STUDY REPORT

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Building Better

Advanced Residential Construction Techniques for New Zealand

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Preface

The hypothesis of the Advanced Residential Construction Techniques project is that there are ways the New Zealand residential construction industry can build better with regards to quality, cost, speed and sustainability.

This interim report is based on a desktop study looking at the barriers to the evolution of the New Zealand residential construction sector and compares it with overseas. The report then assesses techniques for improving the construction process and outcomes that are yet to be introduced in a meaningful scale in New Zealand. For the techniques and technologies found to have the highest potential to improve construction, the second part of the project will investigate their economic feasibility in the New Zealand context.

What is Building Better?

Building better is a way of providing more quality and functionality for less money, time or effort. This goal transcends the usual boundaries of low, middle and upscale housing, with more people being able to afford housing at the lower end and higher-quality homes for people at the upper end.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for government, building industry, manufacturers and construction industry readers.

Building Better – Advanced Residential Construction Techniques for New Zealand

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1. EXECUTIVE SUMMARY

The Advanced Residential Construction Techniques (ARCT) project was funded by the Building Research Levy to examine ways to address and improve productivity, quality and value within New Zealand's residential construction sector – in other words, build 'better'.

New Zealand's construction sector is often criticised for low productivity, low formal skill levels, low quality and high construction costs. Moreover, a long-term and deep-seated housing shortage continues in Auckland, while Christchurch has 15,000 homes damaged beyond repair in the Canterbury earthquakes to replace.

Further investigation shows that a set of political, economic and social barriers is compounding these issues. These have the effect of stymying innovation, dis-incentivising industry transformation and restricting housing development to typologies with the highest margins and/or profits available.

Five main areas of change are needed in order for the industry to transform – addressing just one or two facets will result in an incremental shift, not a step-change to the sector.

1. Changed business strategy to promote cooperative ventures (e.g. collaboration on projects and pooled research) and provide greater purchasing power that is necessary to reduce barriers from fragmented supply chains and small firms.
2. Employing greater use of off-site construction as well as innovative building materials and techniques can assist in boosting productivity, improving speed, reducing waste, increasing quality and improving health and safety of workers.
3. A concerted and holistic effort by government is required to reduce barriers, such as compliance paths for innovative design and construction. This needs to be paired with incentives for the industry to get involved in selected housing typologies and markets that are currently under pressure from shortages.
4. The challenge to innovate needs to come from within the sector in order to promote lasting transformation and continual evolution.
5. Land prices need to fall, especially in Auckland, in order to lower the price threshold for acceptable margins at which developers will build lower-value housing.

Recommendations arising from the key findings:

A. Transformation needs to be both organisational and technical.

B. The industry should pursue excellence through innovation.

C. The industry should challenge its members to innovate.

D. Government needs to incentivise, assist and support a shift.

E. Offsite construction should be pursued.

Some potential ways to encourage transformation of the residential construction sector include the following:

- Incentivising residential construction in housing types and areas where there are shortfalls in stock and marginal benefit for developers to invest.
- Reducing barriers to the use of innovative construction materials and techniques whilst ensuring products are fit for purpose.
- Supporting research and development for innovative construction materials and techniques.
- Supporting the creation and maintenance of an export market as well as diversified markets. These need to be created and maintained to supplement New Zealand's residential construction demand and smooth boom-bust cycles.
- Quantifying the cost of innovative construction materials and techniques in order to demonstrate the cost-benefits to the New Zealand residential construction industry. It is hoped that this will promote discussion on viability of innovative construction materials and techniques and how best to restructure the industry in order to make full use of them. This will be investigated in part two of the ARCT project and results reported in 2014.

The second year of the ARCT project (2013/14) will examine the top technologies from this report in terms of potential for the New Zealand market and investigate the cost and benefits of their implementation and use. The aim of this is to provide a fuller picture of the selected technologies for the construction industry to consider when planning for the future.

2. INTRODUCTION

The Advanced Residential Construction Techniques (ARCT) project is a 2-year Building Research Levy-funded piece of work. The project aims to inform and inspire actors within and around the New Zealand residential construction sector to find alternative ways of doing things in order to improve quality, productivity and value for money of new dwellings. The focus of this project is on detached and semi-detached low to medium-density residential development.

This interim report covers the first stage's investigation of dual streams of research. One stream is the New Zealand residential construction industry characteristics, barriers, economic, social and political contexts and where it is in relation to the rest of the world. The second stream is the techniques and technologies that are being used around the world to address similar issues to those that are facing New Zealand's industry.

The first section of this report looks at the context of the New Zealand residential construction sector, establishing the current situation and examining some of the challenges the industry is facing. This is then compared to the international context to give the reader a feel for where New Zealand is positioned in relation to other countries.

The second section of this report brings together information on business-level theories and organisational structures that have potential for use in the New Zealand context.

The third section of this report examines the technologies that have been implemented overseas and discusses their potential for use in New Zealand.

The ARCT project deliberately excludes focus upon a particular sector of housing and/or society in order to provoke interest across the breadth of the residential construction industry. Improved quality, productivity and value mean more for less, ultimately benefiting every part of society.

3. THE CONTEXT

New Zealand has been grappling with declining productivity, declining residential building consents and housing shortages for several years.

New Zealand's construction industry has felt the Global Financial Crisis keenly since the Wall Street falls began amidst the USA residential mortgage market collapse in mid-2007 (Bedford, 2008, p. 18).

Auckland's housing shortage is becoming increasingly acute, as only 3,800 dwelling consents are issued each year (Johnson, 2012) when 10,000 are required (Ryan and Collins, 2012).

At the current rate of growth, in the next 30 years, Auckland will need to house another million residents in 400,000 new dwellings (Keown, 2012c). According to (Johnson, 2012), "over the next 20 years Auckland will be missing 90,000 houses" – representing around a quarter of the required stock. Some have expressed doubt that the industry can meet demand with its present structure and methods of construction (for example, Keown, 2012b).

House prices continue to rise while affordability falls throughout New Zealand, particularly in Auckland (Shuttleworth, 2012; New Zealand Productivity Commission, 2012; Cox and Pavletich, 2013).

Figure 1: One of up to 17,000 houses destroyed in the Canterbury Earthquakes. Photo: Getty Images (Macfie, 2011).

The 9th Annual Demographia International Housing Affordability Survey (2012: 3rd Quarter) showed severely unaffordable house prices (a median house price of over five times the median household income) in Auckland, Christchurch, Dunedin, Tauranga/Western Bay of Plenty and Wellington (Cox and Pavletich, 2013). No centres were affordable (2.1–3 times the median household income) or moderately affordable (3.1–4 times the median household income). Palmerston North, Napier-Hastings and Hamilton were seriously unaffordable (4.1–5 times the median household income.

However, the price a house sells for by definition cannot exceed what the market is prepared to pay. The market price of new properties can be assumed to closely relate to existing properties of similar amenity and quality. However, investigation of these factors is a social study that is outside of the scope of this project.

With Auckland's population predicted to keep increasing and the numbers of people per household to keep decreasing, these crises can only be remedied by the construction industry catching up and then continuing to meet demand across the different types of housing and across the affordability spectrum. Currently, new housing investment is heavily skewed towards upper-end housing so as to not undercapitalise on expensive sections (New Zealand Productivity Commission, 2012). Under 'free' market theory, the market will meet demand providing there is enough incentive (e.g. profit) to make it worthwhile. However, if demand is present yet the incentive is not there, either new ways to produce products need to be employed, changes need to be made to make the building process easier and/or external incentives need to be brought into play (e.g. government tax breaks).

To add to the growing issue in Auckland, in 2010 and 2011, a series of earthquakes damaged 15,000–17,000 houses beyond repair in Canterbury. This constitutes a loss of 7–8% of Canterbury's occupied private dwellings as identified in the 2006 Statistics New Zealand Census (Statistics NZ, 2011). Another 15,000 houses have repair bills exceeding $100,000 (Ryan and Collins, 2012). The February 2011 earthquake was the third most expensive in terms of insurance claims for a natural disaster in history (Wood, 2012).

Christchurch continues to experience high pressure and price escalation on new rental accommodation contracts (MBIE Building and Housing Group, 2012; Environment Canterbury, 2013). Delays in the settlement of insurance claims and decisions surrounding rebuilding rentals compete with homeowners seeking temporary accommodation, with the shortfall of accommodation predicted to get worse as the speed of the rebuild increases (Environment Canterbury, 2013).

Between the end of 2010 and September 2012, an 18% increase in rent prices in Christchurch for new rental agreements was observed (Parker and Steenkamp, 2012). This, in part, seems to stem from landlords needing to recoup increased insurance premiums and rates (Turner, 2013). Meanwhile, for owner-occupiers, Christchurch house prices rose by around the same rate as the national average in the year to November 2012 (MBIE Building and Housing Group, 2012; Parker and Steenkamp, 2012), and houses were selling 5 days faster than the national average of 35 days on the market as of September 2012 (Parker and Steenkamp, 2012) in the highly competitive market (Environment Canterbury, 2013).

Although the current government has expressed concern surrounding housing affordability for both renters and owners, it has thus far refused to intervene due to a belief that the market will rectify itself. Following the Productivity Commission calling on the government to address these issues, Finance Minister Bill English acknowledged that "the market is not working properly" and that "housing affordability remains a deep-seated, complex and serious problem" (Shuttleworth, 2012). However, when asked what the government was doing about it, his response was that the situation with wages and low interest rates had meant repayments were less. The implication of this is that buyers are able to service higher loans and pay more to secure a house, putting upwards pressure on prices, especially in areas of high demand and low production. Renters, on the other hand, are paying for increased insurance and rates on the houses they rent and competing with those who would not ordinarily be in the rental market.

The current situation with low interest rates, low builders' margins and high land prices encourages high capital investment in construction and effectively disincentivises low to mid-range residential construction.

As well as high prices, the quality of outputs and productivity of New Zealand construction has been criticised (New Zealand Productivity Commission, 2012; Keown, 2012b, 2012c). Despite this, there remains little incentive – political, economic or social – to pursue improvements to the status quo when demand outstrips supply.

It is clear that the construction industry must be assisted to transform in order to fulfil New Zealand's housing needs, both now and in the future. Drivers such as government policy, regulations, labour force, finance, compliance regimes and land development all impact on house prices alongside the actual cost of erecting a dwelling and as such need to be addressed. This project concentrates on one way to assist with this transformation – the way a product is delivered.

Productivity Limited by Current Practice

According to the UK Encarta Dictionary, productivity is “the rate at which a company produces goods or services, in relation to the amount of materials and number of employees needed”.

Productivity can be boosted through reduced waste, reduced labour requirements, better labour efficiency and increased production, quality and outputs. Basically, raising productivity is about getting more for less.

The New Zealand construction industry’s productivity is low by comparison to other industries (New Zealand Productivity Commission, 2012; Shahzad, 2011). A significant proportion of the sector is made up of sole traders (New Zealand Productivity Commission, 2012). In the year ending 2007, 61% of construction industry enterprises were recorded as having zero employees (e.g. sole traders) (Statistics NZ, 2009).

Firms with 19 or fewer staff members employed 53% of the construction industry workers in the year ending February 2007 (Statistics NZ, 2009). The remaining 47% of construction industry workers were employed by the 2% of firms with over 20 employees (Statistics NZ, 2009).

This is not unusual, with Britain, Canada and the USA’s industries possessing a similar makeup with a vast proportion of small companies including sole traders (Egan, 1998); however, this is beginning to change (Shahzad, 2011).

The New Zealand Productivity Commission (2012) identified that “the lack of scale in the New Zealand residential construction industry presents a significant barrier to productivity growth”.

Along with lack of scale, the cost of construction has risen faster than inflation, yet the quality has remained highly variable, the skill level remains low compared to other industries and productivity remains stagnant at best (New Zealand Productivity Commission, 2012).

The New Zealand Productivity Commission (2012) found this country’s construction industry to have productivity levels 87% of that of Australia between 1995 and 2000, and 55–60% lower than that of the UK’s between 1995 and 2003. The UK industry, despite being far more productive, is being pushed to raise productivity after the Egan Report (1998) identified scope for a sustained improvement of a 10% increase in productivity per year.

In order to boost the construction industry’s ability to at least meet the current and future needs of New Zealand, it is clear that things will need to change. Innovation in both business processes and construction, and indeed acceptance of innovation, is critical.

Incremental Innovation in a Conservative Sector

“Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change.” (Slaughter, 1998)

The New Zealand construction industry is often criticised for lacking innovation and being conservative, rigidly traditional and unproductive in comparison to other industries. These accusations are also levelled at the construction industries in many different countries (Barrett, Abbott, Ruddock and Sexton, 2007; Lessing, 2006; Egan, 1998; Atkin and Wing, 1999), including some where key performance indicators (KPIs) are actually improving (Barrett et al., 2007, pp. 8–9).

Innovation means different things to different sectors, industries and players within those industries from tradespeople through to suppliers (Ozorhon, Abbott, Aouad and Powell, 2010). There have been a number of definitions of innovation in the context of construction coined over time; however, Slaughter's construction industry-specific definition remains one of the most cited (Blayse and Manley, 2004; Ejohwomu and Hughes, 2008; Koebel, Papadakis, Hudson and Cavell, 2004; Ozorhon et al., 2010). She defines five types of innovation – incremental, radical, modular, architectural and system (Slaughter, 1998).

Peter Barrett et al. (2007) propose three forms of innovation – sector level, business level and project level. Sector level innovation is said to be the most noticeable and radical and to create the biggest changes. These may be instigated by rules and regulations or demanded by influential and large-scale clients. Business level innovation focuses on improvements within businesses, often surrounding processes, procurement, upskilling and strategy. Project level innovation is the least visible, happening within the confines of the design team and construction site. Incremental innovation cannot be ignored, as many small incremental changes can lead to more fundamental changes, either as risk adversity drops or as a culmination of the incremental innovations (Barrett et al., 2007).

This report examines not only construction processes but also construction techniques; therefore, a classical definition of innovation does not fit. For simplification, this report breaks innovation into two key forms to define the impact of the innovations – incremental and fundamental. Incremental innovation is a small step or improvement to a product, system or the way something is done. Fundamental innovation is something new, different and a catalyst for a new way of doing things.

Incremental innovations are critical, occur every day on most building sites and often go unnoticed or uncaptured. Incremental innovations are small-scale changes that make things work or make things easier to achieve without shaking up the entire process. Incremental innovation is often found in constant process improvement programmes. This is not to say that incremental changes work in isolation – enough incremental changes can lead to fundamental innovation.

Smaller changes are easier to implement than large changes for a variety of reasons. The status quo remains only with minor upgrades – costs, risks and the need for retraining are minimised, and there is usually little capital outlay. Smaller changes are more socially acceptable (Bell, 2009), and as De Geest noted (quoted in (Bell, 2009)), "small changes will ensure enduring change".

An example of an incremental change is the modification of concrete blocks from solid to hollow. This reduced their weight and, as theorised at the time, could be used to provide ventilation to the wall cavity to remove water and even to ventilate inside the building (Isaacs, 2011). The hollows in the blocks would lead to another incremental innovation. In New Zealand, partially filled and lightly reinforced concrete blocks were used from the 1950s, with complete fill from the 1980s (MacRae, Clifton and Megget, 2011, pp. 1–2).

Fundamental innovation, on the other hand, can turn processes on their head and create a new way of doing things. An example of fundamental innovation is the American modular industry's method of modular construction. Designs are split into modules that will fit onto the back of a truck, constructed and often finished in a factory, then transported and placed together onsite, a bit like building blocks. This allows efficiency gains in time, two parallel workstreams with onsite foundations and offsite environmentally-controlled construction and a change in scale with materials being sent to one place for potentially multiple houses.

Even this is not entirely fundamental – homes are still built with traditional materials, and in many cases, companies opt for traditional construction methods rather than automation in order to reduce the amount of capital investment required in the factory. The fact that the industrial revolution has encapsulated all other forms of manufacturing so far suggests that moving construction into a more industrialised and corporatised setting is an evolutionary rather than revolutionary move.

Innovation and especially fundamental innovation requires commitment, courage, often high capital outlay and relies on early adopters for uptake and diffusion. However, “the marginality of profits and the risk of unforeseen failure and damage during project execution have reinforced conservatism and the reluctance of construction firms to engage in ventures for technological change”. (van Egmond, 2012, p. 112)

In addition, the risk associated with traditional boom and bust cycles of the construction industry provide a disincentive for major investments in offsite production.

It is important to recognise that an innovation for one sector may have been used in a similar way for many years (or indeed centuries in the case of industrial production lines) in another sector.

Most Research and Development Spending Embedded in Materials

Innovation carries with it risks and costs that much of the industry is not prepared or cannot afford to cover. Research and development (R&D) into obviously different technologies are also perceived to be inherently risky. “The very high cost of individual houses, the difficulty of prototyping and the fragmented nature of the construction industry make it very hard to justify taking chances by building innovative and obviously ‘different’ houses.” (Edge, Laing, Craig, Abbott and Hargreaves, 2003)

As a result, research and development is left to manufacturers, industry groups or government-funded or independently funded research (such as this project, which is funded by the Building Research Levy). Unsurprisingly, R&D figures for the industry are very low compared to other countries – particularly those that are more mechanised.

The issue of quantifying the amount spent on R&D in the construction sector is not a simple one to measure and is frequently misrepresented through measuring only direct spending (Barrett et al., 2007). In reality, much of the R&D is done by the manufacturing sector, which is by no means distinct in operation from those it serves in the construction sector (Barrett et al., 2007).

Therefore, a lot of R&D (and indeed innovation) that benefits the construction industry as a whole is commissioned by the supplying manufacturers. Ultimately, this cost is passed on to the construction industry, and thus it is unfair to specifically compare amounts directly invested in R&D by the construction industry. Critical research for the construction sector is most often based upon systems, techniques and detailing due to this inherent contribution to materials R&D via purchase.

There is a definite difference between R&D and innovation. R&D does not necessarily lead to innovation – often, it leads to no more than incremental change by ways of refinement. Innovation also is not always the result of R&D in its purest form – a lot of innovation takes place onsite in response to unique challenges and is not always captured.

