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Prefabrication and standardisation potential in buildings

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Preface

This is a report on the current use of standardisation and prefabrication (S&P) in New Zealand buildings, the potential for additional use, barriers and drivers of uptake. It builds on earlier work at BRANZ on environmental and cost issues of prefabrication in the housing sector. This work extends the research to non-residential buildings, issues raised by the fabricators, and consideration of hard-to-quantify factors such as quality.

Acknowledgments

This work was wholly funded by the Building Research Levy.

Note

This report is intended for designers, contractors, manufacturers and prefabricators to promote the advantages of S&P.

Prefabrication and standardisation potential in buildings

BRANZ Study Report SR 312

Ian Page, David Norman

Abstract

The extent of existing use of prefabrication in New Zealand buildings is discussed. Prefabrication and standardisation (S&P) are both generally thought to have benefits in building construction, but quantifying these benefits has proved difficult. The initial cost when using S&P will not necessarily decline from traditional methods of construction. Instead, benefits such as quicker construction, savings in the use of standardised panels and modules, and better product quality are seen as the main potential benefits. A method for combining these hard to quantify savings with costs is discussed. The potential for further use of prefabrication and standardisation is analysed by building type and component. This finds that the amount of prefabrication could be increased to more than $5 billion per year, while $2.7 billion of standardisation could occur. These two figures are not additive, as they overlap, but this indicates that the overall S&P potential is somewhere between $5 billion and $7.7 billion.

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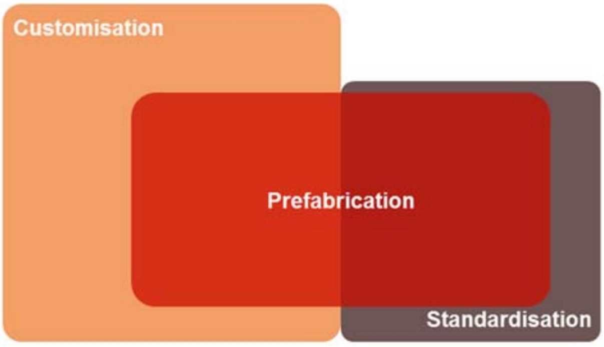
1. EXECUTIVE SUMMARY

This report estimates the current uptake of prefabrication in residential and non-residential building in New Zealand, sets out some obstacles to improving uptake of standardisation and prefabrication (S&P), estimates the potential for increased S&P, and highlights some ways to encourage S&P through pointing out the benefits they offer.

Standardisation is the repeated production of standard sizes and/or layouts of components or complete structures. Examples include modular bathrooms, standard kitchen cabinet sizes, standard prison cell or classroom designs, standard window sizes or wall panel sizes and finishes. This repeated production of identical components or structures may occur on-site (in which case it is simply standardisation), or it may occur off-site (in which case it is also prefabrication).



Prefabrication is the off-site production of standardised or customised components or complete structures. Examples may include pre-cutting and pre-nailing of wall framing and roof trusses, or off-site construction of wall panels, or bathrooms, whether they are standardised or customised. Prefabrication may be for bespoke (customised) components and structures (in which case it is simply off-site production) or standardised components and structures (in which case it is also standardisation).

We estimate that around **$2.95 billion of prefabrication currently occurs** in New Zealand each year, most of which is in the area of wall and roof framing. A limited amount of standardisation occurs. Yet, based on the components of buildings that can be prefabricated relatively easily, we estimate that up to **$5 billion of prefabrication can be done** each year, an increase of $2 billion. **Standardisation has the potential to reach $2.75 billion a year**. There is an overlap between S&P, meaning the potential for S&P is likely to lie between $5 billion and $7.7 billion a year.

Benefits occur right across the value chain. The **home buyer** benefits through a reduced build time, increased time and cost certainty, and through improved value for money and fewer defects. The **builder**, large or small, benefits through fewer weather disruptions, and when demand for building services is high, is able to complete more projects per year. More S&P also reduces the number of contracts the builder will have to manage, defect call-backs, and on-site accidents. The manufacturer increases the opportunities to add more value and increase profits on-site.

