STUDY REPORT

SR 311 (2014)

Advanced Residential Construction Techniques – Opportunities and Implications for New Zealand

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Funded by BRANZ
from the Building Research Levy

The work reported here was funded by BRANZ from the Building Research Levy.

ISSN: 1179-6197

Preface

The hypothesis of the second part of the Building Research Levy-funded Advanced Residential Construction Techniques project is that different levels of operational transformation and automation will suit different sizes and activities of residential construction businesses.

This report follows on from the interim report, *Building Better – Advanced Residential Construction Techniques for New Zealand* (Buckett, 2013). *Building Better* found that panellised offsite construction offers perhaps the most potential for New Zealand's residential construction sector in terms of addressing criticisms of productivity, quality and value for money.

This report investigates the potential and implications of moving to panellised offsite construction for New Zealand's residential construction industry. The two-part report first looks at current set-up of New Zealand's residential construction industry, with a comparison to more advanced offsite construction industries. Part 2 examines the resulting potential and implications of moving to panellised offsite construction for the New Zealand residential construction industry. The report draws on extensive international literature reviews, industry interactions and findings from an industry-organised prefabrication study tour to Germany and Austria in 2013.

Acknowledgments

This work was funded by the Building Research Levy. Thanks to the following individuals and organisations who rendered their assistance during this project:

Pamela Bell, PrefabNZ
Johann Betz, J S Betz Consulting
Eli Nuttal, First Light Studio
Kevin Stanley and Sean Wood, Stanley Modular
Hans Roberti, BRANZ Ltd
Roman Jaques, BRANZ Ltd
Daniel Hepburn, Online Logistics Ltd

Note

This report is intended for home builders, construction companies and the broader construction industry. This report is designed to begin a conversation and thought processes surrounding possible transitions to offsite construction and is not intended to be a basis for business decisions. This report is intended to provide a broad overview of the opportunities and implications for moving towards panellised offsite construction. Any cost examples provided are current as of the time of writing and are presented for information and comparison purposes only. Individuals or organisations wishing to explore a transition towards incorporating advanced residential construction techniques (ARCTs) in their work are responsible for undertaking due diligence to verify the appropriate path for their particular context.

Advanced Residential Construction Techniques – Opportunities and Implications for New Zealand

BRANZ Study Report SR 311

N. R. Buckett

Reference

Buckett, NR. (2014). *Advanced Residential Construction Techniques – Opportunities and Implications for New Zealand*. Study Report SR311, BRANZ Ltd, Judgeford, New Zealand.

Contents **Page**

Figures Page

Tables Page

EXECUTIVE SUMMARY

This report is the culmination of a 2-year Building Research Levy-funded project looking at ways to address and improve productivity, quality and value within New Zealand's residential construction sector. This report follows on from *Building Better – Advanced Residential Construction Techniques for New Zealand* (Buckett, 2013), which looked at novel and uncommon construction techniques that may have potential for application in New Zealand. The 2013 report found that panellised offsite construction has perhaps the most potential for New Zealand's residential construction sector in addressing criticisms of productivity, quality and value for money.

This report goes further – investigating the potential and implications of moving to panellised offsite construction for New Zealand's residential construction industry. The report is in two parts. The first looks at the current industry set-up, then compares it to a country with a more advanced offsite construction industry – Germany. Part 2 then examines the resulting potential and implications of moving to panellised offsite construction for the New Zealand residential construction industry in light of decades of overseas experience. The report draws on extensive international literature reviews, industry interactions and findings from an industry-organised prefabrication study tour to Germany and Austria in 2013.

Key findings from this report include:

- the New Zealand residential construction industry is in an ideal position to benefit from decades of overseas experience and adapt the knowledge and techniques to suit the local context
- although there are opportunities for all sizes of company to utilise offsite construction, going by overseas examples, it is likely that a medium to large-sized company would be required to operate efficient and effective factories in New Zealand
- of all the different offsite construction methods, panellised construction offers perhaps the most potential for New Zealand at present because of its quality and speed attributes as well as its applicability to the range of residential typologies and techniques that are in use
- early engagement between architects, designers and manufacturers is critical in order to get the maximum benefits from panellised offsite construction for all involved, as the process is more rapid and data intensive than traditional forms of construction
- there is significant scope for New Zealand's residential construction industry to create aspirational industry quality standards or labels to enable the consumer to better understand the quality of what they are buying, following successful German examples.

The forecast construction boom is an ideal opportunity for New Zealand's construction industry to transition towards methods of construction that deviate from tradition. With the value of new construction work predicted to peak around 2017, New Zealand has precious little time available to transition in the current upswing in production.

It is essential that the industry responds quickly, yet informs their response with research findings and understanding of the market. This will ensure the transition to offsite construction will maximise the benefits. The outcomes of such a transition will have long-term implications for the residential construction industry, their clients and indeed the whole of New Zealand.

INTRODUCTION

Overseas literature suggests that traditional construction industry structure, like much of New Zealand's residential construction sector, hampers the uptake of advanced residential construction techniques (ARCTs). ARCTs are technologies and business strategies that can improve productivity, quality, value for money and sustainability of all types of construction.

This report follows on from the interim report, which found the hypothesis that there are ways the New Zealand residential construction industry can build better with regards to quality, cost, speed and sustainability to be true. The work also established that, at present, panellised offsite construction technology, also known as panellised prefabrication, has the most potential and overall benefits to the sector out of the ARCTs found in the desktop study.

This final report explores the considerations of the use of panellisation and associated technology for small to large companies and investigates the complex relationship between market size, investment and return for New Zealand's residential construction industry.

This report is split into two main sections – Part 1: Residential Construction in New Zealand – Industry and Market Characteristics and Part 2: Opportunities for and Implications of Offsite Construction in New Zealand. Part 1 examines New Zealand's residential construction industry, looking at the characteristics of firms, their operations, what they build and the implications of this structure.

New Zealand's residential construction industry and market are compared to that of a mature offsite construction country – Germany. This chapter draws on knowledge gained on a panellised prefabrication study tour of Germany.

Those familiar with New Zealand's construction industry and its outputs may choose to begin at Part 2, which investigates the potential and implications of offsite construction for New Zealand's residential construction industry. Section 2 looks at the benefits from panellised offsite construction from quality, speed, value and labour points of view.

Section 3 looks at the implications of offsite construction with respect to the way the broader residential construction industry currently operates. It includes information surrounding the planning, set-up and operations required to maximise the potential of offsite construction. It also covers the potential standards and compliance implications of moving to panellised offsite construction and the relationship between quality and performance.

PART 1:
RESIDENTIAL CONSTRUCTION IN NEW ZEALAND – INDUSTRY AND MARKET CHARACTERISTICS

1. CHARACTERISING THE CURRENT MARKET

There is significant concern over the shortfall between increasing populations in many of the main urban centres in New Zealand and the rate of construction of new dwellings. Auckland is particularly hard hit, with around a third of New Zealand's population (Statistics New Zealand, 2014d). Christchurch has housing pressures relating to a decrease in housing stock and a sudden increase in population as trades move in to rebuild (Ministry of Business, Innovation and Employment, 2013).

In Auckland in particular, inflation of house prices and rent that far exceeds the national rate of inflation has become a major concern and a highly political topic.

While there is little information available on the future of residential construction in New Zealand and what it will look like, we do know how many new houses are likely to be needed in the near future (Department of Building and Housing, 2011). As present, the rate of construction is not meeting demand, particularly in Auckland (Johnson, 2012).

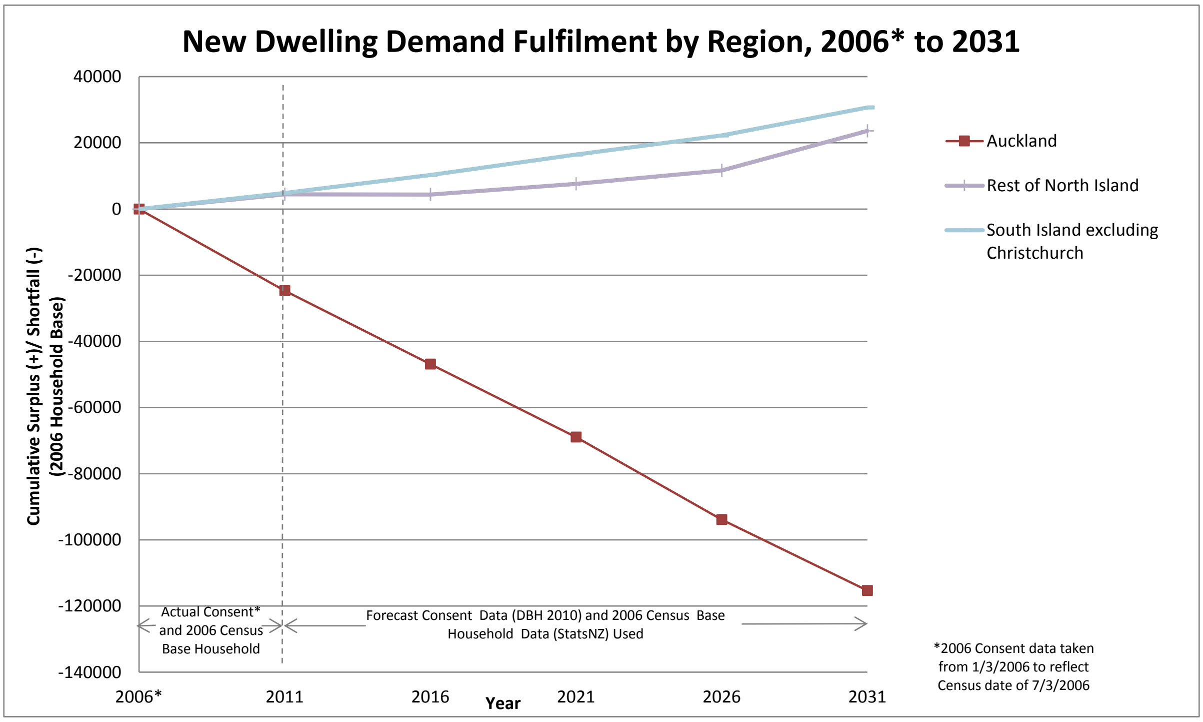

Figure 1: Auckland's housing demand is forecast to outstrip supply through to at least 2031, according to figures from DBH (2010).

Figure 1 shows the predicted housing shortfall based on forecast new dwelling consent data (Department of Building and Housing, 2011) and 2006 Census base household data (Statistics New Zealand, 2013). This is presented as a cumulative figure starting at 2006, demonstrating the relationship between new households to the region and new dwellings being built. Assuming one household per dwelling, this graph shows the unmet housing demand between 2006 and 2031. During this period, the predicted new demand for housing in Auckland may exceed the predicted delivery of new housing by nearly 120,000.

Too few dwellings being built has already led to rising prices and falling affordability as people compete to secure a property by paying more and more money. If the rate of increase for households and new dwelling consents follows the predicted trend, the severity of the housing shortage will continue to increase unless there is a large change.

It is important to note that the data in Figure 1 was produced before the damaging Canterbury earthquakes. This has changed and is still changing the outlook for the building industry in Christchurch, and for this reason, Christchurch has been removed from the data in the graph. At the time of writing (March 2014), there are still no solid figures for the number of houses damaged beyond economical repair due to the constant reassessment of damaged homes. An estimated 10,000 houses were removed from the housing stock by the fourth quarter of 2011 and another 1,500 in the following year (Ministry of Business, Innovation and Employment, 2013).

It is estimated that the percentage loss in population from Christchurch after the earthquakes was less than the loss of housing stock, thereby putting upwards pressure on the housing stock (Ministry of Business, Innovation and Employment, 2013). Further, many of those who are working on the rebuild have moved into the city from elsewhere, adding to housing pressures.

There are a number of companies adapting to better meet the demand of the market in Christchurch, and some are beginning a transition to offsite construction (Canterbury Development Corporation, 2014).

1.1 Industry characteristics

New Zealand's residential construction sector has a long tradition of onsite construction using traditional construction techniques. Few companies build offsite, let alone in a factory.

The New Zealand residential construction industry is predominantly made up of small businesses. The average firm size between 2000 and 2010 hovered around 1.5 positions (Page and Fung, 2011). Combined, the number of sole traders and small businesses with one to five employees made up 96% of New Zealand's residential construction enterprises in the year ending February 2012. 72% of residential construction enterprises were sole traders in the year ending February 2012. This was a slight reduction compared to the year ending February 2000, when sole traders represented 75% of all construction enterprises.

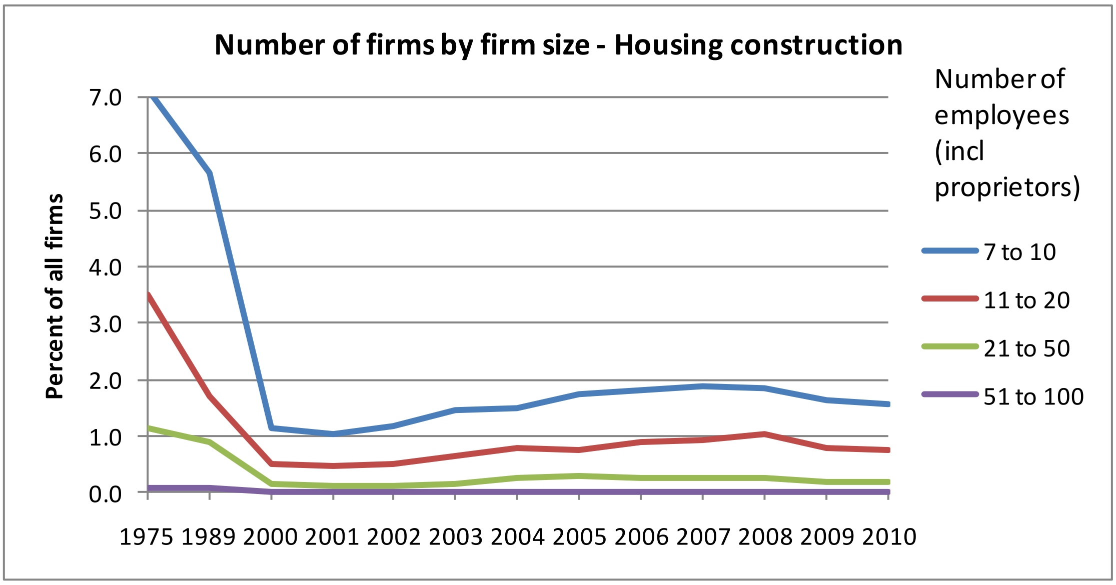

Figure 2: Housing construction firms by firm size (Page and Fung, 2011).

In 1975, around 25% of all housing sector employment was as sole traders (Page and Fung, 2011). From 1975 to 2010, the percentage of housing sector employment in small firms with two to six people (including a working proprietor) has remained relatively steady at around 52–55%.

The number of medium and large businesses changed dramatically between 1975 and 2000, as shown in Figure 2. (Note here that there are only three data points from 1975 to 2000. This and the data for firms with 1-6 employees is contained in (Page and Fung, 2011)). This change is partially due to a different method of counting firms after 1975, and partially due to the rapid drop off in new housing starts, from the all-time high in 1975, to 2000 when the numbers of larger firms levelled out (Page and Fung, 2011).

The analysis in this section uses Statistics New Zealand industrial classification data from 2006 to 2012 according to ANZSIC 06 categorisation, for which construction forms Division E. Division E includes residential building construction (group 301), which was used wherever data was publicly available to this level.

For the purposes of the following analysis, employment is defined as people who, during the reference week:

- "worked for one hour or more for pay or profit in the context of an employee/employer relationship or self-employment
- worked without pay for one hour or more in work that contributed directly to a farm, business, or professional practice operation owned or operated by a relative
- had a job but were not at work due to: their own illness or injury, personal or family responsibilities, bad weather or mechanical breakdown, direct involvement in an industrial dispute, or leave or holiday." (Statistics New Zealand, 2013a)

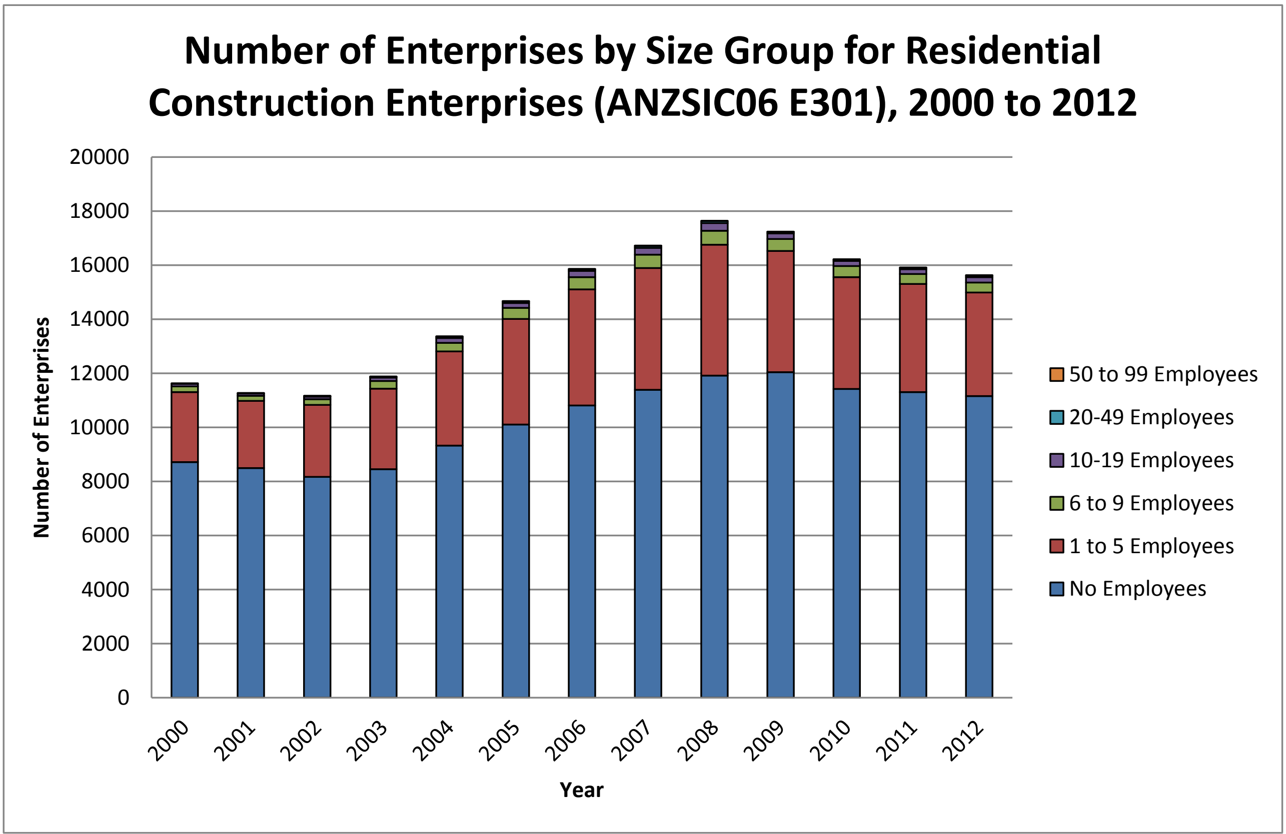

Figure 3: The number of construction enterprises has fallen since the year ending February 2008, roughly correlating with the economic downturn.

It appears that there is a trend emerging of businesses becoming bigger – between 2000 and 2012, there has been a steady increase in the number of businesses with employees. While the number of sole traders has continued to grow, by percentage, the number of enterprises with employees has grown faster. Between 2000 and 2012, the number of enterprises with 50 or more employees went from none to nine. Enterprises with 20 to 49 employees represented 0.4% of the residential construction sector.

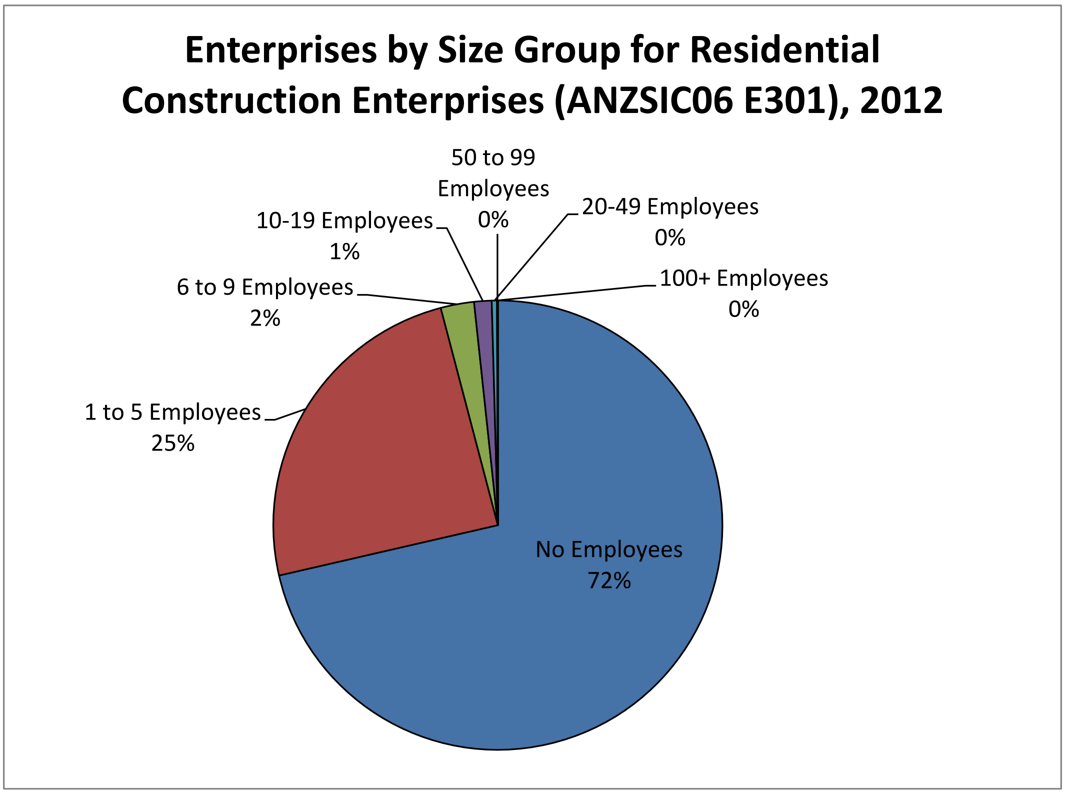

Figure 4: In the year to February 2012, over two-thirds of New Zealand's residential construction industry enterprises were sole trader businesses.