Demonstrating innovation to consumers is not straightforward in the construction industry. Fairweather, Lambert, Rinne and Steel (2009, p. 9) made the following point:

> Trialability poses a problem for house builders since low volumes and working with many subcontractors limits opportunities for trials. For this reason, it is often research centres which operate demonstration parks. However, these have high costs and low portability. Observability poses a problem since many innovations are invisible to the consumer.

A new house is not like a new phone where you can go into the menu and scroll through to find the specifications. Consumers may see materials that are innovative, but because they appear to be virtually identical to traditional materials, the innovation is not noticed. The consequent benefits of a material or system may not be immediately noticeable and may not become apparent for many years after installation (Edge et al., 2003).

Small, Adversarial Firms and Poor Feedback Loops

The New Zealand construction industry's high number of very small companies paired with a market with a preference for bespoke housing virtually prohibits economies of scale at present (New Zealand Productivity Commission, 2012). New Zealand's construction industry is vertically fragmented, with subcontractors making up a large proportion of many project teams (New Zealand Productivity Commission, 2012).

Fragmentation has been singled out as a major inhibitor of the construction industry, both in New Zealand (New Zealand Productivity Commission, 2012; Scofield Potangaroa and Bell, 2010) and overseas (Blayse and Manley, 2004; Robichaud, Lavoie and Gaston, 2005; McCoy, 2007; O'Brien, Wakefield and Beliveau, 2000; Olson, 2010; Barrett et al., 2007; Zawdie, 2012).

Paired with a lack of or poor communication, fragmentation can lead to severe difficulties. As noted by the New Zealand Productivity Commission (2012), "without good management and procurement practices, this fragmentation in the supply chain can generate inefficiencies, time delays and re-work, which drive up cost and reduce quality".

The prevalence of small-scale operations can breed major difficulties for the ability to innovate – small players are less likely to have the funds or the time to innovate. New Zealand's industry will have to form and maintain "strong industry relationships if innovation opportunities are to be maximised". (Blayse and Manley, 2004, p. 147)

The traditional construction process involves three distinct parts, as defined by van Egmond (2012, p. 107):

1. Development and production of building materials and elements.
2. Development and production of building design and engineering.
3. Construction process development and execution.

Each process is undertaken by one or more different players, and there are no formal feedback loops across the stages. For example, often builders will use a product but have no communication back to the manufacturer – any innovations that happen onsite to improve a product or troubleshoot are not necessarily conveyed back to the manufacturer or even to the designers and engineers.

This can also cause problems in the long run. The New Zealand Productivity Commission (2012) describes efficient feedback loops as "vital for the fast

dissemination of productivity-enhancing innovations" and "even more important [in] that they allow for rapid dissemination of information about defects in materials, designs or building methods". If problems in a construction type or method occur, such as with the leaky building syndrome, it is essential that the knowledge is disseminated throughout the industry, from governance to tradespeople and maintenance staff (New Zealand Productivity Commission, 2012). If knowledge of any issues is fed back quickly, damage can be minimised and designs adapted.

Van Egmond (2012) proposes "innovation-by-integration", where building product and process innovations are integrated. New products and construction processes are thereby theorised to develop systemically in an integrated way.

Joining forces not only promotes innovation and circular feedback loops but also breeds potential for improved procurement methods. The current adversarial method of procurement aims to get the materials and labour at the lowest possible cost and in many distinct purchases.

Low Formal Skill Levels, Low Incentive to Train

New Zealand's construction industry has a been criticised for low formal skill levels of workers as compared to those in other industries (New Zealand Productivity Commission, 2012; Scofield, Wilkinson, Rotimi and Potangaroa, 2009; Scofield et al., 2010), like the UK (Craig et al., 2002; Goodier and Pan, 2010; Craig, Laing and Edge, M et al., 2000; Phillipson, 2001; Stirling, 2003), Australia (Daly, 2009), North America (Koebel et al., 2004; Robichaud et al., 2005) and Malaysia (Thanoon et al., 2003).

The cyclic nature of industry demand hampers both upskilling and staff retention (New Zealand Productivity Commission, 2012) – short cycles means employers are less likely to invest in education for their staff. From an employee's perspective, there is less incentive to train for a career in the construction industry when the majority of positions are temporary and project-based. The number of people working in the field fluctuates dramatically between boom and bust parts of the cycle, and thus many move into other fields by necessity, if not by choice.

Skills and education affect not only the pace and quality of existing processes and technologies but also the uptake of new materials and technologies. An Australian survey-based study found that "any new materials introduced, necessarily result in new skill requirements" (Daly, 2009) and that the processes of time and 'due diligence' were needed before new materials were effectively integrated into widespread use in the sector.

The study also found that, despite manufacturers and the Ministry of Business, Innovation and Employment promoting training and upskilling as part of best practice models for the implementation of new materials, it is not considered important in the formal training of industry apprentices. Instead, the emphasis is on learning from onsite practitioners by way of knowledge built up with experience and thus the domain of more senior professionals (Daly, 2009). As a result, knowledge transfer is usually "tacit and not codified" (van Egmond, 2012, p. 112). It is learned but not necessarily recorded, making the uptake of knowledge difficult and slow to diffuse throughout the industry.

This lack of skill development, especially surrounding innovative techniques and materials, may well be holding the industry in the current traditional form of relying on those taking on apprentices (a vast number of which are small firms) to demonstrate innovative and advanced techniques, materials and technologies. As expressed in the UK Egan Report (Egan, 1998), "… upgrading, retraining and continuous learning are not part of construction's current vocabulary. There is already frustration amongst component suppliers that their innovations are blocked

because construction workers cannot cope with the new technologies that they are making available."

Indeed, fragmentation within firms can be enough to topple an innovation agenda. A firm's management team may have a commitment to innovation; however, this does not mean that downstream there is the same enthusiasm. Horizontal fragmentation across the firm can be a significant barrier to the production of a well rounded and marketed product (Craig et al., 2002, p. 39) or indeed implementation of a non-traditional programme of work.

At present, the New Zealand construction sector is risk adverse. Most practitioners prefer to use tried-and-true materials, systems and techniques that have passed the test of time and 'due diligence', deeming them to be low risk. Demonstration projects, where materials, systems and techniques can be seen and touched are often the only way to persuade industry practitioners to try them (Sharman, 2013).

Land Challenges – Price, Speculation and Policy

With the spread of New Zealand's cities going relatively unchecked since the settlement of the country in the 1800s, councils began imposing boundaries, with the vision of constraining growth and encouraging higher-density construction and infill housing. However, this has recently come under the spotlight when the New Zealand Productivity Commission (2012) concluded that "a lack of available land ... present[s] a significant barrier to productivity through inhibiting the development of group home builders and scale developments".

As identified by Motu Economic and Public Policy Research in its report to CHRANZ (Grimes andAitken, 2005, p. ii), between 1981 and 2004, the CPI-adjusted price of vacant residential sections rose by 286% on average across New Zealand, compared to 105% for house prices. Auckland experienced the most significant price rise of almost 700% for sections, compared to 200% for house prices. In neighbouring Manukau, North Shore and Rodney, section prices increased by around 460% over the same period (Grimes and Aitken, 2005, pp. ii–iii).

This rapid increase in land prices, combined with the cost of residential construction rising faster than inflation, puts upward pressure on house prices and reduces housing affordability. The geographic constraints lead to small-scale construction sites in geographically diverse locations, thus reducing the ability to utilise economies of scale, increasing pressure on the industry to profit out of smaller numbers of builds and leading to large amounts of travel and materials movements. As a result, high-end houses are built to maximise profit per project. Put simply, "… the current industry structure is influenced by the environment in which it operates, which is characterised by a fragmented and expensive land supply". (New Zealand Productivity Commission, 2012)

The collapse of the new housing market from 2008 onwards may have contributed toward high house and land prices, with the market restricting the release of land to prevent a glut and resulting loss in value (Goodier and Pan, 2010). By retaining the land and releasing it slowly, investors can wait for prices to improve. Land-banking works to ensure supply for investors through economic busts, but undermines potential numbers of houses that can be built and leads to big boom and bust cycles in employment within the sector as the market fluctuates. The variability of employment means that only a few remain within the sector through the cycles, resulting in an ageing skill base (Goodier and Pan, 2010).

The New Zealand Government has announced a plan to extend the Auckland City limits; however, Mayor Len Brown raised the point that there are over 18,000 sections available for development (Keown, 2012a). Whether the blame lies on a

slow residential construction market or on land availability is a chicken-and-egg scenario. Adding on to the city limits will not necessarily improve the situation for those in the lower to middle income brackets – fringe living may be ‘affordable’ due to lower house prices; however, when travel costs and time are included, this may be unfeasible for many of Auckland’s population.

4. WHAT CAN WE LEARN FROM OTHER COUNTRIES?

The following is an expanded review of residential construction industries and their operating contexts from across the developed world.

Japan – High-end Consumable, High Technology

The Japanese treat housing quite unlike the West. The culture places greater value on the land than they do the building, treating housing as a consumer item (Groak and Gann, 1995) or depreciable asset that is replaced every 20–30 years (Johnson, 2007; Craig et al., 2002). Some 74% of homes in Japan were built after 1981 as at the 2008 Housing and Land Survey (Official Statistics of Japan, 2012). As such, the value of new housing is highest, with very little ability to sell older houses due to the perception (Craig et al., 2002) of the asset being near the end of its life. Modern technology is perceived to be of the highest value. As such, the attachment for Japanese families is with the land as an appreciating asset. Rapid depreciation of houses after completion means that speculative building is relatively uncommon.

On top of this, its prefabricated housing market is quite unlike the rest of the world. Japanese restrictions, such as rigid seismic engineering requirements on prefabricated housing (traditional onsite builds were exempt) meant low-cost prefabrication was not viable. In order to achieve economies of scale, the industry had to target higher-value housing, going mid- to upmarket. This marketing strategy played on the higher quality controls, strengths, consistency of product and ability to 'customise' the housing with a multitude of options to personalise the end product. The quality is regarded as of higher value than with traditional housing (Bell, 2009; Craig et al., 2002).

The mechanisation and embrace of technology in Japan also creates a rich environment for prefabrication in its broadest sense and a focus on working smarter, leaving the workforce to get on with jobs that cannot be done by machines, leading to a knowledge-based, value-added economy.

In 2008, there were over 48 million houses used exclusively for living in Japan, 63% of which were privately owned (Official Statistics of Japan, 2012). Most Japanese construction is owner-initiated (Johnson, 2007), as it is in New Zealand.[1]

The USA – Modular High-end Architecture

The USA's construction industry is similar to New Zealand's in the respect that the majority of construction companies are small (Johnson, 1989); however, the 10 largest firms account for 66% of all new housing starts (Koebel et al., 2004).

Like New Zealand, the majority of houses in the USA are single-family homes, housing more than two-thirds of the population (Huang, 2008). Homes are also growing larger, having gone from an average of 290 square feet per person in 1950 to 900 square feet per person in 2004 (Kaufmann and Remick, 2009).

Similar to New Zealand, the beginnings of non-traditional construction, including modular, panellised, transportable and hybrid, began with the early settlers to the USA. 'Kitset' catalogue houses were popular through the early 1900s. Offsite production went through a third phase of popularity after World War II with pressure to build homes to accommodate returning soldiers (Bell, 2009). In current times, prefabrication has become a new form of architecture for some (e.g. Rocio

[1] Personal communication with Ian Page, BRANZ Ltd, 24 October 2012.

Romero, Michelle Kaufmann, Marmol Radziner, Taalman Koch, Minarc) and a fast way of cost-effective and energy-efficient construction.

While the percentage of homes being built using non-traditional methods in the USA remains relatively low, the number of houses being built is high by New Zealand standards. In 2011, 20,000 new single-family houses were completed using non-traditional construction techniques out of 447,000 homes in total.

Figure 2: Modular craftsman style home (Condominium Pattaya, 2012).

Figure 3: Site-built craftsman style home (Chelsea and Kyle, 2011).

The typical American house design is well suited to typical prefabrication techniques – most houses are constructed from timber 'stick' framing, and cladding tends to be lightweight. Because of the dominance of lightweight site-built construction, the lightweight prefabricated options do not appear to be too different for consumer taste. In fact, for the majority of modern prefabricated houses, it would take someone with a fair amount of awareness to pick that they had not been built from scratch onsite (see the comparison in Figure 2 and Figure 3).

Modular houses are often mistaken for manufactured or trailer housing. However, with the introduction of 'HUD' building codes (Manufactured Home Construction and Safety Standards), the two industries were split into 'trailer' housing and modular home construction (Huang, 2008; Nahmens and Ikuma, 2009; Olson, 2010). Modular housing constituted 24% of all new housing and 38% of all homes sold in the USA in 1996 (Bates and Kane, 2006), however; traditional construction still dominates.

There appears to be a split in the USA market, with larger builders more likely to use prefabrication and a tendency to be more innovative than their smaller counterparts (Koebel and Cavell, 2006). This is likely to reflect the disparity in available capital for investment in advanced building technologies.

The UK – Government Push to Break Prefab Aversion

The UK's building industry bears striking similarity to New Zealand's in structure and state. The UK has been experiencing a severe housing shortage for many years. The number of households has increased as demographics have changed, and this has exacerbated the shortages as production fell to the lowest levels since World War II. Some 225,000 houses a year were predicted to be needed in the UK in the lead-up to 2016; however, in 2001, only 173,100 homes were built (Goodier and Pan, 2010).

The UK construction industry is highly competitive and operates based on a competitive tendering system, as is used in New Zealand. This has the effect of discouraging group procurement and partnerships and encourages a culture of cost before quality.

The fluctuating markets have led to risk adversity, an ageing workforce, skill shortages as people are 'hired and fired' as work comes and goes and a lack of

investment in and commitment to innovation and training (Goodier and Pan, 2010). The bottom-line and easy-to-sell houses are the primary focus, although prefabricated, modular and standardised construction techniques were seen to be something to utilise in the future.

The traditional UK housing construction differs vastly from New Zealand's with a strong and partially market-driven preference for homes that look 'traditional' (more often than not, brick and mortar). Client resistance to non-traditional construction has come from a variety of historical sources.

The consumer has been observed to shy away from 'prefabricated' housing due to relating this with post-war housing and memories of design flaws from historical prefabricated housing blocks, a poignant one of which was the Ronan Point collapse (Craig et al., 2002; Goodier and Pan, 2010).

More recently, the timber-framed housing demand virtually disappeared overnight with the airing of a television programme back in 1983 that put doubt on the structural stability and length of service life of the framing (Phillipson, 2001). This tainted the view of the public, and when paired with the dislike for post-World War II prefabricated timber-framed housing, resulted in a strong consumer preference for either solid masonry or steel-framed construction. Interestingly, this does not carry through to Scotland, where most housing starts are for timber-framed homes.

Some companies go to the extent of prefabricating what they can but advertising the fact that one cannot tell the difference between a traditional build and the partly prefabricated houses they are offering. This stymies the ability to press into niche markets with innovative design and does not allow prefabrication, modular or standardised construction techniques to be used to their full advantage.

The UK construction industry is widely criticised for its perceived lack of innovation, efficiency and lack of quality outcomes. These criticisms and others culminated in the UK Government commissioning the Construction Task Force to investigate such issues. The Construction Task Force issued its report in 1998, challenging the industry to achieve a 10% reduction in construction cost and time each year and to reduce defects in projects by 20% per year (Egan, 1998). The report identified five key target areas: "committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda and commitment to people".

This work brought about a surge of promotion of 'modern methods of construction' or MMC. MMC is a loose term used to encompass a variety of business and construction processes that are theorised to "build good quality homes more quickly and efficiently" (Fawcett and Allison, 2005, p. 1). MMC are generally regarded as "offsite manufacture and other innovative production techniques" (Goodier and Pan, 2010), including site-built through to factory-built housing (Daly, 2009).

UK Government initiatives were used to demonstrate the potential of MMC; however, the low or unskilled labour force, resistance to the methods and lack of ability of subcontractors to comply with the needs of MMC timing led to reduced success of the projects, higher costs than anticipated and barely lower costs than conventional construction.

Hence, 10 years later, it was identified that the targets had not been met, although there had been some improvement (Zawdie, 2012). A range of barriers have been identified, including lack of impetus at management and government levels, poor integration and knowledge exchange and the persistence of fragmentation and tradition in the industry (Zawdie, 2012). Ultimately, this meant that the prevailing culture stymied opportunities for widespread and total change.

A serious barrier to building innovation in the UK is the perceptions and practices of the valuation fraternity. Perceptions that prefabricated housing will last less than the 50–60 years required for lending (Craig et al., 2002) reduces the chances of funding being available to undertake a project. Companies are encouraged to "consult widely and early throughout the lending and insurance industries to confirm that mortgage funding will be available" for properties built using the product. This compares with New Zealand, where the Building Code mandates performance of structural elements to have durability for 50 or more years – lenders appear not to consider materials for any more than aesthetic and quality considerations.

While valuers consider age, location, floor area, numbers of rooms and a multitude of other physical characteristics, they do not consider aspects such as quality and precision of construction, energy savings (e.g. high levels of insulation) or energy creation (e.g. photovoltaic-integrated roofing).

The effect of this is that mortgage lending is based on valuations of homes as though they were of a typical type. This, in turn, restricts the use of innovative design to those willing to invest capital over and above the deposit.

The result is that the homeowner has to decide whether or not to invest the extra capital in higher specifications. However, homeowners are resistant towards paying a premium for higher specification homes due to a lack of demonstrable payback (Goodier and Pan, 2010).

However, the push for MMC has provided some impetus for both public and industry to consider commissioning and constructing at least parts of houses utilising its concepts. By educating the public, the English industry is managing to incorporate a degree of prefabrication of componentry, if not modular housing (Phillipson, 2001).

Scandinavia – Prefabrication for Better Buildings

Sweden, Finland and other Scandinavian countries have had strong architectural tradition with prefabrication (Bell, 2009) and have long embraced offsite construction.

Sweden's prefabrication is based on a manufacturing industry and began with panellised walls to speed up construction after World War II. Houses were designed in Finland, manufactured in Sweden and sent back to Finland after the Winter War (1939–1940) (Craig et al., 2002). Today, around 90% of Sweden's homes are prefabricated (Lindburg, Howe, Bowyer and Fernholz, 2007).