But there are **barriers** to the uptake of S&P, identified in our discussions and with the industry and through an international literature review. Many of these are linked to **misconceptions about S&P**, often based on negative connotations of how this was done 30 years ago. Further, different players in the value chain, whether designers, builders, or home purchasers often don't see the value to them of increased S&P. A move to greater S&P would also require on-site workers to improve skills in order to handle and assemble panels correctly. Some builders believe more S&P would mean less work for them although in many cases it would simply mean many of the “outdoor” construction jobs may move into weathertight prefabrication facilities.

Despite these perceived challenges posed to uptake of S&P, there are several manufacturers producing panels, modules and complete buildings off-site. With workloads in Christchurch and Auckland forecast to increase significantly, builders are considering further prefabrication associated with housing and several initiatives have been announced recently. The role of S&P is expected to rise and the challenge will be to maintain and further extend the use of S&P after the boom in the two centres subsides.

In the non-residential sector, standardisation occurs in industrial, hotel and school classrooms and more is possible, which also favours more prefabrication assuming sufficient workloads are available. While many non-residential buildings are one-offs with limited opportunities to use standard panels and modules, opportunities for health, corrections and retirement facilities do exist. Uptake is often driven by the constraints put on the contractor, including time, site, and lack of skills

Boosting uptake of S&P will require a holistic approach that incorporates a focus on:

- **Awareness**: Perhaps the biggest challenge to be overcome, more needs to be done to help all players in the value chain appreciate the benefits S&P offers them.
- **Procurement and process**: All the literature, and local experience, says that early involvement of the designer, fabricator and contractor in any particular project enables the benefits of S&P to be better realised. Other stakeholders such as lenders, insurers, planning and building control authorities also need more involvement.
- **Benchmarking**: The real-world benefits of time, quality, health and safety, and sustainability improvements through greater use of S&P need to be highlighted and the findings disseminated as they are often hidden and not fully appreciated by the industry.
- **Training**: An understanding of the techniques and precision involved in prefabrication is essential both off-site and on-site. There is a need to train staff on the longer-term benefits of prefabrication and to reduce staff turnover by promoting a holistic approach to innovation.

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2. INTRODUCTION

This study builds on work previously done by BRANZ on potential prefabrication benefits in New Zealand buildings (Burgess, et al., 2013). That report looked at a typical small house and the environmental and cost impacts of four types of prefabrication:

- Components
- Panels
- Modules
- Complete houses.

Its emphasis was on demonstrating potential cost savings and reduction in waste and carbon emissions through more use of prefabrication.

This report identifies the various types of building work typically done in New Zealand and each building type is assessed for its current prefabrication uptake, and potential standardisation and prefabrication (S&P) potential.

We look at four questions with regard to S&P in the New Zealand building industry:

- What is the current uptake of prefabrication in New Zealand?
- What are the obstacles to uptake, and who makes the decision between S&P and traditional construction?
- What potential exists for S&P in New Zealand?
- What is the value case for S&P and how can intangible factors be included in the decision process?

First, we present a model measuring the uptake of prefabrication.

Next, we discuss who makes the decision to adopt S&P, including the results of a number of interviews we have undertaken. These case studies of who makes prefabrication decisions are presented.

Through a literature review, we identify the obstacles to adoption of S&P cited internationally, before estimating the potential S&P market size if these obstacles can be overcome in New Zealand.

