven. A series of successful design moves, notions and theories combine to create the framework to be tested. Covered in this chapter are the key elements, attributes and gestures that aim to improve the failings that past prefabricated systems have had. In particular, this chapter explores what architectural choices and options are needed to make such a system a success.

FIGURE 41 - Early panel testing in REVIT software, demonstrating immediate areas of issue such as eaves

SINGLE

END

SINGLE

CONNECTOR.

SINGLE

CORNER CONNECTOR

4800

END HALF (single)

GOVERN

HALF

CONNECTOR HALF

CORNER END

CONNECTOR
HALF JOIN

END HALF (half)

CORNER END HALF JOIN

CONNECTOR
HALF HALF JOIN.

CONNECTOR
HALF 2.

JOIN

CORNER HALF JOIN
CONNECTOR

END HALF
JOIN

CONNECTOR
2 HALF JOINS

JOIN

6.1 - Volumetric Modular Testing

Influenced by the vernacular nature of New Zealand's remote houses, Test 1 looked to develop a system. This system was based upon the typical spatial needs, including form, sizing and location, identified in the New Zealand home. It looks to also extend design traits from the SARC 455 case study and learnings from the other case studies.

Five types of module end were identified in order to join the units: single, single corner, half, half connector, single end, and half end. This immediately demonstrated the limitations of developing a directional system, as more types of modules needed to be developed in order to create sufficient choice for house plans and types.

The set house module system quickly presented problems in the construction and formation of a dwelling. Figure 42 demonstrates the difficulty in categorising set modules in order to assign their room programme. This design test focused on the module type, and a method in how modules could join onsite. The 3600mm x 4800mm units were chosen to fit most room sizes in relation to the New Zealand home. The half module served multiple purposes. It allowed for a smaller space, and a link module to allow the home to adapt at a point in the future. This provided some architectural articulation.

FIGURE 42 - Tested module types, with a 1200mm or 2400mm join (left)

FIGURE 43 - Scale module types at 1:100, using 3mm mdf allowed rapid testing and discovery of limitations (above)

FIGURE 44 - 1:25 scale model testing overlap joining methods of the volumetric units on the previous pages

The models were deliberately simple in form. They used specifically placed windows and doors in accordance with the desired programme, each of which could be mirrored to allow for site and sun direction.

This design test highlighted some key findings. The link module (where a home can expand) is a crucial transition to adaptability, something Donovan Hill outlined in their Post Fab Housing project. The design uses a 'collar' as a designated area for modules to be attached onto, as well as a location for external fenestration (London and Anderson 2008). This reinforced that the link or adaptable area for expansion needed to be a key consideration as the research moved forward.

Further detail testing was undertaken to confirm a limitation from SARC 455: the bi-directionality of joints. Having a male/female overlap was tested, but this limited the direction each module could go in. It reduced the adaptability of each module by half. A method to avoid this could be the use of a connector part, but this adds more complexity to the assembly process.

FIGURE 45 - Room module units at 1:100 scale models quickly outlined the limitations of asymmetric floor plans

FIGURE 46 - Donovan Hill Post Fab housing concept - collar is orange frame at middle of module (above)

6.2 - IBS 1:25 Model Testing

In alignment with the method of this design research there was a constant conversation between different scales of modularity. Because of this, the IBS case study was chosen as a key influence. It dealt with advanced home building techniques that were well ahead of their time for New Zealand in the 1970's (Bell and Southcombe 2012).

The aim of this 1:25 scale test was to not only provide a physical summary of the design of the system, but to test the limitations as far as a scale material would allow, up to 1:5. With the parts laser cut from 3mm MDF, the floors and walls were constructed as accurately as possible to modern day materials. Using a pin system at each of the four corners of the panel, the first mock up produced surprising results. It braced the entire box strongly enough for a human to stand on it, a scale equivalent of almost 2 tonne. This could indicate the IBS box could take loads far in excess of current codes.

FIGURE 47 - 1:25 scale reinterpretation of the IBS panel system with a monopitch secondary roof structure

The 200mm corner posts provide the initial assembly strength, allowing the installation of the ceiling plate. The panels are then placed around the structure, dependant on the layout of the home. The tested size was the 3600x4800mm floor plate, yet the panel assembly method quickly demonstrated how a larger floor plate could be used. This would allow for a home to be changed simply by removing certain panels and attaching more on. This would not only futureproof the home, but it would meet a wider spectrum of client needs, particularly on resale.

As the model existed longer throughout the research, it began to wear with the multiple assemblies that took place. This highlighted the weaker areas that had further need for improvement.

FIGURE 48 - Disassembly of two of the 1:25 IBS prototype modules, note the corner posts supporting the roof diaphragm (left)

6.3 - Form in Plan

Understanding the relationships of the New Zealand home, and the extent to which a form-in-plan can be articulated for multiple sites was priority. This took inspiration from award winning architectural homes throughout New Zealand and some of the more traditional villa layouts in Wellington.

Sketching these floor plans began to create a sense of understanding of the form-based relationships that spaces create (Fig. 51). For example, bedrooms would often share a bathroom, which could be used to split two rooms. Or a covered living/dining outdoor area could also connect 2 wings of a home. Both of these relationships could minimise wasted egress space. It was these discoveries that drove the design parameters highlighted below.

Aspired design rules:

Angled walls provide sunlight and view access.
Living and kitchen combinations maximise usable spaces.

House layouts can fall into 2 styles: living/kitchen centred between bedrooms or at opposite ends.

Public (living/kitchen/outdoor) vs. Private (bedroom/bathroom).

Majority of house plans can be broken up into modular sizes.

6.4 - 'Good' Design Attributes

This initiative aimed to develop a series of parameters that create good design principles. It targeted downfalls in other standardised prefabricated housing providers, particularly the transportable home sector. The key architecture traits to challenge are outlined below:

Stud Height

The standard 2.4m stud height offers a typical home aesthetic, often seen in subdivisions across New Zealand. A higher stud height was defined as parameter to achieve for this design, a more suitable height was identified to be 2.7m. This allows for adaption to views, sloping roofs and a higher quality of sunlight access.