Most Swedish prefabricated houses are timber-framed rather than steel-framed; indeed, most materials tend to be timber-based (Craig et al., 2002). Between 1990 and 2002, 74% of one-family detached homes were built by Sweden's industrialised timber-frame housing companies (Bergstrom and Stehn, 2005). The industry tends to incorporate design and manufacturing processes, leading to a simplified supply chain and long-term client-oriented relationships (Bergstrom and Stehn, 2005).

In Sweden, prefabricated construction has been used for energy efficiency right back to the energy crisis of the 1970s (Lindburg et al., 2007). Sweden's built environment uses around 36% of the country's energy – a similar percentage to New Zealand (Janson, 2008). In June 2006, the Swedish Government issued a decision that energy use per square metre of heated floor area should be reduced by 20% by 2020 (Janson, 2008).

Reflecting this drive for energy efficiency, the country's primary reasons for utilising prefabrication focuses on energy, maintenance and environmental benefits before economic and construction savings (Craig et al., 2002).

Sweden has experienced similar issues to New Zealand with regards to housing shortages and industry productivity. In the 1990s and early 2000s, there were historical lows in the numbers of houses built. The Swedish construction industry has also been characterised as inefficient, uncooperative, lacking commitment, fragmented in building processes and lacking of a holistic view of the process (Lessing, 2006). Despite this, they aim to deliver 30,000 houses per year (Atkin and Wing, 1999) for a population of 9.5 million people (Statistics Sweden, 2012).

Sweden has an export market of prefabricated housing, exporting around 140 million Euros of industrialised timber-framed houses per year between 1999 and 2002 (Bergstrom and Stehn, 2005).

Along with Finland and Japan, Sweden is at the top of the OECD for investment in R&D (Bell, 2009).

Finland began standardising houses around 1940, after Alvar Aalto designed the first standardised workers' house in 1937 and "succeeded in introducing modern concepts of architecture to prefabrication" (Craig et al., 2002).

Finland builds around 60% of its one-family houses using industrialised building systems, which is increasing by around 20% per year (Thanoon et al., 2003). Alongside Sweden, Finland is regarded as a lead performer in the areas of prefabrication and construction output (Bell, 2009).

Europe – Mainstream Prefabricated Construction and Architecture

As a whole, offsite production and prefabrication is in use as an accepted method of construction throughout much of Europe.

In Germany, prefabrication is an accepted form of construction. The market share in East Germany is 11%, while in West Germany, it is higher at 24% (Craig et al., 2002). The current wave of popularity for German prefabricated architecture has led to widespread exposure on television programmes, such as the British *Grand Designs*. This popularity is echoed by industry in other countries, with an Australian study finding high regard of German innovation (Daly, 2009).

The German prefabrication industry utilises a wide variety of products (Craig et al., 2002), including steel, timber, concrete, glass and composite products (Grant, 2010). A prime marketing factor is ecological, sustainable design and efficient housing (Bell, 2009).

Some 17% of the German construction market uses industrialised building systems (Thanoon et al., 2003), and around 10% of new homes are prefabricated offsite (Bell, 2009).

The German market favours single points of contact when it comes to house construction, covering everything including finance, design and building the house (Craig et al., 2002).

Germany has experienced housing affordability issues over recent years, and studies have suggested there are potential cost savings for prefabricated house construction of 22% over traditional construction (Edge et al., 2003; Craig et al., 2002).

Germany's construction industry has become increasingly skilled over the years. Between 1974 and 1996, the proportion of labourers declined from around 33% to 17.5% (Clarke and Wall, 2000). The country's construction industry has a grading

system that allows workers to rise through the ranks with experience, as in the Netherlands where the proportion of labourers is even lower (Clarke and Wall, 2000). In both Germany and France, the training systems also have strong emphasis on 'artisan' practices (Daly, 2009).

As in Britain, the Dutch prefabrication industry was established to assist with the rebuild after the war (Craig et al., 2002).

The Dutch and Belgians tend to focus more on panellised systems, such as tunnel form, than prefabricated housing per se (Craig et al., 2002). The amount of structural trade labour used on worksites is around half that of Britain (Clarke and Wall, 2000).

As in Japan, the Dutch tend to demolish and replace out-of-date housing stock rather than renovate (Craig et al., 2002), as is the tendency in both the UK and New Zealand.

The English building industry has perceptions very similar to those of the New Zealand industry surrounding non-traditional materials and systems. The perception is that using out-of-the norm materials and construction types is costly in terms of delays (Craig et al., 2002), and at least in England, some of this may be founded on reality.

An apartment project by the Peabody Trust called CASPAR was delayed for months when going through the planning process, a delay perceived to have been caused by the use of modular construction and timber framing and a lack of understanding and risk adversity held by local planners. This cost the project dearly, with it ending up over budget and over time; however, this was still less than if it had been undertaken by traditional construction (Craig et al., 2002). The 18-week time-saving during the construction phase allowed rental income that "was equivalent to approximately the cost of an additional flat" (Craig et al., 2002, p. 41).

Discussion

Stage one of the Advanced Residential Construction Techniques (ARCT) project has identified that the New Zealand residential construction sector cannot keep up with demand within the confines of current political and economic circumstances. The ability to build depends on the ability to firstly obtain land and secondly to make sufficient profit from the project to make it worthwhile. However, there are techniques and technologies available both here and overseas that have the potential to catch up with shortages and meet demand.

The New Zealand construction industry is frequently criticised for its low productivity, lack of consistent quality, insufficient innovation and lack of ability to address the housing shortage existing in most of New Zealand, but particularly Auckland and post-earthquake Canterbury.

Current Format of the Industry Hinders Change

The New Zealand residential construction industry tends to consist of many small businesses compromising of as few as one individual. These firms tend to work on single sites in built-up areas, while large-scale companies tend to focus on new, large-scale developments.

The current fragmented and adversarial typical company set-up and inherent conservatism surrounding construction methods are hindering the growth and development of the residential construction sector by creating a barrier to change and innovation. This is detrimentally impacting on New Zealand's economy,

society and environment, which then detrimentally impacts on company growth and development – a chicken and egg scenario.

The Global Financial Crisis of the past few years has further stymied growth in the industry and slowed construction rates, compounding housing shortages, career attrition and lack of training in the area.

Insufficient Drivers for Change

The majority of the residential construction sector observes traditional onsite construction methods of building using tried-and-true materials (Page and Curtis, 2011) and techniques. Issues with and poor perceptions of non-traditional construction and materials have led to a risk-adverse industry. Without incentive to innovate and with excessively restrictive and time-consuming compliance avenues and low margins, risk adversity can manifest.

The ARCT project seeks to encourage the residential construction industry to adopt and adapt innovative and advanced construction techniques used both here and overseas in order to more productively build better quality, better value housing that is better for the people who build them and live in them and the environment around them.

International Perspective – What Can We Learn?

This project reviewed overseas technologies and techniques to find out what is done differently from New Zealand, alongside the context in which the residential construction industry operates in those countries. The results are shown in .

Table 1.

Table 1: International residential construction and contexts

Country	Characteristic
Japan	Housing a consumable or 20–30-year depreciable asset
	74% of homes 27 years old or less in 2008 (Official Statistics of Japan, 2012)
	Prefabrication a high-end product
	Customisation through choice of fittings, options, finishes
	Highly mechanised, automated
	Work smarter – people do what machines cannot
	Most construction owner-initiated
USA	Big firms build 66% of new houses
	Most single-family homes
	Similar materials
	Industry split between traditional and offsite
	Established modular and factory-built home construction industry
	Prefabrication as high-end architecture (limited ‘affordable’ housing)
UK	Similar industry set-up to New Zealand but higher productivity
	Barriers to innovation
	Housing shortages

	Aversion to timber structure (England only)
	Wary of prefabrication/offsite construction
	Government push for modern methods of construction – prefabrication and offsite construction
Scandinavia	Long acceptance of prefabrication/offsite construction
	Quality focus for prefabrication/offsite construction
	Drive for energy efficiency, environmental protection
Broader Europe	Long history and acceptance of prefabrication/offsite construction
	Drive for quality and cost efficiency

The review identified a number of techniques and technologies that New Zealand could learn from countries with more advanced residential construction.

In summary, many industries in other developed countries are moving towards offsite construction in an effort to improve quality, efficiency and affordability and reduce environmental impact. These will be discussed in the following two sections of the report.

New Mainstream Construction Methods Needed

ARCTs involve more than just a step-change – they involve innovation, which is defined by the Encarta Dictionary (UK) as “a new invention or way of doing something”.

ARCTs are usually aimed at process improvement and efficiency, as opposed to just the use of more advanced materials or products. They include a diverse portfolio, including planning, business processes and actual hands-on construction. While the focus is on residential construction, ARCTs may come from non-residential backgrounds where there is potential for them to be used in residential applications.

The techniques discussed in the next two sections of this document provide an overview of potentially viable systems that could be adopted by and adapted by New Zealand’s residential construction industry with the aim of ‘building better’. The list of techniques is by no means exhaustive and aims to give a broad overview with sufficient detail to look at the merit of the techniques in the national context.

5. SMART BUSINESS STRATEGIES UNDERPIN INDUSTRY TRANSFORMATION

This section looks at the business-level and advanced techniques that have potential for New Zealand's industry. There are three levels of innovation within the construction industry – sector-level, business-level and project-level (Barrett et al., 2007). A step-change will involve sector-level change, encompassing multiple business and innumerable project innovations.

Most of New Zealand's construction firms are small, entailing five people or fewer. Many consist of an owner-operator. This is very similar to the makeup of the UK's construction industry, which faces similar challenges to New Zealand.

The key challenges of small construction businesses include, but are not limited to the following:

- Low capital, resulting in low investment in R&D.
- Low succession, resulting in lost knowledge.
- Limited resources, leading to limited skillsets.
- Adversarial operation to preserve one's business and preserve the benefits of one's own work.
- Limited ability to experiment with materials or processes.
- Limited ability to take on risk and thereby having high risk adversity.
- Procurement issues.
- Fragmented supply chains with multiple manufacturers, multiple suppliers and poor feedback loops for manufacturer innovation.

The most radical and sweeping changes occur when rules and regulations change or a large client, such as the New Zealand Government, pushes a certain agenda.

The challenge of partnering and collaboration by the industry in the UK, as issued by Egan and the Construction Task Force (Egan, 1998), had not yet happened to any meaningful degree 10 years after the challenge had been issued due to failures from government level right through to the coordination of subcontractors (Zawdie, 2012). In order to successfully meet Egan's challenge, five areas needed to be addressed: committed leadership; a focus on the customer; integrated processes and teams; a quality driven agenda; and commitment to people (Egan, 1998).

> The industry therefore needs to remove fragmentation, embrace change, and leverage innovation drivers through new business models and strategic directories that streamline and align corporate energy and competence to business goals and new market opportunities. (Zawdie, 2012, p. 41)

To date, the structure of the industry has led to the pervasion of traditional methods to remain. In order to address this, a strong business culture is essential for generating lasting change.

As Koebel et al. (2004, p. 11) pointed out, the context in which firms operate defines their actions to a large degree:

> Criticisms of the residential building industry as technology adverse and 'backward' have ignored the social system characteristics that contribute to business success. Technology is but one means of adapting to a complex

> environment, and the contribution of technology to a building firm's profit has been unexplored. If the control of land might be the primary determinant of profit … technological innovation might be an unnecessary expense.

Construction companies are more inclined to invest in technology that can be seen, touched and interacted with (Sharman, 2013). The physical containment and inaccessibility of most structural innovations show the inherent difficulty of demonstrating benefits of non-cosmetic innovations to clients (Koebel et al., 2004). This therefore may pose questionable benefit of delving into new business practices and technologies without a strong drive for structural innovations of others similar to this type.

This drive for innovation is especially critical for smaller companies, as Edge et al. (2003) pointed out. "Though a circular argument, it is a very powerful one in a risk-averse industry producing very expensive products which [makes it] extremely difficult to prototype". A show home is an expensive investment and an innovative home is therefore an expensive experiment for a small company.

Some argue that construction industries fail to industrialise due to focusing on flexible production methods, rather than "conform[ing] to the ideal of mass production" (Harris and Buzzelli, 2005). While this may be true, this statement assumes that there are just two types of construction – bespoke (individually designed and crafted) and mass-production (mass-manufactured, usually identical units). However, this is a simplistic view that neglects to consider the merits of mass-standardisation (designed from a standardised catalogue), mass-customisation (tailor-made made to order using a small number of core components) and hybrid construction, as described in the introduction. These philosophies take the best out of both bespoke and mass production and open up opportunities through procurement and value-creating networks as well as offsite production. Both of these topics will be discussed in this chapter.

5.1 Networking for Procurement and Value Creation

With such a proliferation of small companies, procurement is not a simple issue for New Zealand's construction industry. There are a handful of large businesses, a handful of large manufacturing suppliers and a multitude of merchants operating as tradesperson-owned companies. The New Zealand market is small compared to overseas – only a limited number of businesses can survive. New Zealand's materials have a propensity to be more expensive. However, Housing Affordability Inquiry participants indicated a preference for local materials as a way to ensure performance in local conditions (New Zealand Productivity Commission, 2012).

Overseas experiences have taught us one thing – size is not everything, but cooperation is. Bulk procurement direct from the manufacturer and the maintenance of strong feedback loops are key to both cost efficiency and industry-led innovation, acknowledging that much of the construction industry's innovation starts with the manufacturer.

After a challenging period of declining profitability in the USA, three key trends are emerging amongst the largest builders: increased industrialisation; product substitution at the design level; and consolidation (Lefaix-Durand et al., 2005). Builders are searching for ways to make installations more efficient and faster to install, with lower maintenance requirements (Lefaix-Durand et al., 2005).

Companies are seeking to boost performance through merging with and acquiring other companies. Increased cost savings through economies of scale and rationalised business functions provide more influence in the marketplace (Lefaix-Durand et al., 2005). However, the majority of firms prefer to acquire competitors rather than enter arrangements with suppliers and manufacturers.

Inter-firm cooperation has not traditionally been a feature of the New Zealand construction industry due to the competitive, adversarial nature of firms (New Zealand Productivity Commission, 2012).

Even with mergers and cooperative ventures, without integration of the entire supply chain, only a certain amount can be achieved:

> The traditional approach to building procurement is characterised by a largely fragmented and sequential process, with little contribution made at the briefing, design and cost-planning stages by key contractors and specialist suppliers. This failure to capture the supply chain expertise early in the process is one of the primary causes of uncertainty, additional cost and contractual conflict. (Stirling, 2003)

In addition to this, our conservative mindset may have helped entrench traditional construction in the New Zealand construction industry:

> Procurement systems that tend to discourage construction firms from risking the adoption of non-traditional processes and products are most injurious to innovation. These systems include those that place a premium on speed and urgency or on competition on the basis of price alone…. (Blayse and Manley, 2004, p. 148)

The current procurement systems tend to focus on capital cost of materials rather than the installed systems including the variables of labour and time.

A main inhibitor of innovation is the competitive tendering process. Those who take risks by innovating need to be rewarded in order for levels of innovation to be maintained or increased (Blayse and Manley, 2004). Partnering (client and builder working together), alliancing (companies working together) and cooperative problem-solving (potentially involving clients, designers and builders) provide opportunities to increase bargaining power, share innovation risks and investment expenses and exchange knowledge (Blayse and Manley, 2004).

Group procurement typically works in fragmented industries where small-scale customers do not have much purchasing power. By pooling procurement, an overseas study of multiple industries found savings of over 13% (Taylor and Björnsson, 2002).

Economies of scale will always be a challenge for a small country such as New Zealand; however, there are strategies that can assist. Outside of business operations, there are also opportunities to grow markets and therefore the purchasing power of the company. Expanding operations to include an export market may be a strategy worth considering for New Zealand firms as a means to gaining scales of economy and producing value-added exports. New Zealand's Building Code requirements, access to raw materials, set-up for exporting and 'green image' can be put to advantage.

5.2 Planning – Cooperation, Communication and Coordination

Cooperation, communication and coordination are essential to enable good planning. The current fragmentation within the residential construction industry and often adverse relationships with building consent authorities (BCAs) are a barrier to good planning.

There is a perception held by many in the New Zealand building industry that out-of-the-norm designs and materials are tedious to get through the consenting process. This is despite Alternative Solutions offering a compliance path for non-

traditional constructions. However, the leaky homes crisis[2] (weathertightness failure) liabilities have bred risk adversity and increased stringency amongst BCAs with regard to consent applications involving the use of non-traditional cladding systems and design.

Within the industry, there is a perceived inconsistency between BCAs with regards to consenting outcomes, despite adhering to the same codes and regulations. This leads to difficulties for out-of-area work that is not built to conform to simple prescriptive means of compliance and instead relies upon Alternative Solutions. In the case of buildings constructed in one BCA area, and placed onsite in another, two consents may be necessary (Corric, 2012). One BCA may not accept another BCA's Alternative Solution consent outcome due to differences in interpretation. This has the potential to complicate matters and make the use of Alternative Solutions impractical in out-of-territory offsite construction. This, in turn, restricts the architectural and innovative freedom of the project team unless a close working relationship is established and maintained.

In acknowledgement of the challenges for predominantly affordable home builders, the New Zealand Government has implemented two schemes to enable designs to be deemed to comply, providing they are built within the parameters of the consent.

The Simple House Acceptable Solution, launched in March 2010, was intended to provide an easier, cheaper and faster pathway to build a starter home (MBIE Building and Housing Group, 2013a). The Simple House Acceptable Solution was designed to bring the information required to design a 'simple' house, including compliance requirements and construction standards, together in one place (Williamson, 2010).

The MultiProof scheme allows builders intending to construct 10 houses of identical design within a two-year period to apply for a National Multiple-Use Approval, or MultiProof (MBIE Building and Housing Group, 2013). "A MultiProof is a statement by the Department that a specific set of building plans and specifications complies with the New Zealand Building Code. Building Consent Authorities (BCAs) must accept a MultiProof as evidence of Building Code compliance." (MBIE Building and Housing Group, 2013)

The MultiProof design is subject to approval from the local authority for site-specific requirements, such as foundations and utility connections; however, the design from the floor up is deemed to comply for the purposes of building consent (MBIE Building and Housing Group, 2013).