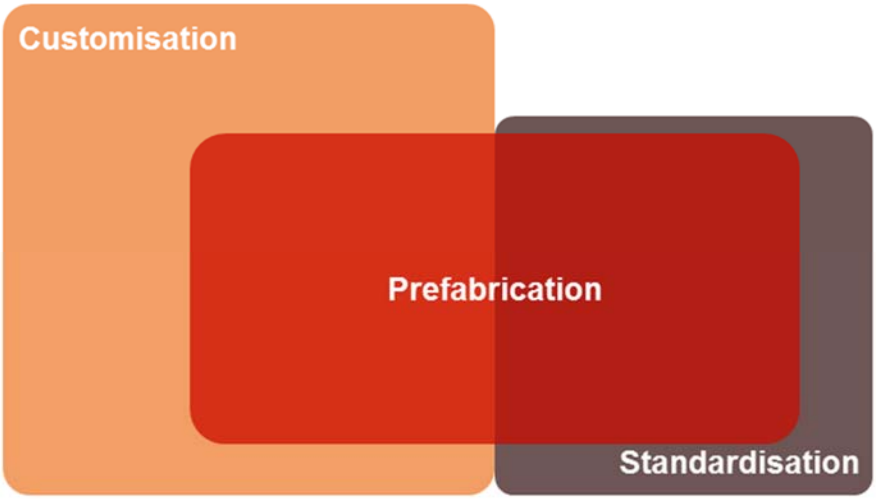
Finally, the research considers the benefits beyond cost savings, such as quality, safety and time certainty. How can these hard-to-quantify benefits be combined with cost saving when deciding between S&P and traditional construction? A technique called weighted evaluation, which can be used at project or firm level, is discussed, and a strategy for boosting uptake of S&P is set out.

2.1 Defining prefabrication and standardisation

To differentiate between standardisation and prefabrication, it is helpful to introduce a third term – customisation.

Figure 1 shows the relationship between the three terms.

Figure 1 The relationship between customisation, prefabrication and standardisation



Standardisation is the **repeated** production of **standard** sizes and/or layouts of components or complete structures. Examples include modular bathrooms, standard kitchen cabinet sizes, standard prison cell or classroom designs, standard window sizes or wall panel sizes and finishes. This repeated production of identical components or structures may occur on-site (in which case it is simply standardisation), or it may occur off-site (in which case it is also prefabrication).

However, in New Zealand, most buildings are bespoke (customised), whether they be residential or non-residential. Work by BRANZ suggests that even when houses based on standard house plans built by the major building franchises are chosen for a new-build, there tends to be significant customisation. **Customisation**, then, is the opposite of standardisation, and has typically been the norm in New Zealand, even when it comes to window sizes, bathroom layouts and other components that one may expect could be produced in standard sizes or layouts. Customisation may occur either on-site (in which case it is simply a customise build) or off-site (in which case it is also prefabrication).

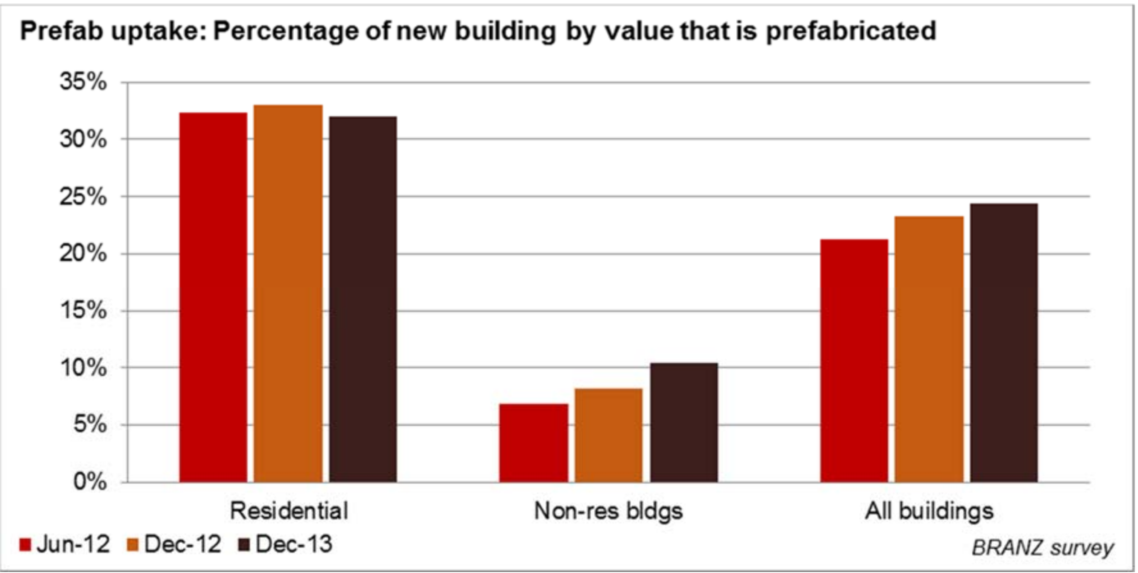
Prefabrication is the **off-site production** of standardised or customised components or complete structures. Examples may include pre-cutting and pre-nailing of wall framing and roof trusses, or off-site construction of wall panels, or bathrooms, whether they are standardised or customised.