In the same period, the proportion of businesses with 20 or more employees has trended upwards from 1.3% to 1.7% nationwide. Medium businesses with six to 19 employees have also increased in number from 5.5% in the year ending February 2000 to 6.7% in the year ending February 2012.

While New Zealand's construction industry remains dominated by sole traders, the number of companies with employees, has grown slightly between 2000 and 2012.

The following section looks at the number of people working in residential construction in New Zealand.

1.1.1 Employment and positions

This section looks at the number of employees within enterprises of different size groups as opposed to looking at the number of enterprises of a certain size. The statistics for this section, unless noted otherwise, are for the residential construction industry as per ANZSIC 06 group E301. It is important to note that these figures are for enterprises operating as their own business entity, as opposed to geographical units which could include multiple 'shopfronts' under single ownership. The data on residential construction industry employees excludes owner-operators and sole traders. As a correction, the number of enterprises in each business size bracket is added to the number of employees in order to factor in an assumed average of one owner working in each company. The combined figure of employees plus a working owner per enterprise becomes the number of 'positions'. This is used to better reflect the number of people working within a business, regardless of whether they own it or are employees.

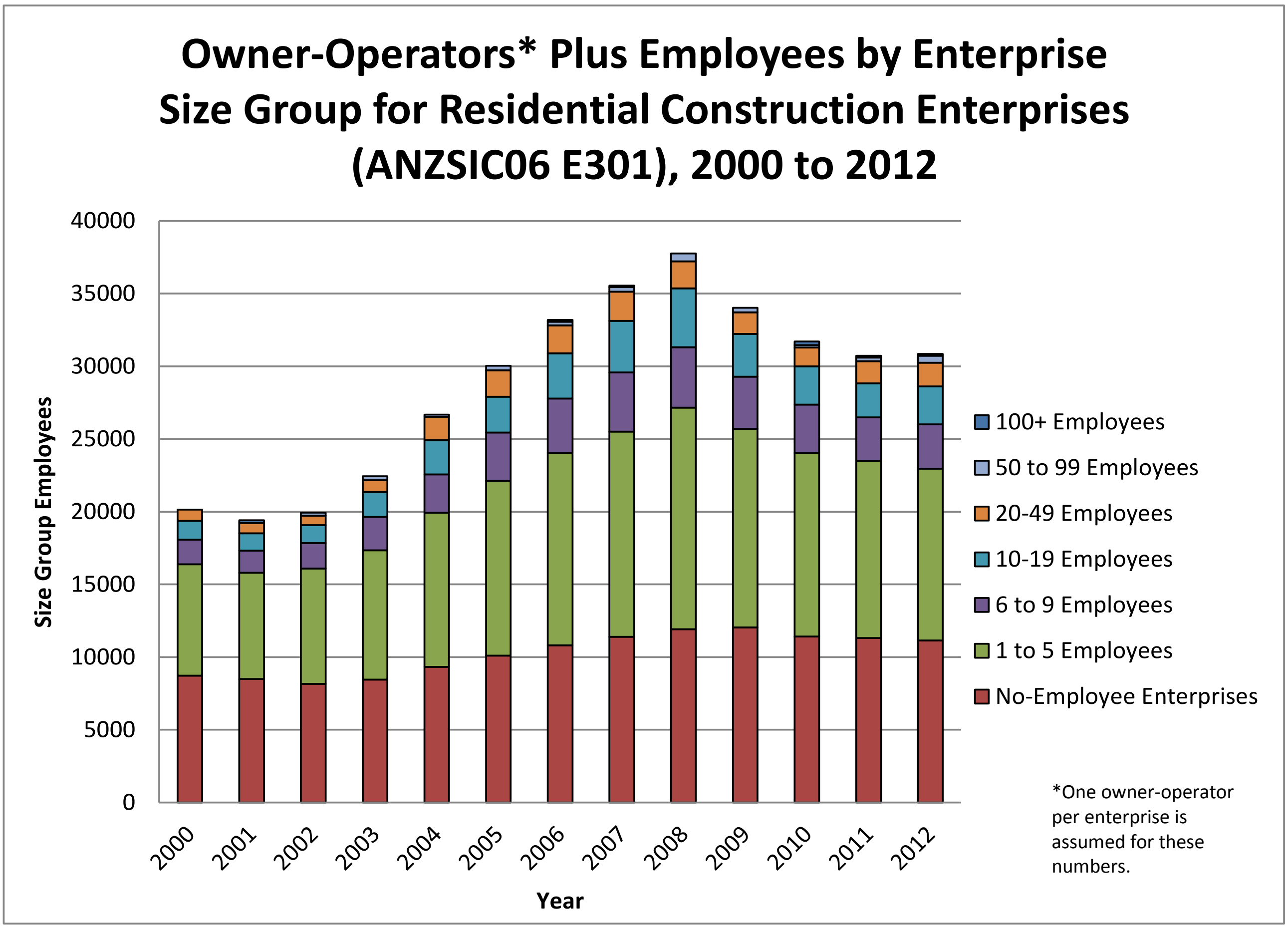

Figure 5: The largest number of residential construction sector positions are in small companies with five or fewer employees.

The distribution of residential construction industry positions across the different business sizes is skewed towards smaller companies, as shown in Figure 3. Nearly three-quarters (74%) of the positions are in small businesses with five or fewer employees (including an owner-operator per enterprise).

The changes in numbers of positions by enterprise size group have had more pronounced change than number of enterprises themselves (as shown in Figure 3), both on the upswing and downswing. This demonstrates a reactive pattern where extra workers are brought in under heavy workload pressure and then let go when the workload begins to dry up.

The most pronounced and sustained change to the employment in enterprise size groups has been in the amount of positions in small businesses with one to five employees, as shown in Figure 6. The number of positions in these firms rose quickly to peak in 2008 before falling quite rapidly until 2010, where they declined at a slightly lesser rate until 2012.

The amount of employment in residential construction firms with over 100 employees remains very small, and in some years, no individual firms reported having over 100 employees.

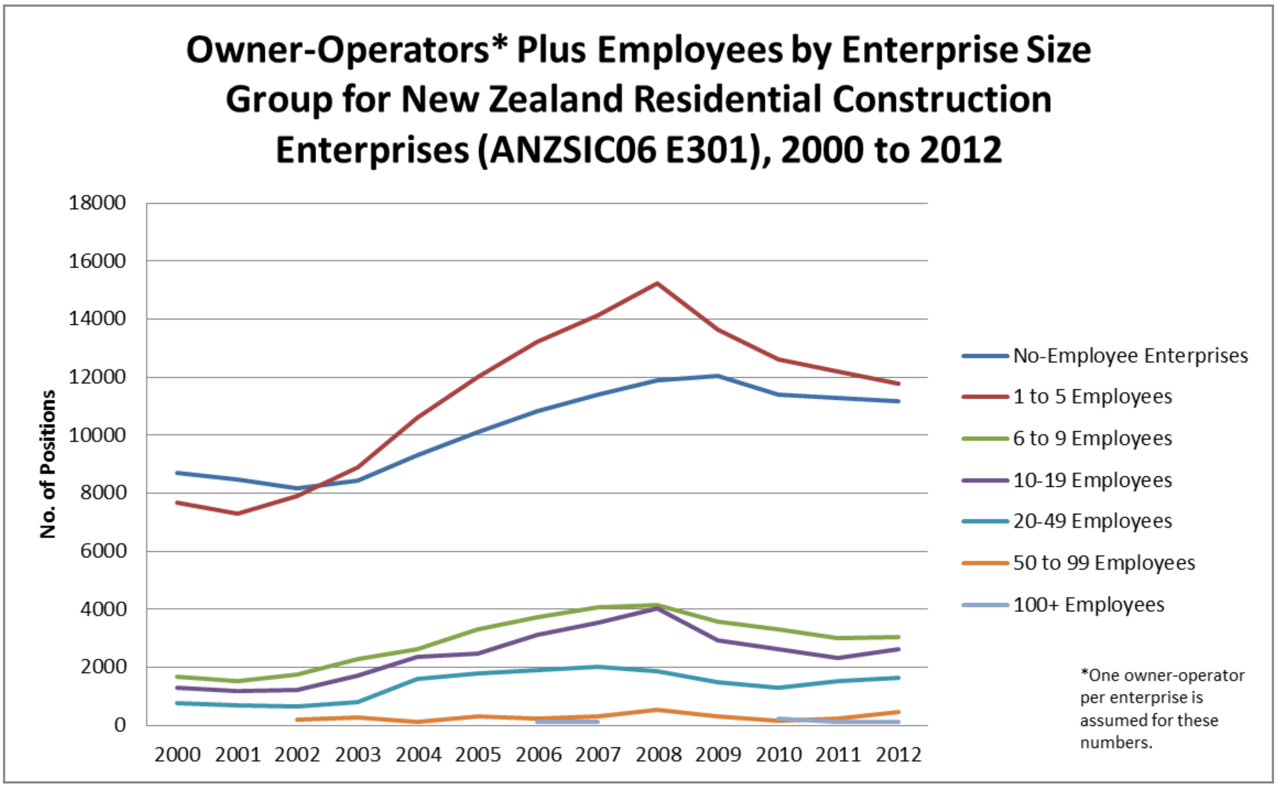

Figure 6: The change in employment by enterprise size group for residential construction enterprises.

As shown in Figure 5, well over a third (38%) of all residential construction industry positions were in small enterprises with one to five employees in 2012. Sole traders made up another third (36%) of positions, with over a third of workers in the residential construction industry working for themselves without employees. Enterprises with over 100 employees employed a very small percentage of the total number of positions, at 0.4%.

The 'closure rate' of construction companies is higher than the average over all industries (Page and Fung, 2011). The Statistics New Zealand Demographics Survey showed that the death rate of firms ranged from around 10% to just under 16% from 2000 to 2010, with deaths increasing after the Global Financial Crisis (GFC) began to affect the industry in 2008. As the number of one-person companies increased over the same period, Page and Fung suggest that some of the employees of dissolved firms may be going into business for themselves.

By far the majority of New Zealand's residential construction companies are very small, with nearly one in four positions in firms with fewer than five employees. There are very few large companies and a very large proportion of small companies. The implication of this is a fragmented industry with low negotiating power when it comes to bulk procurement. This could be a sign of a market sector which caters for niche opportunities – e.g. renovation specialists, and suggests that there are economic gains to be made.

1.1.2 Position turnover

New Zealand's construction industry has a high churn rate of both businesses and staff (Ministry of Business, Innovation and Employment, 2013a). The boom and bust nature of the industry leads to rapid job creation as the market booms and then rapid job dissolution as the boom dissipates into a bust cycle. During the boom between about 2004 and 2007, the construction industry's churn rate was closely aligned to the churn rate in all industries, as shown in Figure 7.

Rapid churn, like that seen in Figure 7 for 2009 and 2010, also leads to loss of skills in the industry as experienced workers change positions or move into other sectors to secure employment.

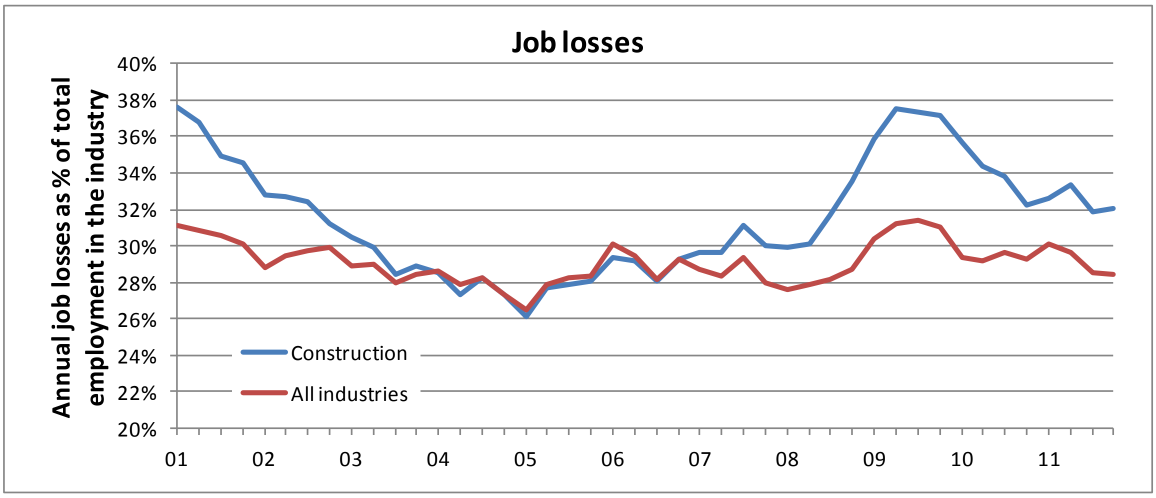

Figure 7: Turnover of staff in the New Zealand construction industry is very high (Page, 2013b).

The boom and bust cycles is a considerable cost to the industry, but also inhibits upskilling. When work is plentiful, there is little time to upskill workers. When work is short, there is less money to invest in upskilling workers. The churn rate acts as a further disincentive, as employers are unlikely to invest in educating short-term workers.

1.1.3 Activity of the new-build residential construction industry

The impacts of the GFC on confidence and financing within the new-build residential construction industry were evident in a noticeable and prolonged reduction in new dwelling consents being issued from mid-2007, as shown in Figure 8.

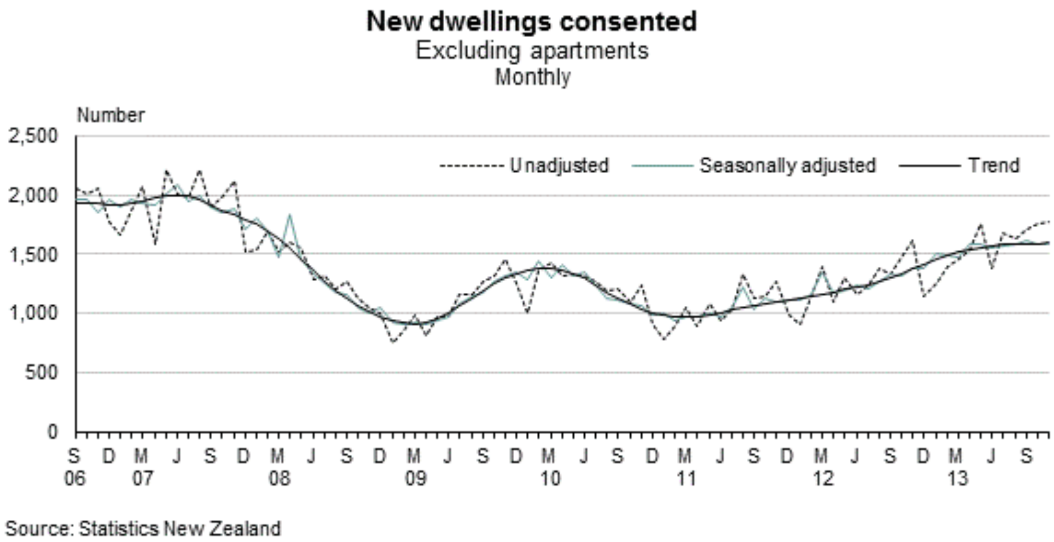

Figure 8: New dwelling consents issued between September 2006 and September 2013 (Statistics New Zealand, 2014).

The number of new dwelling consents has doubled since the low in March 2011, and 58% of the consents were attributable to Auckland and Canterbury (Statistics New Zealand, 2014a).

The new-build activity by different sizes of business is examined in the rest of this section. Business size is based on the number of consents issues to the company between 2006 and 2011, as opposed to number of employees as in section 1.1.1.

This analysis is based on building consent data from building consent authorities and collected by Whats On. For simplicity, this section assumes that each of the dwellings consented with a name attached (e.g. all of the consents in the refined database) were built. In reality, around 20% of consented dwellings are not built for a variety of reasons (Department of Building and Housing, 2011).

Between 2006 and 2011, three-quarters of all named builders built five houses or fewer, as shown in

Figure 9. Approximately 66% of those were recorded for a single new dwelling. This suggests that the named builder may be either the client or the designer in cases where a builder has not yet been contracted for the project. Other consents do not have a builder name associated with them.

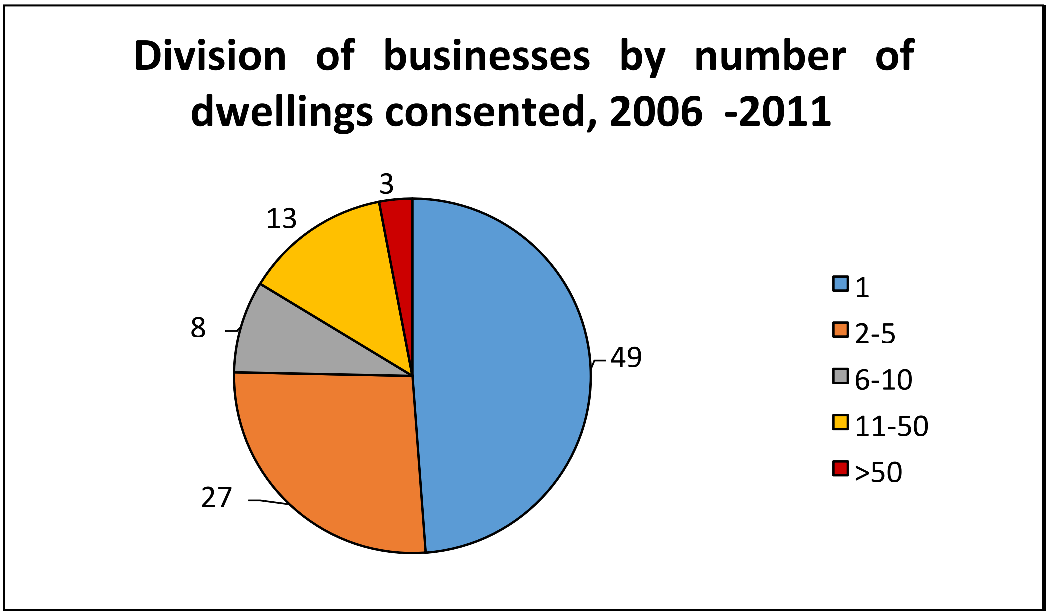

Figure 9: More than three-quarters of businesses built five or fewer dwellings between 2006 and 2011.

Page and Fung's analysis found that 85% of the 'one house per year' builder grouping for the period from June 2009 to May 2010 had the same name recorded for both owner and builder (Page and Fung, 2011). This may occur when a builder has not yet been commissioned for the build upon application for building consent or if the build is speculative and the builder is indeed the owner. Page and Fung estimate speculative builds to represent around 12% of the duplicate owner and builder name applications. Therefore, it is essential to remember in this section that, in most cases, builders had not yet been commissioned when the house plans were submitted for consent. Consents without builder names were excluded for the purpose of this analysis.

Only 3% of builders were named on 50 or more new dwelling consents between 2006 and 2011 – an average of 10 or more per year. As a home is expected to take around 18 weeks to build (Page, 2012), a builder could theoretically construct up to three dwellings per year.

The most floor area of new dwellings from 2006 to 2011 was built by parties named once on new dwelling consent documentation for a single house during this period (55%), as shown in Figure 10. Nearly a quarter of consents were submitted by parties with two to five dwelling consents between 2006 and 2011. In total, 79% of the new-build residential floor area was added to the building stock by parties averaging five or fewer new dwelling consents between 2006 and 2011.

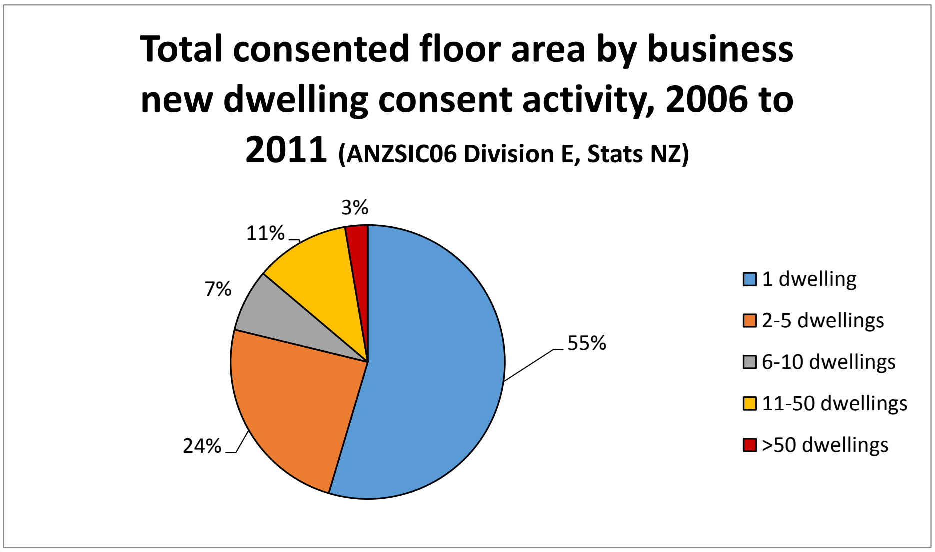

Figure 10: The majority of new residential dwelling floor area was built by companies who built one dwelling between 2006 and 2011.

The trend of so many consents being lodged without a builder to name on the initial consent application is concerning for several reasons. One is that, in most cases, builders are unlikely to have had input into the design, let alone costed the build, as is encouraged by the traditional tendering process. This could be problematic should the design cost more to build than the client and designer initially expect.

A second concern is that there is no project team until the construction phase, which may cause difficulties if certain design features challenge the build and its budget, for example, an unforeseen need for special engineering on a design feature. In addition, a lack of builder involvement early on removes an opportunity to include their expertise in the design process and enhance overall buildability (Wong et al., 2004). A builder may be able to suggest alternative solutions that can save time and cost for the client based on their experiences and provide valuable feedback and ideas for designers.

Thirdly, this is likely to be a reflection of the current tendering process. This process reinforces fragmentation within the residential construction sector, which can lead to adversarial relationships between different parts of the supply chain (New Zealand Productivity Commission, 2012). This often results in the build going to the lowest tendering party, as opposed to the party offering the best overall package, and may have an impact on both cost and quality. Good management is required to prevent inefficiencies, time delays and rework, all of which cost time and reduce the quality of the output. However, many of issues can be addressed with more collaboration and partnerships, which may have additional benefits, such as pooled procurement practices (Taylor et al., 2002) and information sharing (Fairweather et al., 2009).

1.1.4 Cost, value and profit

The highest average new dwelling consent values were for parties with one dwelling consent between 2006 and 2011, as shown in Figure 11. The lowest average new dwelling consent values were for parties with 11 to 50 dwellings consents in the same time period.

In terms of floor area, parties with a single consent allocated between 2006 and 2011 had the largest floor area. There are several reasons this could be. Firstly, many consents had the owner's name as the builder due to the actual builder not having been selected at the time of consent submission.