Roof Articulation

The design sought to eliminate the hip roof and other complicated arrangements of roofing. This was done to best suit not only the IBS style panel module, but other standard panel formats. It also, unknowingly at the time, allowed the wall and ceiling structure to be of the same system and module size. A monopitch 10 degree roof was selected as the main design option to test, and the flat roof with a gable truss was added as an extra.

Thermal/Construction Efficiency (Wall Build Up)

This was the first exploration of possible materials to reinterpret the likes of an IBS system in a modern day context. It was also the first research into the potential for a system to apply to a multitude of structural materials, each with their own strengths and weaknesses.

Wall Articulation

The angled wall allows for more building articulation and sunlight access as well as views.

FIGURE 49 - House aesthetic tests with full height panel using rapid viz sketching (left)

FIGURE 50 - Topography and module relationship using rapid viz sketching

FIGURE 51 - Polyvalent dwelling and space relationship study of the New Zealand home (left)

FIGURE 52 - Module layout planning for aiming to tackle symmetry issues (above)

FIGURE 53 - Incorporating plans into REVIT for visualisation and dimensioning (bottom)

6.5 - Materials

Creating a high level of adaptability meant considering not just the design, but the material of the wall panel. Four materials were chosen, with the intention that each of these could be produced in any factory across New Zealand. IBS dealt with a very exclusive method of manufacturing, in their own factory. The Laplock design aims to avoid this, using methods and materials that are accessible. The following briefly outlines the benefits and drawbacks for each structural material in relation to the LapLock modular panel:

Structural Insulated Panels (SIP)

A SIP panel consists of PUR insulation laminated with two layers of 9mm or 13mm Oriented Strand Board (OSB). SIP's are commonly used in colder climates, with excellent thermal properties at a reasonable price. Difficulties with SIP arise around services, where channels need to be cut and allowed for. Internally, a cavity is needed to house services and battens to support standard internal claddings. Each panel needs to be custom produced and designed for windows, doors and any structural reinforcing needed. Predesign of non-standard panels always incurs a higher cost. 115mm thickness provides an R value of 4.5.

Benefit – insulation already installed, high thermal value, easy to install.

Drawbacks – needs additional work for services and claddings, can be costly.

FIGURE 54 - SIP panel LapLock pre-clad wall assembly

PLYWOOD

Plywood is less frequently used as a structural element in New Zealand building. Typically, sheets are used for bracing and claddings. In using a plywood material to create a modular panel, CNC/CAD CAM technology would be used in conjunction. Plywood sheets would be cut out to make structural cassettes or pieces to form the panel. Insulation (either glass wool or PUR/PIR) cladding, bracing sheets and services would then be installed in the factory.

Benefit – readily available product, suits CNC, reduces need for skilled labour, reduces material wastage.

Drawbacks – can be costly, CNC technology in NZ is limited at present, structural use hasn't been proven.

TIMBER FRAME

The traditional stick timber, a 140mmx45mm stud would be used, to provide a thicker wall offering more architectural detail opportunities. The system would use 90x45mm dwangs. This option was included to show how a traditional material, associated with onsite construction, could be reinterpreted for a prefabricated format. This aims to prove that just because the system is innovative doesn't mean a high tech or new material is needed to be used.

Benefit – cheap, readily available.

Drawbacks – requires higher skilled labour, material wastage.

FIGURE 56 - Plywood LapLock pre-clad panel assembly (left)

FIGURE 55 - Timber Frame LapLock pre-clad panel assembly

CLT

Cross laminated timber (CLT) has made significant inroads in New Zealand. Known for its higher cost, CLT makes on site structure and assembly easy. Designs have come across challenges in accommodating services and insulation, which have to be designed in conjunction. It is mainly used for its internal finish characteristics, creating warm timber interior spaces. This instance would see a CL3/75mm panel used as structure, with cavity battens then external cladding. The interior would host a cavity that would provide the 80-100mm insulation (usually PIR/PUR) and then internal linings and services.

Benefit – adequate structural strength, internal timber finishes can be desirable.

Drawbacks – expensive, layering and penetration issues with services and insulation.

Chosen Material

The panel design proceeds with two materials: plywood and timber frame. The price and versatility of both these materials suit the aims of the research. Whilst the IBS system used what is now considered a SIP panel currently, plywood technology in particular gives the greatest control of adaptable parameters.

FIGURE 57 - CLT LapLock pre-clad panel assembly

Modular Housing

Improving design features.

Bay Windows

Gettimg

WARM/INSULATION/QUALITY/Adaptability

Climate choice

Horiz
vent
clad

Systemised
Wall choice
↓
modular grid
line.

Roof/Ceiling Shapes

Matrix

- Set of plans
- Stud height 2.4
- Can't move window

Keep it

- Limited options
- already designed

Lacking - connection
w/ site

'House on stilts'

'Lacking joining' design

FUNCTIONAL WALLS

PLUMBING

ELECTRICITY

Planning
Grid

Window

Need to
start doing
stuff

Hide
window
FRAME?

6.6 - Finalising Parameters for Design

The research so far presented a set of defined parameters to bring forth to the concept and developed design phase. The aim of this is to understand the limitations and successes of these parameters, and reform or improve these in the detail design phase (Chapter 9).

Materials:

Panel design to be structural.

Units pre-clad.

Plywood and Timber Frame Structure.

140-150mm wide structure.

Claddings to fit standard 1200mm module such as 115mm face cover weatherboard.

Design:

Panel dimensions (bold being most used):

400 ; **800** ; **1200** ; 1600 ; 2000 ; **2400** ; etc in 400mm increments.

Room/space design maximises space – no excess floor areas.

Designed to use 400mm increments (shown above).

External Walls to provide structural bracing.

External wall panels to be removable.

Fenestration able to be placed in any location on a panel (large windows still an issue, resolved in later chapter).

Roof articulation and roof slope to be created through skillion roof.

Floor/ceiling cassette to be insulated and use floor framing.

Construction:

Able to be produced in numerous factories over NZ.

Brought to site in multiple forms – as panels or modules.

FIGURE 58 - Good design attributes
sketched rapid viz by
author

07

CONCEPT DESIGN

The concept design chapter will cover the rationale behind the test sites for the design. It will also cover some early design testing such as massing and forms based on site constraints. It will also critically reflect on the decision to begin with a holistic overall 'can the panels fit this context' design, as opposed to designing for the panels from the outset.