These definitions help explain that the estimates of the potential for prefabrication and standardisation presented in this report are not additive. Some standardisation may be done off-site (prefabrication), but other standardisation (such as the same floorplan being used for side-by-side townhouses) may be achieved on-site.

3. PREFABRICATION IN NEW ZEALAND: MEASURING UPTAKE

BRANZ is monitoring the uptake of prefabrication through the regular materials survey. Questions are included in the survey on use of prefabrication by building component. Trends are shown in Figure 2.

Figure 2 Trends in uptake of prefabrication



The analysis is based on assessing buildings by component. The component share of total cost for each building type is derived from breakdowns provided in Rawlinsons New Zealand Construction Handbook 2012. The BRANZ materials surveys disclose the share of prefabrication for each component, including pre-cutting and nailing, and prefabricated wall and roof claddings. Building consents data are used to scale up the value of work so that the value of prefabrication in new housing, housing alterations and additions, and non-residential buildings can be added to together to give an estimate for the vertical construction industry.

The boundaries of prefabrication as defined here are somewhat arbitrary. The aim is develop a measure than can be used to follow progress in uptake of pre-fabrication, rather than derive a total dollar value for all prefabrication.

Figure 2 suggests that uptake is increasing gradually, but further survey results are needed to confirm this trend. Note, earlier measures of uptake reported in Burgess (2013) had lower percentages because some components, namely windows and joinery, were omitted, but these have been included in Figure 2.

An estimated $3 billion worth of prefabrication was implemented in the 2013 calendar year.

The details of the analysis are in the appendix, including a component and building type breakdown in Figure 10. By this estimate, **around $2.95 billion worth of prefabrication**, mostly in the form of wall framing, roof trusses, windows and joinery, **was implemented in the 2013 calendar year**, or 25% of the value of all consented building projects in that year. This indicates the market is already relatively substantial, but limited to a small number of components.

4. PREFABRICATION OBSTACLES AND DECISION-MAKING

This chapter considers the **misconceptions and obstacles** related to S&P that are highlighted internationally, some of which overlap with what we learned in New Zealand.

We then discuss who makes the decision to adopt prefabrication at this time in New Zealand. Discussions were held with prefabricators and builders on their understanding of how prefabrication is chosen for individual projects at present in New Zealand.

4.1 Literature review: Obstacles and international uptake

There are a large number of research reports on use of S&P in buildings. This review examines selected studies from the United States (US) and the United Kingdom (UK) with the aim of identifying what factors beyond costs are considered in the choice between S&P and traditional construction, and what are the barriers and opportunities.

The UK Construction Industry Research and Information Association carried out a major case study survey of construction clients on the use of S&P and their understanding of advantages and disadvantages. The results reported by Gibb (2001) identified misconceptions, applications, and lessons from use of S&P:

- **Misconception One**: "Houses are like cars". i.e. that a factory production process is applicable to housing. Their response, in brief, is that this is only partly true. Houses are fixed and erected spatially apart which means the industry needs to be mobile with a "virtual" factory at each site to which machines, people and materials are transported. In contrast, production line manufacturing has dedicated worksites, unchanging supply lines and specialised workers and it is the end product that moves during assembly. This can be done for components and panels but is more difficult for modules and complete houses.
- **Misconception Two**: Maximum S&P is always best, but this implies stable demand and limiting choice, which is unlikely to occur for an extended period.
- **Misconception Three**: Standardisation means "boring". There are examples of where standardisation has produced uninteresting buildings. Conversely the author note that Georgian residential design is attractive, (as are villas in New Zealand). Also, components may be standardised but not the building in a "customised" design.
- **Misconception Four**: Pre-fabrication is always cheaper. Often economies of scale were not realised so pre-fabrication will not necessarily be cheaper, but other benefits such as quality control and time certainty can be more easily realised.
- **Lessons and applications**: Clients want choice and some customisation, they accept that one-off products are likely to cost more, and they are interested in the end product, not the construction process, so prefabrication is not necessarily an advantage or disadvantage in their mind. On-going performance is as important as initial appearance.