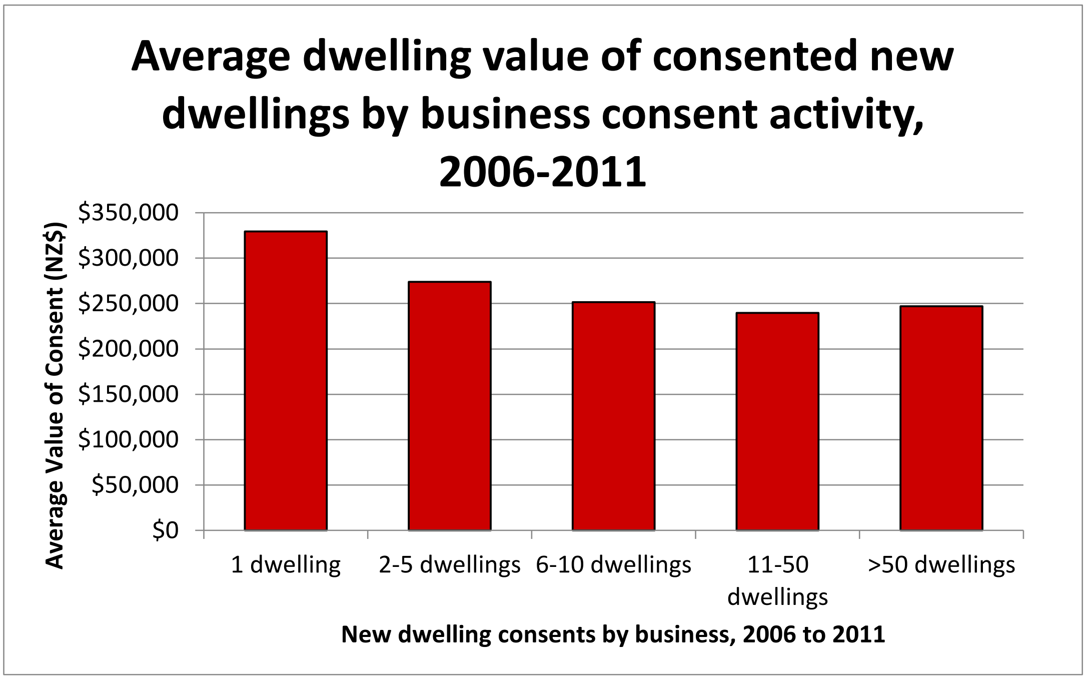

Figure 11: The highest average new dwelling consent value was for businesses that built one dwelling between 2006 and 2011.

Secondly, due to the client and builder name match, many of these homes will be bespoke homes designed by a design practice as opposed to design and build through a group builder. This may suggest higher building budgets, which may entail higher floor areas.

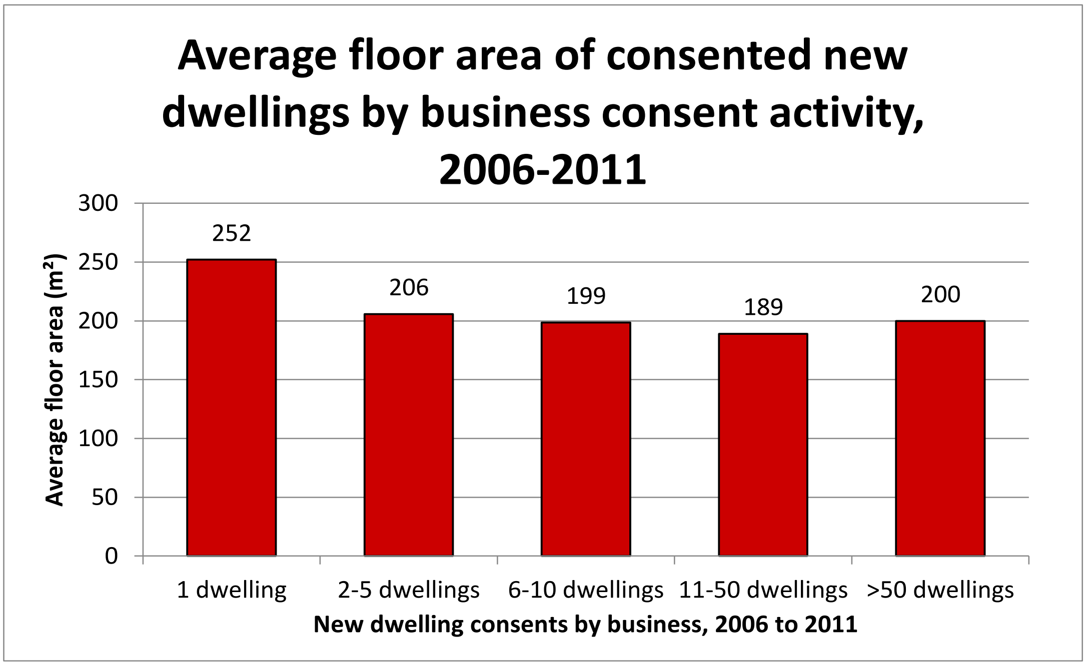

Figure 12: The average floor area of dwellings was largest for companies that built a single dwelling between 2006 and 2011.

Parties consenting between 11 and 50 dwellings between 2006 and 2011 had the smallest average consented floor area per dwelling at just under 190m², as seen in

Figure 12. For parties consenting two to five dwellings over this period, the floor area was the second to highest at 206m². However, the average cost per square metre was higher than for any of the other segments, as shown in Figure 13.

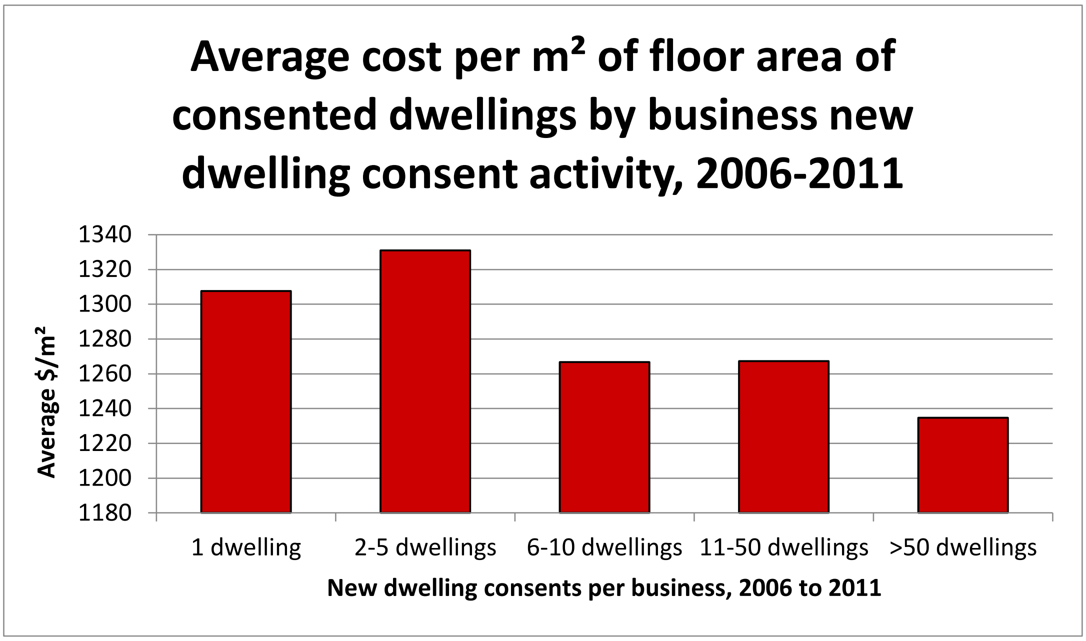

Figure 13: The highest cost per square metre of floor area belonged to dwellings built by businesses that built two to five dwellings between 2006 and 2011.

The cost per square metre that is nominated on the consent is of questionable reliability – some builders place the same cost per square metre on all of their builds (Page, 2013b). In the case of speculative builds, the builder may exclude profit margins due to being unsure what the house will sell for.

Bearing this in mind, the cost per square metre of floor area was approximately the same for parties that consented six to 10 dwellings and 11 to 50 dwellings between 2006 and 2011. The highest average cost per square metre of floor area of new dwellings belonged to parties that built two to five dwellings between 2006 and 2011, also shown in Figure 13.

The lowest average cost per square metre of floor area belonged to parties that had more than 50 new homes consented between 2006 and 2011. This is likely due to a variety of reasons including:

- higher ability to bulk procure materials
- improved strength in negotiating subcontractor rates due to higher throughput
- higher ratio of productive to administrative time compared to smaller companies
- focus on new housing as a specialty area.

The figures suggest that some economies of scale seem to be present for parties that consented six or more dwellings between 2006 and 2011 – or more than one per year.

Interestingly, the build costs allocated by parties with one new dwelling consent issued between 2006 and 2011 were not the most expensive in terms of cost per square metre of floor area. This is counterintuitive to the rationale that routine house construction improves efficiency and reduces cost. As many of these are likely to be clients seeking builders (possibly going through a tendering process) or speculative builds with profit margins excluded, these figures may well be underestimated. Either way, the nominated cost figures should be regarded with caution.

Parties that submitted consents for two to five dwellings over the 5-year period averaged a higher cost per square metre of floor area. It is likely that, in this category, the builders are more likely to actually be builders, either speculative or employed (few bespoke housing clients are likely to build multiple houses during a 5-year period). In this case, it is likely that the builder will have a better idea of the build cost than clients that have not yet commissioned a builder. However, having a better idea of costs does not explain why the average cost per square metre of floor area is higher than the cohorts building more homes. Instead, this may be due to proportionally higher costs associated with administration, regulatory and planning requirements relative to the increase in productivity.

In addition, a small company size is likely to be at a disadvantage compared to larger companies in terms of bulk procurement or strategic alliances with partner firms.

As companies shift from sole traders to employers, there is more paperwork (for example, tax requirements) and higher health and safety obligations and a need to insure workers for indemnity. In essence, more income is needed to cover expenses, which may be problematic during a downturn in workload. However, it is unclear when the higher administration burden and employee-related costs becomes lower in proportion to turnover to the equivalent expenses for sole traders.

This would have the effect of increasing the cost to build and thereby increasing the cost to the consumer over sole traders and larger companies in order to maintain the same profit margin. However, the average profit margins for house construction have been shown to decrease the larger the firm becomes, as shown in Figure 14.

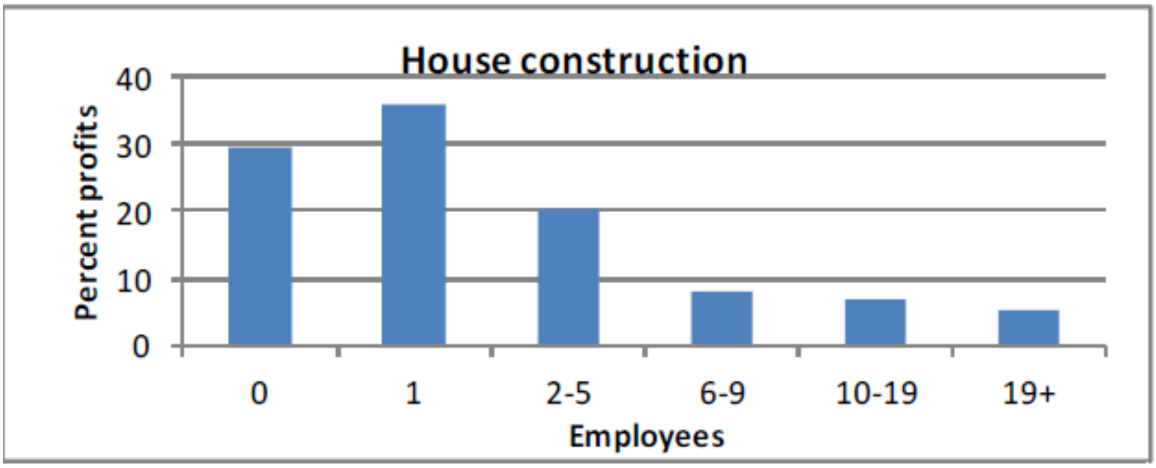

Figure 14: In general, the more employees, the lower the profit margin of house builders (Page and Curtis, 2013).

As shown in Figure 14, the highest percentages of profit are within small companies, while the smallest percentages of profit lie in medium to large companies. This can be attributed to higher overheads of larger companies, which are distributed amongst higher turnover.

This decrease in profit margin for larger companies suggests that the consistency of the workflow may be key – where workload and income is consistent, there is less need to reserve cash for use to 'tide over' during downturns in work. Thus, non-payment from clients is not as critical, as other income is also available, and they are less vulnerable than their smaller peers in terms of cash flow. Conversely, or perhaps additionally, lower profit margins may be required to remain competitive in the marketplace despite higher administrative cost burdens.

1.1.5 Diversity of work

Page and Curtis's survey of New Zealand construction companies showed that 15% of small firms with five or fewer people specialised in new housing while 20% of firms with more than five people did so, as shown in Figure 15.

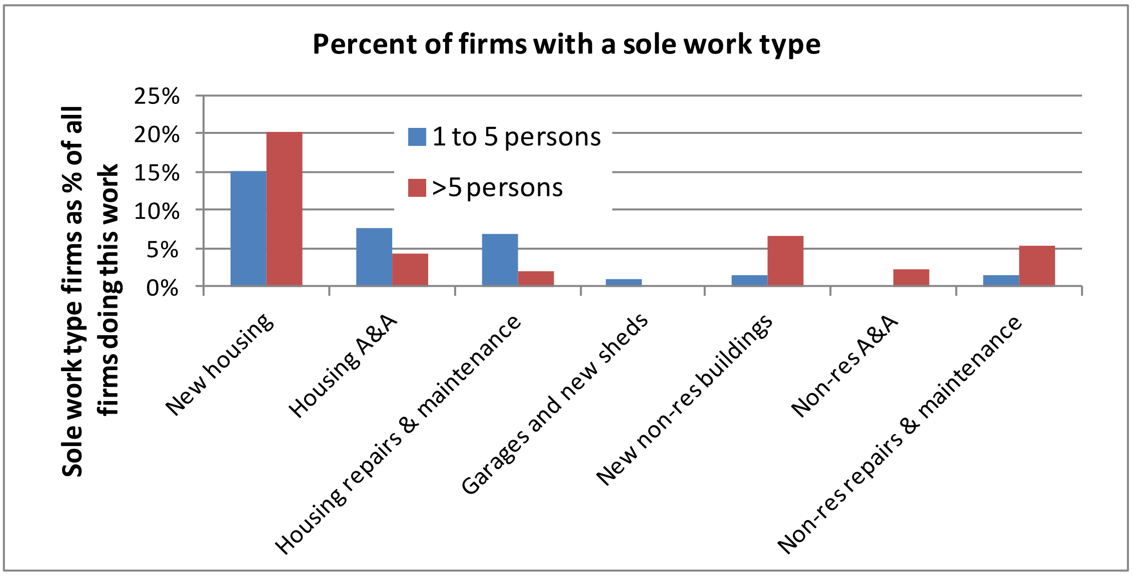

Figure 15: Few New Zealand construction firms specialise solely in new home building (Page and Curtis, 2013).

The low production rate of new dwellings by builder may be a protective measure for periods where fewer new houses are being built – alternative lines of work can be pursued to keep the company viable over the long term. The dominant residential construction business type produces few houses yet appears to remain competitive in the new build market.

A lack of specialisation in new houses, paired with a low build rate, has negative implications for innovation, evolution and scales of economy in new dwelling construction. There is little incentive to invest capital and training in new or innovative production processes for so few new builds.

1.1.6 Operations

Small companies (with five employees or fewer) are more often than not a sole trader or owner-operator with a single employee. Small companies contract in other labour as required and, by not having a company premises, keep overheads down. Homes built by small builders tended to cost a little more than medium companies but less than large companies in terms of cost per m² of floor area. This may be due to building more bespoke housing than the medium-sized companies and possibly to a higher level of finish on average. Small companies have flexibility that larger businesses do not due to a simple business structure with few decision makers (Köster, 2013).

Constant workload provides constant income for owner-operators and any staff they may have. Transitioning to offsite construction enables jobs to be completed faster than they would onsite, therefore the number of projects per year can be increased, in turn leading to higher turnover. However, if additional jobs are not secured, lower turnover and periods without cash flow could lead to financial difficulty without forward planning for such events. Needless to say, this is also true in boom and bust cycles under the current regime. However, smaller overall profits from shorter jobs that are few and far between could be a concern for small businesses.

Medium-sized companies (six to 50 employees) have improved purchasing power over small companies and are able to spread overheads over more jobs. Preferred supplier arrangements may result in lower rates for trades due to regular jobs and therefore cash flow to the tradespeople.

Larger companies (over 50 employees) are typically not as agile as small companies when it comes to change and adaptation due to the need for agreement from multiple stakeholders, often at multiple levels where parent companies are involved. Large companies are more likely to have full-time employees and may employ their own tradespeople. The scale of these operations paired with their market presence maximises the potential to implement preferred supplier agreements and bulk purchasing arrangements.

1.1.7 Productivity and output

Productivity is commonly described as the ratio between the value or volume of inputs (capital, labour and material) compared to the value or volume of output(s). New Zealand's construction industry has been criticised for low levels of productivity compared to other industries (New Zealand Productivity Commission, 2012).

Multi-factor productivity (MFP) is "a measure of technological, managerial and regulatory impacts, i.e. after accounting for labour and capital inputs it measures the effect of other factors that can influence performance of the economy or an industry" (Page, 2013b).

The MFP of the New Zealand construction sector remained relatively stagnant between 1978 and 2010, whilst the MFP of the agricultural sector rose as innovative technology improved the output of the sector per worker, as shown in Figure 16.

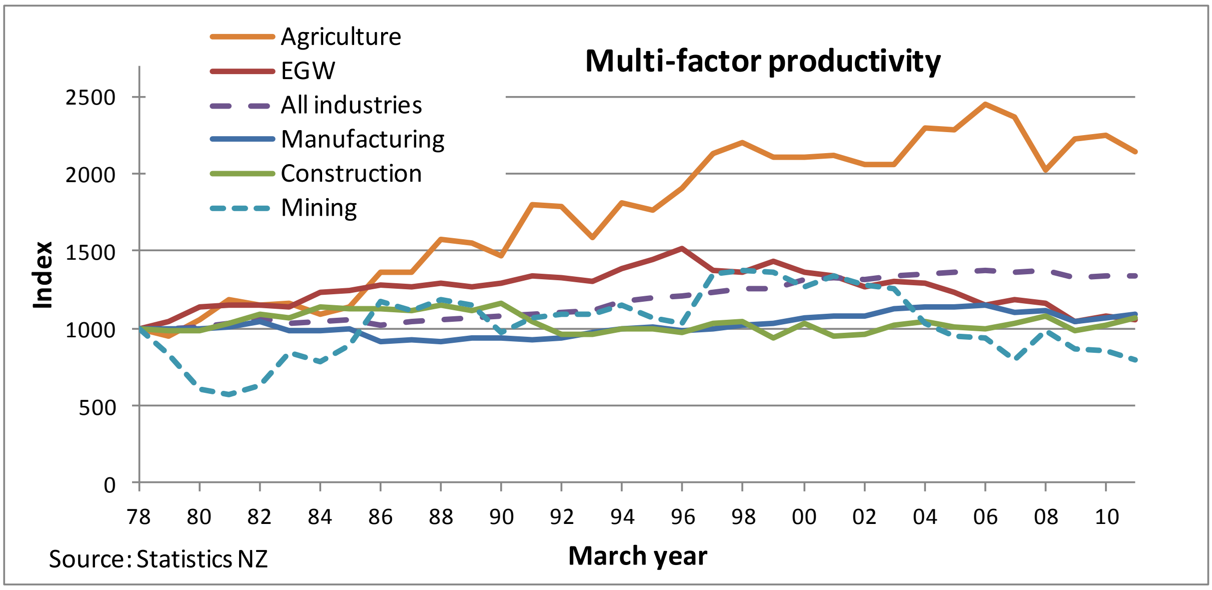

Figure 16: The multi-factor productivity of the construction sector has fallen since 2006 (Page, 2013b).

Productivity measures are a particularly blunt instrument when it comes to assessing the amount of work done per worker. Productivity measures focus on tasks that directly add value. Tasks that are necessary but do not directly add value, such as applying for necessary consents and doing other paperwork associated with running a business, are considered 'unproductive'. Thus, if the required administrative work increases, the output per worker is likely to decrease.

It is interesting to note in Figure 17 that the 'inefficient' use of capital is bringing the level of MFP down, despite the labour component remaining roughly steady. This shows that capital investment by the sector is not achieving sufficient gains in labour productivity to lead to improved MFP – in fact, it has fallen since around 1987.

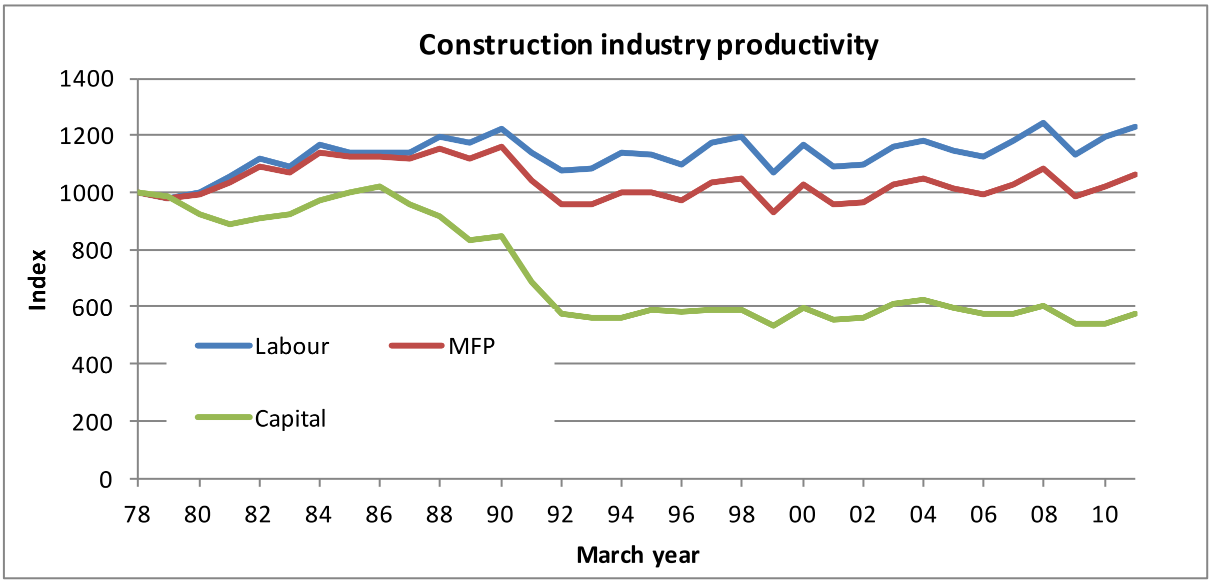

Figure 17: The inefficient use of capital in the construction sector brings down multi-factor productivity (Page, 2013b).