The MultiProof and Simple House Acceptable Solution by nature impose restrictions on innovative design. The Simple House Acceptable Solution also restricts the materials that can be used. For designs and systems outside the scope of the MultiProof and Simple House Acceptable Solution, appropriate research, testing and new rules surrounding liability for faulty workmanship lying with the registered building practitioner, risks can be minimised and the industry can press forward with new solutions.

Consistency in the application of the Building Code is essential for enabling innovative design and construction methods to infiltrate and transform the market.

[2] Weathertightness failures of some cladding systems installed on houses from mid-1990s through to the early 2000s.

5.3 Operational Efficiency

The USA residential construction industry has been through a period of consolidation in order to boost performance (Lefaix-Durand et al., 2005). Mid-sized construction companies have merged to rationalise business functions and improve cost efficiencies, while small-scale builders are expected to flourish in niche markets (Robichaud et al., 2005; Lefaix-Durand et al., 2005).

The number and size of large construction companies in the USA is expected to grow and their focus to turn to growing their market, expanding geographically, vertically integrating and diversifying their product portfolios (Lefaix-Durand et al., 2005, pp. 5–6). In a push for greater efficiency, ease of construction and maintenance, companies will produce their own componentised and panellised products (Lefaix-Durand et al., 2005; Robichaud et al., 2005). This approach has also been suggested for New Zealand (New Zealand Productivity Commission, 2012).

However, much of the literature suggests that cooperative ventures, partnerships, and key supplier arrangements may provide the same benefits (New Zealand Productivity Commission, 2012). The most essential elements, according to Blayse and Manley, are “absorptive capacity, champions, culture, knowledge codification, innovation brokers, and relationships with manufacturers” (Blayse and Manley, 2004, p. 151).

In their work, Blayse and Manley established nine strategies for innovation in construction:

> (i) enhancing client leadership, through high levels of technical competence, advanced demand patterns, and prudent risk-taking;
>
> (ii) building robust relationships with manufacturers supplying the industry, in view of their involvement in R&D programs;
>
> (iii) mobilising integrated approaches to construction projects, in response to the fragmentation of the industry arising from the one-off nature of most projects and the proliferation of small players;
>
> (iv) improving knowledge flows, by developing more intensive industry relationships to offset the disadvantages of production based on temporary coalitions of firms;
>
> (v) integration of project experiences into continuous business processes to limit the loss of tacit knowledge between projects;
>
> (vi) active use of innovation brokers to facilitate efficient access to technical support providers, and other external players with complementary knowledge bases;
>
> (vii) promoting innovative procurement systems, including partnering or alliancing, to enhance cooperative problem solving, the adoption of non-standard solutions, and equitable allocation of risk;
>
> (viii) strengthening of performance-based regulations and standards, through the enhancement of technical knowledge held by regulators and other key players, and through the formulation of simple enforcement strategies; and
>
> (ix) building up organisational resources, including developing a culture supportive of innovation, enhancing in-house technical competence, supporting innovation champions, and developing an effective innovation strategy. (Blayse and Manley, 2004, pp. 151–152)

In each of the following philosophies, there is reliance upon all actors in the supply chain carrying out their duties to specification and on time. This requires buy-in from the entire project team and comprehensive planning. As Fawcett and Allison (2005, p. 1) point out, “benefits will be wasted if projects are not properly planned”.

5.3.1 Lean and Agile Construction

Key principles:

- Integrated teams and networks.
- Communication and feedback loops.
- Maximise resources.
- Eliminate waste.
- Continuous improvement.

Lean and agile construction is about maximising the added value of the construction process to the end product (Abdelhamid, 2004). Lean construction focuses on the technical efficiency of processes, while agile construction focuses on the customisation and effectiveness of production (Bergstrom and Stehn, 2005). Agile construction can involve the ending of the manufacturing process before completion to allow for batch orders and bespoke finishes. ‘Leagile’ (a combination of lean and agile) production “achieve[s] both the minimisation of resource requirements through the elimination of waste in the supply chain and the maximisation of customer service at an acceptable cost” (Pan and Dainty, 2007).

Toyota Motor Company in Japan was the first to implement Taichi Ohno’s Lean Production Principles in the early 1950s, leading to a revolution in manufacturing (Abdelhamid, 2004). Lean construction is the principle of using the least resources to make the ideal outcome for the client in terms of cost, quality, time and sustainable outcomes.

Toyota’s housing division has identified seven types of waste, or Muda, for the homes they produce:

1. Overproduction – built to order.
2. Transportation – continue product on its way.
3. Motion – clean workspaces, organised with flow of assembly.
4. Waiting – linear organisation clears obstacles of waiting for processes to be completed.
5. Processing – processes with no customer value, for example, paperwork, cleaning.
6. Inventory – only what is needed by customer.
7. Defects – imperfections, missing parts can double time required (Davies, 2005, p. 64).

By minimising waste, materials and the amount of labour, buildings are created in minimum time, at minimum cost and with maximum results for the investor. As quoted by the UK’s Construction Taskforce:

> Lean thinking presents a powerful and coherent synthesis of the most effective techniques for eliminating waste and delivering significant sustained improvements in efficiency and quality. (Egan, 1998)

Several types of waste are addressed by lean construction protocol:

- Resources.
- Labour.
- Downtime.
- Injury and illness leave.

Minimisation of materials also minimises cost and environmental impact. Toyota has a philosophy of 'jidoka', which involves humans doing what can be done better by hand than by machine. Machines are not a substitute for humans, rather a tool (Davies, 2005).

Minimising labour and constant improvement of workflows leads to health and safety improvements (Nahmens and Ikuma, 2009) and adds value through wages being concentrated on value-added activities. Minimising downtime through reprioritisation of work and building it into the schedule reduces wasted labour. Reducing workers' exposure to hazards and maintaining a controlled environment has a two-fold effect: leave due to illness or injury is minimised as is subsequent investigation time for work-related injury and illness leave (Abdelhamid, 2004).

"Lean construction forces the explicit consideration of workflow and value management in addition to the traditional construction management focus" (Abdelhamid, 2004). Lean construction is best used in a factory setting, where quality can be controlled, waste minimised and projects planned. By being able to quantify the material use and time required for upcoming projects, waste from one project can become material for another. This diverts the waste from landfill and saves the project money. Lean construction's basic principles converge with those of sustainability in many cases (Huovila and Koskela, 1998) – minimum resources for maximum result with minimal impact on the environment.

Lean construction has been shown to reduce urgent requests for resources, improve the stability of workflow and reduce construction schedules when buy-in by the whole construction team is achieved (Pontes Mota et al., 2008).

Lean construction is also known as lean project delivery:

> … the principles of lean are not just about construction or even its precedent in manufacturing, but about the entirety of the building industry including architects and engineers. It is a paradigm shift to integrate the design and construction delivery process to encourage new methods of contracts, innovations in design and supply chain management, and especially to encourage advances in the development of offsite fabrication for onsite assembly. (Davies, 2005, pp. 55–56)

In order for lean construction to work, a Canadian survey identified "the need for continuous interaction between all participants in the manufacturing process, the internal company participants but also the customers and suppliers and government regulators in an open, communication system" (Suthey Holler Associates, 2009)

The main drawback with lean and agile construction is the need for a rigorous planning process and to finalise the design early (Höök and Stehn, 2005). However, this has benefits of keeping to schedule and cost and set expectations for the end product.

Lean and agile construction both involve manufacturing to order rather than stockpiling product. Therefore, to minimise cost and waste, just-in-time methodologies are an importance part of lean construction.

5.3.2 Pulling Production through Just-in-Time Scheduling

Key principles:

- Right part at the right time.
- Precision of schedules.
- Precision of manufacture.
- Quality control to prevent rework.
- Pull jobs rather than push.

Just-in-time involves manufacturing to order and keeping a bare minimum of parts in stock at a time. This has the effect of minimising space and waste and maximising the speed at which products flow through a factory. Just-in-time requires that “every process should be provided with the right part, in the right quantity at exactly the right time” (Lessing, 2006, p. 44).

Some operations in New Zealand are supplied using just-in-time principles, mostly inner-city projects where there is little to no room onsite to store materials. Rather than large deliveries of one type of component, smaller deliveries of components that are about to be used are made on a more frequent basis.

In the factory, the effect of just-in-time methodology is fast turnover of materials and rapid response to product orders (Davies, 2005). Response times to orders can be in a matter of hours, allowing project managers onsite to programme their work schedules to fine detail.

In instances where a defect is found in a delivered product, a replacement can be obtained very quickly and issues resurrected. In a factory setting, the notion of ’mistake-proofing’ or ‘poka-yoke’ is to eliminate wasted time and materials from the production line (Sadri, Taheri, Azarsa and Ghavam, 2011). Every process is arranged so that mistakes cannot happen, but if they do, they are found and corrected quickly to avoid costly rework. In order for mistake-proofing to work, every member of the production line must be able to report mistakes freely and without fear of repercussion. This allows issues of all sizes to be found and addressed in order to improve processes and prevent the mistakes happening again (Sadri et al., 2011).

A downside of just-in-time production is that it relies on a multitude of players to keep to their schedule. If a design is adjusted or trades arrive onsite late, delays can occur that can hold up a line of people waiting for that piece of work to be completed. Orders have to be halted for materials for the subsequent jobs, and finely balanced construction schedules can be put in jeopardy. Surge piles allow processes to continue and the production line to keep working when there is variability in workflow (Abdelhamid, 2004). This essentially is a backlog of work to continue with until normal workflow resumes.

Both lean production and just-in-time methodologies rely on good communication and integration across the project from the client through to the tradespeople.

6. CONSTRUCTION TECHNIQUES AND TECHNOLOGIES

> "We cannot solve our problems today with the same thinking we used when we created them." – Albert Einstein (Daly, 2009)

In order to improve productivity and quality, a break from tradition is required. This may be in the way things are built (techniques) or by using different materials and systems (technologies). Adoption of new techniques often involves using new technologies and vice versa. The inclusion of changes to both techniques and technologies constitutes a step-change to construction processes and thereby true innovation.

This section covers emergent technologies – including materials, methods and systems – that are not yet widely used for residential construction in New Zealand. Many come from a commercial background, while others are designed specifically for residential construction.

Acknowledging that the industry may wish to begin with incremental measures on the way to deploying truly innovative measures, this section includes emergent technologies and techniques that may be deployed without drastic changes to traditional skills or easily procured materials. Any specific products or materials mentioned are for information only and do not constitute either an endorsement or an advertisement. The introduction of new techniques and technology may form part of a solution to increasing productivity in the construction sector.

6.1 Offsite Construction for Efficiency

Key principles:

- Maximum offsite work equals minimum onsite work.
- The most for the least.
- Undercover worksites are more productive that those exposed to the elements.
- Controlled environment for materials.
- Lower health and safety risks.
- Quality, quantity and custom design working together.
- People do what machines cannot do well.
- The designer has far more control over the product.
- Quality can be controlled in a factory but is difficult and time-consuming to control onsite.

Also known as offsite manufacture (OSM), offsite production (OSP) and a modern method of construction (MMC), prefabrication or pre-engineering, offsite construction is the act of shifting construction from the building site and into a factory environment.

There are several forms of prefabrication, which are outlined below.

Componentisation – Incremental Changes

Componentisation offers the opportunity to speed up construction by preassembling pieces; however, the value added and time savings are less than for the following options.

Panellisation – Practical and Efficient

Panellisation involves the construction of a building into prebuilt panels. These come in two forms – open and closed panels. These are explained in Table 2.

Table 2: Open versus closed panel construction characteristics

<table>
<tr><td>Open panel</td><td>Framed wall</td><td rowspan="4"> 
(Virginia Tech Institute for Critical Technology, 2013)</td></tr>
<tr><td></td><td>Clad on one side</td></tr>
<tr><td></td><td>Usually no electrics or plumbing</td></tr>
<tr><td></td><td>Sometimes insulated</td></tr>
<tr><td>Closed panel</td><td>Clad and lined</td><td rowspan="4"> 
(Knapp Connectors, 2013)</td></tr>
<tr><td></td><td>Electrics and plumbing in place</td></tr>
<tr><td></td><td>Insulation installed</td></tr>
<tr><td></td><td>Windows and doors installed</td></tr>
</table>

Panellisation is an order of completion less than modular construction, yet it can be more practical where access is restricted. Panellised construction can be used where site access does not permit the use of large volumetric modules, such as on sites where power lines restrict the height of access points or down narrow entryways. Panellised homes are usually delivered ‘flat-packed’ for assembly, cutting down on transportation requirements in comparison with other construction types.

Panellised construction requires precision and the use of heavy lifting equipment to place elements. Panellised homes are far faster to make weathertight than traditional construction.

Modular – Highly Efficient but with Limitations

Modular homes incorporate the highest amount of added value of the researched building types. Transportable homes of one module are incorporated under this banner. Homes with multiple modules are one order of completion less than transportable houses, yet they have the size and design flexibility that transportable houses do not have.

Modular homes are restricted by the size of the modules; however, modules can be put together to make large open-plan rooms or double-height ceilings. The modules have height restrictions due to the need to conform to road and/or rail transportation rules.

The bulk of the modules mean that transportation is less efficient than for panellised homes. However, modules are at a more advanced state of completion when they reach the site on which they are to be placed. Modules are bolted together onsite and made weathertight, and the interiors are usually fitted out ready for final decoration. Modular construction is faster than the other construction methods, and a full house can be completed in a couple of weeks.

Utilising the principles of mass customisation, modular homes can have design freedom that is close to that of traditional construction. However, materials are restricted due to weight limitations, potential for damage and ability to brace modules during transport.

Hybrid Construction – the Best of All Worlds

Hybrid construction uses two forms of construction, including at least one type of offsite construction. For example, modular construction can be used with traditional construction or panellised construction can be used with componentised construction and some modular construction. This opens up designs to having large, open spaces incorporated amongst modules and special design features.

About Offsite Production

The founders of offsite production or prefabrication included a long list of illustrious architects in the 19th and 20th centuries, after the Industrial Revolution introduced modern-day manufacturing. These included Le Corbusier (Charles-Édouard Jeanneret) (French, born in Switzerland, 1887–1965), Richard Buckminster Fuller, Frank Lloyd Wright (American, 1867–1959), Frank Lloyd Wright's son John Lloyd Wright (American, 1892–1972), Walter Gropius (German, 1883–1969) and Adolf Meyer (German, 1881–1929).

Offsite construction or prefabrication has been a part of New Zealand's history since the days of the first settlers. Londoner H Manning exported precut kitset houses to Australia and New Zealand between 1833 and 1840. The cottages were made with prefabricated walls that were bolted together, which meant no cutting, joints or nailing (Bell, 2009). Despite this history, offsite construction is by no means common in New Zealand, and "factory technology is virtually non-existent" (Bell, 2009, p. 259).

Figure 4: Modular home under construction in a factory (Pinpoint Construction Corp., 2012).

In New Zealand, as in the UK, offsite construction or prefabrication has an image that is unfairly tarnished with mass-produced, cookie-cutter worker housing and school classrooms (Bell, 2009; Daly, 2009; Craig et al., 2002). This is in contrast to overseas, where offsite construction is often seen as higher value and an upper-market solution (Johnson, 2007; Lindburg et al., 2007).

Despite their unpopularity, however, these homes and buildings are still standing today. For a select few, history has meant acceptance, with prefabricated 1920s railway cottages becoming popular and even protected in some cases (Titus, 2003; Ruapehu District Council, 2012). As with other countries, there has been success in prefabricated homes, despite their commercial failure (Bell, 2009; Davies, 2005).

Offsite construction or prefabrication is merely a way to build and not a descriptor of the outcome (Bell, 2009, p. 31). As proffered by Bell (2009, p. 31), prefabrication "can be viewed as an approach, a methodology, a mind-set, a tool, a pattern, or a philosophy". Bergstrom and Stehn (2005) made the observation that "prefabrication is useful, if subservient to the delivery of the end product".

Just like a hammer and a nail gun are suited to different purposes yet can be used to achieve the same means in most cases, the same exists for offsite construction. Each project has a different client, site location and regional labour context in

which it must function (Davies, 2005, p. 45). Therefore, offsite construction is not the ultimate solution for every project. Using offsite construction in some cases may be detrimental and even damaging to the image of prefabrication.

> One of the major lessons from the failures in prefabrication trials of the past is that offsite construction should not be used in every situation and each project should be specifically evaluated for the potential to use prefab[rication] methods. (Davies, 2005, p. 45)

In order to be successful (either partially or fully), offsite construction has three contexts in which it must work – environment, organisation and technology (Davies, 2005, pp. 47–48). If the environment does not suit, the organisation cannot adapt and/or the technology cannot be adopted for the context in which it suits, offsite manufacture cannot be effective (Davies, 2005, pp. 47–48).

Offsite-manufactured buildings are commissioned faster than site-built (Bell, 2009; Craig et al., 2002; Lefaix-Durand et al., 2005; Davies, 2005), producing savings for both investor and owner-initiated clients, as laid out in Table 3.

Table 3: Benefits of offsite construction for investor and owner-initiated construction projects

Benefits of Offsite Construction		
Benefit	**Investor**	**Owner-initiated**
Reduced interest	✓	✓
Reduced capital	✓	✓
Lower energy bills	✓	✓
Smaller project team	✓	✓
Increased quality	✓	✓
Reduced timelines	✓	✓
Higher predictability of outcome	✓	✓
Fixed-price outputs	✓	✓
Reduced interim accommodation cost		✓
Increased marketing options	✓	

According to Fawcett and Allison (2005, p. 14), “faster construction and reduced onsite work bring financial benefits that go about a third of the way to offsetting average increased construction costs for hybrid and volumetric construction methods”.

In a factory setting, the amount of control for designers and engineers is far higher – substitutions are generally only made with client approval, and designs are subject to quality control due to their factory setting, reducing the defects and variable quality found in New Zealand’s onsite construction work at present (New Zealand Productivity Commission, 2012).