The following sites were selected based upon a series of criteria. The test aimed to cover a range of site locations and conditions. Therefore, varying degrees of remoteness were needed, along with opposing site constraints such as surrounding buildings or no road or vehicle access. It also built upon the idea that these were infill sites, in that sharing of land will become more of a necessity in future (Gray and Witcher 2013).

FIGURE 59 - Brooklyn House, 1:100
concept model on
stepped site

62 SYMONDS STREET

7.1 - Auckland (Urban)

The Auckland site aims to use a higher density solution and applies a residential panel to multiple floors. By doing this it explores how the connection would be detailed between units. This would offer the chance to create longer panels. This site, located on Symonds street, is one of the very few larger empty sites in the Auckland CBD. The steep, sloping topography, falling to the South East, provided a unique challenge in allowing sunlight access. A opportunity of this site is to increase the designs validity as a medium density option.

FIGURE 60 - Auckland CBD aerial image (left)

FIGURE 61 - Auckland site location map (above)

FIGURE 62 - Auckland medium density units concept model at 1:100 scale

Note: further design and development is undertaken in Chapter 8

FIGURE 63 - Auckland medium density units showing rhythm and using offsets for sunlight access (left)

FIGURE 64 - Concept sketching for Symonds Street Apartments (above)

7.2 - Wellington (Remote)

The Boomrock site on Wellington's North-West coast began as a real client project. A wedding and events venue, the client required a unique and specific accommodation to branch into a broader area of hospitality for their clients.

Whilst broad in its investigation, the brief detailed a clear set of parameters to which the conceptual design could be tested. The actual project would proceed separately to the scope of this thesis. The unique constraints of the site gave the opportunity to test the benefits of a pre-clad panel system.

The intended building platform is located on the edge of a 200m cliff that drops down to the Tasman sea. It is a unique location that gets battered by the infamous Wellington northerly wind. The Boomrock site falls into the remote category, somewhere where traditional construction methods would prove challenging.

FIGURE 65 - Ohariu coastline (background)

FIGURE 66 - Pipinui Point location at Boomrock, Ohariu - Wellington

FIGURE 47 Pipinui Point site collage

FIGURE 68 - Pipinui Point 1:100
concept model (left, top)

FIGURE 69 - REVIT 3d concept render
and exploded modular
assembly diagram
(above)

7.2 - Wellington (Suburban)

The second Wellington site is an infill suburban section. A flat-top site with a steep bank descending to an existing dwelling. The bank faces South East, with views across Brooklyn to the Rimutakas. These site constraints are a significant influence on form and aim to test the limits of a parameter-driven panel system.

A series of stepped house designs were sketched and experimented with. The difficulty and weaknesses with this site are the sunlight access plane and the changing levels from road to the edge of the bank. Timber piles were chosen for their cost effective nature on sloping sites over timber slabs (BRANZ n.d.).

FIGURE 70 - Mitchell Street site in Brooklyn, Wellington (left)

FIGURE 71 - Wellington suburban site location diagram

FIGURE 72 - Mitchell Street site views

FIGURE 73 - Mitchell Street concept
model at 1:100

FIGURE 74 - Mitchell Street stepped site concept sketches (left)

FIGURE 75 - Mitchell Street site boundary

In order to test the modular panel assemblies, another model iteration was undertaken. It aimed to improve and redesign a series of parameters and joints from the IBS and NZSIP systems. It would also test the efficiencies of the corner and wall panels. It was hoped this level of scale design research would expose some structural and assembly challenges, as well as demonstrate areas that would require a bespoke assembly.

The Wellington site concept was chosen to model as it would best represent a range of architectural gestures and construction applications such as two levels. A central section of the home was chosen to construct at 1:25 (see Fig. 76). Nominated was the use of a stressed skin floor/ceiling cassette that could house services and insulation and provide diaphragm strength. This would then allow the focus of the research, the wall panel, to be tested.

These panels improved on the joins explored in the IBS test model. This was achieved by increasing the joining edge overlap creating a continuous 90-degree lap for the floor and ceiling diaphragms to be seated in. The fixing system in this model aimed to replicate a threaded tension rod. This would then be fixed with a nut from the interior of the building.

FIGURE 76 - 1:25 scale of Mitchell Street concept house testing validity of prefab and preclad

The rod design allowed for efficient locating of the panels in the scale tests, and whilst not threaded, the hole tolerance provided sufficient friction to retain the panels in place. A strength of using a common and simple fixing system, as opposed to the patented IBS bearing tab system, is that it can be widely sourced and manufactured; an important milestone in phasing out components that increase the exclusivity of a system.

The rod design additionally allows the fixing of sloped panels as they connect to a 10-degree sloping roof/ceiling diaphragm. An issue arose in the creation of the intermediate floor. A decision needed to be made whether to double the diaphragm, similar to the methods done in high rise CLT construction, or use a single diaphragm. The double floor plate was opted for, in order to provide enough tolerance for two fixings of the panels above and below (Fig.78).

To critically reflect on this model, other than cladding overlaps, the wall panels do not address the vertical joints between panels, this needed to be revised at the detail design

FIGURE 77 - External entry door panel with floor plate locating connections visible

phase of the panels.

Highlighted were the issues of bespoke components. The small clerestory window/wall panel that links the two sloping roofs was a challenging part to make as a 1:25 model, demonstrating its probable difficulty as a panel in a full-scale build. Further design would need to be incorporated into this concept to achieve full panelisation. This could be mitigated with running a steel lintel across the living room area or similar and have the clerestory panels as non-structural.

In summary, this scale model build is a success in addressing its limited scope of testing, yet it begins to demonstrate further issues in creating architectural design with a set amount of designed parts.

FIGURE 78 - Using similar methods to CLT multi level connections by doubling the floor plate

08

DEVELOPED DESIGN

The developed design chapter presents the majority of the design work. It aims to apply the ability of the parameter-driven modular panel to a series of adaptable and efficient dwellings. As opposed to fully elaborating on the design of each site, this section reflects on the strengths and shortcomings on each of the sites. The chapter additionally highlights the discoveries of the limitations of modular design. It reflects on the success of addressing the aim of adaptability, efficiency and providing architectural choice.