The value added per worker in house construction was just over $60,000 in 2010, rising very slightly in 2011 (Page, 2013b). In 2010, house construction had taxable profits on sales of around 10%, which fell a little in 2011 to around 9%.

The quality of construction outputs has been criticised both in regards to the life expectancy and maintenance requirements of materials used and the build quality (New Zealand Productivity Commission, 2012). The amount of rework being done to rectify issues with outputs has been signalled as a major concern for the industry and a critical area for improvement. Any piece of rework that has to be done comes off the profit of a project – rework is, by definition, the repeat of work already done that would not have needed to be done again if it had been done correctly in the beginning. In 2011, a survey of new house owners found that 68% had to call their builder back to fix defects present at handover (Page, 2013b). Although the majority of this re-work is paint defects and other minor issues, builders see these defects as having less potential for cost savings than in areas of designer and client-instigated redesign and rework.

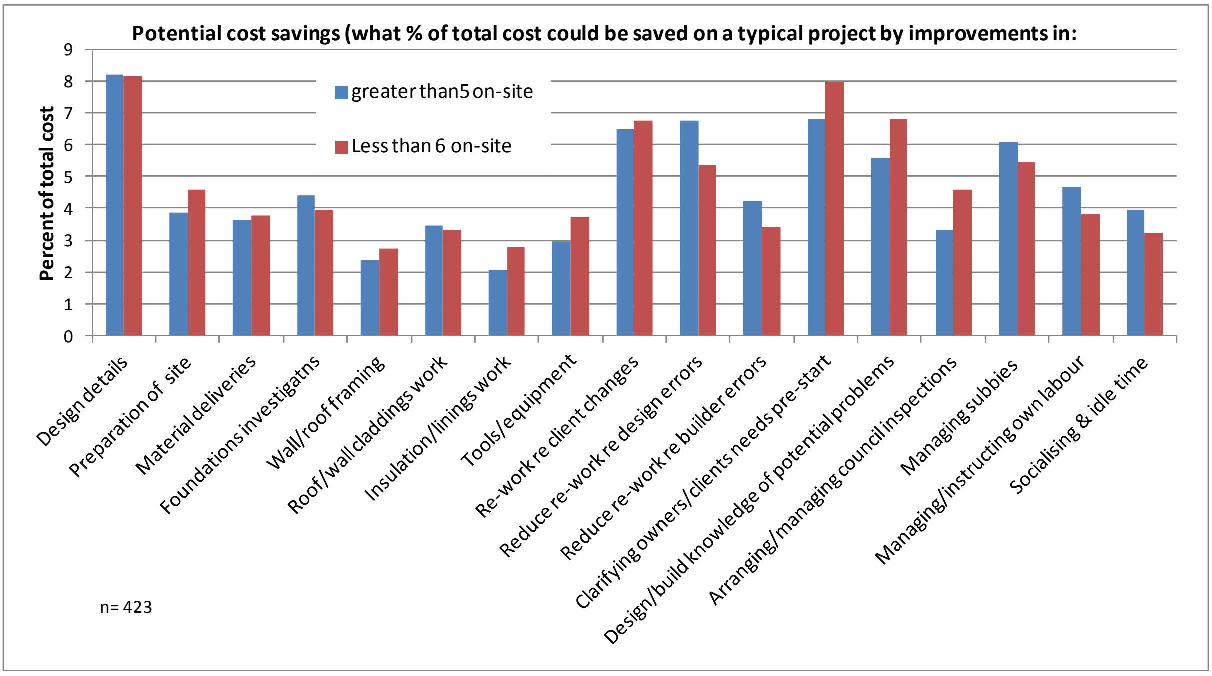

Figure 18: Potential cost savings from project improvements as estimated by building professionals (Page and Curtis, 2013).

A survey in mid-2012 showed that many builders were of the opinion that time could be saved with improvements in a wide variety of areas (Page and Curtis, 2013), as shown in Figure 18. The responses were quite different for most areas for small businesses (five or fewer staff onsite) and larger businesses (six or more staff onsite).

Both small and larger builders perceived that getting the design details right could save 8% of the total cost of a project. Having clients well informed was believed to have potential cost savings of 8% of the total project cost for small companies or under 7% for larger companies. Larger companies saw design/build knowledge of potential problems as having more potential for savings at nearly 7%, as compared to small builders at around 5.5%.

Design, detailing and clarifying client needs before the start of the project were seen as the areas with the most potential for project cost savings rather than defect-related rework. The potential total project savings for reducing rework due to builder errors was around 3% for larger builders or 4% for smaller builders. Rework due to design errors was estimated as having higher potential for cost savings at nearly 7% for larger companies and just over 5% for smaller builders.

1.1.8 Innovation and research

Innovation is a constant within the building industry – innovation is necessary as the business world and markets shift and change. Statistics New Zealand (2012) defines innovation as:

> "the development or introduction of any new or significantly improved activity for a business. This includes activity to improve products, processes, and methods that a business was the first to develop and those that have been adopted from other organisations."

The rate of innovation by New Zealand industry in 2009 and 2011 is in Figure 19.

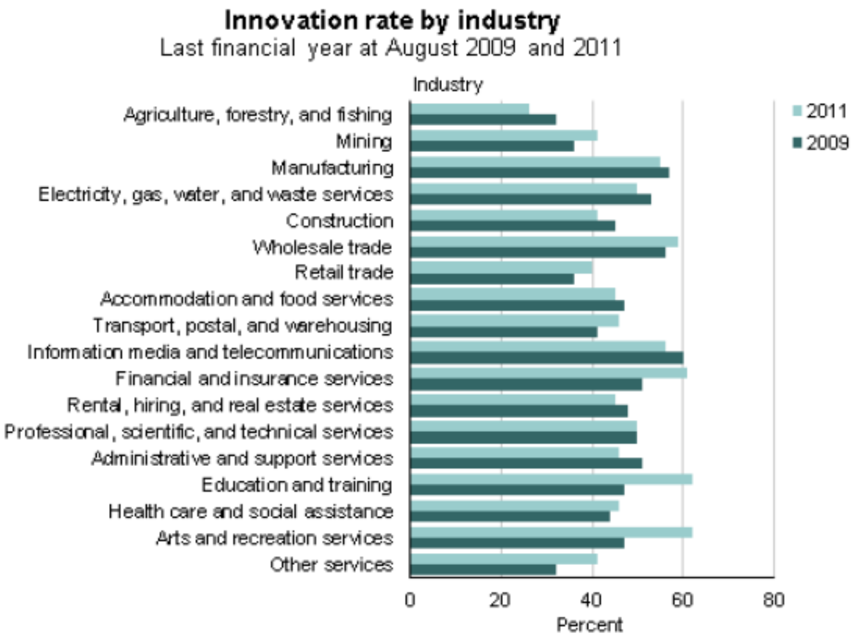

Figure 19: The rate of innovation by industry in New Zealand in 2009 and 2011 (Statistics New Zealand, 2012).

The percentage of New Zealand construction companies in the survey that undertook innovation in the prior financial year fell from around 45% in 2009 to around 41% in 2011, according to the results of the Statistics New Zealand Business Innovation Survey. This rate is similar to many other industries.

The biggest reason given for innovating was to increase revenue, at around 90% in both surveys, as shown in Figure 20. Other reasons included increasing productivity, responsiveness to customers or increasing market share. Under 30% of businesses undertook innovation activities to reduce environmental impact, and under a quarter innovated to reduce energy consumption. The amount of innovation in both of these areas fell between 2009 and 2011, potentially reflecting the economic downturn increasing the level of importance placed on short-term financial priorities over long-term environmental goals. The number innovating to replace goods or services being phased out remained steady over both years at just over 20%.

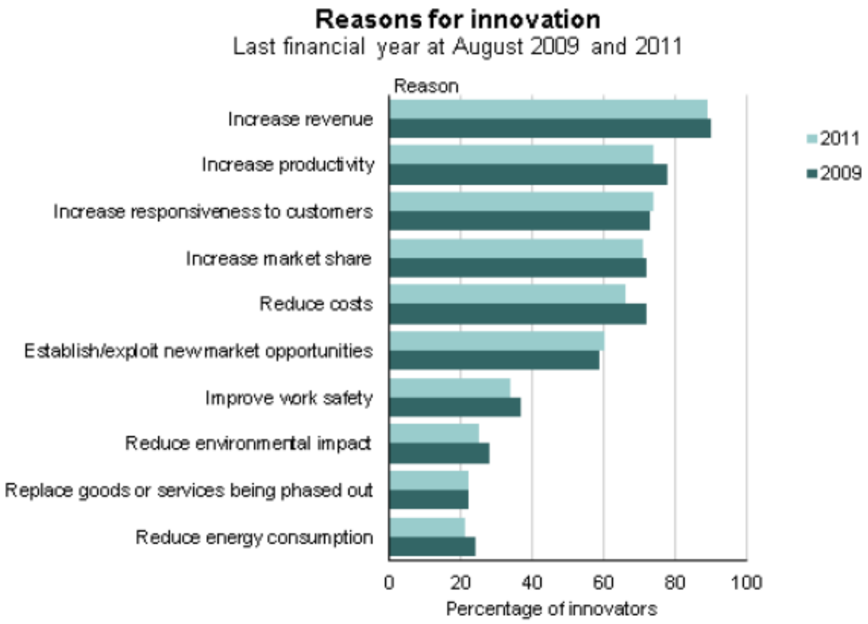

Figure 20: The reasons for innovating by New Zealand companies in 2009 and 2011 (Statistics New Zealand, 2012).

In terms of types of innovation, Page (2013b) showed that the majority of innovation happening in the construction industry between 2005 and 2011 was around management practices. In terms of growth, innovation in the area of services changed the most, increasing from around 12% in 2005 to around 21% in 2011, as shown in Figure 21.

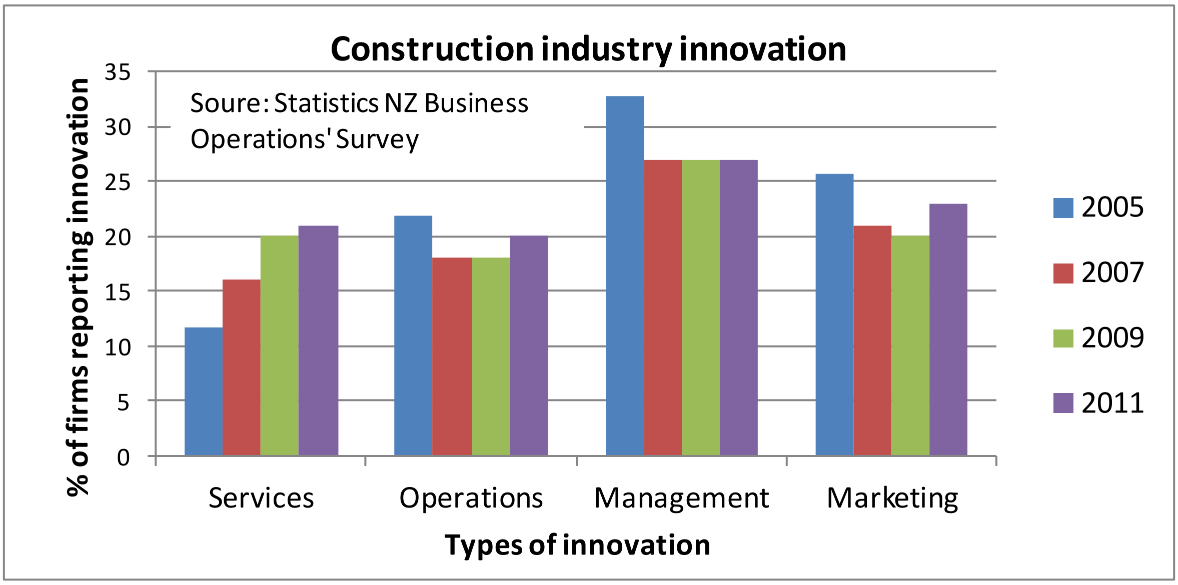

Figure 21: The highest amount of innovation occured at management level of New Zealand's construction firms between 2005 and 2011 according to Statistics New Zealand's Business Operations Survey (Page, 2013b).

The degree of innovation identified in these surveys is uncertain. What the respondent understands by 'new' or 'substantially improved' activities is subjective – it is based on the respondent's own viewpoint and experiences. What one person sees as an incremental change another may see as a breakthrough.

The rate of innovation in the New Zealand construction sector is low relative to other industries and other countries (New Zealand Productivity Commission, 2012). This is symptomatic of risk adversity, small firms and low investment in research and development by the construction sector.

Few firms in the construction sector are likely to have sufficient funds or incentive to run individual R&D programmes as is the case overseas (Blayse and Manley, 2004). However, internationally, there has been a move towards collaborative R&D programmes, often involving researchers and the industry pairing up (Michael O'Brien, 2000). Others involve partnerships between the house manufacturers and the materials manufacturers (Zunhammer, 2013).

Small architecture firms may develop their own details with engineering partners. However, these still cost each time they are used due to the engineering firm having to ‘rubber stamp’ each consent submission, including each detail that falls outside of Acceptable Solutions or affiliated standards. As a result, small firms generally rely on public good research and predominantly use standard details that are readily accepted by BCAs. In other words, they tend to follow the prescriptive route to gain compliance through Acceptable Solutions rather than lead with innovation and Alternative Solutions.

1.1.9 Areas with most potential for improvement

As found in the BRANZ study (Buckett, 2013), the most potential for improvement in residential construction lies not just in the products that are used but also in the way houses are built. A fundamental shift in the ways that homes are built is required to increase production, reduce waste, improve productivity, and reduce the labour cost per home.

At approximately half the cost of an average build, materials are a significant cost in New Zealand construction. When the cost of land is excluded, the cost of labour makes up approximately a third of the cost of a build, as shown in Figure 22.

When land is included, the cost of materials constitutes around 18-19% of the cost of an average house (Page, 2008).

Considering upwards of 80% of the cost of an average house build is in materials and labour, clever procurement combined with the efficient use of both materials and labour are particularly critical with regard to keeping the cost of builds down.

Profit is slightly higher in the 145 m² home example at 10% of the build cost, while for the 195 m² home example, this was 9%, as shown in Figure 22. This may reflect builders expecting to make a certain amount out of each build as opposed to a certain percentage. There is no information available as to how much profit is reinvested into businesses to expand and/or upgrade plant and/or equipment.

The cost of plant is a very small proportion of the build cost, as can be seen in Figure 22. Other overheads, such as legal costs, building consent and Building Levy contribution add up to around 5% of the cost of the build in both examples.

1.2 What are we building?

Alterations to construction methods will only be successful if the alterations utilise materials and create aesthetics that are accepted by the current market. This section explores the typical new-build materials and architecture that are being used in new residential construction in New Zealand.

1.2.1 Size and density

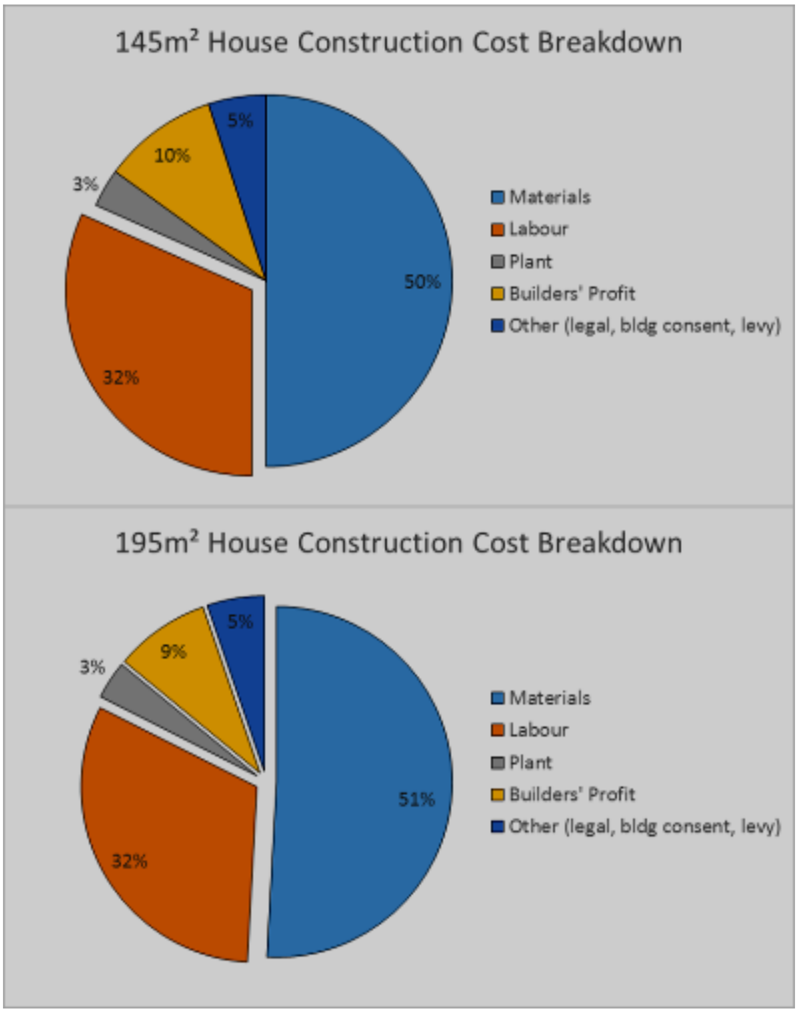

Figure 22: Construction cost breakdown for new homes built in Auckland (Page, 2008).

In 2012, New Zealand's new houses were the third largest in the world in terms of average floor area at 191 m² in June 2012 (Kiernan, 2012), as shown in Figure 23. The floor area of new builds in New Zealand has increased over time. Houses built in the 1940s average 140 m² of floor area (Quotable Value New Zealand, 2011), and this has increased through the decades to average 208 m² in November 2013.[1] This is despite pressures on land, lower occupancy rates and concerns about affordability.

[1] Based on Statistics New Zealand's November 2013 consents data for new dwellings. Pers. Comm. David Norman, BRANZ Ltd, 7/1/2014.

In terms of the types of houses being built, the majority are detached houses, with attached dwellings making up around 17% of all new dwellings in 2011 (Page, 2013c). As shown in , detached dwellings have made up over three-quarters of the housing units built in any one year since 2000.

However, it is expected that, with the Christchurch rebuild, pressures on affordability in Auckland and a preference for higher density over urban sprawl, the amount of medium and high-density housing is forecast to increase in coming years (Page, 2008a).

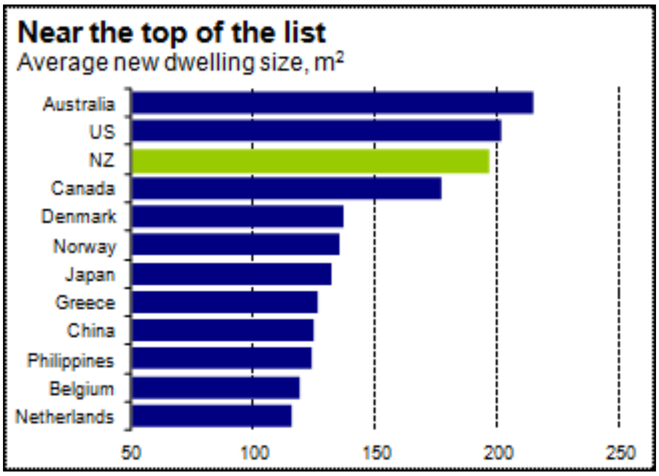

Figure 23: In June 2012, New Zealand's new homes were the third largest in the world in terms of floor area (Kiernan, 2012).

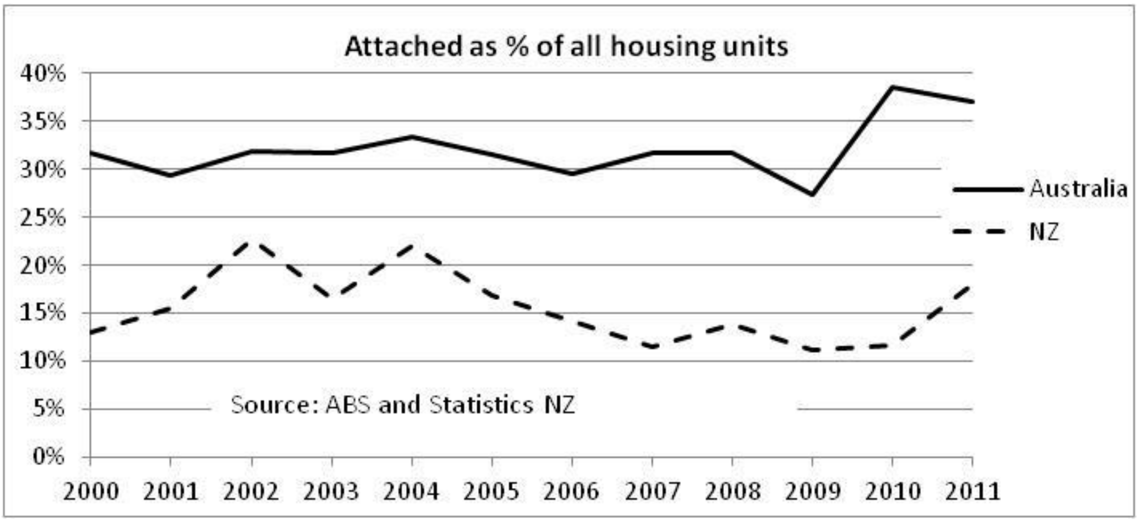

Figure 24 Detached dwellings are the dominant type of new dwellings in New Zealand (Page, 2013c).

1.2.2 Materials

The BRANZ materials survey of 2012 (Page, 2013) found there are a small set of dominant materials and construction types used in New Zealand's new dwellings. This section explores the market shares of these materials between 2002 and 2012.