Health and safety has been proven to be far better for offsite production than onsite (Yorkon, 2012; Huovila and Koskela, 1998; Craig et al., 2002; Bell, 2009; Goodier and Pan, 2010; Iulo, 2008; Pan and Dainty, 2007; Scofield et al., 2009; Shahzad, 2011). Considering New Zealand’s high rate of construction industry deaths and injuries (Department of Labour, 2012), offsite construction may be a key way to reduce the risks to employees and costs to employers and the country.

6.2 Automation – Humans do What Machines Cannot do Well

Key principles:

- Accuracy.
- Computerised manufacturing.
- People do what machines cannot do well (Davies, 2005).

Automation is defined by the Encarta Dictionary (UK) as the “replacement of human workers by technology”. The use of automation in construction is where offsite construction becomes offsite fabrication (OSF) or offsite manufacturing (OSM). One part of automation that has been making significant inroads into factory-built housing overseas is computer numerical control (CNC) machines.

CNC machines have revolutionised the way modular house manufacturers work overseas providing the ability to precision cut components according to computer-aided design (CAD) drawings.

CNC is being used to some degree in New Zealand (Bell, 2009); however, its use and application appears to be limited at present.

Figure 5: An automated production line processes timber panels (Oasis Homes, 2012).

The distinct advantage of the use of CNC machines as a tool in offsite construction is the ability to utilise many of the advantages of mass production on bespoke designs. Bergdoll and Christensen proffered that “the power of the computer to accommodate the expression of the architect and the individual needs of a client promises to offer an unpredictable panorama of choices to the consumer rather than the limited palette of types that characterise the prefabricated systems of the modern movement” (MoMA Home Delivery Exhibit, cited in Bell, 2009, p. 290).

These machines may cut using traditional saws or may laser cut. CNC machines are also capable of predrilling pieces, enabling assemblers to bolt them together quickly. Top-end machines are more complicated still, linking with automated construction of panellised walls.

Machines are able to inscribe barcodes or piece numbers onto each part of the ‘jigsaw’ so that, at delivery stage, each piece can be identified quickly and put into place.

This offers the possibility of providing an ‘app’ to onsite builders, where scanning the barcode on a piece of structure with their smartphone could bring up its place in an annotated three-dimensional model of the house, complete with installation instructions and maintenance plan. This would form part of building information management (BIM) systems, which could be kept on file to inform later additions, changes and replacements. The tracking of the components could provide a

wealth of information for warranty issues and assist materials scientists investigating product failures.

CNC machines require a factory setting; however, some manufacturers in the USA are using transportable factories whereby they move from development to development. These are generally large by New Zealand standards, and considering the small size of this country, fixed factories are likely to be the most feasible option.

By using CNC, the levels of materials can be anticipated very precisely and just-in-time stocking methods utilised to the maximum extent. Waste can be minimised, with offcuts returned to a stockpile for use in later commissions or recycled.

The precision of the product depends on the precision of the CAD models put into the machines. With proper specification and sizing, the quality of the product will generally be far higher than any person can produce. By getting machines to do what they can do best, manual labour tasks can be transferred to doing what humans can do and machines cannot – co-existing in a way. This increases the output and allows workers to become very skilled in their individual tasks.

The main disadvantage of CNC manufacturing and automated manufacturing in general is the initial outlay (Smith, 2010). For even a modest machine, the initial outlay is often upwards of $500,000 (Betz, 2012).

The majority of early adopters in the New Zealand construction industry are from small-scale firms (Betz, 2012), with larger firms seemingly reluctant to change their processes without a burden of proof.

Figure 6: Laser-cut steel panel balustrades (BokModern, 2012).

One of the main concerns with large capital investments is that demand will fall after the investment in such a technology. The scale of the Auckland housing shortage and the rebuild task in Christchurch may provide the level of demand necessary to adopt and embrace automation technology.

6.3 Clever Components – Incremental Changes

Key principles:

- Standardise sizes and systems.
- Group or simplify parts.
- Speed up assembly.

Componentisation is the minimum level of prefabrication, where an item replaces a group or number of items in order to make construction easier, faster, higher quality and/or more accurate.

New Zealand has operated for a long time with the notion that complete custom design, down to the last millimetre, is what sets architecturally designed houses apart from designs picked from a catalogue of standard plans. However, standardisation does not necessarily mean an entire house needs to be customised.

To some degree, this is already happening in the New Zealand construction industry – over 80% of New Zealand's timber framing is precut (Bates and Kane, 2006). The use of componentisation has predominantly been used for kitset houses and has historically been targeted at the consumer rather than the builder. Even then, standard plans can be customised to add on another window here or a whole room there and so on.

Houses are made up of a huge number of individual components – "factory-produced elements of each house typically contain around 30,000 items, comprising 700 different component types" (Gann, 1996). Therefore, it makes sense to group them and reduce individual parts as much as possible to lessen the amount of work done onsite.

The degree of standardisation in New Zealand is less than overseas. In Japan, prefabricated houses are upper market, and clients personalise their homes by choosing from a wide range of options as per their particular taste and needs.

By standardising components, scales of economy can be reached while still allowing customers choice. By habit or by reason, many designers repeat sizes, dimensions, patterns, even layouts of houses and aesthetics of the envelope.

Componentisation generally adds little value to construction projects. Although it may speed up construction a little and boost quality within the components created, overall, it cannot encourage a transformation in the way homes are constructed. Rather, componentisation enables the status quo of operational behaviour and construction methods to remain. Higher levels of added value are contained within more complete fabricated parts of homes, such as panels or modules.

6.3.1 Windows and Glazing

Most countries also have standardised window sizes rather than each window being made to measure, in comparison to New Zealand and Australia's bespoke window manufacturing environments. There are two major areas where innovation could see a reduction in cost and increase in choice in the area of windows and glazing. These are standardisation and materials.

Unlike many countries, windows in New Zealand and Australia are all bespoke, made to whatever size the designer wants. Each window is fabricated individually and by hand in a workshop from a selection of profiles. Lengths of material are cut to the specific size requested. There is currently little cost advantage to having a standardised line of window sizes for buyers of these windows, as most jobs tend to lack the scale required to bring the prices down.

One could liken this to the pre-Industrial Revolution's custom-made bolt and nut sets. Unlike today, bolts were not of standard sizes and neither were threads. Each nut and bolt set had to be purpose-made, which meant they were expensive. If a bolt or nut was damaged, the set would need to be remade to the specific diameter of the hole. And so it is here today with windows.

There are two ways to promote productivity in the areas of framed windows. An incremental change is to standardise sizes, thus allowing runs of windows to be cut and put together without having to hand-make every unit to specific coordinates. The reality is that many designers use a set number of sizes in many

designs. There are few circumstances where windows are needed to be sized exactly. In saying this, standardisation does not mean bespoke windows will disappear from the market or even become more expensive – the way they are made continues as is, while the price for the standardised windows could be expected to fall.

Another incremental change is to automate window production utilising computerised cutting and welding for frames. Depending on the extent of automation employed, precut glass can be framed and loaded onto a pallet for shipping without the direct intervention of human hands.

There are two fundamental challenges surrounding the large-scale employment of machinery to automate window production lines. Firstly, manual labour is reduced or in some cases eliminated. Secondly, market acceptance may pose a challenge, unless sufficient benefit can be conveyed.

A fundamental change would be the combination of the two incremental changes – standardised and automated construction of windows. Without standardisation of sizes, there is a limited ability for automation to lower costs. Conversely, without significant cost benefits there is little gain from using standardised window sizes in designs.

Therefore, the challenge in this case is to encourage window manufacturers to introduce a standardised line of windows and then to make them inviting enough for the design profession to utilise them. There may be an opportunity for an export market of high-quality windows to countries where windows come in standardised sizes. Likewise, there may be a concern that overseas products could flood the market if bespoke window manufacturing is reduced.

In New Zealand, the most common materials used for window frames are aluminium and timber, followed distantly by PVC. Aluminium windows account for over 80% of the current market (Jaques, 2012); however, in the USA, fibreglass and hybrid systems are increasingly being used.

Nonetheless, fibreglass framing has not yet achieved high market share in the USA, in part because of the cost. Fibreglass is pultruded rather than extruded (pulled through the mould rather than pushed) and forms a strong, rigid framing with good thermal resistance. This means that larger lengths can be used without the need for steel reinforcement, which reduces the thermal effectiveness of more flexible PVC (Burgess and Bennett, 2006).

Fibreglass contracts at about the same rate as the glass within the frame, does not rot, is strong and does not absorb water. Fibreglass frames can be filled with foam to increase thermal performance to high levels.

Due to New Zealand's small market, there are currently few advanced window panes available beyond low-emissivity argon-filled double glazing. The window frames on the market tend to be made to take panes of a thickness that no more than double glazing will fit. However, thickness is not necessarily conducive to higher performance.

Evacuated windows are popular in the Japanese market (Burgess, 2012); however, they have not yet been introduced into the New Zealand market. Evacuated panes can be used to replace single-paned windows due to possessing similar thickness (Burgess, 2012). The panes have excellent thermal performance compared to other glazing types; however, the pillars holding the two panes apart are visible and the glass cannot be made in large sizes, thus rendering it unsuitable for many New Zealand applications.

Figure 7: Installation of soy-based polyurethane

6.3.2 Soy-based Spray-in Insulation

foam (Durability and Design, 2011).

Benefits:

- Airtightness.
- Natural product.

Disadvantages:

- Waterborne.
- Professional installation.
- Messy.

Applications:

- Wall, ceiling insulation.

Spray insulation has gone through waves of popularity in New Zealand. The achievable coverage and speed of installation has been overshadowed by concerns over water-based spray wetting timber, off-gassing of insulation, particles used, settlement of contents and ingress of water through externally unlined cavities to name a few. This has left the segment insulation market with the majority share of the market in New Zealand. Overseas, however, alternatives are being formulated that go some way to rectifying the perceived issues of spray-in insulation and to appeal to the 'green' movement.

A system that has been used overseas in 'green' architecture in recent years is soy-based spray-in insulation. The systems are closed-cell, water-based spray foams made of natural ingredients and containing no VOCs (volatile organic compounds) (Alter, 2009). Types of foam used include polyicynene and polyurethane from recycled beverage bottles. The foams work by adhering to surfaces and creating a tight seal. The foam is screeded off after spraying to neaten the cavities and is generally applied by professionals.

Michelle Kaufmann, from the former MK Homes in the USA, had a strong eco-focus to her homes and chose soy-based spray-in insulation due to its thermal performance and environmentally friendly ingredients (Kaufmann and Remick, 2009).

6.3.3 Rainscreens

Benefits:

- Fast to install.
- Cavity aligns with common New Zealand practice.
- Skillset and systems available due to use in commercial buildings.

Disadvantages:

- Capital cost.
- A façade – lack of structural contribution.

Applications:

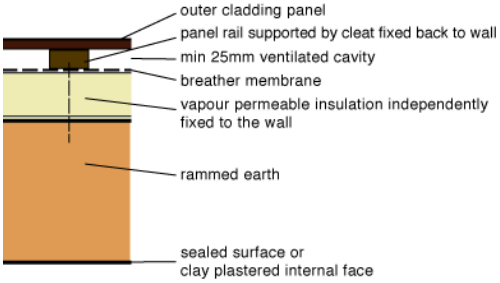

Figure 8: Rainscreens can be used over a wide variety of substrates, including existing façades (Greenspec, 2012).

- Wall cladding over a substrate.

Rainscreens are predominantly used on commercial buildings in New Zealand and are designed to provide a weatherproof barrier to resist water penetration, while allowing any water that does penetrate to escape as well as allowing air in to dry the cavity. They can be used in front of existing claddings or as a protective layer in front of less durable or water-resistant wall construction, as seen in Figure 8.

Figure 9: Rainscreens allow water to exit and air to dry the cavity (Euroclad, 2012).

The large tiles or panels most often used provide an industrial aesthetic; however, overseas many are being designed to have a traditional look but with the fixings being anything but traditional. Both traditional and non-traditional aesthetics will be introduced in this section.

As prefabricated housing in the UK is plagued by misperceptions of low quality and durability, builders go out of their way to ensure homes look as traditional as possible. As buyers perceive timber framing as inferior, much effort is put into making the house appear to be of traditional construction from acceptable materials, such as brick and mortar. As brick and mortar are labour-intensive, heavy and slow to put up, façade systems are now in use.

Figure 10: Brick façade system designed for fast installation yet traditional appearance (Wienerberger Ltd, 2011).

Another example of reinventing the fixings of traditional claddings is the creation of a substrate to hold a brick cladding of traditional appearance. The bricks are designed to click into the formwork behind to secure them before grouting, as shown in Figure 10. The weight of the bricks is also decreased through the use of profiled shapes rather than solid rectangular forms.

Damaged bricks could conceivably be chiselled out and replaced; however, colour matching after a period of weathering may lead to colour variation. In the event of an earthquake, the flexible backing is likely to allow the bricks to move, possibly leading to the cracking of the grout. It is likely that any bricks that come away from the cladding due to torsion across the wall could be put back in place, providing the structure remains true and the substrate is undamaged.

At the end of life, the galvanised sheet backing substrate can be recycled. Bricks and mortar could be crushed and used as hard fill.

The system shown in Figure 10 also comes prepanellised with

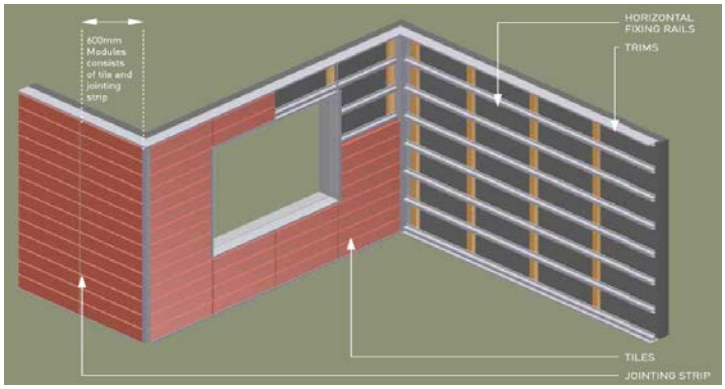

Figure 11: Steel runners and fixing replace grout on modern 'masonry' systems (Austral Bricks Ltd, 2009).

unitised aluminium sections (Wienerberger Ltd, 2011, p. 8).

6.3.4 Floors and Foundations

6.3.4.1 Deep Foundations

Benefits:

- Can be used in difficult soil conditions.
- Fewer required than standard piles.
- Higher bearing capacity.
- Fast to install.
- Skills base established through use in commercial buildings.

Disadvantages:

- Longevity depends on material and soil conditions.
- Cost more than standard foundations.
- Specialist equipment needed.

Applications:

- Areas where soil conditions are marginal or unsuited to traditional foundations.

Deep foundations are by no means new to New Zealand; however, they have commonly been used on commercial and industrial buildings rather than residential buildings. Due to the large number of homes that need to be rebuilt in Christchurch as well as the number of infill sections with variable ground conditions, deep foundations are likely to become more popular. Not all of the technologies in this section will be suitable for all ground types, especially with the complexity of soil in some places.

6.3.4.2 Micropiles

Additional benefits:

- Smaller than standard driven piles.
- Small footprint.

Additional disadvantages:

- Small diameter means little strength to resist lateral forces.

Additional applications:

- Ecologically sensitive areas.
- As tie-backs for retaining walls.

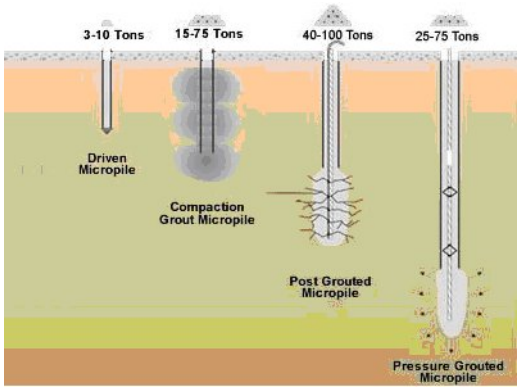

Figure 12: Types and capacities of micropiles (Geonusa, 2012).

Micropiles are small-diameter, high-capacity drilled and grouted deep foundations. There have been numerous names for this type of pile, including pali radice, micropali, mini piles, pin piles, root piles and needle piles (Bruce, 2008), which are used in Europe and the USA where difficult or variable ground conditions exist (Tarquinio and Pearlman, 1999).

The piles are used in areas where ground vibrations are undesirable (for example, densely populated urban areas), there is delicate ecology or restricted access (Bruce, 2008; Tarquinio and Pearlman, 1999).

Due to their small diameter, these piles may not be suitable for areas where sudden high lateral stress can be expected along the length of the pile (Bruce, 2008), for example, in seismic areas prone to liquefaction.

6.3.4.3 Pier Foundations

Additional benefits:

- Can be spaced quite widely.

Additional disadvantages:

- Large diameter.
- Corrosion may be an issue if all steel.

Additional applications:

- Can carry the weight of raised concrete floors.

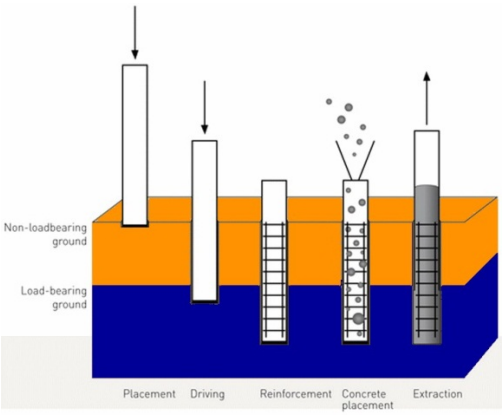

Figure 13: Hollow piles (usually steel) are driven into predrilled holes, then filled with reinforcing and concrete (Equipment4all, 2010).

Pier foundations are driven into the ground to provide a stable footing for buildings. There are three main types – plain piles, which are hammered or driven in by vibration, hollow piles, which are hammered or driven in and then reinforced and filled, and screw piles, which are literally screwed into the ground (see Figure 14).