This phase uses Revit as the programme of choice to test the capabilities of architectural design of the panel. Covered further in the detail phase, this choice of computer program was due to the parameter based families able to be created in Revit, and how these families could then form shop drawings for each panel type.

FIGURE 79 - Brooklyn House kitchen and dining area looking toward Rimutakas

0 // Ground

1 // First

2 // Second

8.1 - Symonds Street Apartments

4-5 bedroom apartment within 135m²

These apartments set about testing the panel system at a larger density and scale. They started with a methodical site analysis of constraints such as sunlight access, view shafts and topography. The design set about not only utilising the efficient panel system to construct, but placed importance on efficient planning for the medium density development. After all, the panel and the modular format at this stage had been frozen, in order to test its successfulness as a housing solution.

The apartment floor plans are based off two 3m x 7.2m floor cassettes, arrayed up 3 levels. Bedrooms are located on the ground and top floor, with living centralised on the first floor. Massing proved challenging. The box forms were required to be staggered down the site by 1m for each unit and then offset by the same amount to the North to allow for increased evening sunlight access. As Figure 86 shows, the assembly method begins with subfloor, floor cassettes, corner posts and then external walls. The process repeats upward.

FIGURE 80 - Final perspective floor plans for Symonds Street Apartments

Initially, the apartments lacked rhythm and architectural language. It had appeared they had fallen victim to a 'box' approach, based on the parameters of the module. The site constraints study had generated the massing and forms on site, yet the design had manifested upward from the perimeter of the floor plate. In order to change this, half of the southern side of each unit was extruded by one module length (1200mm) as shown in Figure 82 (timber vertical cladding). This immediately introduced a more pronounced rhythm, whilst showing that the module could extend to create such diversity in design. These design moves allow more evening light to penetrate into the middle level of each unit. This learning highlights the risks in designing a set panel system, and demonstrates the need to constantly test and push the limits of such.

FIGURE 81 - Interior living perspective, panelised floors expressed on ceiling (top left)

FIGURE 82 - External street perspective with developed rhythm and material language (bottom left)

FIGURE 83 - Section through units (above)

The scope of this design largely ignored the party wall between units as this would require advanced fire and structural engineering. The intention is to use a similar method to the duplicate floors; that two walls will be shared by the exterior fireproof lining and include acoustic separation.

The final stages of the developed design looked at the possibility of how panels would arrive. It was envisioned that the potential existed for a two storey panel to be constructed, and then craned onto site.

Limitations of the panels were demonstrated when a corner window was identified as a key representation of quality architecture. This would require a significant lintel design across the head and sill of each panel, and further design to ensure the validity of this element.

The Symonds Street design is a successful representation of how a pre-clad, ready to install onsite, panel system could be used at a medium density scale.

FIGURE 84 - Early concept sketch of materials, form for Symonds Street (top)

FIGURE 85 - Site analysis, constraints and environment for Symonds Street (bottom)

1 // Subfloor

2 // Floor Cassettes

5 // Internal Wall Panels

6 // Floor Cassettes

3 // Corner Panels

4 // External Ground Walls

7 // Large Scale Panels

8 // Roof Panels

FIGURE 86 - Assembly sequence for Symonds Street Apartments

8.2 - Pipinui Point Lodge

Pipinui Point is the name given to the accommodation lodge situated at Boomrock Lodge. The design required a 2 bedroom, 1 bathroom lodge with expansive kitchen/living/outdoor area that would entertain guests if needed. The building platform not only sat on the edge of a 200m cliff, but the unique nature of this design meant it was 50m down a steep, grassy slope. The challenge was configuring a panel that could either be flown in as a stack and manually lifted into place, or the preferred option of flying each individual panel into place.

The design uses two floor plates to achieve the long, sleek look on the cliffside. The roof undertook a major design change from the traditional gable to the 10 degree slope. The gable was the traditional and vernacular look the design aimed to exude, but having a flat structural ceiling diaphragm meant extra trusses would be required to actually define the roof shape. The mono-pitch roof allowed for a single ceiling diaphragm that could incorporate insulation, services and lighting in an internal strapped cavity. This also meant the roofing could be installed onto the walls immediately, creating immediate weather tightness of the dwelling in under a week.

FIGURE 87 - Pipinui Point exterior perspective showing recessed deck for maximum entertaining space

A significant weakness with this design is the need for a bespoke panel. Two 3-bay sliding doors, to allow an open entertaining area, meant a unique panel design to create a sufficient lintel. Outside the scope of the research, the doors would require a steel or timber lintel attached to the corner post.

Whilst high end, Pipinui Point lodge demonstrates the ease of assembly that the design offers onsite in comparison to a traditional build. In an environment as harsh as the West coast of Wellington, this time-saving eliminates issues with waterproofing, making changes on site and the reduced amount of labour in exposed and dangerous conditions.

The Pipinui site assumes a GIB internal lining, which would need to be done once close-in had been completed. The benefit of using a helicopter for panel placement is that larger window panels can be placed, with glazing and joinery already installed. This would significantly outweigh any other method of lifting.

The Pipinui dwelling demonstrates the difficulties in conforming every element of a building to a standardised panel design. It shows that in order to retain architectural character and choice, certain bespoke elements need to exist. The Pipinui lodge, removed from its location and simplified, would best represent a small design to test as a full scale build. It is likely removing the bespoke elements would reduce costs in an overall build. Again, this developed test highlights the fight between a standardised element and the adaptability for multiple situations.

FIGURE 88 - Perspective floor plan of Pipinui Point Lodge (top left)

FIGURE 89 - Perspective section through Pipinui Point Lodge showing continuous roof overhang (bottom left)

FIGURE 90 - Proposed panel delivery and installation method (above)

FIGURE 91 - Bedroom with view connection to sea (top left)

FIGURE 92 - Living and kitchen area with sliders creating more entertainment capability (bottom left)

FIGURE 93 - Site analysis sketch (above top)

FIGURE 94 - Materials and features development sketch (above)

1 // Subfloor

2 // Floor Cassettes

5 // External Window Panels

6 // Internal Wall Panels

3 // Corner Panels

4 // External Walls

7 // Roof Panels

8 // Complete Design

FIGURE 95 - Assembly sequence of Pipinui Point Lodge

VIEWS EAST

FOUNDATION WALL

0 // Downstairs

1 // Upper Floor

8.1 - Brooklyn House

The Brooklyn House was developed into a liveable family or young professional dwelling. The strongest and most thoroughly designed of the three sites, the home incorporates 4 bedrooms in a 150m² dwelling including a 2-car garage.