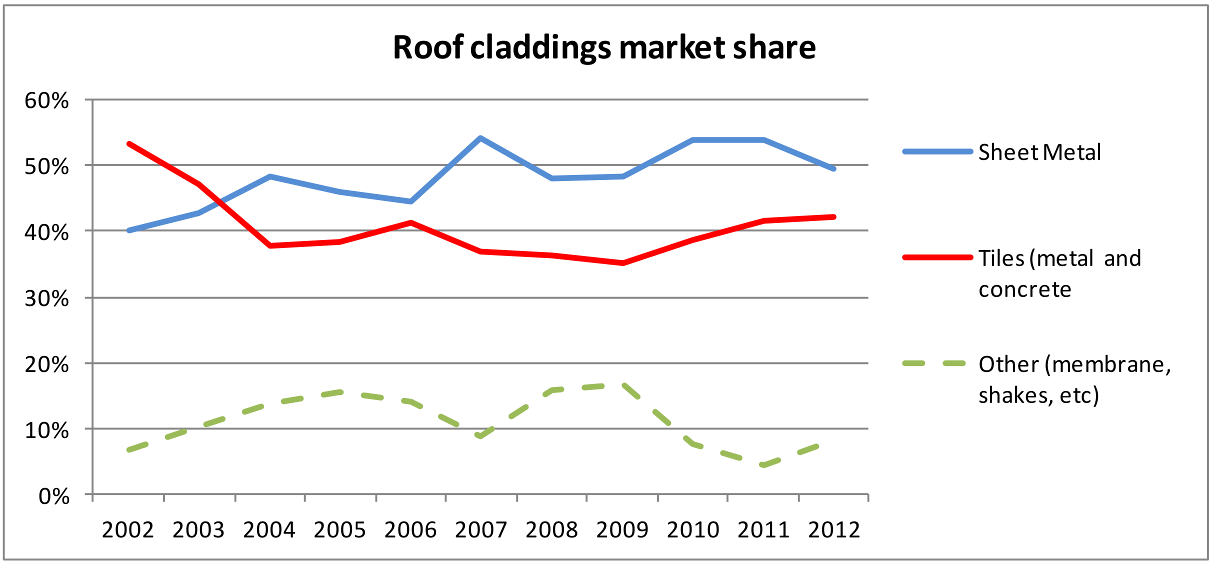

Figure 25: Sheet metal has been the predominant roof cladding type in new housing since 2004 (Page, 2013).

As shown in Figure 25, Page's new-homes surveys (2013a) have shown a variation in the dominance of each of the three roof cladding types recorded since 2002, most likely demonstrating shifts according to fashion. Tiles have fallen in popularity since 2002, from being used on over 50% of new homes to just over 40%. Sheet metal roofing on new homes has increased in popularity from 40% in 2002, to around 50% in 2012. Other roof types, such as membrane roofs, shakes and the like, represent a small proportion of roofs on new homes, fluctuating between around 15% in 2009 to 5% in 2011. Other roof cladding systems are at present a small share of the market, and therefore unlikely to be a candidate for examination in terms of advanced residential construction techniques.

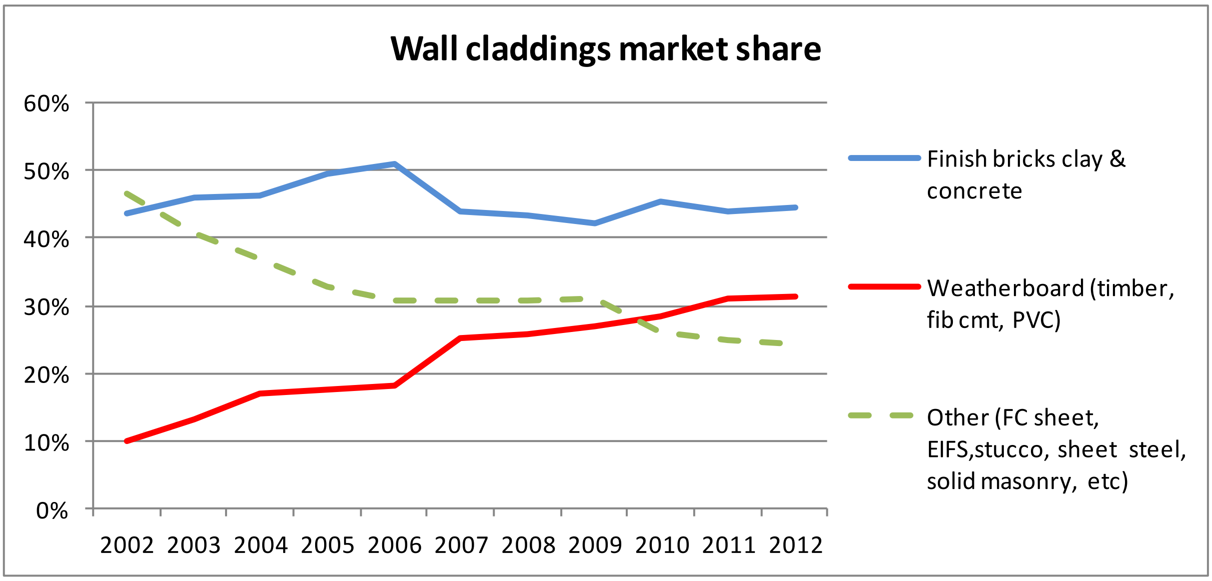

Figure 26: Brick cladding finishes were the most common type in new housing from 2003 to 2012 (Page, 2013).

The most common finish to exterior walls from around 2003 was clay or concrete brick veneer, which took over from 'other' claddings, including monolithic-type, sheet steel and solid masonry finishes, which fell in popularity from over 45% in 2002 to around 25% in 2012. Weatherboard (including timber, fibre-cement and PVC) increased in popularity from 10% of the finishes on new homes in 2002 to over 30% in 2012. As the three types each make up a considerable part of the new home wall cladding market, each finish is worth exploring in terms of advanced residential construction techniques.

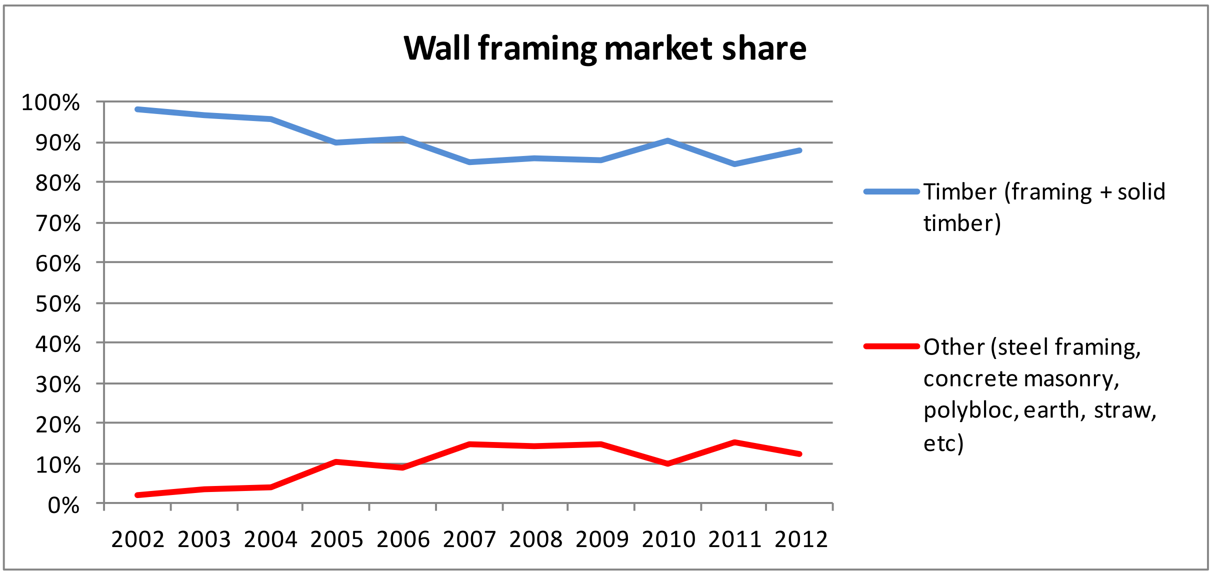

Figure 27: Timber and solid framing remained the most popular wall structure in new houses in 2012 (Page, 2013).

Timber framing was by far the most common choice for new houses from 2002 to 2012, although the proportion of 'other' wall types increased slowly but consistently over this period to just over 10%, as shown in Figure 27. As a result, timber framing currently has the largest potential for exploration of advanced residential construction options.

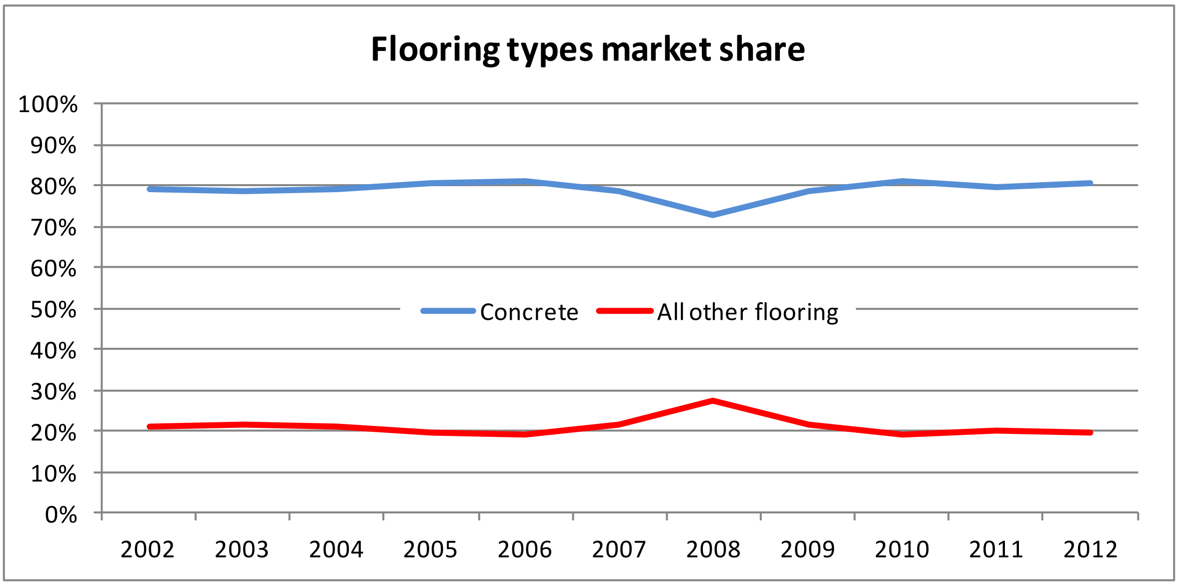

Figure 28: Concrete floors dominate in new housing (Page, 2013).

The predominant flooring type in New Zealand's new homes has consistently been concrete floors, representing around 80% of the floors of new houses from 2002 to 2012, with a small and unexplained decrease to around 72% in 2008. However, this is the main floor type, and many homes, especially on hilly topography, have at least part of the floor as suspended timber. For multiple storeys, the mid-floors are most likely to be timber, and structurally similar to those of ground floor timber suspended floors. As shown in Figure 29, multi-storeyed homes are more prevalent in larger urban centres (Page, 2013) where it is generally more expensive to build. Urban intensification is also likely to increase the number of homes built with multiple storeys and/or on hilly sites, therefore, the examination of the prospects for advanced residential construction timber suspended floor systems is necessary alongside concrete.

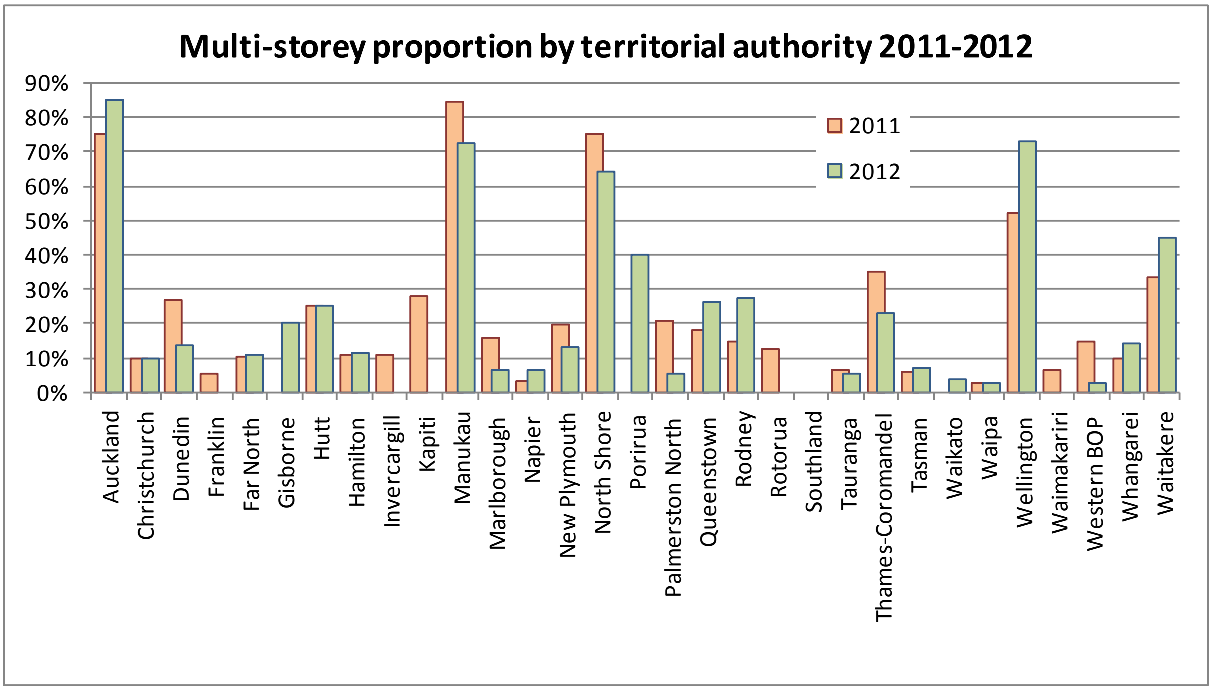

Figure 29: The main urban centres have the highest proportion of new dwellings with multiple storeys (Page, 2013).

The priority for improvements must lie with the most common construction materials and systems at the beginning in order for change to have the most effect with limited time and resources.

The most frequently used construction types include timber-framed construction, weatherboard construction, brick façade cladding, steel sheet and steel tile roofing and concrete flooring. These options are conducive to panellised construction, which is also compatible with the often restricted access of medium-density and urban infill housing, as is being encouraged for Auckland and Christchurch.

This directs the focus of construction towards offsite methods, and is discussed in Part 2 of this work.

1.2.3 Architecture

The current design aesthetic lends itself to panellised prefabrication, with its simple bold shapes, minimalistic detailing and often monopitch roofs. While panellised prefabrication can be used to produce the bulk of most house designs, its optimal use is in relatively rectilinear designs. The timber-framed construction used for many of New Zealand's new homes is ideal for offsite construction in general.

Figure 30: An architecturally designed New Zealand house (Kellands Real Estate Limited, 2014).

Some aesthetics are less suited to offsite construction. These include designs with multitudes of short walls, curved walls or complex rooflines. Traditional trusses must be installed on site or turned into volumetric modules. A hybrid system of panellised walls and onsite built roof could be used in this case. However, the value added offsite would be less, and weather protection of the panels would be a concern. For this reason, countries with high levels of panellised prefabrication design roofs in cassettes, which often has the additional benefit of making attic spaces habitable.

Figure 31: New architecturally designed New Zealand home (Bayleys Real Estate Limited, 2014).

Both panellised and volumetric modular construction can be used for low, medium and high-density construction projects. Both methods allow the contractor to erect multiple dwellings in a short period of time with minimal site traffic, dust, environmental disruption and noise to inconvenience neighbourhoods.

Figure 32: The offsite-built First Light House (First Light Studio, 2014).

Large scales and repetition improve the cost-effectiveness of using offsite construction, and this is particularly true for medium and high-density housing projects. In terms of practicality, panellisation is smaller in dimension and generally lighter than modules, which suits sites where access may be a challenge, for example, rear sites or sites with restricted height access (for example, because of power lines or large trees).

In 2013, 52% of homes in New Zealand were designed by either an architectural designer (30%) or a registered architect (22%) (Sharman, 2014). Another 27% sourced plans from a home building company, many of which will have had architectural input. A tiny number of these homes are built offsite. However, the number is likely to grow as more architects, designers and their clients recognise the potential benefits of utilising offsite construction (Bell, 2010).

There is growing interest in offsite construction and the potential benefits for the architecture and design professions. Traditionally, much of the tertiary education has been based on traditional onsite project design and construction processes. While this is beginning to change, many of the current generation of architects and designers have not been exposed to the offsite construction process – as is the case for many builders and subcontractors. If the maximum benefits and uptake of panellised (or indeed any form of) offsite construction are be realised, enhanced understanding of the design process and uses of prefabrication in architecture is fundamental.

1.2.4 Prefabrication in New Zealand

Offsite construction is not new to New Zealand. Prefabrication of varying degrees has been present in New Zealand since the early European settlers with their kitset cottages (Bell, 2009). However, misperceptions of offsite construction bred from narrow amounts of past experience - particularly with 'temporary' buildings being used well past their planned lifetimes - has tarnished the image of prefabrication. In addition, there is confusion with regard to the meaning of prefabrication. Technically, prefabrication is any value added to materials off the construction site. In reality, much of New Zealand's prefabrication activity refers to components such as prenailed trusses and wall frames.

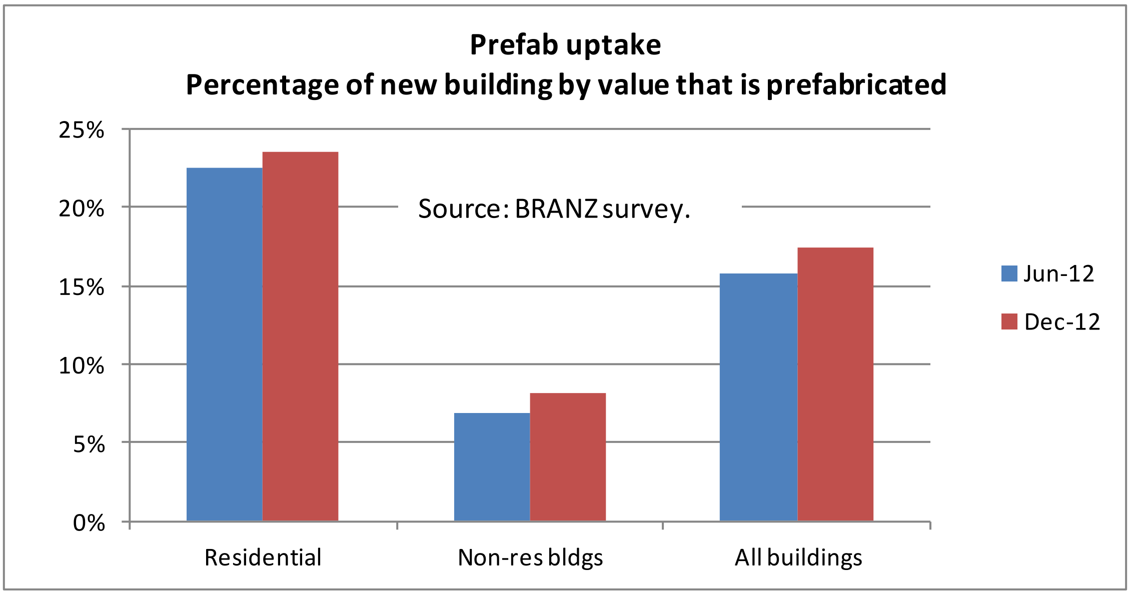

Figure 33: The percentage of new building value of prefabrication in the New Zealand construction industry is highest in residential construction (Page, 2013b).

Over a fifth of the value of residential construction projects was classified as prefabricated by respondents to the BRANZ New Dwelling Survey, as shown in Figure 33. These responses are open to interpretation – the extent of prefabrication could vary from preframed trusses to a clad and lined wall to a transportable home.

At present, there are very few offsite construction companies operating in New Zealand that produce panellised or modular housing (Bell, 2009), and of the few, many are relatively new.[2] Recently a joint venture between Mike Greer Homes and Spanbild in Christchurch has been announced, where the design-and-builder will panelise new homes to help meet demand from the Christchurch market (Robinson, 2014). The more established companies predominantly undertake work on a diverse portfolio of building projects. Companies tend to combine educational, high-rise residential (for example, apartments) and commercial projects with low-density residential construction. Most

[2] Pers. Comm., Sean Wood, Stanley Modular, 11/2/2014.

factories have a low degree of automation and predominantly undertake a variation on traditional construction, using traditional equipment, labour and subcontractors.

Offsite construction companies tend to have full-time permanent employees rather than subtrades or casual labour. When work is scarce, some shift employees to other jobs within the company. This allows the skilled staff to be retained for when work picks up again or a large contract is signed.

When it comes to trades such as plumbers and electricians, some manufacturers employ staff to undertake these duties, and others subcontract preferred suppliers that understand the business and the tight timeframes. In terms of factory-based labour, quality assurance processes and supervised environments allow for training of unskilled or low-skilled employees.

1.2.5 The implications

Low-volume builders dominate the New Zealand new-build residential construction market. The low numbers of new dwellings for most builders indicates that most builders do not rely solely on new builds for income. Where companies have low reliance on new-build dwellings for income, there is little impetus for investing in new technologies and using new production techniques, especially where capital and training time investments are required.

Sole traders with limited turnover have lower ability to experiment with ARCTs and less capital to invest in new technologies. Evolution and transformation in residential construction may be slower with so few new builds on average per company. For this group in particular it may be necessary to outsource some phases of production, form cooperative ventures as Mike Greer Homes and Spanbild have done, or collaborate in order to make the most of new technologies and techniques.

Companies with a low frequency of new builds have the largest floor area. Larger homes tend to cost less per square metre of floor area due to the expense of fixtures and fittings being more spread out. However, larger houses built by small companies had a higher average cost per square metre than companies building more houses with smaller average floor areas. This suggests limited ability of small residential construction companies to enter business and procurement arrangements to reduce costs.

Large-scale building companies that had more than 50 consents between 2006 and 2011 represented just 0.4% of positions within the industry and yet were responsible for 3% of new dwelling floor area. This suggests that the larger the scale of the outfit, the higher the productivity that can be expected. These companies are also likely to have the highest ability and incentive to implement new technologies and techniques into their business – yet this is not currently happening to any real degree (Bell, 2009).

Offsite construction offers the opportunity to improve value for money, quality and speed in residential construction. However, in order for it to work, businesses and their employees will need to adapt to use the techniques to their maximum benefit.

The following section assesses New Zealand's offsite residential construction industry and output in relation to a country with a well-established offsite construction industry. Germany.

1.3 Drawing Parallels – New Zealand and Germany

As part of the ARCT project, the author went on an intensive panellised prefabrication study tour to Germany and Austria with a number of representatives from the New Zealand and Australian construction industry. The tour members included representatives from frame and truss manufacturers, residential construction companies, architecture firms, government, academic institutions, industry associations and research institutions. The tour provided a useful comparison of the characteristics of New Zealand's residential construction industry with another country's industry where offsite construction and industrialisation is well established.