Helical piers, also known as screw piles, have been used for many years in New Zealand – predominantly for commercial buildings. Piles are screwed through the earth and into the 'good ground' below. (For the definition of 'good ground', see Appendix A.) These are often used where top layers of soil lack the stability required for concrete slabs or standard piles (Affeldt and Rhoades, 2006). Piles can be grouted once in place to increase stability and carrying capacity or left ungrouted.

Figure 14: Helical pier piles are screwed through the ground into a stable substrate (Basement Systems, 2012).

Figure 15: Precast concrete piles are driven into the ground (Simplex Westpile, 2012).

6.3.4.4 Hollow Timber Piles

Additional benefits:

- Rapid installation.
- Reduced noise and vibration to surroundings.
- Can be spaced quite widely.
- Can be jointed to reach greater depths.
- Grouted centre allows for connection to raised concrete floors.

Additional disadvantages:

- Large diameter.

Additional applications:

- Can carry the weight of raised concrete floors.

Christchurch's MLB Consulting Engineers recently won an NZWood Innovation Award for their hollow timber piles, as seen in Figure 16. The young timber at the core of the pile is removed, providing a hollow centre. The removal of the juvenile core allows rapid full-depth timber treatment of the piles and reduces the amount of time it takes to kiln-dry the timber by up to 80%. The stability of the timber is greater, with less twisting and drying checks (NZWood, 2012; MLB Consulting Engineers, 2012). The tips of the piles are armoured for installation.

The piles can be rapidly driven into granular subsoils using high-pressure water and a high-frequency vibrating hammer, with less vibration and noise for surrounding properties (NZWood, 2012; King, 2012; MLB Consulting Engineers, 2012). Jetting can then be used to excavate a hole at the bottom of the pile, into which grout is injected forming a bulb base. Piles are up to 18 metres long and can be connected to form greater lengths. Steel reinforcing can be inserted into the grouted core for the attachment of concrete floor systems above ground (NZWood, 2012).

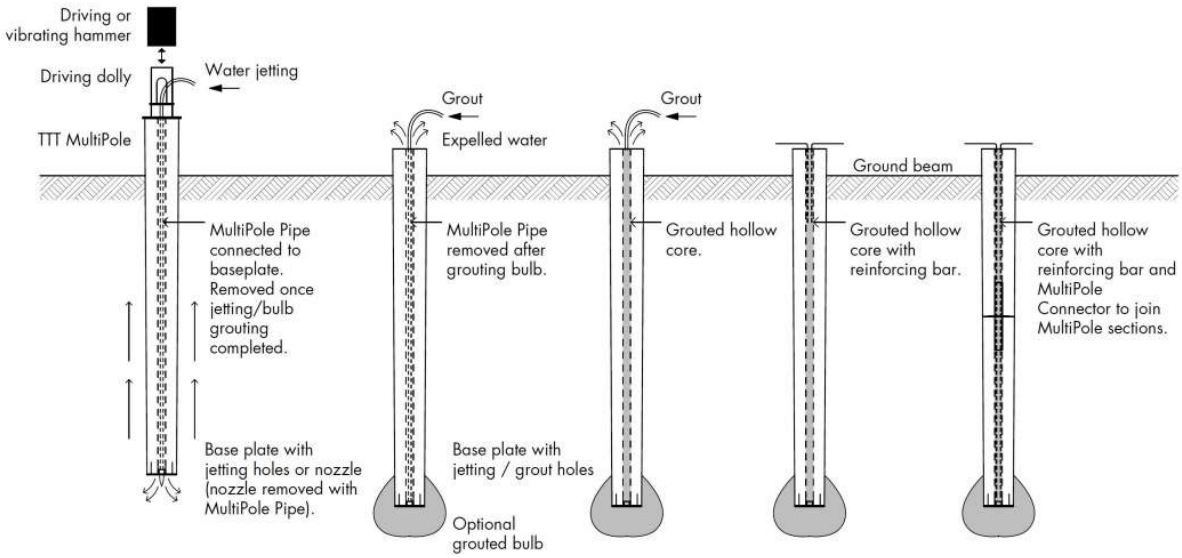

Figure 16: Multipole piles, invented by Mark Bachelar of MLB Consulting Engineers, are a New Zealand development that allows piles to be driven using a combination of vibration and high-pressure water (NZWood, 2012).

The system was designed for Christchurch's soil conditions where raft foundations and pads are unsuitable and deep piles can be required to reach deep gravel layers (MLB Consulting Engineers, 2012).

The piles are hoped to reduce the cost of the rebuild and reduce the vibrations resulting from the rebuild work to minimise the potential for further vibration damage and stress to surrounding buildings and their inhabitants (King, 2012).

6.3.4.5 Engineered Timber Structural Members

Benefits:

- Minimises materials.
- Lightweight and easy to work with.

Disadvantages:

- Requires additional fire protection compared to solid joists.

Applications:

- Midfloor joists.
- Rafters.

Figure 17: Engineered timber I-joists 'hung' off a laminated veneer lumber (LVL) beam (James Jones and Sons Ltd, Timber Systems Division, 2012).

With the cost of timber rapidly increasing over recent years, the popularity of engineered timber has increased. There are several different types of engineered timber, including laminated veneer lumber (LVL), glue-laminated timber (Glulam) and cross-laminated timber (CLT), which is more commonly used in panellised construction and is discussed in section 6.4.2.

Engineered timber has the advantage of providing maximum in-service strength for the amount of material. For engineered timber structural members, the main imperfections are removed, and sheets of timber are laminated together and then cut to create webs, chords and solid members.

Figure 18: Engineered timber I-joists often employ steel as a webbing material (Timber Engineering Europe Ltd, 2012).

Engineered timber can be made to longer lengths than standard timber, and due to the removal of imperfections and use of glue for lamination, the timber is much stronger and dimensionally more stable. Engineered timber beams are most commonly used for floor joists, beams and rafters and come in a range of forms – timber-webbed, galvanised steel-webbed and solid.

There is concern from fire engineers that, where the amount of timber being used is minimised, there may be some unintended consequences from the viewpoint of fire safety.

In the USA, there have been instances where modern homes have had floors fail after a short amount of time due to the loss of integrity of fire-damaged I-joists. This has led to the deaths of fire-fighters as the floors beneath them have suddenly given way when the web has burnt through and the chords have collapsed into them.

The issue is not that the joists have a finite ability to withstand fire – most materials are at least affected by extreme temperatures. The issue is that structural elements are not immediately visible in most cases and therefore the performance

of the structure is difficult to predict. Where failure could occur sooner than an alternative and more common construction, it becomes difficult for fire-fighters to anticipate the behaviour of the environment they are entering for the purposes of saving lives or preserving property.

There are certainly opportunities to rectify this, however, which will be investigated in the second part of this project.

Engineered timber structural members can be manufactured straight, curved or precambered during the timber lamination process.

Post-tensioning rods and cables can also be used to minimise slump and also stiffen structures. An example of this is in the College of Creative Arts (CoCA) building at Massey University of Wellington, where strict seismic requirements needed to be met. The LVL beams were post-tensioned in order to stiffen the entire building, meaning that, while the building will move during an earthquake, it will be pulled back into shape by those post-tensioned cables (Massey University of Wellington, 2012).

Figure 19: The post-tensioned LVL beams in the CoCA building at Massey University, Wellington, are the first of their kind in the world (Massey University of Wellington, 2012).

6.4 Panellised – Practical and Efficient

Figure 20: An open panel wall being put into place onsite (Davis Frame Co., 2012).

Key principles:

- Panellise and construct offsite for erection onsite.
- Speed.
- Control quality.
- Precision.
- Waste minimisation.
- Early finalisation of design.

Panellised construction resembles componentised operations only in a larger scale. Parts of the building are constructed offsite and transported to site for rapid erection of structures. Panellised construction is usually built in a relatively traditional manner. Most are predominantly timber-framed systems for ease of manufacture and their lighter weight in transportation.

Several firms in New Zealand have been using panellised construction in their business operations for many years; however, none has yet achieved mainstream acceptance.

The main types of panellised construction include compressed wood fibre boards, insulated sandwich panel, precast concrete panel and preframed and preclad walls (Bell, 2009). There are a number of technologies beginning to enter the New Zealand market, some of which are at the earliest stages of adoption.

6.4.1 Traditional Framed Panels

Figure 21: Closed panel wall being craned into place (The Timber Frame Company, 2013).

Benefits:

- Traditional construction known to trades.
- Faster to put up.
- Tighter quality control.
- Climate-controlled assembly environment.

Disadvantages:

- Needs early planning.
- Requires a factory.
- Often requires a crane or hiab.

Applications:

- Walls, roofs, sometimes floor panels.

Overseas, there are several European countries where walls, floors and roofs are constructed offsite and transported to the construction site for rapid erection of homes. The factory settings allow construction to occur year-round in all climates,

while the speed of assembly allows houses to be protected from the elements before damage can occur.

The most complex element to prefabricate into panels is walls, considering the plumbing, wiring, windows and doors. Many companies frame and clad walls before inserting doors and windows and finish electrics, plumbing and internal linings onsite (Baufritz, 2012). There are companies who frame, clad, insulate, plumb and wire and line walls in factories. Connectors are provided at the base of the wall plates for plumbing and electrical services, requiring a high degree of accuracy, which can be achieved in a factory setting. Windows can be preinstalled before delivery, maximising fit and quality.

6.4.2 Cross-laminated Timber

Benefits:

- Strong in compression, tension, shear.
- Higher mass than timber-framed panels.
- Can be self-supporting.
- Fast to put up.
- Releases no more VOCs than plain timber.
- Worked with traditional tools.
- Can be post-tensioned.

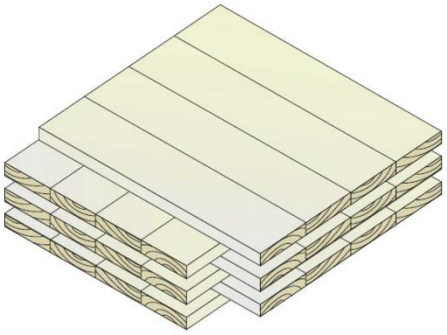

Figure 22: Cross-laminated timber can be made from wood that would otherwise be fed into waste streams (Proefrock, 2011).

Disadvantages:

- Heavy compared to framed panels.
- Need to route out for services.
- Should be insulated.
- Usually requires specialist lifting equipment.

Figure 23: CLT timber can be used for walls, floors, roofs and structural members (Proefrock, 2011).

Applications:

- Floors, walls, roof substrate, decks.
- Bracing.

Cross-laminated timber or CLT technology came about in the early 2000s in Europe and has recently been introduced into the southern hemisphere. CLT is made from pieces of timber that are glued and cross-laminated in perpendicular directions to those on the previous layer, a little like plywood but using pieces rather than leaves of timber.

Timber that is used for CLT does not need to be of structural strength due to the combined strength in both tension and compression of the cross-laminated layers (Cambridge, 2012). Glue is used to bind the layers under high pressure. This is commonly a polyurethane single-component glue free of VOCs.

CLT is also used like glulam (glue-laminated timber) and sliced into beams and other structural elements. Steel rods can be bonded into the CLT for reinforcing,

and as shown in the (glulam) CoCA building (Figure 22), steel post-tensioning can be used for bracing and stiffening the building.

CLT can be designed to be self-supporting, so no framing is needed. Unless externally insulated, the R-value depends on the thickness of the walls.

CLT was selected for use in the world's tallest timber building – the Forté Apartments in Melbourne. This was due to its ability to withstand the same amount of pressure as concrete, its ease of use with traditional tools and the speed of construction (Morgan, 2012).

Recent preliminary testing done by NRC-CNRC on 150 mm thick CLT on eight different systems showed failure after an hour on all but one test. Test 8's loaded wall structure, made of five-ply CLT with 21 mm plies failed after 57 minutes (Osbourne, Dagenais and Benichou, 2012). Fire and earthquake tests have been carried out in Kobe.

For residential applications, CLT has already been used to construct a home on remote Waiheke Island. Panels were helicoptered in and assembled onsite. In Europe, the use of CLT prepanellised and modular homes is increasing, with purported benefits including increased airtightness complemented by a Swedish innovation of using rough-sawn surfaces for humidity control (Cambridge, 2012).

Airtightness is, however, a double-edged sword. While reduced air changes help to keep heat in, homes need air changes to remove odours, moisture and combustion gases. Insufficient ventilation can lead to poor indoor environments, with mould issues and high levels of VOCs from furnishings and increased levels of gases such as carbon dioxide and even carbon monoxide. Therefore, it is important to ensure adequate ventilation through either passive or active (mechanical) means for highly airtight homes.

At the end of its life, CLT can be chipped and turned into chipboard or the like. CLT is often untreated or is treated to suit the application (Cambridge, 2012).

6.4.3 Concrete

Benefits:

- Strong.
- High thermal mass.
- Durable.
- Fireproof.
- Flood resistant.

Disadvantages:

- Can be cold if not insulated.
- Heavy to transport.
- Hard to work after it sets.

Applications:

- Onsite pour into formwork, precast panelling, cladding, structural members, walls, floors, roofs.

Concrete is not as transportable as lightweight materials; however, it has the advantage of high thermal mass. Thermal mass is important from a passive design point of view, acting to moderate temperatures and store solar energy when used properly.

Precast concrete panels have been around since the 1920s (e.surv Chartered Surveyors, 2012). Precast panels have been used in the construction of commercial properties for many years, providing large, fire-rated walls quickly with the use of a crane. Panels have also been insulated to improve thermal performance.

Concrete releases significant amounts of carbon dioxide as part of its manufacturing and curing process, with 5% of global CO_2 emissions from construction said to come from the use of cement (Monahan and Powell, 2011). However, in Australia the amount of CO_2 emitted per tonne has been reduced by 21% between 1990 and 2004 (Oxley III, 2006). The increase in its use in construction has meant the overall reduction was 3.6% during the same period (Oxley III, 2006). There continues to be much debate over its ability to 'store' carbon.

Experimentation with aggregate and aerating has led to the commercial availability of lightweight concretes, while experimentation with reinforcing has led to the introduction of fibreglass-reinforced concrete.

Formwork has also adapted over time to adapt to thermal efficiency expectations and provide a faster way to pour concrete onsite.

This section explores these technologies in light of their residential potential.

6.4.3.1 Precast Panels

Additional benefits:

- Fast to erect.
- High thermal mass, increasing with depth.
- Able to be rendered.
- Factories are already established.

Additional disadvantages:

- Heavy.
- Need to hire specialist equipment (e.g. cranes).
- Needs insulation for maximum thermal performance.
- Factory precision required as hard to adjust.

Additional applications:

- Walls, floors, occasionally roofs.
- Shear walls.

There has been some use of precast concrete panels, mostly in architecturally designed housing in New Zealand (Bell, 2009); however, it is not yet a dominant material in the residential sector.

Figure 24: Workers casting concrete panels in a make-shift factory (Department of Corrections, 2009).

Figure 25: Precast concrete panels are craned into position and fixed in place (Charleson, 2012).

Precast concrete panels are produced in factories as opposed to site-built tilt-slabs, which are cast onsite (Bell, 2009). Precast panels can be made faster with differing surface detailing and to a higher quality than onsite panels (Bell, 2009).

Figure 26: Precast concrete panels can be pre-tensioned to minimise panel thickness, provide higher structural rigidity and strength in tension and prevent slump (ACP Concrete Ltd, 2012).

In the UK, precast concrete slab floors supported by precast concrete beams are popular (Clarke and Wall, 2000), providing inter-floor sound insulation and thermal mass to homes. Typically, these are used in multi-storey residential applications (Groak and Gann, 1995).

In some instances, slabs are poured to half depth, leaving some of the reinforcing exposed (see Figure 27). This allows for pouring of a topping slab onsite.

Figure 27: Reinforced concrete half-slabs form a deck onto which a topping slab can be poured (Ebawe, 2012).

As seen in Figure 24, concrete panels are traditionally reinforced with steel mesh. Steel reinforcing can also be used to pre-tension panels to avoid slump over long horizontal spans, such as floors (see Figure 26).

Carbon fibre reinforcing is now also being used in precast concrete. This comes in two forms – integrated into the concrete mix or in mesh, like steel reinforcing (see Figure 28). Carbon fibre does not corrode like steel and thus is used closer to the surface in overseas applications (Architerials, 2010).

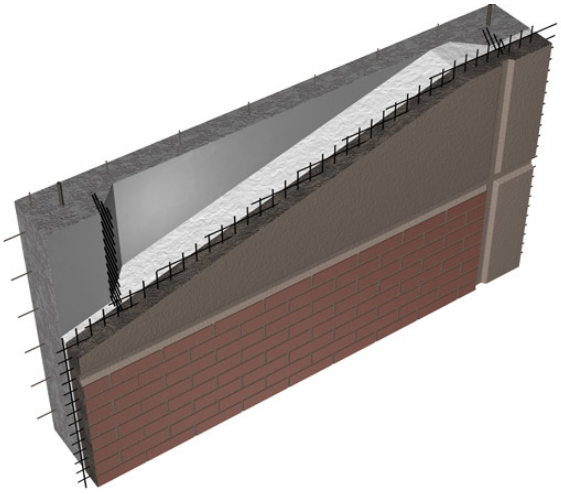

Figure 28: Carbon fibre reinforcing does not corrode like steel reinforcing (Architerials, 2010).

Carbon fibre concrete panels tend to be lighter because less concrete is required to bury and protect the reinforcing from corrosion. This reduces transportation costs and makes them easier to manoeuvre into place onsite (Architerials, 2010; Buffalo Plastering and Architectural Casting, 2012). The reduced steel is also said to have thermal benefits (Architerials, 2010).

Some products now use lightweight aggregates or aerated concrete to reduce panel weight, although a crane is still usually required to manoeuvre them into place.

6.4.3.2 Insulated Concrete 'Sandwich' Panels

Figure 29: Insulated concrete sandwich panel (Reid Construction, 2012).

Additional benefits:

- Insulated for thermal efficiency.

Additional disadvantages:

- Thicker than standard panels.

Applications:

- Passive design houses.
- Houses in high-noise areas.
- Walls, floors, occasionally roofs.