After critically evaluating the Brooklyn House concept, a change was made to reduce the floor area. The concept worked off the 4800x6000mm floor plates, which produced a house size of well over 200m². This was a size that did not demonstrate the values and ethos this research was working towards. With a reduction in size (to 3600x4800mm) came a higher efficiency of space, and, as showed by the illustrations, a more inviting and warmly home.

A key finish tested in this design was the inclusion of the internal lining pre-installed on the panels. Having removable sill and head covers allowed the fixing of each of the panels to the floor and ceiling diaphragms. This attempted to express the panelised nature of the design, celebrating the joins with a black negative. This would also significantly reduce internal finishing costs compared to GIB – whilst plywood is more expensive as a material, it reduces the labour and time components.

Using parameter based design can often produce undesirable results. With a system like this, external walls cannot be adjusted slightly as they are located on dimension critical grid lines. The overall system layout is compromised if they are adjusted. The lower floor design output created a challenging situation in that the second bedroom was restricted once the 1m width for the stairs and 1m width for hallway were included. It was decided to leave the space, which included built in storage, as a smaller study or kids room. The incorporation of a cavity sliding door made the space more efficient.

FIGURE 96 - Perspective plan of Brooklyn House

Part of the research aimed to incorporate an angled corner panel, as opposed to using 90 degree corners. This not only provides a form-based aesthetic quality and design articulation, but offers more sunlight penetration. In the case of the Brooklyn House this was from the low evening sun. A 30-degree internal and external corner panel was 3D modelled to understand the difficulties in such a complex form. The issue with creating an angled panel is the connection back to the 90 degree grid lines, as this creates 4 options with varying angles.

Overall, the Brooklyn House personally appears the most successful representation of how the panel product could be used in order to create a more adaptable dwelling.

FIGURE 97 - Brooklyn House Entry showing shadowclad with battens used to hide panel joins (top left)

FIGURE 98 - Bay window unit on east side of house captivating views (bottom left)

FIGURE 99 - Section of house show private spaces (downstairs) and public spaces above (below)

FIGURE 100 - Living and kitchen area with plywood internal lining expressing internal joins

1 // Subfloor

2 // Floor Cassettes

5 // External Wall Panels

6 // Internal Walls

3 // Downstairs Floor Walls

4 // Upper Floor Cassettes

7 // Roof Panels

8 // Completed Design

FIGURE 101 - Assembly sequence of Brooklyn House

Family Types

Type name:

Search parameters

Parameter	Value	Formula	Lock
Dimensions			
Dwang Spacing	512.8	=	☐
Dwang Ctr	512.8	=	☐
Dwang Width	1200.1	=	☐
Panel Height	2700.0	=	☐
Panel Width	1200.1	=	☐
Stud spacing	400.0	=	☒
Other			
Dwang Array	6	=	☐
Stud Array	4	=	☐
Identity Data			

Manage Lookup Tables

[How do I manage family types?](#)

OK Cancel Apply

Family Types

Type name:

Search parameters

Parameter	Value	Formula	Lock
Dimensions			
Dwang Spacing	512.8	=	☐
Dwang Ctr	512.8	=	☐
Dwang Width	1200.1	=	☐
Panel Height	2700.0	=	☐
Panel Width	1200.1	=	☐
Stud spacing	236.5	=	☒
Window Void Height	925.6	=	☐
Window Void Width	691.5	=	☐
Other			
Dwang Array	6	=	☐
Stud Array	6	=	☐
Identity Data			

Manage Lookup Tables

[How do I manage family types?](#)

OK Cancel Apply

8.4 - Learnings + Revit Limitations

The Revit based modelling of these dwellings allowed for quick adaption and input of panel parameters. Revit provides a family/component based system, where individual panels can be made as a group, and placed into the project. These allow for efficient parameter based changes to panel heights, thicknesses and materials, all live in the 3D model. Unfortunately, complications arose with the file size and input of these families causing the working file to crash frequently. The family parameters would often break or produce undesirable results, a downside known to Revit. Therefore, the developed design stage used default walls, split into segments, to best represent the panels. It used the structural core centreline of these panels on the edge of the slab. Cladding overhangs could be digitally represented and changed also. It was during the start of the designed development stage that the research method had to be refined to take into account Revit's limitations. It was decided the detailing and family modelling of each panel would be undertaken once the developed design stage had been completed, and a critical reflection taken place. This way, improvements could be made from the developed to detailed stages.

FIGURE 102 - Wall and window plywood cassette families in REVIT (top)

FIGURE 103 - Parameter based modelling means customisable wall panels for output (middle, bottom)

DETAIL DESIGN

The detail design chapter looks to ground the developed and concept design phases by examining the LapLock panel in detail. At this point, the choice to pursue details around the individual panels and their connection took place, as opposed to this occurring prior to the developed design phase. By letting this take place subsequent to the developed design phase, this allowed comments and improvements to be taken on board after critical reflection, and the learnings fully incorporated into the detail stage.

FIGURE 104 - LapLock Panel demonstrating flexibility and adaptability on a small unit

9.1 - The Loblolly House

Whilst case studies often start and influence design-led research, their inclusion at different stages help solidify reasoning. The Loblolly House became a critical addition to the body of research. The Loblolly House is widely known for its innovative use of Revit and BIM to create a prefabricated system that is efficient and certainly changes the housing model. Unfortunately, a weakness of the project in relation to this research is the design was highly site specific and responded to a contextual need. Although in their book Kieran and Timberlake do mention toward how the system could be used for further designs, it doesn't continue to use the system and design to contribute to varied types of housing.