There are a number of differences to consider between the two countries that help to understand how the respective construction industries have evolved to where they are now.

The origins of the prefabricated housing market in Germany began with a massive housing shortage after World War II – there were 9 million housing units left to house 40 million people, and most of the large cities had much of their housing stock destroyed. After a bumpy start, the industry began to scale up their production, experiencing construction boom and bust cycles like New Zealand. Their offsite construction industry has weathered these and flourished in spite of them. Offsite construction has assisted Germany's government in achieving its housing aims. However, with rapid growth in some cities and population decline in others, housing shortages are again a concern.

For German new builds, an average 150 m² single family home costs around €1,500/m² including tax but excluding land or around NZ$2,500/m² as compared to $1650/m² in New Zealand in 2013 (excluding land).[3] Germany has a higher gross domestic product (GDP) per person than New Zealand. In terms of GDP on a purchasing power parity basis as at 1 July 2012, Germans earned US$38,700 per annum compared with New Zealand's US$30,200.

In Germany, offsite built homes average around 2% more expensive per square metre due to the market being higher end than that of onsite built homes (Windsheif, 2013). As shown in Figure 34, the average cost of a house built offsite, shown in red, overtook site-built homes between 2004 and 2005. Prefabricated housing was no longer the "cheap and cheerful" option, rather coming into favour in an increasingly quality and sustainability-driven market place. The focus on quality is synonymous with the pursuit of high sustainability performance. This is driven both by customer demand and the offsite construction industry's self-imposed quality mark system.

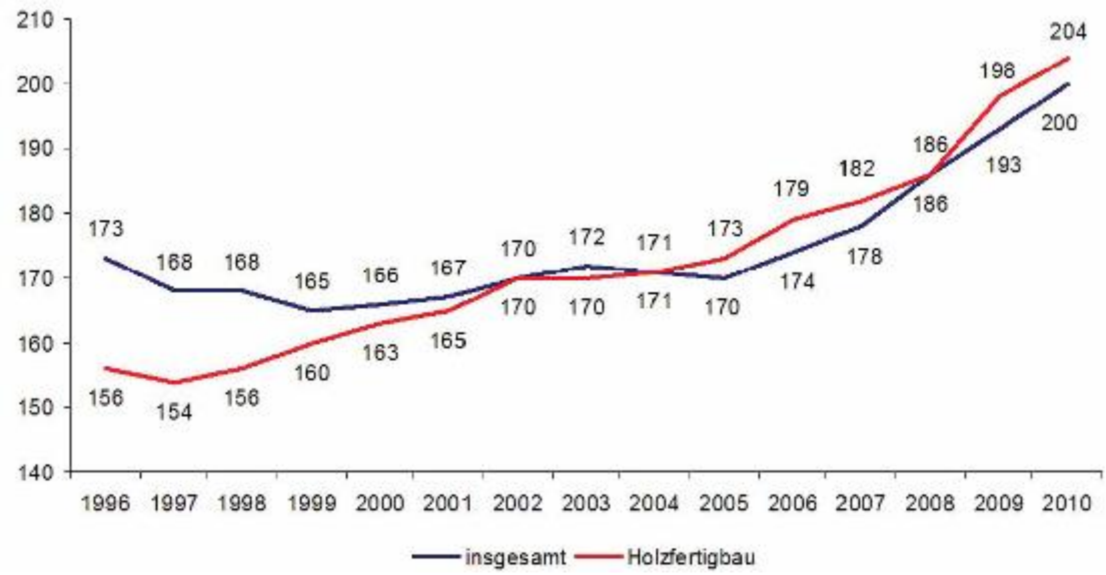

Figure 34: Onsite constructed house costs (insgesamt, in blue) versus the cost of those built offsite (Holzfertigbau, in red).

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[3] Based on Statistics New Zealand's November 2013 Consents Data for new dwellings. Pers. Comm. David Norman, BRANZ Ltd, 14/1/2014.

In considering cost differences between the two countries, it is essential to note the structural, thermal insulation and quality differences in construction between German and New Zealand homes. In essence, the materials used in construction in the two countries are similar. However, the amounts used and ways they are constructed differ.

Figure 35: The walls of German and Austrian houses tend to be far thicker than New Zealand's and contain far more insulation.

German homes tend to have walls of around 250–300 mm thickness for timber-framed walls with lightweight cladding (see Figure 35), as opposed to around 114 mm thick in New Zealand. The greater thickness constitutes the use of more insulation and more timber. In addition, windows tend to be triple glazed, often with argon filling. Window frames are usually either timber or u-PVC for improved thermal performance. In addition, they have a strong focus on airtightness and vapour barriers paired with balanced mechanical ventilation systems. All of these factors push the cost of construction up considerably compared to the typical New Zealand new build.

In New Zealand, new houses also tend to be bigger, averaging 208 m² of floor area in November 2013[4] as compared to Germany's 150 m² (Köster, 2013).

In Germany, the industry has transformed itself over time, player by player, from providing the market with houses at the cheapest possible price to leading the market to seek quality outcomes (Windsheif, 2013). The German industry leads the consumer, as opposed to New Zealand, where the industry tends to follow prescriptive standards and Acceptable Solutions.

The German residential construction industry sees innovation as a competitive advantage and a cornerstone of a successful business strategy (Vangerow-Kühn et al., 1984). The German companies spend time and money in collaborative or individual research and development projects and promote it to consumers once the product or system is fully developed. Their view is that innovation and advances in systems and techniques need to be seen and preferably experienced by the market (e.g. show homes) before they can make informed choices (Windsheif, 2013).

German offsite construction companies are predominantly supported by the local population (Köster, 2013). Of the 16 regions, 11 have a population smaller than New Zealand (German Federal Statistical Office (Destatis)). However, their market has become more than just local, as international attention was drawn to German prefabricated homes through a proliferation of architecture and designs shows on television networks. The tight precision and push for quality, comfort and performance have led to companies selling their products to overseas buyers in a number of different countries (Zunhammer, 2013). The bulk of the export is over the border to countries such as Luxembourg, Switzerland, Austria and Italy. Baufritz has shipped their houses to the United Kingdom, Spain and even Kazakhstan (Baufritz, 2014a). These buyers, both abroad and within Germany, typically are environmentally

[4] Based on Statistics New Zealand's November 2013 Consents Data for new dwellings. Pers. Comm. David Norman, BRANZ Ltd, 7/1/2014.

conscious, quality focused and looking at the investment over the long term – often over generations. Some German companies are exploring the potential of partnering with international factories to make their product to reduce transport costs (Baufritz, 2014a).

The strong export sector exists despite some particular challenges that affect the manufacturing industry. The cost of labour in the German manufacturing sector has encouraged the use of automated machinery (Buxton, 2011), especially in offsite construction. This allows one person to do multiple jobs while machines undertake a significant proportion of the manual work.

An additional challenge with exports is meeting the regulations for the destination country – 32 countries within Europe accept European Standards, including ETAG 007, which includes European guidelines for timber building kits, and a German guideline for timber element construction (Lange, 2013). However, some municipalities do not accept these, instead requiring the use of their own standards (Lange, 2013).

In contrast to Germany, New Zealand is geographically isolated but with multiple major seaports with container terminals – Auckland, Tauranga, Gisborne, Taranaki and Wellington in the north and Nelson, Westport, Lyttelton, Timaru, Otago and Bluff in the south. Sea freight is regarded to be a comparatively low-cost way to move large and heavy cargo around the world (BiaManagement.com, 2013).

In Germany itself, industry has introduced a raft of optional quality certifications. The industry-driven improvement in residential construction has influenced the building regulations (Windsheif, 2013). There is strong market demand for homes predicted to use less than half the energy of the German Building Code-equivalent minimum.

PART 2: OPPORTUNITIES FOR AND IMPLICATIONS OF PANELLISED OFFSITE CONSTRUCTION FOR NEW ZEALAND

2. POTENTIAL FOR OFFSITE CONSTRUCTION IN NEW ZEALAND

Offsite construction could enable New Zealand's residential construction industry to address some of its criticisms surrounding the quality, speed, productivity and value for money of new housing of the typically traditional onsite construction processes.

While much of the information in the following sections applies to most types of offsite construction, the particular focus of this report is on timber-framed panellisation for residential projects. Panellised offsite construction is predominantly used for whole homes. However, it can also be used to build additions.

Panellisation can be used for any size of home and for all types of housing density. Panels can be transported into tight urban settings, and due to being lighter than volumetric modules, hiabs can be used to lift panels into place instead of fixed cranes. Panellisation allows homes to have virtually any appearance. Timber framing has been focused on because of the complexity of the clear industry preference for timber framing at the present time (see Figure 27).

2.1 Quality

Offsite construction has potential to improve a key area of criticism of the New Zealand residential construction industry – quality (New Zealand Productivity Commission, 2012). The potential to control quality on a project is far higher in an offsite setting. The factory floor provides the opportunity to incorporate quality assurance checks as part of the construction process in between clearly defined tasks.

Production lines strengthen the need for quality assurance to promote accuracy and precision. The team for the next phase inherits the previous team's work, and if there is a defect from a previous team that needs to be fixed, this results in the loss of productive time for both teams. This will then have a flow-on affect to the rest of the production line. In this case, time is money, so quality assurance processes are essential to avoid costly defects.

The controlled climate of a factory protects the materials and the workers from the weather. Materials are less likely to be exposed to the weather or to get damaged or vandalised due to both covered storage and just-in-time (JIT) delivery. Factories often employ basic checks on materials deliveries for items to check they conform to requirements. Timber is often checked on delivery to ensure the moisture content is within an acceptable range, reducing the chance of warping and twisting as it dries. Ensuring the materials meet specifications before they reach the production line reduces rework, improves the quality of the outcomes and reduces waste.

The skill levels of the staff working on a project have perhaps the biggest influence on the quality of the outcomes. While formal skill levels may be low, proper training and supervision can ensure the work that is done is high quality. Often, factory workers specialise in a certain part of the production, completing the same task over and over. This enables the worker to become increasingly skilled and fast at completing their work. A common practice in manufacturing is to shift workers to learn new tasks after one has been mastered in order to maintain their interest and transfer expertise (Lessing, 2006).

Along with a strong focus on process to reduce the opportunity for defects to occur, goals and incentives are another method used to ensure both quality and speed outcomes (Bruno Pontes Mota et al., 2008).

2.2 Speed

Panellised offsite construction has the potential to be considerably faster than traditional onsite construction, typically halving construction time. This has a number of benefits for the client, architect or designer, manufacturer and locality surrounding the final site.

For the client, a shorter construction period means a shorter time before occupation. For those where the home is to be their residence, this means less time renting or paying the mortgage on alternative accommodation and/or faster realisation of the capital value of the other property. For investors, this means a faster realisation of investment earnings.

For architects, more design work is required upfront. However, the benefits are shorter periods of project management and supervision in the short term and usually higher quality outcomes over the medium and long term. Good outcomes that are on time, on budget and meet expectations resulting from the use of offsite construction may also improve client satisfaction.

In terms of benefits for the panel manufacturers, the more work that can be put through the factory, the more potential for profit, the more the overheads can be distributed across the jobs and the more cost competitive the company can be. This is a balancing act, however, as more equipment and automation does not automatically mean more work – just more potential capacity. The balance between demand and capacity must be managed carefully – underutilisation paired with over-investment may lead to the failure of a business.

At a neighbourhood level, the inconvenience, traffic, dust and noise associated with traditional construction sites are greatly reduced in both length and amount by taking construction offsite. This may influence the tolerance of a neighbourhood towards proposed projects, with staged developments, moderate and large-scale medium-density projects particularly likely to benefit.

The degree to which the build can be sped up depends on the set-up and automation of the factory and the level of completion of the product before it is shipped to site. While building a house onsite usually takes 14–26 weeks, some highly automated factories can build panellised houses ready to ship offsite in a matter of hours (Gann, 1996).

Figure 36: Automated equipment such as this automatic nailing bridge can be used to enhance the production line and supplement existing labour.

However, for companies with low to medium degrees of automation and equipment, it is common for houses to take 4–6 weeks to build in the factory (concurrent with site work to prepare the foundations), a couple of days to install onsite and another 2–4 weeks for fit-out and finishing. Larger or more complex homes may take longer, while smaller or simpler homes may take less time.

Companies with more sophisticated equipment and higher levels of automation build a house in a week, install it onsite in a day or two and finish it in another week or two.

Offsite construction has the potential to reduce project timelines for all sizes of business due to the covered-in nature of the factory setting. This reduces or eliminates weather-related delays and prevents moisture damage to materials if they are stored undercover.

Well planned ordering and deliveries from suppliers maintains sufficient stock to keep the production going and reduces the number of short trips made to material merchants to pick up consumables or missing items.

Workstations on the production lines are designed and equipped to maximise the ease with which work is carried out. Specialist machinery, such as computer numerical controlled (CNC) cutters for beams or plasterboard, also aids in reducing time and labour through taking over duties and also reducing the potential for human error and resulting waste.

The amount of time required to finish the product onsite is also highly dependent on the degree of finish done at the factory. Often it is more economical in terms of time to complete the work in the factory rather than onsite.

Figure 37: An open wall panel being craned into place in Vancouver, Canada (IDEAbuilder, 2014).

There are two generic types of panellisation, which reflect finishing to different degrees before they are sent to site.

The more straightforward in terms of factory production are open panels. These are clad on one side and may have glazing units installed. The work onsite includes insulation, electrical, plumbing, internal linings, plastering and finishing. These are virtually preclad, prenailed frames. Due to the higher amounts of finishing required, the time-saving potential from this type of construction is less than for closed panel construction.

Figure 38: Closed timber-framed wall panels awaiting final touches at Huber and Sohn, Austria.

Closed panels are those that have been clad, insulated, lined, had electrical conduits or electrical wiring installed and usually have water and waste pipes installed. The higher level of completion is intended to reduce the amount of finishing required onsite and minimise the time before occupation. Overseas manufacturers have devised simple and reliable service connections to speed up work onsite (Kaufmann, 2013). The more complete the panels, the higher the need for accurate site works, particularly with regard to services.

The more finished the product is leaving the factory, the more potential there is to use the benefits associated with offsite construction and the higher the opportunity to increase overall value for money.

2.3 Value for money

It is important to consider panellised construction in terms of value for money rather than absolute cost. When higher levels of specification is used for materials, insulation levels and fit-out, panellised and other types of offsite construction can end up around the same price or slightly more expensive on average than traditional construction (see section 1.3).

In plain terms, the quality assurance, improved precision and short timeline of a typical offsite build would be difficult to replicate through traditional onsite construction.

Overseas, there is a push for top-quality prefab architecture. Architects and designers have acknowledged the benefits of offsite construction in terms of creating a premium product for clients. This has focused on precision, speed in the construction phase and environmental benefits such as reduced waste and better thermal performance through airtightness and quality installation of insulation. These benefits are being realised here, as an increasing number of architects and designers begin turning to manufacturers to fabricate high-end designs.

Government programmes to build large numbers of new social housing and prefabricated additions to existing social housing stock are driving the lower, mass-customised end of the spectrum.

The more work that is put through housing manufacturers, the higher the potential scales of economy and the lower the overhead contribution for each job. More research needs to be done to figure out whether offsite construction can be more cost competitive than traditional onsite construction in New Zealand and the circumstances that would lead to this. Offsite construction stands the best chance of becoming mainstream if its products can be cost competitive with traditional onsite construction. Offsite construction is also impeded by a lack of recognition of the value of non-visible quality in houses, which Germany has addressed with the voluntary quality labels (see sections 3.3.2 and 3.5).

2.4 Labour

The amount of labour involved in offsite construction is highly dependent on the utilisation of automation equipment. Some firms build undercover using much the same equipment. Reduced travel time, downtime and improved workflows may reduce the amount of labour required per house. The reduction is dependent on the efficiency of the factory workstations, the equipment used and the amount of automation employed.

Firms that employ automation use it as a tool to enable workers to do their work more efficiently and to the desired standards. This may enable a worker to work on several jobs concurrently. Close supervision and training paired with tight quality assurance and repetitive tasks can allow unskilled labour to be used in lieu of trained tradespeople, reducing labour costs (Bell, 2009).

The most highly automated factories eliminate as much of the manual labour component of the products as possible, often only having production line engineers to keep the equipment running.

A common medium-sized house prefabricator model in Germany is for one average sized house to take 6–12 weeks from design to completion using three builders or construction labourers, one crane operator and one site supervisor. The annual output for workers is based on 1,600 hours as opposed to New Zealand's 2,050 for most industries, which is to minimise fatigue and therefore mistakes and accidents (Köster, 2013).

To put this into context, here is a rough labour-only calculation based on the German example for an average new German home of 150 m². It assumes:

- 37.5 hour week/worker
- a moderately automated factory
- moderate timeline of 9.4 weeks from start of construction to completion.

	Timeline	Personnel hours	Rough cost
Foundations traditional timeline (Page, 2012))	Week 1 to 6	2 weeks x 37.5 hours x 2 builders = 150 hours	@ $35/hr = $5,250
Factory labour		6 weeks x 37.5 hours x 3 builders = 675 hours	@ $30/hr = $20,250
Site install	Week 7 to 7.4	2 days x 7.5 hours x 3 builders = 45 hours	@ $35/hr = $1,575
		2 days x 7.5 hours x 1 site supervisor = 15 hours	@ $50/hr = $750
		2 days x 7.5 hours x 1 crane/hiab operator = 15 hours	@ $30/hr = $450
Site finishing	Week 7.4 to 9.4	2 weeks x 37.5 hours x 3 FTE equivalent of trades = 225 hours	@ $40/hr = $9,000
Total estimated labour excluding design phase and transport	**9.4 weeks**	**1,125 hours**	**$37,275**

With labour representing around 32% of the total cost of a traditional onsite house build in New Zealand (see Figure 22), for a 150 m² house at $1650/m², this would equate to $247,500 x 32% = $79,200. In the illustrated example, the cost of the labour component is less than half. However, the 50% reduction would vary depending on the degree of automation and the efficiency of the workstations and workers. The reduction in labour is also accompanied by a rise in overheads to factor in the cost of the factory and the equipment and the added cost of transport to site and onto the foundations.

Higher output per factory worker compared to that found on a traditional construction site would enable more houses to be built for the number of workers that exist. The current labour shortage and shortage of new housing construction are two compelling reasons to pursue offsite construction. However, the other end of the boom needs to be considered too.

The construction industry is subject to cyclical demand – booms and busts. With pent-up housing demand in Auckland and rebuild pressures in Christchurch, it seems inevitable that, once the demand has been met, the pressure will come off the new-build market. Traditionally, this results in transient labour moving out into other industries, companies downsizing and some companies ceasing to trade.

If the construction market moves to a more efficient method of construction, the amount of output per worker will be higher and thus fewer workers will be required to build housing in downturns. This combination could lead to new lows in the number of people and skills retained in the residential construction industry. However, a sufficiently diverse portfolio may lessen the loss of jobs in offsite construction companies. Other countries with established offsite construction industries also experience boom and bust cycles in construction and do not report disproportionately high numbers of job losses or company closures compared to onsite construction (Koch, 2013).

3. IMPLICATIONS OF OFFSITE CONSTRUCTION FOR NEW ZEALAND

With the potential offered by offsite construction, there are a variety of implications that come along with it. This section explores these implications and the effect that offsite construction may have on the New Zealand residential construction industry in terms of company size, the ways businesses operate and market themselves and the planning of factories.

3.1 Company size

As the German and Austrian examples show, even small companies can utilise offsite construction. However, the nature of factory production and the segregation of duties means the average offsite construction company in Germany has seven workers, which constitutes a medium-sized residential construction company in New Zealand. For the large proportion of the New Zealand residential construction industry that are currently sole traders, the question is whether the company should make the foray into factory production or whether they should commission a manufacturer to build offsite and concentrate on managing the site preparations, final assembly and finishing.

The size of the company does not necessarily define the success of the business. Smaller firms with more basic set-ups and less overheads may be more competitive in terms of pricing and be able to sustain construction downturns better than larger companies with high overheads. In Germany and Austria, the small companies pick up the extra business during boom times rather than the larger ones (Köster, 2013).

Figure 39: Fingerhaus factory production line for new housing in Hessen, Germany (Windsheif, 2013).

Although small businesses can be more adaptable than larger ones, their ability to raise capital for investment such as equipment and premises may be less than for medium and large companies due to a less constant workflow and resulting income. Large companies may be subsidiaries of a parent corporation and have rapid access to large amounts of capital as a result. Family-owned and operated companies may be more able to take commercial risks since they do not have to answer to shareholders.

The amount of capital required to make use of offsite construction techniques will vary depending on whether the company wishes to commission another to manufacture elements for it to install onsite or whether the company wishes to both manufacture and install or to manufacture for external installers.

Irrespective of the size of the company, the business operations of offsite construction companies are different from traditional onsite construction. Those considering moving to offsite construction and those working closely with manufacturers need to fully understand what is different about the design and construction process and why.

3.2 Business structure

The way an offsite construction company is structured is different to traditional small construction firms in New Zealand. The process from design to installation onsite has perhaps more similarity to product development processes than traditional onsite construction, and aspects that are considered optional extras in onsite construction become far more important.

The main clients of offsite construction companies are developers, builders, architects and designers. It is essential that the commissioning party understands the offsite construction process, the increased design requirements and the implications of offsite construction and communicates these to their client(s) before the project is commissioned.

The design requirements for offsite construction are generally higher than for onsite construction. The amount of detail that is required is usually far higher, as the drawings are effectively production drawings and used by those on the shop floor in the construction phase. Exploded drawings of every element in every panel is preferred and show the workers which pieces go where and how they come together. In order to get this right, it is essential that the architect or designer and the fabricator align to ensure the detailing works for both parties.

Up-front collaboration between the architect or designer, client and construction team is a fundamental ingredient for a project's success, and it needs to happen from the concept stage. From the beginning, it is essential to design with consideration to the strength and rigidity needed in each element. This may complicate certain design features such as floor to ceiling glazing. If not properly designed, the weight of the glazing unit and a lack of cross-bracing could lead to the element twisting when it lifts, causing breakage and/or deformation. This is where collaboration with both the factory and an engineer should occur.

In some cases, the design requirements may lead to the need to come up with innovative solutions to create the desired aesthetic. Cost and practicality may require concessions to be made, at which point, buy-in from the architect or designer's client becomes important.

Once the design has been finalised, the rapidity of the offsite construction focus and the fixed production times mean that it is usually not possible to make late changes to plans. This does have benefits in terms of costs, however.