Another concrete panel system developed for improved thermal efficiency is insulated concrete panels (ICPs). These systems incorporate a rigid foam layer sandwiched between two outer concrete layers. The insulation core reduces moisture transfer and has the effect of preventing heat stored in the mass from escaping outside the building (Losch et al., 2011).

As outlined in Losch et al. (2011), there are four types of concrete sandwich panel:

- Non-composite: The two concrete 'whythes' act independently of each other – generally one is structural and one is not.
- Composite: The whythes are tied together and act as one unit under loading as full shear is transferred between the whythes.
- Partially composite: Panels are tied together with shear ties but full forces are not transferred between the whythes.

Like standard panels, sandwich panels can be patterned and pre- and post-tensioned.

6.4.3.3 Site-Poured Concrete

Benefits:

- Transportation is reduced through direct delivery to site rather than to a factory and then to site.

Disadvantages:

- Requires formwork.
- Can be messy.
- Time to cure.

Applications:

- Foundations, floors, walls, retaining, roofs, in some cases tunnel-form.

Site-poured concrete has been a popular choice for floor slabs for many years due to its speed of installation, low cost of installation and thermal mass benefits when properly insulated. The use of site-poured concrete has generally been restricted to floors and basement footers, however. Concrete formwork is expensive and time consuming to erect, and getting a desirable finish on exposed sections takes work. Uninsulated concrete, while having good mass, also has low thermal resistivity; therefore, the pairing of the concrete with external insulation is desirable from a sustainability perspective.

Site-poured concrete includes tunnel-form construction where an onsite permanent form is moved from house site to house site. This is used frequently in European countries and usually for row-houses and apartment blocks.

Tilt-up concrete panels are formed onsite and lifted into position. The finish is hard to manage in the open environment, and as such, tilt-up is used for commercial construction more than residential.

6.4.3.4 Insulating Concrete Formwork

Additional benefits:

- Provides insulation as well as formwork.
- Formwork fast to put up.

Additional disadvantages:

- More costly than ordinary formwork.
- Isolates the thermal mass from the inside of the building unless it can be peeled off.

Applications:

- Walls.

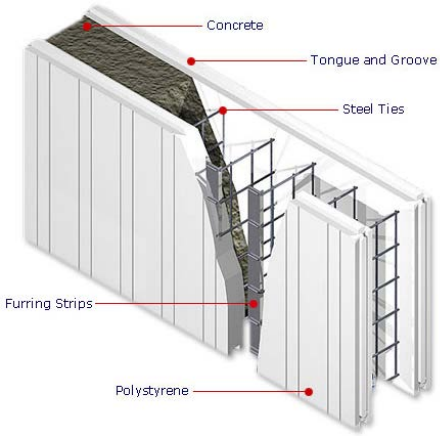

Figure 30: Insulating concrete formwork panelling as commonly used in the UK (Insulating Concrete Formwork Association, 2012).

In response to these challenges, insulating concrete formwork (ICF) was invented. The formwork usually comes in bricks, planks or panels and is made of rigid, expanded polystyrene. Planks and panels are used overseas but are not yet available in New Zealand (Cement and Concrete Association of New Zealand, 2012).

Reinforcing is inserted into the formwork before the concrete is poured. The formwork remains in place for the life of the building. Plank and panel insulation pieces can be removed to expose thermal mass to the inside of the building.

6.4.4 Photovoltaics for Panellised Construction

Photovoltaic panels are increasing in use; however, their predominant use is as an energy-generation device rather than a cladding. Building-integrated photovoltaics are now available and can be used as a roofing material, wall cladding or integrated into window panes. Their primary function as an energy generator puts them out of the realm of advanced residential construction techniques and into the realm of renewables engineering; thus, they will not be examined in this report.

6.4.5 Structural Insulated Panels

Benefits:

- High thermal performance.
- Airtightness.

Disadvantages:

- Utilises materials containing petrochemicals.
- Mechanical ventilation may be required.

Applications:

- Walls, floors, roofs.

Figure 31: SIPs come in a number of material combinations. Image: Ashley Balsam Baz (Rodriguez, 2013).

Structural insulated panels (SIPs) are panels of facing materials bonded to an insulating inner core. There are many combinations of materials that are used:

- Oriented strandboard (OSB).
- Plywood.
- Fibre-reinforced polyester.
- Fibre cement.
- Steel.
- Plasterboard.

Each material can be used with the following insulation types:

- EPS (polystyrene) with polyurethane/emulsion polymer.
- Polyurethane (self-adhering).
- Polyisocyanurate (self-adhering).
- Compressed straw (USA).

Another SIP that is not mentioned above due to its different makeup to those examples is PALC (precast autoclave lightweight ceramic) panels.

SIPs have been used for many years, predominantly in the USA. SIPs are lightweight in comparison to most other construction types, consisting of an insulating core material and clad on both sides. SIPs most often have traditional claddings on their outside, leading to a conventional appearance.

Steel-faced SIPs with a polystyrene core are commonly used in industrial applications in New Zealand, such as in coolstores. SIPs are designed to be structurally strong enough to bear the load of the building without the need for framing. The lack of thermal bridging between the faces of the panels means the thermal resistivity of SIPs can be very high for their thickness.

The R-value is largely dependent upon the type of core insulation. Polyisocyanurate cores resist heat up to 30–40% more than polystyrene cores (Brown, 2010), while compressed straw cores have a lower R-value.

The use of SIPs is increasing in the UK as part of the MMC movement and continental Europe as the push for greater airtightness to control heat loss gains momentum. SIPs' airtightness and lack of thermal bridging mean the system is often specified for houses designed to meet the Passivhaus Standard, which is becoming increasingly popular in New Zealand.

Figure 32: SIPs house under construction (Sunlight Homes, 2013).

The Passivhaus Standard requires mechanical ventilation to ensure adequate indoor air quality (Passivhaus Institute, UK, 2013) by using a balanced ventilation system. The standard is designed in such a way that the heating needs of a dwelling are able to be met by a preheater in the ventilation system.

From the New Zealand perspective, specific ventilation system design (whether active, passive or hybrid) is essential in very airtight houses in order to maintain enough ventilation to dilute internal moisture. Mould on interior walls has been more commonly observed in newer housing stock – an indication of high air moisture levels and inadequate ventilation to remove that moist air (Cunningham, 2011). While new houses are being built with higher airtightness (McNeil, 2012), simple passive ventilation techniques combined with mechanical extraction in wet areas should be sufficient for adequate ventilation.

Internationally, SIPs tend to be competitive in cost with traditional construction. This is due to the rapid assembly of the large and usually precut pieces, resulting in lower labour costs and reduced waste (Brinkley, 2010). Lifting machinery is often required to place the panels, as seen in Figure 32. Conduits for services are usually routed out of the panels.

SIPs are usually lined on the inside with a non-combustible lining product, such as gypsum plasterboard, to prevent structural failure during fire events. Providing SIPs are adequately protected, their fire resistance can compete with more traditional construction types.

Some types of SIPs perform better than others under extreme heat or extreme moisture. Polyisocyanurate SIPs are typically more expensive than other options but are also more resistant to water-vapour diffusion and fire (Brown, 2010; US Department of Energy, 2012).

Some resins used in manufactured wood products (e.g. OSB) and insulation materials (e.g. polyisocyanurate) in SIPs off-gas VOCs (Hodgson, 2003). However, it is broadly accepted that the release of VOCs virtually stops once the foam or resin has finished curing, a few weeks after manufacture (Luther, 2008).

6.4.6 Precast Autoclaved Lightweight Ceramics

Additional benefits:

- Natural materials.

Additional disadvantages:

- Thicker than most standard New Zealand walls.

Applications:

- Wall cladding.

Figure 33: PALC panel (Misawa Homes, 2012).

Precast autoclaved lightweight ceramics (PALC), first formulated by Misawa homes in Japan, are steel-reinforced panels that are used for interior and exterior cladding. The material resembles European aerated concrete and is designed to function as a type of SIP, servicing structural, insulation, fireproofing and finishing needs (US Congress, Office of Technology Assessment, 1986).

The panels were used by Misawa Homes in 1986 to clad modules in one of their 23 housing factories. At the time, there was little consideration of insulation, as Japan's climate was perceived to be relatively mild and central heating was uncommon (US Congress, Office of Technology Assessment, 1986). However, the product has since further developed and now consists of layers of ceramic, fibreglass insulation, an air gap and plasterboard. According to Misawa Homes:

> This construction yields a very high insulation value that helps make a home's interior cooler in summer and warmer in winter, thus lowering the electricity bill. Also, its high humidity adjustment performance deters water condensation, which can prolong the life of houses. (Misawa Homes, 2012)

The total thickness is 234 mm – up to twice the width of a standard New Zealand timber-framed, clad and lined wall (Misawa Homes, 2012). The walls weigh around the same as timber (Craig et al., 2002, p. 8) and are predominantly made from local materials – limestone and sand (Misawa Homes, 2012). Maintenance on the product is very low. Export markets include Taiwan and Japan (Craig et al., 2002, p. 8).

6.5 Modular – Highly Efficient but with Limitations

Benefits:

- Speed.
- Economy.
- Quality.
- Energy efficiency.
- Waste minimisation.

Disadvantages:

- Finalisation of designs needs to happen early in the process.
- Some façades need to be clad onsite.

Applications:

- Whole house.

Generally, the more work that can be done offsite, the faster the end product is achieved and the more predictable the outcome. Modular construction is the ultimate in offsite production, where a factory-made house, either whole or split into modules, is shipped onto premade foundations onsite. Contrary to popular perception, modular homes can be made to virtually any shape and size, providing they are strong enough to be transported on the back of a truck.

Due to the need for transportation of modules, the amount of offsite construction can differ if claddings are heavy or brittle. While it is less efficient, it is common for modules to be shipped onsite and then clad in traditional masonry claddings (Edge et al., 2003).

The degree to which technology and automation is used for modular housing assembly varies widely. In Japan, Toyota's housing firm's Kasugai Housing Works factory employs "people-free production of residential buildings" (Galileo, 2012). This high degree of automation enables workers from the company's automobile production facilities to "share and transfer production line workers between its car factories and its housing factory in order to transfer expertise and also level out fluctuations in the demand for labour" (Lessing, 2006).

Figure 34: Modular home with a double-height interior (All American Homes, 2012).

Figure 35: American modular home (All American Homes, 2012).

Figure 36: The Confluence 3 is delivered finished with appliances (Ideabox, 2012).

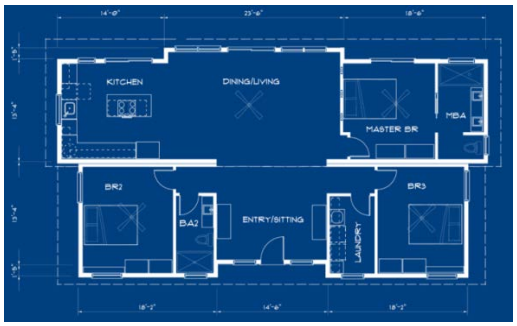

Figure 37: The Confluence 3 is delivered in two halves (Ideabox, 2012).

Toyota is not the only firm branching out into housing production. Scandinavian brand IKEA has diversified by entering a joint venture with Oregon's Ideabox Architecture to pioneer modular homes (see Figure 36 and Figure 37). IKEA and Skanska now produce BoKlok modular houses, terrace housing and apartments buildings, which have infiltrated the market in the UK and Scandinavian countries.

As well as modular houses, IKEA also produces cubes – modules that fit together to form a self-designed home. This concept of interchangeable, interconnectable modules is widely used in the USA.

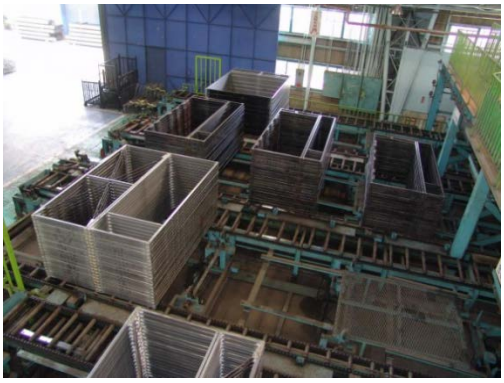

Figure 38: The steel module production line at Nara Works, Sekisui House (Galileo, 2012).

Breaking a house into modules, rather like building blocks, presents the opportunity to build it based on predefined block sizes or on a grid. Modular home manufacturers in the USA have shown exemplary skill in producing homes that look virtually indistinguishable from their site-built counterparts while allowing virtually all of the architectural and stylistic freedom of a site-built home.

Double-height rooms and cathedral ceilings can be achieved by using advanced bracing. This is removed once modules are 'knitted' together and structural elements put in place.

Steeply pitched roofs are possible through the use of 'hinged' roofs (see Figure 39), which also allow conformation to transportation height limits without placing undue restrictions on the design.

It is interesting to note that, in the USA, modular homes (as opposed to manufactured or 'trailer' homes) must meet the local building codes that apply to site-built homes (Huang, 2008, p. 6). Many exceed these codes for at least structure due to the transportation of the modules. Minimising the flex of the modules minimises the potential for cosmetic damage (Guest, 1991), which is a particular concern for those that are fully lined and decorated before leaving the factory floor.

While site-built homes often cost about the same overall, the quality, finish and sustainability benefits of factory-based construction, alongside reduced timelines associated with the transportation of volumetric modules onto prelaid foundations, appears to have developed its own niche market, as it has done in Japan.

The economics of modular housing has been a topic of debate, but generally it is agreed that the method is more cost-effective in respect of quality and finish and has the potential to save money on the same house build onsite (Davies, 2005; Edge et al., 2003; Pan and Dainty, 2007; Shahzad, 2011; Winter, Crosbie, Vierra and Kollaja, 2006).

A modern trend has been for 'prefab' architects to emerge, such as Rocio Romero (Romero, 2012), Jennifer Seigal, Michelle Kaufmann (Bell, 2009). Before the Global Financial Crisis, Kaufmann and Remick (2009) found the following when moving from onsite construction to offsite modular construction:

- Time savings of 30% due to standardised design and construction processes.
- Reduced waste of 50–75% compared to onsite – no theft or vandalism.

- Quality control – protection, quality, precision, craftsmanship.
- Strength – houses meet or exceed international building codes. There is more framing and strapping. Factory workers have access to tools that are not accessible for onsite builders.
- Less gas – "[P]eople who work in the prefab factory typically live closer to work than the average contractor or subcontractor who drives to a remote job site. In addition, the shorter time frame for building prefab results in less gas used to get to work. Less fuel and electricity are expended on a home built in 24 days (modular) versus seven months (stick-built). Truck transport for materials to the factory could reduce gas use further. Not only does a prefab home require putting fewer trucks on the road (due to larger loads supplying multiple homes), but also as deliveries become more consistent, the trucking company dispatcher can arrange return loads so that trucks don't come back empty. This level of coordination and fuel savings would be almost impossible to accomplish with a stick-built jobsite, where deliveries are more unpredictable." (Kaufmann and Remick, 2009, p. 71)
- It is green – efficient, low maintenance, fewer resources, less debris

Figure 39: The hinged roof enables modular manufacturers to include steeper pitches without exceeding transportation height limits. Image: Ellen McDermott (Gorman, 2012).

Other case studies have found 22–25% savings from using prefabrication (Winter et al., 2006; Edge et al., 2003; Craig et al., 2002). Literature puts waste savings at 20–40% and has found that the greater the levels of prefabrication, the more savings were achievable (Monahan and Powell, 2011).

In the past, it has been argued that:

> The development of industrialised building in New Zealand would probably not be successful though for different reasons than those in the United States. Firstly, it is likely that the capital costs of an industrialised housing plant in New Zealand would be relatively higher than in the U.S.A. This is partly because of the higher cost structures of the New Zealand building industry and the higher cost of imported plant. These higher capital costs coupled with higher real interest rates require larger margins than an equivalent factory in the US. Secondly, any potential market for a New Zealand housing factory would be significantly smaller than that available to a North American plant. (Johnson, 1989)

The market has also been limited in the past by the cost of transport to get prefabricated homes onto site (Sharman, 2013). This may still be a barrier for areas outside of the main urban centres for volumetric prefabrication, such as transportable houses or modules.

However, with strict Building Code requirements, real-time international communication, locally produced building materials and mass export opportunities, New Zealand firms may now be able to break into the lucrative export market for quality, factory-made homes. This makes particular sense with recent emphasis on growing a knowledge economy (Department of Labour, 2009) and moving away from primary exports to value-added exports.

6.6 Hybrid – the Best of All Worlds

Benefits:

- Restricted only by site size and any standard sizes of chosen modules.

Disadvantages:

- Less efficient than full modular.

Applications:

- Varies from whole house to part house.

Hybrid construction combines a combination of modular, panellised and/or componentised construction. An extreme example of this is Loq-kit houses, where three types of components make up a whole house – modular metal frame, modular infill panels and modular cladding (Loq-kit, 2012). The system allows for swapping out of components, additions, materials and window sizes (including photovoltaic panels on the roof) or downsizing after construction (Loq-kit, 2012a).

For traditional construction, the combined use of modular items with components and panellised construction have the potential to allow bespoke housing to be built in a minimal amount of time onsite.

By using modular, panellised or componentised systems with standard specification, additions and renovations during the life of the house can be done more easily than in traditional construction and without the need for partial demolition. Surplus items may be able to be reused elsewhere, and conversely, worn out or even unfashionable items can be easily sourced. Just as there is a market for second-hand car parts in New Zealand, there could be a larger market for second-hand building parts, diverting demolition waste from the landfill.

We tend to think of adaptable homes as those that can accommodate people and their needs but not necessarily change with people and their needs. Using such highly standardised homes, rooms or entire floors could be detached and sold. Whilst foreign to the New Zealand culture, this has potential and could become particularly important over the next few decades as New Zealand's demographic ages and household sizes shrink – people who wanted to downsize a home could sell surplus floor area rather than moving.

7. DISCUSSION

> A successful construction industry is essential to us all. We all benefit from high quality housing [that is] constructed efficiently. (Egan, 1998)

The evolution of the New Zealand construction sector, particularly the residential construction sector, has lagged behind other manufacturing sectors and other countries. The lack of market and government drivers, domination of small businesses, proliferation of independent tradespeople, geographically spread locations of construction sites and small scale of the projects worked on tend to remove much of the impetus to change the status quo.