The two key ideas of the build that were of influence to the author's LapLock panel were the parameter-based design of a family in Revit and the categorisation of building components. Kieran Timberlake consider the structure as a scaffold; the floors and walls as cartridges; bathrooms, kitchens and mechanical as blocks, and building accessories as equipment. The understanding that these parts are separate components in the factory, but are complete assemblies onsite, is a view not typical in traditional New Zealand construction. Kieran Timberlake's design was "assembled, not constructed," stating that assembly is fast and construction takes much longer. (Kieran and Timberlake 2008)

FIGURE 105 - Loblolly house with 'pixelated' timber cladding

The LapLock is designed with this in mind – the panel is fabricated in a factory, and the completed panels are then quickly assembled onsite. It does not require a demolition crew; the panel stays whole and can be removed when needed.

The Loblolly House design grappled with some early BIM technology; nowadays, what Kieran Timberlake achieved has become common practice in some form or other. But their detailed design of the panel challenges the limitations a series of panel families have. It pushes the limits of what can be designed and plugged into a working file to construct a dwelling.

FIGURE 106 - Loblolly 3D image showing scaffold frame and 'blocks' (kitchen and bathroom module) (top)

FIGURE 107 - Loblolly bedroom demonstrating expressed cross bracing of scaffold structure

1 // 800 mm Panel

2 // 1200 mm Panel

3 // 1200 mm 10° Slope

9.2 - The LapLock Panel

The research up until this point had been focused on the LapLock panel and the detailing of it as a wall product. A significant body of historic and current research had been undertaken, with numerous thorough design tests and modelling. The wall product focus was the result of a refined scope. It was acknowledged the floor/ceiling diaphragm would be a separate component. This would change as the discovery of the unknown adaptable nature of the panel was revealed.

To continue with the discourse between the 3D BIM world of modelling and physical scale modelling, a corner section of the walls was made at 1:5. This scale is sufficient enough to show layers of detail, tolerances and highlights any fixing or geometric difficulties. The model proved useful in demonstrating these conditions:

Assembly

With the jigsaw style, sheet-cut parts, assembly was super-efficient. The studs would locate themselves within the bottom plates, and the 3mm MDF provided enough scale tension to hold these together. The tabs and holes did wear over time though, creating slipping and therefore weakening the strength of the panel. At full scale, the shrinking and swelling of plywood would have the same effect. Rather than a straight friction joint, these would likely need to be cut with an angle, something that is a possibility with a 4 axis CNC or an accurate skillsaw.

FIGURE 108 - Laplock panel types with stepped overlap visible

1 // 200mm Internal Corner Panel

2 // 200mm External Corner Panel

1 // 1200mm Window Panel

2 // 2400mm Split Window Panel

Fixing to floor/ceiling

Initially the system was intended to be fixed in two directions, the bottom plate is the main fixing point for the panel, typical to that of traditional framing. Either the LapLock arrives on site with no internal lining (as shown in the 1:5 model) or with a ply internal lining that has a removable panel for fixing access. The second point of fixing was to be on the vertical of the slab edge, but access to this area proved difficult. A threaded rod with nut system, as tested in the 1: 25 scale Brooklyn House model could be used. More design is required around the secondary fixing of the panel, but with structural testing just the bottom plate fixing could be sufficient.

Material thickness + stability

3mm MDF (due to availability) was used at a scale of 1: 5, representing a 15mm sheet ply product. It was immediately apparent, even at scale, that this would not be sufficient structurally, and without the ability to test a 1:1 plywood scale, estimates on thicknesses could only be motioned toward. 17-24mm would be more suitable. The panel model was strong and solid in X and Y directions, and also with face loads (once it had the bracing sheet fixed on the front). It did, however, suffer instability and twisting until panels were placed adjacent to it, and the ceiling panel fixed on. This demonstrated the reliance each panel had on its surrounding counterpart. This is similar behaviour to timber framing, demonstrating the similarities in structure, with the Laplock being more efficient.

FIGURE 109 - LapLock corner panels above provide sufficient structural support to erect the roof cassette (top)

FIGURE 110 - LapLock window panel and split window panel allowing for large assemblies of fenestration (bottom)

Fixing panels together and Watertightness

Laplock panels are fixed through the plywood stud to the adjacent panel using heavy duty screws at specified centres. These pull the panels tightly together. This also waterproofs the vertical join between each panel (as shown in the model images).

Services

Plumbing and electricity are predesigned into each panel, and are plugged in once onsite. The panel lap that seats itself over the slab edge allows for services to be run horizontally along the channel at the base of the panel, visible in the details on the following page (Fig.117).

Timber Frame

One panel in the 1:5 model was crafted from scale timber framing. Representing 140mm x 45mm framing, each stud had the required lap notch cut from the top and bottom. Using 90x45mm scale framing to form dwangs reduced thermal bridging, a significant improvement compared to traditional framing.

Reflection

While 1:1 scale modelling wasn't an option for testing, the 1:5 scale model demonstrates at scale some difficulties. It strengthens the research through using as accurate as possible construction techniques

FIGURE 111 - Laplock slab edge (top left)

FIGURE 112 - Laplock window sill and jamb (top right)

FIGURE 113 - Laplock panel assemblies 1:5 model (bottom left)

FIGURE 114 - Black vertical cedar cladding modelled from MDF completes an architectural aesthetic (above top)

FIGURE 115 - Plywood LapLock frame test in MDF (above bottom)

Fixing Sequence:

- A- Wall panel fixed to floor
- B- Timber top plate fixed to wall panel
- C- Roof panel fixed to top plate
- D - internal linings fixed to panels

It was discovered upon testing configurations in assembly of the panel, that one design could be used for wall, ceiling and floor panels, using the same lap. Panel laps, albeit not symmetrical, fitted neatly into each other when used as a floor and wall. Admittedly, this crucial discovery came late in the research.

The wall panel lap that connects to the edge of the floor slab can be used as the floor panel, creating a continuous seal around the entirety of the structure. It was a downfall that this was discovered so late in the research. With further investigation, the system could have been reduced to a number of key panel sizes and dimensions for the walls and the floor/ceiling. Nonetheless, the focus was the wall panel, and the design's ability to be used as floor/ceiling panel is an added benefit.

The LapLock Final Method

The LapLock panel is based off a CNC cut structural plywood frame (alternatively timber frame) assembled in a factory. The panel sizes and pieces are output from Revit software to a cutting bed. The Revit parameter-driven families allow quick changes in panel heights, penetrations and materials, reducing design time. Once assembled, the panel, be it floor or wall, is installed with services, wiring and then insulation. From here, it moves to a claddings area and receives the cladding of choice, and any windows or doors installed, ready to be shipped to site. The LapLock panel addresses slab edge insulation, cladding overlaps and watertightness all in one package.