While the increased amount of upfront design may cost more than onsite projects, the level of detail enables prices to be fixed. This, paired with the set construction timeline, provides the client with greater cost security. For investors, the shorter time period could allow faster generation of income as tenants are able to move in earlier.

However, traditional financing for small clients may pose issues to those with low deposits. Due to the materials and product being on a premises owned by another party, some types of lending will not cover the goods until they are onsite. The implication of this is that the client must pay upfront, and then once installed onsite, the bank can take over finance. For panellised construction that is delivered on a ‘Just in Time’ (JIT) basis, this may have less impact than the delivery of an entire house. Clients may be able to seek a less traditional method of finance to enable the build. Alternatively, these complications could potentially be avoided by billing clients after installation onsite.

JIT construction is where the materials are delivered and construction work is carried out using those materials soon after. This means that minimal materials are kept onsite and minimal storage is needed for the finished items. The success of the JIT concept relies on suppliers, the manufacturing team, architects and designers and the final clients being fully aware of the expectations of prompt delivery. For manufacturers, this means careful anticipation of material requirements for a certain period, coupled with accurate and timely ordering and close communication with suppliers. For suppliers, this means delivering the specified amount at the specified time – not doing so leads to costly time delays for the manufacturer. For architects, designers and their clients, this means having the project manager organise all of the trades to fit around the delivery of the finished product to site to avoid the need for storage. Further information regarding the impact of just-in-time construction on premises can be found in section 3.4.

Where the concept of lean construction is used, the principles are to make the most efficient use of materials, time and labour. By minimising the amount of materials and labour used, the operational costs are reduced. By minimising the build period, the number of jobs that can be done in a year are increased, and overheads can be spread over more jobs. The emphasis is on defect-free construction to avoid costly rework, which comes off the bottom line. Reduced costs per job and more work can lead to higher profits and/or a more cost-competitive operation.

The principles of JIT and lean construction are used in offsite construction both in New Zealand and overseas. The success of both principles depends on good relationships with suppliers, good communication to set appropriate expectations of both designers and clients and an appropriate operational structure. Continuous improvement processes that involve people at all levels of the firm help to maximise the benefits of lean and just-in-time production methods (Abdelhamid, 2004).

Offsite construction usually involves a team of core staff, led by floor supervisors and/or managers. Some companies use low-skilled labourers for the construction work under the supervision of a qualified person on the floor. Others employ highly qualified persons who work reasonably autonomously under the guidance of a manager or management team.

The number of staff required depends on the required output and the timelines of the projects. In general, the faster the project, the higher the need for staff – unless automation takes the place of some of the labour. Any contractors, such as electricians and plumbers, need to conform to the timelines of the project and work in their other jobs around those of the factory. For this reason, companies sometimes have tradespeople as permanent staff.

In any industry, it is generally accepted that the bigger the company’s turnover and payroll, the more management and administration work is required. To maximise the potential of offsite construction, sole traders may have to adapt and grow or come together to form larger organisations. Professional managers are often employed to run the administration and client services side of the business, while factory floor managers or supervisors run the technical and construction side and manage the health and safety of the workers.

The storage of materials is typically in specifically designed housing, and clean floor policies also reduce the trip hazard for workers. Many companies operate a zero-lift policy, which means items over a certain size or height are lifted mechanically to avoid injuries. The dust and potential off-gassing of materials and adhesives in a factory setting mean appropriate levels of natural or active ventilation are required.

Each company will have a different operational balance due to the number of staff, the products being produced and the principles the business utilises in terms of production and management. While there are rules of thumb in terms of turning a profit overseas, there are none in New Zealand, leaving the industry with little solid information with which to consider moving to offsite construction.

A primary impediment to the decision-making process surrounding moving to offsite construction is the lack of New Zealand-specific information on the cost-effectiveness of different sizes and set-ups of offsite construction. If offsite construction is to be part of the arsenal when it comes to catching up with unmet residential construction demand, this information is critical for the industry's decision-making process. However, most well established manufacturers have spent decades working their way from traditional onsite building companies into a viable operational model through trial and error. Newcomers to the market will need better access to cost-benefit information in order to increase the likelihood of successful transitions to offsite construction. If this is not provided, poor business decisions (such as over-investment or inefficient operations) could endanger the sector and its reputation or leave it vulnerable when the inevitable bust cycle begins.

This area would benefit from New Zealand-specific research in the form of cost-benefit analyses on a range of offsite business set-up scenarios. Investigating the influence of equipment and automation costs and capacities, labour, operations, product, turnover and marketing in the viability of a business would provide valuable information for potential manufacturers.

3.3 Marketing

Marketing is an essential part of a successful factory in obtaining work and maintaining workflow. With an industry that heavily relies on word of mouth and experience, more formal types of marketing become important for new players and those changing the face of their operations.

A commonality among countries with higher uptake of offsite construction is a focus on the product rather than the process. For example, quality, precision, energy efficiency and environmental friendliness are promoted, but how the company gets to this point is not. The client looks at the product that they are to receive rather than being sold the process by which it is built.

In New Zealand and overseas, many companies doing offsite construction have focused on speed and cost as the two primary factors in prefabricated housing. However, this restricted the market to the lower end, and mass production of cheaply built, identical houses destined for low socio-economic areas further tarnished the reputation of prefabricated housing. The poor perceptions associated with prefabrication have been identified as one of four main areas inhibiting its growth (PrefabNZ, 2014).

The 'cheap and tacky' factor has shaped certain neighbourhoods and their demographics. Despite this, a fixation on obtaining the lowest prices possible is still evident in the market and reinforced by the tendering process.

In the private market, the focus is on bigger rather than better despite New Zealand's ageing demographic (Statistics New Zealand, 2012a) and the continuing shrinkage of average household size (Statistics New Zealand, 2010). The increase in the average floor area of new dwellings may suggest that cost savings are simply used to build smaller and smaller households into bigger and bigger homes. From a developer's point of view, high land values mean there is a need to maximise the value of the project with an upmarket house. In some instances there are covenants that require clients to adhere to strict regulations that require large homes to 'protect' the value of surrounding homes. In effect, the market is currently demanding the largest possible houses in lieu of above-Code specification, above comfort and above quality.

Especially for new companies, marketing is an essential part of a successful business. The marketing itself must be carefully designed for maximum impact within the target market while fitting within the means of the company on an ongoing basis. This budget is likely to change as the company grows, but it should remain based on the minimum expected or reliable earnings of the company. Companies looking to start up should consult with marketing experts as part of the initial stages of forming the business plan.

3.3.1 The 'lowest price' mentality

Arguments that the market leads demand only work where feedback loops in the construction sector are working both ways, and this is frequently not the case. An investor or consumer who is not professionally involved in the design or construction side of the building industry is unlikely to be exposed to the full suite of options from which to choose nor might they have the opportunity to understand the quality differences between products.

In turn, these arguments drive the assumption that purchasers of new homes want them as cheaply as possible. For individuals designing and commissioning the build of their own home, there is the opportunity to investigate other options and work with the builder to implement them. However, with speculative builds, the option of higher-quality fittings is often never given. Instead, the presumption that cheap is valued more highly by the market than other features suppresses innovation, research and development within the industry.

The German construction industry was bound by the 'cheap is best' mentality until around a decade ago, when industry members decided that, in order for a consumer to demand something, they had to experience it or at least see it (Windsheif, 2013). Innovations were displayed in show home villages (see Figure 40), and rather than increasing the size of their homes, buyers chose higher specifications and higher-quality homes.

Figure 40: Bauzentraum Poing Showhome Village, near Munich, Germany, December 2013.

3.3.2 Quality over quantity

While being cost competitive is likely to be a fundamental condition of offsite construction becoming mainstream in New Zealand, a quality focus could lead to infiltration of the high-end market niche. Precedents for success in this niche have occurred in a number of countries. With noted architects and designers such as

Michelle Kaufmann (USA) and Shigeru Ban (Japan) recognising the potential for higher quality control and precision on their projects compared to traditional construction, offsite construction for high-end products is becoming more desirable and high profile.

Many markets consider minimised environmental impact as an inherent aspect of a quality product. Sustainably harvested timber in construction is being promoted throughout much of the developed world as an alternative to masonry homes. New Zealand's 'clean green' image paired with vast natural resources and sustainable forestry provide an ideal foundation for sales based on environmental principles – providing the environmental cost of shipping the product can be rationalised.

For both domestic and exported projects, it may well be possible to have lower embodied energy than local onsite builds. With abundant timber resources, relatively small distances travelled and domestic manufacturing of much of the required materials, New Zealand may be able to produce houses with less embodied energy than other countries despite long-distance shipping. Minimising embodied energy would require a tight material supply chain, well managed logistics and efficient factory arrangements. An additional benefit of a tight and rationalised materials supply chain is reduced materials transport costs, which are often built into the price of materials. This is an area that would benefit from more research, particularly around value-added timber products such as laminated veneer lumber (LVL) and cross laminated timber (CLT).

The German industry recognised the difficulty of getting clients to understand standards and have created and introduced a voluntary series of quality marks. These effectively demonstrate that the product exceeds the relevant regulatory minimums by a certain level or by providing other benefits. The Qualitätsgemeinschaft Deutscher Fertigbau (QDF) mark demonstrates not only the quality of the factory's processes and record keeping but also the use of materials that do not contain volatile organic compounds (Lange, 2013). For more detail on this, see chapter 3.5.

3.3.3 Certainty of outcomes

Offsite construction is able to offer the client more certainty than traditional construction in areas of time and final cost, and also with a known product, where a consumer gets to 'try before they buy', e.g. with a show home. With design features finalised early in the process, time delays and cost increases due to design changes are unlikely to occur. In addition, faster production times reduce the likelihood of price fluctuations of materials and labour during construction.

In terms of time, offsite construction allows multiple trades to work in a co-ordinated and tight timeframe at one central site. Tradespeople are usually full-time employees, so travel time and jobs for other clients are not causes for delay. This means schedules can be tightly programmed, labour can be used as efficiently as possible and time-movement studies can be initiated to further improve efficiency and productivity. Whole houses are finished in overseas factories in as little as a day, but more commonly around 4–6 weeks. Depending on the level of completion and the type of offsite construction being used, it can take anything from a few hours to 2 weeks to complete the house onsite.

With higher design requirements and tighter quality control comes greater certainty of materials quantities and less waste resulting from human error. Protected construction sites reduce downtime and reduce or eliminate the risk of theft, vandalism or damage to materials caused by site movement or weather.

3.4 Factory planning

Moving to offsite construction requires planning in order to establish a successful factory set-up. This section gives a brief overview of the things that need to be considered before moving to offsite construction.[5] Considering the complexity of the task, a profession has grown up around fabrikplannung (factory planning) in Germany for offsite construction. This topic is taught in German technical universities in order to support the industry.

3.4.1 Starting out

The first stage of planning a shift to factory construction is to define the goals of the business, which will then define what the factory will need to produce, and how much output. Once this is established, planning for the factory can begin. In order to plan out an efficient factory, reverse engineering is helpful to ascertain what will be needed to produce the desired end product. This involves going from the product back through the process to the design stage. The goal is to find the most efficient solution. This is applicable to both new facilities and redesigning existing set-ups.

1. Define goals then search for ways to achieve them

By deciding what the company is going to do, how and why, the basic outline of the company can be formed. At this stage, it is important to look at the target market along with the product to consider how to gain a competitive edge or whether to shift focus. At this stage companies may choose to engage an independent consultant to fully explore the available options.

2. Investigate the options then illustrate the solution

This stage involves looking at all of the ways that a company could achieve their long-term aims. This means scoping out the different options and assessing them with regards to their benefits and drawbacks. The aim is to find the best solution considering both initial outlay and long-term goals.

Prime things to consider include what the target market wants in terms of product, the location, restrictions and characteristics of the sites where the bulk of the product is likely to be assembled and how the product will be transported. Once the type of construction (for example, timber or steel framed, lightweight concrete or Structural Insulated Panels [SIPs]) and degree of factory completion (for example, open or closed panel, glazed or unglazed) is decided upon, the decision process surrounding the location, size and amenities of the factory and need for specialist equipment and automation can be examined.

3. Find the most efficient solution

Using the parameters defined in step 2, it becomes easier to select the right equipment as opposed to relying on a supplier to design the set-up based on the limited items in their range. It is entirely possible to have a factory without the expensive equipment and automation. However, whether this is the best solution depends on a variety of factors including local labour availability and cost, the type of product being produced and the short to medium-term company goals in terms of output.

Where there is benefit from automation and specialist equipment to supplement, enhance or even replace labour, it pays to investigate a range of options, even those that seem to be out of the price range. The viability of a piece of equipment should be based on more than just price and should be considered in light of the whole production line. A higher specification item may eliminate the need for other equipment or enable less expensive equipment to be purchased for other places in the production line. In addition, it may improve the flow of the production line, increase the potential product range or enable higher output.

[5] The author wishes to acknowledge the assistance of Johann Betz of JS Betz Consulting in producing this section.

It is possible to mix and match equipment to get the best combination machinery for the job rather than sticking to one supplier. Local engineers may be able to create a piece of equipment for a lower price than buying it overseas and shipping it over. It also pays to investigate the option of using second-hand machines – it is not uncommon for a piece of equipment to still be in operation 20 years after its purchase. Another thing to consider is the availability and cost of parts and maintenance.

Another aspect of efficiency is the operational model. Lean construction and just-in-time (JIT) methodologies are often used in offsite manufacturing. Lean construction is more focussed on the factory, and requires buy in from factory workers to make the most efficient use of time and resources and prevent downtime or rework. The success of JIT methodologies depends on close relationships with suppliers who both understand the concept and are set up to deliver the required items in the required amounts at the required times.

This process will help to define the facilities required in order to produce the desired product. This includes the size of the factory, the amount of equipment and the degree of automation.

The information gathered in these three steps can be used to develop a feasibility study to establish that the economics of the project stack up. From here, detailed planning can take place to establish how the factory and business model will work and the training and/or additional personnel that will be needed. Then the implementation phase can be planned and carried out. Continuous improvement processes will then enable the operations to be fine-tuned once production begins.

Often people tend to rely on suppliers to tell them which equipment they need to fulfil a purpose. However, this advice will be based on what the supplier can provide. By working backwards from desired outputs through to the design process, the purchaser can then define what a supplier must supply. This has the effect of putting the purchaser into a position of power, requiring the supplier to prove that their equipment will perform the tasks required within the preset parameters.

3.4.2 Premises

The size requirements of a factory are defined by the type of product, the way the business operates and the medium-term aims of the company in terms of output required. Internationally, companies work out of premises of vastly varying size depending on their method of operation and the product they are constructing. These may be as small as a double garage or as large as a rugby field or even larger.

By planning out the factory workstations in blocks allowing for equipment, storage, tasks and movement of people and materials, it is possible to estimate the floor area requirements. The more tasks that are done and the more finished a house is before it leaves the factory, the more workspace may be required. Panellised construction requires less room on average than modular construction due to the space efficiencies of working with flat panels as compared to volumetric modules.

The size of the working space is also affected by the business operations of the company. JIT ordering and production reduces the amount of space required for the factory by keeping materials and finished product storage to a minimum.

Premises do not necessarily have to be fixed to one site. Other countries employ the use of portable factories that are moved around residential developments (Olson, 2010). In Sweden, it is common to effectively have a temporary factory onsite – companies build within a tent that rises as the building gains height (Hedges, 2013). This may have potential for New Zealand's onsite residential construction industry, although wind may prohibit the use of construction tents in some areas. A similar technique is being used for cladding remediation work in New Zealand, where the buildings are ‘shrink-wrapped’ for weather protection until the work is complete.

Most manufacturers operate out of permanent sites, many of which are based in provinces located reasonably close to cities instead of in cities themselves. Being based outside of the city has advantages in terms of premises costs, freer labour markets, availability of trades, lack of congestion, closer relationships with local councils, business and communities, and lower-density populations.

3.4.3 Equipment, automation and labour

The three aspects of equipment, automation and labour are interlinked. While some of this material has been presented in the earlier sections, it is brought together in this section, so clarify the inter-linkages.

The number of people needed to work on a project depends on the size of the project, the extent of the project being completed by the builders (design, build and/or installation), the set-up of the factory and the staging of the construction process.

The amount of labour also depends on the degree of finish of the offsite-built components, as mentioned in section 2.2. Fully enclosed wall panels with services will require plumbers and electricians to complete the bulk of the work in the factory and just making the connections onsite.

The level of technology required for offsite construction can be as simple as a factory equipped with standard builders’ kit or as complex as one with moving production lines, automated cutting and nailing and multifunction bridges doing the bulk of the labour. For basic set-ups, the equipment used can be as traditional as current onsite construction. For fully automated set-ups, the production line and all its components can cost in the millions of dollars.

Equipment is primarily tools to enable the workers to build the desired product to the desired quality. Its ability to do this depends on the training and abilities of the workers and the quality assurance of the factory.

Automation is an optional extra for offsite construction. It is principally employed to give better outcomes over traditional methods, including quality, speed, health and safety, cost savings and workflow. Where the local labour force is expensive or restricted, automation may be used to replace some of the labour. Manufacturers of any size may choose not to use automated production for practical reasons (such as restricted factory space) or financial reasons (such as poor payback).

Automation is best used as a tool for the existing labour force to enable them to do their job better. Automation may be employed to increase production or speed up parts of the production line. The nature of the local labour market is a key component in the viability of automation for any given company. It may be used to reduce the impact of local labour shortages or reduce the cost of labour by enabling less-skilled workers to do the job.

Other reasons to employ the use of automation and specialised equipment include quality improvements and waste reduction. Automated equipment can be used to improve precision in construction, which is particularly important in high-performance homes. Waste can be reduced through reducing human error – using CNC beam and sheet cutting, for example.

Even without automation, overseas examples exist that show large house manufacturers do not necessarily need to employ high or even moderate levels of automation. The largest German prefabricator, producing around 700 houses a year[6] (Fingerhaus, 2014), uses traditional construction techniques rather than automated production. As of late 2013, the company was not running a single multifunction bridge (Bölter, 2013).

The way a company is organised will also influence the amount of labour required. Companies that concurrently build and assemble onsite will need more workers than one that builds first and assembles later or one that contracts in others to do the onsite assembly.

The cost of equipping a factory depends on what is being made, how much is being made and whether the purchaser has a preference for new equipment or a certain brand. The cost of setting up a factory can vary from the low tens of thousands to millions of dollars, depending on its product, capacity and sophistication.

In order to be cost-effective, both automation and equipment must save or bring in as much money as it costs to implement. The type and completion level of the factory-based construction should be considered in cost-benefit analyses for both, as the more labour that can be saved or substituted, the faster the equipment can pay itself off.

The labour savings will vary in money terms according to the characteristics of the local labour market. If there are labour shortages and/or high wages in the region in which the factory is to be based, the savings are likely to be more pronounced than in other regions.

In terms of savings resulting from reduced waste and material use, these are likely to be comparatively small, and will vary depending on the local prices of materials. Therefore, the benefits of automating parts of the production will vary across the country.

3.4.4 Transportation

The cost of transportation is more obvious for offsite construction than it is for onsite construction. Traditional builds still have transportation factored into the cost of building, although this is normally incorporated into the cost of materials and labour and therefore is not transparent nor quantifiable.

Offsite construction often entails larger deliveries to the factory on fewer trucks, as multiple projects are often constructed at the same time. Trips to get additional items can be minimised with a well organised JIT ordering system and sufficient materials and hardware onsite to maintain the flow of work. Reduced transportation has flow-on environmental and economic benefits.

However, JIT construction may result in an increased number of consignments that otherwise may have been delivered in one bulk load (Voordijk, 1999). This reduced efficiency could have associated detrimental impacts on the environment through increased emissions per load and potentially a higher cost of transportation built into the materials due to increased operator hours.

In terms of the finished product, the cost of transportation depends upon five main factors, which are:

- distance
- freighting methods
- number of vehicles required (road)

[6] This number factors in the effect of around a month and a half of downtime in mid-winter when the ground is frozen too hard for onsite installation work in some areas. Construction in the factory continues, albeit at a slower pace, until the product can be exported to site.

- distance from freight routes
- sea crossings (for example. interisland).

There are several ways to rationalise the cost of transport. These include:

- keeping panels and modules within standard vehicle dimensions where practical
- back-loading the shipment where possible onto ships returning to a main freight hub to avoid paying for a return journey
- minimising the volume of the shipment – the fewer trucks required, the less it will cost to move
- renting or owning factories on sites that are en route or close to a freight transfer point, which is likely to be cheaper due to continued journeys by trucks.

The cost rises the more trucks are needed, for example, if extra panels are needed for a large house or if large volumetric models are shipped instead of flat-packed panels. A small house with a long perimeter (for example, U or L-shaped) that is shipped as volumetric modules may take several trucks to get it to the destination, depending on the dimensions of the modules. The same house panellised may be delivered on one truck and trailer unit.

Figure 41: An open panel house ready for transport to site in Vancouver (IDEAbuilder, 2014).

In Europe, house manufacturers often own simple truck trailers set up to take packs of panels. These essentially look like a low-set trailer frame, where panels sit upright in two packages supported by a central support.

Packages are forklifted or craned on at the factory, and standard trucks pull the packages to site on a JIT delivery basis. At the site, the panels are craned off in order, usually using a hiab, and put in place on the pre-prepared foundations. A 150 m² house is typically delivered on a truck and trailer unit (Koch, 2013).

Transporting volumetric modules is technically less efficient than transporting flat-packed panels. However, in terms of time and construction, it can be more efficient to use hybrid prefabrication, where at least some parts of a home are built as volumetric modules. Service modules such as kitchens, bathrooms and laundries are often delivered as a module in order to put in services and test them at the factory, both for cost and time reasons. This reduces the amount of work and testing required onsite.

Figure 42: Wrapped and heat-sealed wall panels awaiting transportation in Austria.

The cost to move a home can vary hugely. Shipping a small home in one piece can be as little as $2,000 for a site close to the factory on a main freighting route (backloaded on an empty truck returning to a main freight hub), or significantly more if many loads are required over long distances. In some cases, one oversized load may be more cost-effective to move than multiple shipments of standardised dimensions due to reduced labour and crane costs onsite.

3.4.4.1 Interisland transport

Shipping a medium-sized home across Cook Strait in New Zealand could cost less than $20,000[7] depending on the number of trucks required, the distance by road and the dimensions of the load. As with international sea freight, keeping within standard road freight size restrictions (for example, a container) is generally more cost-effective than moving an oversized item.