The terms ‘offsite construction’ and ‘prefabrication’ tend to be synonymous with the terms ‘mass customisation’ and ‘standardisation’ to the market. The terms breed images of cookie-cutter homes lacking individuality and not custom-designed. This is symptomatic of viewing the house from the product end without considering it to be part of the building process. The reality is that mass customisation and standardisation can apply to anything from a component through to a wall panel system, through to an entire house. A new car can be ordered with alloy wheels, different levels of trim, different coloured fabrics, spoiler kits and in different shell colours, all of which are chosen by the client. On the other hand, a house built from standardised methods may only be confined by block sizes, base structure or an array of set window sizes and styles. This standardised housing system would then allow it to have one bedroom or 15, be English Tudor or post-modern in style, have a monopitch or gabled roof with dormer windows, and fittings and finishes of differing qualities.

For some people, character holds enough value that the upsides of modern homes are shunned in return for the psychological and ontological comfort of an older home that was made by hand, and finished to emphasise value and quality. This implies that the modern aesthetic must be able to be altered in order to appeal to a broader range of customers and be of a high-quality finish. It may seem on the surface to be contradictory to the minimalist construction techniques and push for prefabrication and modularisation. There is a perception that character cannot be incorporated into these systems of construction. However, character is evident in the finishing, not in the structure.

The perception that these systems produce homes of lower quality is flawed – the precision, strength, thermal properties and quality control of industrially manufactured homes will be far higher than most, if not all, older, hand-crafted homes. The challenge for the manufacturer is to offer added value and options to increase appeal to customise homes built using these methods in order to instil the psyche of ‘home’.

The question is this: Why is this view of inferiority so pervasive when nearly all cars made today are built in a factory? The thought of bringing steel, paint, welding, shaping and cutting equipment onsite, then importing craftspeople and components to assemble a car in a driveway is inconceivable. Not only is it impractical and expensive:

- the materials are exposed to the elements
- there is limited systematic quality assurance
- the purchaser must pay for the wasted material
- the purchaser must then pay for wasted material to be disposed of

- all materials are bought in small orders, which reduce the ability to benefit from bulk procurement.

It does not make sense financially, practically, environmentally or socially. In fact, as the units are transportable, car makers have been using factories for production since the earliest days of the automobile. So, seeing as we have the ability to transport whole houses, the land on which to build factories and the need to boost productivity and quality in the construction sector, why do we as a nation not see factory-built housing as a quality solution?

There are concerns that the true value of innovative housing is not being captured:

> There is also some concern within the construction industry about housing valuation standards that take physical area into account but do not take time or environmental savings into account. (Bell, 2009, p. 185)

A valuer's role in building valuations is to provide a final cost to financers rather than a market value. Their role is to look at the cost of the build from the most conservative view possible, not necessarily the market value of the final, completed and decorated item, thereby protecting the lender in case of non-completion. This, in turn, leads the early adopting clientele to be those with large deposits and a willingness to put their own money on the line until post-completion valuations can occur.

While initial cost of construction is of prime concern to investors, generally this is not the price paid by subsequent owners. Instead, the market value of the investment package is realised. Quality construction, fit-out, appliances, landscaping, views, maintenance and style all become critical factors.

However, there is concern that, even if construction becomes more cost-effective, the current market will seek to get the maximum amount possible for the product rather than passing on savings – especially where suppliers are not manufacturers (Pan and Dainty, 2007). This is reflected by industry opinion in the UK that non-traditional construction costs more than traditional construction (Phillipson, 2001). While this has been disproven, the perception remains a barrier to uptake (Phillipson, 2001).

While innovation is essential for the evolution of the residential construction industry, it is clear that there are constraints other than the obvious financial, environment, sectoral and structural ones. Consumers are becoming more aware of sustainability issues and demanding of environmentally friendly products and even lifestyles. Trends are likely to follow those of overseas, where the 'green' factor has become a key purchasing point and marketing agenda.

There is potential for unintended consequences of innovative products and especially those used to address sustainability priorities. By nature, many highly insulating materials are either flammable or prone to melting. In addition, minimising materials in structural members can lead to brittle failure during fire events, endangering lives and property. So while fire was not initially a part of this project due to lack of explicit requirement in stand-alone housing, it has been identified as an area of concern.

8. SUMMARY OF FINDINGS

Changing Tack to Meet the Challenge

There are techniques and technologies from this and other countries that have potential to assist what are colloquially known as advanced residential construction techniques (ARCTs). The techniques and technologies investigated in this report are not yet commonplace in New Zealand to any real degree in residential construction. In order to facilitate the consideration of adopting ARCTs, the second half of this project will look at the financial viability of shifting the industry to utilise these techniques and technologies.

Smart Business Strategies Underpin Industry Transformation

In an industry dominated by sole traders and small companies, group procurement and cooperatives allow small players to combine to have a bigger influence and enhanced buying power. Pooled capital research and development funds could enable the smaller players to undertake (and share the risks of) their own research and development projects and experimentation with materials and processes. Pooled skills can be distributed to improve operations and workflow across multiple companies. Improved workflow and larger buying power can lead to lower costs and improved competition. Less fragmentation in supply chains means improved feedback loops from builder to manufacturer.

Consistent application of the Building Code is essential for enabling innovative design and construction methods. Construction in a different building consent authority jurisdiction to that of the final destination requires consistency in the interpretation of the rules in order to avoid compliance issues. This is particularly important where unusual designs or materials are used. Open communication and collaboration between the builder, client and involved BCAs is essential.

Factory Construction for Enhanced Efficiency

Taking construction offsite offers a series of practical benefits, including: climate-controlled environments (for protection of workers and materials), reduced onsite work (tighter health and safety environment and mostly weather-independent construction), onsite staff (for tight scheduling and teamwork), heightened quality control (improved precision of thermal envelope and structure, less rework, improved ability to meet requirements for product warranty eligibility), enhanced waste minimisation and recycling (environmental protection and cost reduction), quality, quantity and custom design teams rather than individuals and improved health and safety.

The use of automation in offsite construction leads to the employment of skilled workers. Machines do what they can do well and humans do tasks that require skilled hands. Menial tasks are removed from skilled workers, leaving skilled workers to apply their expertise to more value-added work. With sufficient simplification of assembly, unskilled workers can assemble the product onsite with sufficient supervision/site management. Automation can improve speed, cost and quality and minimise waste in projects; however, it does not remove the need for management staff and skilled labour in construction.

There are four main types of prefabricated offsite construction – componentisation, panellisation, modular construction (including transportable) and hybrid.

Sustained Change will Require Support and Incentive

Industry will require assistance in order to make and sustain changes. Historically, New Zealand's offsite construction industry was supported by the government at

its inception (Bell, 2009). However, sector transformation is a long-term initiative, not a short-term fix. Short-term assistance can be detrimental by removing the supports when advances are not yet entrenched and markets not yet established. In most developed countries where housing construction is advanced beyond our own, government plays a role in funding research and development, asserting innovation as part of its procurement agenda.

There will need to be a step-change to transform the way the construction industry builds homes if we are to resolve the multiple housing issues that New Zealand is facing, and even then it will not be a short-term fix. As cited in Bates and Kane (2006):

> In the short term, a great deal (but not everything) cannot be changed; in the long term, almost everything can change; in the medium term, there is a messy combination of predictability and choice. (Meadows, 1999)

Transformation will require changes to both the way the residential construction sector does business and how the residential construction industry builds. A change in one or the other can only result in a step-change. This is not enough to transform the speed, quality and value of construction projects to meet demand, let alone achieve the Productivity Partnership's target of 20% productivity improvement by 2020 (Productivity Partnership, 2012).

As can be seen from events in the past 100 years, the most notable being World War II, crises have enabled step-changes to happen in the industry to cope with housing shortages and large-scale migration. These changes have often ended years after they began. Without a transformation occurring, the residential construction industry has reverted to the former status quo, as in the case of prefabrication.

For transformation to occur, the industry itself must choose to push forward and break with tradition. As the UK's experience to date with the adoption of modern methods of construction shows, only limited success can be achieved when changes are being imposed, rather than being owned by the industry and pushed from within.

From the marketing perspective, prefabricated state houses and low-cost transportable homes built in the early to mid-1900s led to a stereotype of uninspiring, 'cheap' housing that remains today. Overcoming stereotypes such as these will be essential to enable non-traditional construction and techniques to become commonplace. In the case of prefabrication, quality of process, architectural merit and end product are likely to be the keys to breeding market acceptance.

9. RECOMMENDATIONS

Transformation needs to be both organisational and technical

The residential construction industry needs to transform the way it both operates and builds to meet the housing demand profitably and productively across the spectrum. Changing business operations as well as the way houses are built is required to achieve maximum benefit and lasting change. Just changing the business side or just changing materials used will not transform the residential construction industry.

Transformation needs to be maintained in order to create a step-change, otherwise the industry may revert to former practices once pressure is removed.

The industry should pursue excellence through innovation

Innovation is essential to catch up with and create demand (domestically and internationally), improve value, speed and quality of product. Excellence through innovation can give companies a competitive edge in a highly competitive industry. By improving demand, the industry can improve scales of economy.

The industry should challenge its members to innovate

In order to change, there must be pressure to change from within. The industry is in an unparalleled position to improve the quality of our lives through building excellence into the places in which we live, work and play. Innovation champions are essential for successful implementation of innovative projects.

Government needs to incentivise, assist and support a shift

Market forces are not enough. Medium to long-term political and financial assistance is essential – previous short-term schemes in this area have led to failure of fledgling companies before they could get established. There is potential for the use of the New Zealand Building Code to drive innovation.

Offsite construction should be pursued

Overseas industries have demonstrated the benefits of offsite construction compared to onsite construction. The specific benefits and disadvantages of offsite construction need to be explored to test their viability in the New Zealand context. Demonstration of the benefits are likely to be one of the highest motivators of change.

10. AREAS FOR FURTHER RESEARCH

In order to provide a clear picture of the viability and long-term benefits of ARCTs for the New Zealand residential construction sector, New Zealand-specific data may be necessary in some cases. The following areas have been identified through this work as ones that would benefit from further investigation in the New Zealand context.

10.1 Economics – Do They Stack Up?

A major confining factor for the New Zealand residential construction sector is the tight economic parameters within which they work. The main principles surrounding maximising the profitability of new house construction include:

- minimise cost
- minimise maintenance
- minimise outgoings
- maximise returns.

The issue of economics for these techniques is not straightforward and is worthy of discussion. There are several different perspectives that need considering – upfront costs and savings, on-going maintenance, operational expenditure and return on investment.

Offsite construction – be it whole-house, modular, panellised or componentised – may save money compared to traditional building. However, this depends on a huge number of variables, including scale of production (single house or standardised design), materials choices, design and context of the build.

Cost savings for the Elliott Group (2012) quote savings of 20% on whole-of-life and running costs, and they can build a house in a weekend. Japanese housing company Sekisui can build 'large' houses in less than 4 hours in the factory before transporting them to site (Gann, 1996, p. 446).

The primary advantage of offsite production in the eyes of the industry is higher-quality outcomes (Bell, 2009). The consumer, however, holds the perception that its primary advantage is being a lower-cost solution, not helped by the proliferation of basic and non-architect designed plans. Bell (2009) proffers that increased architectural influence will shift the image of prefabrication from budget to high-quality housing.

Partnering or alliances have the potential to bring prices down for small to medium-sized residential construction companies, allowing them to compete more effectively with the largest builders. This partnering is particularly relevant for procurement – reducing initial capital costs. This may also reduce subcontracting costs for bringing in skilled tradespeople from partner companies, thus providing more consistent workloads (Egan, 1998) and thereby income across multiple companies. This, in turn, increases job security, increases knowledge and skill transfer and increases opportunities to retain and upskill staff.

Risks to economic outcomes in the past have included incompatibility of manufactured parts with those from other manufacturers and the potential for productivity and timelines to remain much the same as traditional construction (Gann, 1996), especially if there is insufficient buy-in from within the construction company.

The economic viability and implications of employing ARCTs in the New Zealand residential construction sector is as yet unknown. The complex relationship between market size, investment and return will be explored as part two of the ARCT project.

10.2 Sustainability – How Much Room for Improvement?

The new housing market is becoming more and more conscientious about the social, environmental and economic sustainability of residential construction. The general international sustainability principles in terms of new house construction are:

- maximising efficiency, outcomes
- minimising energy, water, waste, toxins and VOCs
- managing societal impacts, environmental degradation
- preserving resources and quality of life for future generations.

New Zealand's construction industry has huge potential to boost the country's environmental performance. According to the Ministry for the Environment, New Zealand's buildings consume 40% of New Zealand's energy, produce 40% of the waste, contribute 35% of carbon dioxide emissions and use 40% of raw materials (Bell, 2009).

Interestingly, sustainability is not the prime driver of prefabrication and modularisation adoption in the USA (Fitcher, 2011); however, 'green' construction is a prime focus of virtually all of the companies examined in this study – the common thread is for the methods and materials employed by the makers to be cast in an environmentally friendly light. A few had achieved ISO accreditation (Viceroy Homes, Rubner Haus) or pointed out LEED accreditation points as a sales feature (Viceroy Homes).

> On site construction typically has contingency and error related over ordering, amounting to approximately 10% of all materials brought to site, with 10–15% of the materials imported to a construction site being exported as waste. (Monahan and Powell, 2011, p. 180)

Fitcher (2011) found that over three-quarters of respondents to the SmartMarket Report survey "indicate[d] that prefabrication/modularization construction reduces site waste – with 44% indicating that it reduced site waste by 5% or more. In addition, 62% of respondents believe that these processes reduce the amount of materials used – with 27% indicating prefabrication/modularization reduced materials used by 5% or more". In agreement with this, another report "estimated the waste reduction through substitution of traditional methods with prefabrication systems to be between 20 and 40%, the greater the prefabrication the greater the savings" (Monahan and Powell, 2011, p. 180).

This suggests that, for those who have taken up offsite construction, there are noticeable differences in materials purchasing and outgoings and that the more offsite construction is used, the less wasteful and the more cost-effective construction is.

The choice of construction will also have significant implications on the carbon intensity of residential construction as the era of carbon credits approaches. In England, it was estimated embodied carbon in timber-framed and clad MMC-built housing was 405 kg CO_2 per m², compared to 612 kg CO_2 per m² for masonry-clad homes (Monahan and Powell, 2011, p. 186). The implication of this is that, with such a large backlog of housing stock needing to be constructed, the carbon costs and broader environmental implications for England are huge.

Indeed, in Europe, prefabrication is being used as a tool to improve the sustainability of products (Phillipson, 2001). The sustainability of the product is highly dependent on a set of factors, including:

- leanness of construction
- embodied energy of materials
- quality of outcome
- long-term resource use (water and energy)
- long-term maintenance needs
- ability to serve the inhabitant long term.

The sustainability aspect of a house relies on a combination of design, materials and the methods of construction. As Bell (2009, pp. 47–49) points out, "sustainability is ultimately determined by the system and its implementation, including material choice, material sourcing, efficiency of production, reuse and recycling of scraps, and effective disposal of waste".

For example, if a modular house is built inefficiently from high embodied-energy materials, is transported a long distance to site and has high maintenance requirements, it is likely to have no advantages over a traditional timber-clad, site-built house.

From the international context, this research has found there is space for ARCTs to improve the social, environmental and economic sustainability of new housing markets. Examining the actual potential for ARCTs to improve the sustainability of new house construction in the New Zealand context is a topic worthy of further research.

10.3 Fire – Considerations for New Build Residential

Fire claims more houses and casualties than storm events in New Zealand, yet the Building Code currently has no performance standards for single detached dwellings that are located a metre or more from the boundary of the land parcel. The main principles of fire protection are:

- prevent fire occurring or taking hold
- protect life, property and environment
- preserve life, property and environment.

There has been increasing concern, particularly in the USA, at how non-traditional construction is leading to increased fire intensity and speed of combustion (Robbins, 2012). Integrated design is by its nature multi-disciplinary, but rarely are fire engineers included in design teams to mitigate unintended risks of designs. As Robbins points out, fire engineering has inherent links to sustainability that are not often brought up – fire causes destruction, which leads to waste and the release of toxic, ozone-depleting greenhouse gases. Minimising the risk and severity of fires minimises the negative sustainability outcomes for fire events in a building.

In New Zealand, house fires lead to claims of over $90 million per year (Goodchild et al., 2005), while weather-related claims have averaged less than $50 million over all sectors (industrial, residential, commercial etc.) (derived from Insurance Council of New Zealand, 2012).

It is essential the fire performance implications of new materials and systems be investigated before widespread uptake occurs in order to avoid unforeseen consequences. The high impact and relative frequency of house fires means that

fire should be considered as part of a holistic and broad assessment of the qualities of the systems being reviewed. As systems get more complex and building materials change, the need for guidance and perhaps standards on construction system performance is likely to increase. The true risks of such shifts in technology are not yet known. A standard set of parameters for the assessment of fire risk in new materials could be developed for use in system testing. If industry supported this, it could provide base technical information for codes or standards.

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APPENDIX A DEFINITION OF GOOD GROUND

"Good ground" means "any soil or rock capable of permanently withstanding an ultimate bearing pressure of 300 kPa (i.e. an allowable bearing pressure of 100 kPa using a factor of safety of 3.0), but excludes: a) Potentially compressible ground such as topsoil, soft soils such as clay which can be moulded easily in the fingers, and uncompacted loose gravel which contains obvious voids, b) Expansive soils being those that have a liquid limit of more than 50% when tested in accordance with NZS 4402 Test 2.2, and a linear shrinkage of more than 15% when tested, from the liquid limit, in accordance with NZS 4402 Test 2.6, and c) Any ground which could foreseeably experience movement of 25 mm or greater for any reason including one or a combination of: land instability, ground creep, subsidence, (liquefaction, lateral spread – for the Canterbury earthquake region only), seasonal welling and shrinking, frost heave, changing ground water level, erosion, dissolution of soil in water, and effects of tree roots". (Standards New Zealand, 2011)