FIGURE 116 - LapLock section through small unit demonstrating overlaps (top)

FIGURE 117 - Details of floor/wall and ceiling/wall junctions (bottom)

FIGURE 118 - Laplock's core arrangement of panels demonstrating the assembly and adaptability for a small unit

10

EVALUATION

10.1 - Methodology Evaluation

The research began with the intention to reinterpret a historic system, and detail that process. Instead, the research manifested more into how the panel itself could better represent architectural design in dwellings across New Zealand. It diverted away from the technical and structural efficiency of the panel.

Tackling a significantly wide scope throughout the entire process, it was evident that the research objective changed significantly. In retrospect, a stronger outcome may have arisen from selecting one site, and designing through more detail to a complete drawing set. The methodology though, aimed to show adaptability, and focusing on single site would not best represent such. Had the presented methodology not been undertaken, the LapLock panel would have stayed fixed to a concrete slab, or typical timber floor. In undertaking the developed design phase, the benefit of having the same design solution for floor/wall/ceiling was highlighted. This truly showed a higher level of adaptability and efficiency.

The research as it stands sets up numerous avenues for testing a plywood structural solution that could house New Zealand. The method shows a more holistic understanding of the needs of a dwelling as opposed to the technical requirements of construction.

FIGURE 119 - Pipinui Point bedroom outlook

CONCLUSION

11.1 - Future Directions

As a hypothetical example, an educated client might say: "Yeah, I'm thinking of building my home out of those LapLock panels. The guys build them in the factory, complete with cladding and services installed, and they pretty much courier them to site, you chuck them on any floor system you want, conc slab or their own floor panel – and just whip round and screw them in. How good is that! Plug all the services together as you install them, lights are in place and all! They reckon for some houses it can be closed-in, externally finished in just 2 days!"

The biggest question for a future direction is what still needs to be designed and considered in order to demonstrate the validity of the LapLock panel as a New Zealand Housing solution. To this point, the design research behind the panel has been complete, apart from a few detail areas. The first step in moving this toward a successful program would be addressing the compatibility of plywood as a structure framing element, and the sizing of this to provide sufficient strength in comparison to timber framing. Other styles of plywood framing could be used, such as the X-Frame, a diagonal self-bracing structure, and incorporated into the panel format (Finch 2017).

FIGURE 120 - Brooklyn House 1:25 scale model layout before assembly

Factory

The LapLock would also require a factory setup, something that was much the focus of IBS in the 1970's. Like the general manager at NZSIP stated, multiple trades under one roof require a large space (Maund 2017). Required would be a CNC area, with the capacity to cut up to 3m sheets; an assembly area (low-skilled labour); insulation and services fitting area; a textiles process for Solitex Extasana; carpentry for claddings, and then a finished product line that would protect the panel until site.

Uptake

The LapLock panel has a critical ethos in not making the system exclusive, particularly to certain materials. The system looks towards production in multiple factories across New Zealand, aiming to make the wall, roof and floor into buyable products.

Scale

The Symonds Street design proved that as a dwelling module, the LapLock can create good design at larger scales. If structurally capable, the panel could span over multiple stories, creating fast close in times.

11.2 - Conclusion

This thesis provides insight into how a prefabricated panel system can be utilised as a means of providing onsite efficiencies and adaptabilities in New Zealand dwelling. Making use of BIM and CAD technology, it offers an alternative thinking that increases design flexibility and places architectural design at the assembly level of a wall product.

The research grounds itself around the notion of changing the housing model in New Zealand and the influence of the historic IBS system as a case study. The design solution phases out inefficiencies in the traditional construction process. By considering the building as assemblies, and common construction elements as products, BIM and 3D technology is utilised to create an adaptable building solution.

The architectural design stage tested 3 key buildings. These ranged in sizes and scales, to demonstrate how a series of assemblies can still create typical architectural builds, and best represent adaptable dwelling choices in New Zealand. In conjunction with this, the discourse of scale modelling and digital design allowed the identification of improvements and changes throughout the entire research.

This process produced an improved final design that, dependant on size, would only take 2-3 days to close in on site. This is far more efficient than traditional construction methods, and a product style panel that has a range of capabilities. With the design and detailing completed, a final test of adaptability on the Pipinui Point site demonstrates the adaptable nature of the system, opening up a new realm of renovation and alteration.

Whilst this research does ask many questions, and has areas that could be further refined and improved, the LapLock panel presents a new building method that challenges standard design and traditional construction methods. A commodity which is needed at present, Laplock offers New Zealand a chance to build homes faster and more efficiently.

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APPENDIX

1. Scope as per Clauses 1.0 and 9.4 E2/AS1
2. Compatibility of materials as per Tables 20-22 E2/AS1
3. The flashing system relies upon the joinery meeting the requirements of NZS 4211 and for the relevant building wind pressures
4. Intersect flashings are designed exclusively for use with the Rosenfeld Kidson Cedarscreen Rusticated 45mm system
5. Windows to have a 10 mm perimeter clearance for application of a continuous air seal

<p>INTERSET RECESSED WINDOWS FOR TIMBER CLADDING</p> <p>www.rosenfeldkidson.co.nz</p>	Rosenfeld Kidson & Co. Ltd		Title
	Auckland Branch:	Christchurch Branch:	Window LEFT Hand Jamb Detail
	513 Mt Wellington Highway Mt Wellington, Auckland 1060 T. +64 9 573 0503 F. +64 9 573 0504	15 Edmonton Road, Hornby Christchurch 8042 T. +64 3 349 3316 F. +64 3 349 3317	Drawing
	Postal address: PO Box 621, Shortland Street, Auckland 1140		RK-RWF-09 Revision: F Scale: As indicated @ A4 Date: 29.06.2017

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1. Scope as per Clauses 1.0 and 9.4 E2/AS1
2. Compatibility of materials as per Tables 20-22 E2/AS1
3. The flashing system relies upon the joinery meeting the requirements of NZS 4211 and for the relevant building wind pressures
4. Intersect flashings are designed exclusively for use with the Rosenfeld Kidson Cedarscreen Vertical 45mm system
5. Windows to have a 10 mm perimeter clearance for application of a continuous air seal