Shipping between the two main islands in New Zealand may be worthwhile depending on the cost to build in the destination. For example, at present, the cost of building in Christchurch is reported to be inflated due to significant pressure on labour resources (McDonald, 2013). The build cost in Christchurch rose 9.5% compared to inflation of 1.6% in the year from December 2012 to December 2013 according to the Consumer Price Index (Statistics New Zealand, 2014c). For an average-sized new detached house of 208 m² at an assumed cost of $1650/m² (see section 1.3), a price increase of this scale would add over $32,000 to the cost of a house – potentially more than the cost of interisland transport. In addition, it may be more feasible to transport the product than set up a local factory.

3.4.4.2 Export

In terms of scales of economy, one of the major opportunities to expand the market for offsite construction is the export of houses. As yet, the export of houses from New Zealand is not common. Consequently there is uncertainty surrounding the cost of exports, so in order to better understand the scale of cost, a logistics expert was asked to provide estimates of international export for a shipment that resembles those in Germany. The purpose of this was to provide conservative estimates that represent shipment of the heavier and bulkier German-style house packages from New Zealand.

High Cube 40' Container Dimensions[8]		
INSIDE LENGTH	39'5"	12.01 m
INSIDE WIDTH	7'8"	2.33 m
INSIDE HEIGHT	8'10'	2.69 m
DOOR WIDTH	7'8"	2.33 m
DOOR HEIGHT	8'5"	2.56 m
CAPACITY	2,694 ft³	76.28 m³
TARE WEIGHT	8,750 lb	3,968 kg
MAX. CARGO	58,450 lb	26,512 kg

The theoretical house has a floor area of 150 m² and is shipped as closed timber-framed wall and roofing panels over 250 mm thick. The house is assumed to have a concrete floor, which is cast onsite by local contractors. The house is packaged in two parts that fit into two 40-foot ‘high cube’ containers.

The assumed weight of the content of the containers is 13 tonnes. When investigating the viability of export, it is essential to consider the influence of the construction code requirements of potential markets on the weight and volume of the shipment. The weights and volumes will vary widely according to the structural and thermal requirements of the destination’s equivalent of a building consent authority.

Price fluctuations will occur due to exchange rate, transport cost, any special treatment of the shipment by customs or biosecurity and alterations to duties and unpacking costs at the receiving port.

The cost of road transport to and from each seaport has not been factored into these estimates for a variety of reasons, including variation in road freight price by locality and the potential of additional taxes levied by some regions. For example, in some

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[7] Anonymous source, 2013.

[8] Personal communication, Daniel Hepburn, Online Logistics, 7 February 2014.

parts of China,[9] additional and varying duties may be charged if a product is road freighted across regional borders.

For the purposes of providing comparative prices including duties across the different ports, the product has been given an assumed value of $250,000. (Note that foundations would most likely be done by local contractors at the destination site.) As per the above discussion, the cost of construction will vary according to local construction rules for the destination site.

The estimates below in Table 2 were generated in early 2014 for four New Zealand seaports – Auckland, Tauranga, Wellington and Lyttelton. The exchange rates used are shown in Table 1, and the costs have been rounded to the nearest $100. The figures in the 'Duty' column are likely to include freight forwarding and customs clearances charges, and will be affected by the development of free trade agreements. These costs should be regarded as highly approximate and are provided to assist the industry to further consider export as an option.

Currency	Exchange rate
AUD	0.90
USD	0.82
GBP	0.50
EU	0.60

Table 1: Assumed exchange rates for export costings.

Table 2: Estimated export shipping costs from NZ Seaports for a theoretical panellised house shipment.

Destination Port	Expected Transit Times (Max. Days)	Origin Charges	International Charges	Destination Charges	Value of Goods	Consumer Tax		Duty		Total Shipping to Destination Port
Melbourne (AUHBA)	10	$ 930	$ 1,200	$ 1,900	$250,000	GST 10%	$25,000	5%	$12,500	$ 45,400
Shanghai (CNSHA)	25	$ 930	$ 4,400	$ 1,300		Sales Tax 17%	$42,600	12.47%	$31,200	$ 80,200
San Francisco (USSFO)	19	$ 1,000	$ 4,400	$ 1,300		Tax 9%	$22,600	N/A		$ 29,200
Southampton (GBSOU)	41	$ 1,000	$ 6,200	$ 1,300		VAT 20%	$50,000	N/A		$ 56,400
Hamburg (DEHBU)	41	$ 1,000	$ 5,200	$ 2,800		VAT 20%	$50,000	N/A		$ 57,600
All figures are in NZD, and rounded to the nearest $100.										

In order to be successful, the exported product would need to have a competitive edge over the local product, such as better pricing and/or quality. Destination markets are likely to have far different building regulation requirements compared to New Zealand. This could make the houses cheaper to build if requirements are less (for example, lower seismic requirements) or more costly (for example, cold climates where higher requirements for insulation in envelope components is standard). The viability of exporting houses depends on whether the New Zealand producers can effectively compete with local competitors in the export destinations.

3.4.5 Maximising a factory's throughput

Factories undertaking offsite construction can offer their services to external clients as well as undertaking the standard design-build contracts. Conversely, a builder need not front up with the capital for a factory if they can commission the work to be done through an existing factory. This type of business set-up exists overseas.

Often, German offsite construction firms do work for others as well as themselves. Precutting, prefabricated framing or panels and architect-commissioned jobs (houses, educational, industrial and commercial buildings) are also done by many factories to keep a continuous workflow. Many factories also manufacture retrofit façades for older energy-inefficient housing stock that is being refurbished – particularly concrete apartment blocks.

The advantage of taking on work from other companies is increasing the throughput and revenue of the factory while reducing the overheads for each individual job. Down

[9] Personal communication, Daniel Hepburn, Online Logistics, 7 February 2014.

time can be reduced and the cost of the equipment and site overheads spread out over more projects.

The disadvantage of taking on work for other companies is reduced flexibility to take on urgent jobs and potentially dealing with clients who may not fully understand the clearly defined design process of prefabricated construction when they commission the work (Zunhammer, 2013).

3.4.6 Research and development

There is room for New Zealand's construction industry, both offsite and onsite, to move into more collaborative relationships in order to further research and development. Indeed, part of the success of the German and Austrian prefabricators has been their willingness to collaborate with academia and materials suppliers and their push for quality and innovation even if the profitability of doing so was unclear.

New Zealand's construction industry has historically been fiercely protective of its business models and intellectual property to preserve its businesses and markets. However, the industry appears to be moving towards closer relationships as the benefits of collaboration are realised. While many of these are multiple-disciplined project teams, industry groups are beginning to emerge, such as BuildOffsite UK in the United Kingdom (BuildOffsite, 2014), PrefabNZ in New Zealand (PrefabNZ, 2014), and prefabAUS in Australia (prefabAUS, 2014). These groups bring together a diverse range of people involved in prefabrication in some shape or form, including manufacturers, materials suppliers, designers, engineers, researchers, clients and government, and act as a hub for information and networking.

There are four key areas that New Zealand's design and construction industry believes are inhibiting the uptake of offsite construction – misperceptions surrounding the end product, difficulty connecting with clients to increase the market size, getting innovations to market and spreading technical knowledge to increase the awareness of offsite construction as an option (PrefabNZ, 2014).

3.5 Standards and compliance

There is opportunity to incorporate standardised details used for offsite construction to help mainstream the process, reduce design and compliance costs and encourage the broader architecture and design fraternity to consider its use. This, in turn, offers the opportunity to introduce more rigorous standards for higher-performance housing as higher energy efficiency and comfort standards can more practically be achieved in a factory setting with high precision and tight quality controls.

The development of standards and building codes has historically been onsite-centric for New Zealand. This, plus the perceived expense of using non-prescriptive Building Code compliance paths (Alternative Solutions) has inadvertently discouraged the use of non-traditional construction methods and systems. The length of time required to develop a standard or for a new system to be mainstream enough to include in the Building Code means that innovation is inadvertently discouraged by the regulatory system.

The current consenting regime, with multiple onsite visits from the local building consent authority, is perceived as a major difficulty for offsite construction. Some within the industry have indicated that this is particularly difficult where the house will be assembled in another BCA's jurisdiction. While a BCA must accept another's compliance consent, it appears some companies deem it necessary to pay to bring in a consents officer from the destination BCA to ensure timely navigation of the consenting process through both councils. In addition, construction phase checks by BCAs that create even short delays to the production line are costly in such a rapid process.

The German offsite construction industry has navigated around this issue by introducing strict industry standards and auditing schemes. Rather than relying on local councils for inspection, a factory is accredited and independent audits are carried out to ensure projects are built to standard. If they are not, the factory loses its accreditation and effectively cannot sell their product until it is regained.

There are three levels of standards in the offsite construction market in Germany at present:

Figure 43: The RAL certification shows the building materials meet the minimum German standards.

- The U mark shows that the material complies with the minimum standards of the country.
- RAL (German Institute for Quality Assurance and Certification) certification, as shown in Figure 43, is a basic quality label for the offsite construction industry. It certifies that the operations and production are regularly inspected by independent assessors and that the technical quality of the products meets requirements.
- QDF certification is currently the most comprehensive quality label in German prefabricated housing. It sets the highest standards for construction, including much higher energy-efficiency standards than required by law. There are a set of minimum criteria that must be met for certification. These include basic covered storage facilities and workstations, incoming material quality checks (such as timber moisture levels), sufficient equipment, training, appropriate specification, documentation, reporting and fault management. Independent assessors audit the factory twice and onsite once per year.

Perhaps the most interesting thing about these quality marks is that they were introduced by the industry for the industry. The focus on innovation and quality has meant that demonstrating quality gives a company a competitive edge. This leadership of the industry in terms of energy efficiency is also reflected in the operational performance of the products as is discussed further in section 3.6.

The German example shows how the prefabricated housing industry developed a compliance regime that worked. In New Zealand, the compliance regime has been built with traditional onsite construction as its primary focus, which is reflected in some of the difficulties faced by offsite manufacturers. Alternative models of compliance should be explored that will promote equality between the onsite and offsite compliance requirements and encourage innovation and evolution in the sector.

3.6 Quality, precision, energy and the environment

High-precision and quality construction is a simple way of ensuring that homes perform well in energy and environmental stakes. For example, precise construction enables better control of the indoor environment by controlling the number of air changes per hour. Ensuring quality installation of insulation leads to the highest possible R-value for the system being used.

This higher control of the indoor climate has resulted in a greater ability to control energy used for space conditioning overseas. In Germany, the construction industry has actively worked to reduce the energy consumption of their buildings and has created aspirational standards that assist with marketing to clients. This has encouraged the government to make five decreases to the maximum acceptable energy consumption of new builds since 1977, as shown in Figure 44.

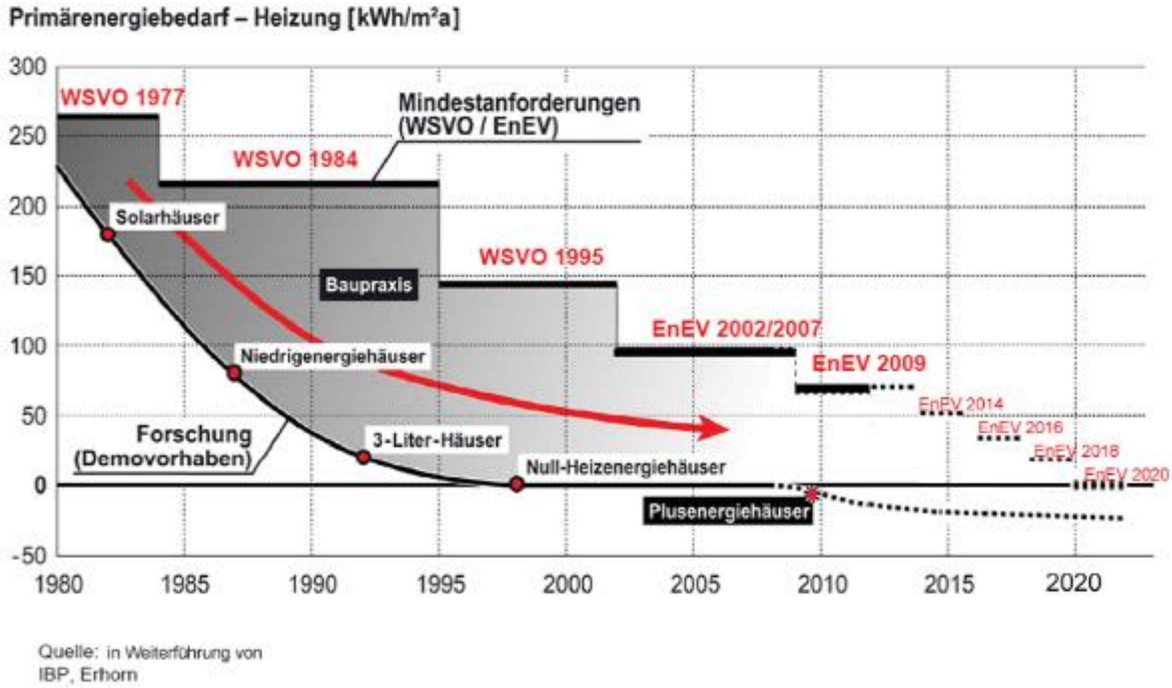

Figure 44: The changing energy standards over time in Germany. Maximum energy consumption levels mandated by the German Government are shown in the steps, while aspirational standards implemented by the industry are shown in the lower curve (Windsheif, 2013).

The potential to improve the thermal envelope is limited by practicality and cost, so many of the industry standards began including renewable generation as part of the aspirational standards. While this does not reduce the energy consumption in itself, it ensures that at least some of the consumed energy is generated onsite using renewable sources. The most ambitious energy standard to date is the Plusenergiehauser, or Plus Energy Houses, which requires homes to generate more renewable energy per square metre per year than they consume. This has clear environmental benefits from reducing non-renewable energy generation on the grid. There are also social benefits in terms of improved health and comfort of occupants resulting from the improved thermal performance and reduced utility costs for the life of the house.

Comparatively incremental changes have been made to New Zealand's thermal efficiency requirements since insulation became mandatory in 1978. The biggest change has been the inclusion of double glazing in non-thermally broken aluminium frames as a minimum requirement for glazing thermal performance under the Acceptable Solutions for clause H1 *Energy efficiency*. This is in part due to having a warmer climate paired with a focus on cost-benefits as opposed to comfort and environment. Another aspect to consider is the lower potential for thermal improvement in the traditional construction systems and techniques that are currently dominant in New Zealand.

Currently, New Zealand's ability to build houses of high energy standards, including Passivhaus, is constrained by both the standard construction systems and the degree of precision to which the houses can be constructed.

In terms of construction systems, the thickness and thermal bridging of the standard nominal 100 x 50 mm timber frame for walls limits the potential construction R-value and thus thermal performance of a house. As this is the dominant type of construction, the New Zealand Building Codes have historically been formed with a view to maintain the viability of the most common systems rather than for the industry to use a construction system they are not familiar with.

It is far easier to ensure a precise build and find weaknesses in an airtight envelope in a factory setting with the appropriate tools and quality checks in place.

It is essential for highly airtight homes to have well designed and adequately sized balanced ventilation systems in constant operation in order to get rid of indoor moisture and pollutants. It is not enough just to make a house airtight, as not all occupants use extraction devices and not all occupants open windows for natural ventilation throughout the week.

New Zealand's offsite construction industry would be well placed to lead the creation of standards and introduce their own quality schemes. This sort of set-up would effectively incentivise innovation and encourage healthy competition. However, it requires large-scale buy in to be successful. In addition it is imperative that the scheme can be well policed to ensure the quality of set-up, operation and output of member factories.

4. CONCLUSION

Offsite construction, if done properly, offers one way to improve the value for money, quality, speed and productivity of residential construction in New Zealand. There are many potential benefits, but there are also many implications to consider for interested stakeholders. It is clear that offsite construction, including panellisation, is a complex topic. This report has sought to explore the various facets of panellised prefabrication in an effort to encourage a more in-depth consideration of offsite construction.

Part 1 of this report has investigated the characteristics of the New Zealand residential construction industry and what it is building. The industry is dominated by small traditional onsite construction companies with low rates of specialisation in new housing. Low capital and constant changes in work typologies dis-incentivise innovation and up-skilling.

Timber framing is the dominant construction type, and there is a market preference for brick veneer or weatherboard walls, sheet metal or tile (steel or concrete) roofs and concrete slab floors. The current architectural trends for aesthetics and materials are broadly compatible with panellised construction.

Being a manufacturer of houses is evidently very different from being a traditional New Zealand house builder. However, at the same time, the types of construction that can be produced in the factory are not that different from what is currently being built onsite with traditional methods.

The second part of this report has looked at the potential and implications of panellised offsite construction for New Zealand's residential construction industry in its current form.

Panellisation has the potential to improve the quality and value for money of output for clients through enhanced quality assurance processes, better protection of materials and workers, higher precision and task specialisation by factory workers. Panellised offsite construction is generally far faster than traditional onsite construction due to the elimination of site factors and weather delays and improved operational processes. The speed also depends on the types of equipment and levels of automation.

With Germany's panellised prefabricators averaging seven people in size, it is likely that a similar number would be required to operate efficiently and effectively in New Zealand. This number of employees constitutes a medium-sized construction company in New Zealand. This suggests that small companies may have to grow, merge or form cooperative ventures in order to reap the maximum benefits of offsite construction. Changing to managing or working in a factory may not be attractive to all builders, and there will still be a need to maintain traditional crafts-based builders for alterations and renovations.

The way that panellised offsite construction projects are run is different from onsite construction. There is a necessity for the design team to engage with the manufacturer far earlier than with traditional onsite construction. This reduces the practicality of competitive tendering and promotes preferred supplier arrangements and broader design committees.

The current generation of architects and designers have predominantly worked with traditional onsite construction and often are unfamiliar with the intricacies of the offsite construction process. It is common for manufacturers to have to teach interested architects and designers about the process, including the extent of detail required for what are effectively production drawings. Time pressures on projects and lack of understanding of the upfront requirements often do not permit the design fraternity to make the foray into offsite construction. A failure to utilise it in one project, or a fear of the unknown, may lead to a reluctance to use the process later on. In terms of the next generation of architects and designers, there is room to include more on the process of offsite construction in tertiary education.

The amount of value added to the materials offsite complicates the financing of projects. Traditional mortgages cannot be applied until the house is assembled and connected onsite. This is a major barrier for the 60% of households building a new home that require finance, unless the manufacturer has the ability to step in to provide it. This, however, ties up capital that could otherwise be reinvested into the company.

Effective and affordable marketing is essential for generating and maintaining the required workflow of a factory. This is even more important for new companies, which cannot rely on the traditional 'word of mouth' advertising. The focus needs to shift from advertising the process to advertising the product, otherwise the stigmas associated with prefabrication from the past will continue to hold the industry back.

The New Zealand residential construction industry as a whole focuses on minimising cost for competitive advantage, while the market appears to prioritise quantity in terms of floor size over housing quality. There appears to be vast scope to use quality as a competitive advantage, both to compete within the offsite construction market and to compete against traditional onsite construction.

Another competitive advantage that panellised offsite construction can offer is the certainty of outcomes – due to the higher amounts of upfront planning, the ability to fix the construction cost of a project is far higher than traditional onsite construction. Rapid production also reduces price volatility in material and labour prices during each project.

The German example has shown the importance of planning when it comes to maximising the success of factories. Germany has had 60 years of development and innovation to advance the industry to where it is today. In order to move to panellised offsite construction, New Zealand's construction industry would need to learn and adapt these lessons in a fraction of that time in order to be of benefit in the current upswing in production.

The section on factory planning looks at a number of critical aspects that need to be considered before a company commits to moving production offsite. The ideal set-up for a company depends on what is being made, how much is being made, how it is being made and where the target market is based. Part of this includes detailed cost-benefit analyses for different extents of set-ups to ensure the amount of investment and operational expenses are appropriate for the expected workload and return over the long term.

An industry transition towards offsite construction will need to be managed carefully to avoid exposure to overinvestment and a resulting failure of businesses once the current boom ends. This is particularly important from a market point of view, as the failure of multiple businesses within a short period of time may raise concerns surrounding the liquidity of others in the industry.

For an offsite construction industry to flourish, it will be critical to supplement the standards and reduce the compliance barriers that hinder offsite construction in general in New Zealand. Ways this could be done include incorporating offsite construction details into what are currently onsite-centric building regulations and standards. This is an area where the New Zealand construction industry could take the lead to provide solutions tailored to their needs. Introducing aspirational standards, as the German industry has done, would let the industry lead the evolution of regulations and help to incentivise innovation and promote competition on the basis of aspects other than just cost. In addition, broader implications include the need for more inclusive standards, and how to demonstrate quality and performance benefits to clients.

The current construction boom, arising from backlogged new housing demand, presents an ideal opportunity to both conduct the research and for parts of the residential construction industry to make the transition. For those who do wish to transition to panellised offsite construction, the compression of the equivalent of 60 years of research and development into the short term will be necessary for the development of strong business plans.

This work has uncovered several key areas where there are large information gaps that need filling.

4.1 Further research

- There is no information available surrounding the cost-competitiveness of offsite construction in comparison to traditional onsite construction in New Zealand at present, let alone for different sizes of set-up and different degrees of automation. While offsite construction can compete with or exceed traditional construction in areas of quality and speed, the present focus of the market is on cost. This information gap means that there is too much uncertainty and therefore risk associated with investing in a move to offsite construction for most construction companies.
- The building industry would benefit from standardised details for connections that are readily accepted by building consent authorities – panel to panel, module to module and panel to module. This would reduce the cost to prefabricators of having to develop their own details, then pay for engineering reports every time they are used. This work could be presented to both industry and the public as a demonstration project in order to shift the focus of prefabrication away from the process and onto the end product.
- Offsite construction particularly suits building projects on sites in dense urban environments. Its potential with respect to 'affordable' housing and medium-density housing solutions is yet to be quantified for the New Zealand context.
- If offsite construction is to be considered as part of the quest to provide 'affordable' housing, the difficulties of securing bank mortgage lending for the construction phase will need to be addressed. At present, lending tends to be

onsite-centric, like the Building Code. Houses built offsite usually cannot be financed under a construction loan until they are placed onsite. This is in part due to complexities surrounding ownership of the materials and structure when the house is in the factory. For panellised homes that are delivered on a JIT basis, the impacts are likely to be less than for transportable homes because multiple deliveries of goods to site may be financed as milestone payments. Where milestone payments are not possible or viable, this usually leaves manufacturers to step in and provide the finance for the construction phase. Companies with little capital are likely to be unable to provide this as a service, narrowing their market to the 40% of households commissioning a new home that do not require finance (Sharman, 2014). The impact of financing difficulties on the uptake of offsite construction is currently unquantified, and alternative ways of financing these types of build are not common knowledge.

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