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Title
Window LEFT Hand Jamb Detail

Drawing

RK-RWF-09

Revision: F

Scale: As indicated @ A4

Date: 08.03.2017

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	Material Specification	Material Quantity	Cost - Material Unit	Fixings	Cost/Unit - Fixing	Material \$ Total	Cost - Fabrication	Fixings \$ Total
Panels								
<i>Allows for 2.7m x 4.8m wall section or (4 x 1200mm panels)</i>								
Conventional Timber Whole Wall (in situ) <i>Insulated</i>	140x45 Timber Studs (2.7m High) +Plates	30	\$6.45	90*3.55mm Nails x150	\$0.14	\$193.50	not applicable	
	90x45Dwangs	9.6	\$4.55	90*3.55mm Galv Nails	-	\$43.68	not applicable	
	Bracing (PLY,RAB or similar)	4	\$6.77	90*3.55mm Galv Nails	-	\$27.08	not applicable	
	KD PG SG8 Radiata Pine	in meters	Placemakers NZ Ltd	NZ Nails Ltd		Rawlinsons, 2011		
Conventional Timber Panels Offsite (in situ) <i>Insulated</i>	140 x 45mm Studs (in 1200mm Panels)	30	\$6.77	90*3.55mm Nails x32	\$0.14	\$203.10	not applicable	
	140 x 45mm Dwangs	19.2	\$6.77			\$129.98	not applicable	
	140 x 45 mm Top/bottom plates	9.6	\$6.77			\$64.99	not applicable	
<i>quote Placemakers trade price (Sept. 14th)</i>								
PlyBox Wall (in situ) <i>Insulated</i>	18mm Gaboon Face Ply 200 sheets	4	\$62.00	n/a		\$248.00	\$150.00	
	18mm Gaboon Face Ply 50 sheets	5	\$80.00	n/a		\$400.00	1 sheet = 30 mins @ \$7 (simplified pattern)	
	cost per m2 = approx \$22					\$433.32		
<i>quote Plyman (13 Sep 2017)</i>								
MagRoc SIP panel (in situ) <i>Uninsulated</i>	165mm - 1200mm x 2440mm panel	2.928	\$135.10	included in material price		\$540.38	included	n/a
	165mm - 1200mm x 2745mm panel	3.294	\$130.13	included in material price		\$520.51	included	n/a
	165mm - 1200mm x 3050mm panel	3.66	\$123.70	included in material price		\$389.37	included	n/a
	<i>quote Magroc - based on 50 panels</i>							
Formance SIP panel (in situ) <i>Uninsulated</i>	165mm R4.2 (Blank Panel)	2.928	\$95.00	included in material price		\$373.77	not included in price	
	165mm R4.2 (Precut for design)	3.294	\$135.00	included in material price		\$540.00	included in price	
	<i>quote Formance email (13 Sep 2017)</i>							
CLT + INSULATION (in situ) <i>Insulated</i>	CL3/75mm		\$111.50			\$1,070.40		
	Cavity (larger for services) internal or external							
<i>nb: price from 2013 Dec based on 20 panels ~ 141 m2</i>								

System Analysis:

Iteration 1: 18/07/17

Cost comparison of different wall construction techniques: (2.4*4.8m Wall Section)

11.52

Note: Wall Core Structure Construction Only. No Wall to Floor Fixings, No Bracing, No Consent, No Foundation, No Roof, No Services.

Reference:

System Cost: \$/Sq m

< of wall surface area

2 Typical Wall in Pan	\$44.91
4 Formance SIP	\$46.88
3 PlyBox	\$45.14
1 Typical Wall	\$43.08
5 Magroc SIP	\$46.88
6 CLT	\$92.92

Reference:

System Weight: kg

per 2.7x4.8m area

3 Typical Wall in Pan	202
5 Formance	300
2 PlyBox	170
1 Typical Wall	120
4 Magroc	300
6 CLT	?

Reference:

System Efficiency: hrs offsite

hours onsite

3 Typical Wall in Pan	40
5 Formance	2
2 PlyBox	30
1 Typical Wall	40
4 Magroc	2

Construction Minutes Cost - Labour			Lining Structure		Cost - Linings	Cost - Cladding		Inflation (7%)	
\$21.00	15	\$15.04	\$97.20		1.125	3.3kg per lineal meter	143.88	Frame construction (onsite)	75
-		\$0.00							45
-		\$0.00							75
Rawlinsons, p. 532, 2011									3.25
\$7.00	15	\$15.04	\$97.20			3.3kg per lineal meter	194.04	Frame (offsite)	
		\$0.00	insulation 3.2 pinkbatts \$58 per sq m						
		\$0.00	\$75 @ 8.4m2 coverage finished SuperForm Building Systems NZ						\$517.32
5/hr	15	\$15.04	\$106.92			34 kg per sheet insulation added=10kg	140	Machine Hours offsite Assembly Hours Insulation	2.00
		\$0.00	556.8						1
			\$58 per sq m finished SuperForm Building Systems NZ						\$519.96
	2	\$2.01	556.8			2440x1200 = 75kg insulation included	300		
	0	\$0.00	\$58 per sq m						
	0	\$0.00	finished SuperForm Building Systems NZ						\$520.51
	2	\$2.01	556.8			85 kg bigger panel	340	sip panel prep @75min p m2	16.2
	0	\$0.00	\$58 per sq m						
			finished SuperForm Building Systems NZ						\$540.00
Labour minutes to complete core structure only						sip pane75mins			
						Overall Cost per SQ/m/ex gst			
						Typical Wall		\$38.30	
						Typical Wall in Panels		\$39.92	
						PlyBox		\$40.12	
						Magroc		\$40.16	
						Formance		\$41.67	

Early costing spreadsheet done in Excel. Not included in main thesis content due to multiple assumptions and inaccuracies in obtaining prices for materials. The intention was to use this to compare each of the 4 main materials chosen, yet its lack of accuracy and assumptions void any relevance.

Plywood and Frame were chosen anyway due to known inexpensive compared to other materials.

Design Review 3 as presented in Nov. 2017

Nov. 2017 Design Review 3 in progress

FIN