A number of misconceptions as to the value of S&P exist on both sides of the argument.

Aldridge et al (2001) undertook a project at Loughborough University, UK, on the evaluation of the benefits of S&P. Benefits were identified in four main categories:

- **General benefits** such as reduced total costs, reduced overall project time, greater certainty of cost and time, better quality, fewer accidents, reduced waste.
- Benefits **specific to the standardised process** (whether for mass-customisation or mass-standardisation) include reduced design costs, simplified construction processes and work schedules, clarity of roles, fewer contracts, and ability to reproduce projects.
- Benefits **specific to use of standardised components** include manufacturer input into the design process, standardisation aids prefabrication, reduced delivery times, secure supply chain, consistent quality of components, reduced need for assurance checks.
- Benefits **specific to prefabrication** include reduced on-site time and storage space, quicker on-site weatherproofing, removal of difficult processes from site to workshop, fewer on-site interfaces, fewer on-site defect repairs, fewer persons on-site.

Many of the benefits of S&P are difficult to quantify in dollar terms.

The report noted that many of these benefits are difficult to measure, and decisions to use S&P are often based on anecdotal evidence rather than rigorous data. The authors advocate tools and techniques for assessing the benefits, either quantitatively or qualitatively. These include benchmarking and KPIs, health and safety measurement tools, human resource measures (e.g. turnover, job satisfaction, career development), risk assessment, quality management, lean construction, value management, cost-benefit analysis, and supply chain management.

Blismas et al (2006) examined new building projects where comparisons were done between traditional and prefabrication methods of construction. The research aimed to find what factors were considered in the comparisons. Both cost and difficult-to-measure factors were included. The proposition was that **current evaluation methods** for prefabrication **are cost and not value-based** and therefore do not account for all the benefits of prefabrication. Six projects, mainly commercial buildings, were analysed and the inclusion, or not, of 16 factors were tabulated.

The research found only one project considered a range of factors, namely seven out of the 16 possible factors identified by the researchers. For all six projects the average number of factors considered was 3.5 for traditional construction and 4.5 for prefabrication construction. There were inconsistencies within some projects with some factors such as design costs considered for prefabrication but not for traditional construction.

Pan et al (2008) examined prefabrication in the UK house building industry. They found the structure of the industry is fragmented, with many small scale builders (only 200 firms built more than 50 homes per year) and a mix of builder types. These ranged from firms providing the complete package (land, design, supply arrangements, all labour) to developers with no construction capability and 100% sub-contracting. There was **little**

sharing of knowledge on prefabrication and standardisation technologies. The main focus of management was on profit levels and control of finances rather than the construction process. A survey of the major house builders used a five point scale (never, rarely, sometimes, mostly, always) for use of prefabrication by component. For most components, the average use was between "never" and "rarely". Highest use was for internal drywalls, upper floor precast beams and precast piles at an average of "sometimes".

It is apparent the **overall quantity of prefabrication is low in UK housing**. The best opportunities were seen in kitchens and bathrooms, external walls, timber framed structures and roofs. Complete modular buildings were not seen as having much potential. Traditional procurement (fixed price from plans) still dominates in UK house building, making incorporation of prefabrication into the early design stages difficult to achieve.

The report found the **drivers for prefabrication**, where it is used, **are quality, construction time, time certainty, reduced health and safety incidences**, bypassing skill shortages, and cost certainty. The barriers seen by most respondents were high initial cost, uncertainty about the economies of scale, the joining of components, and possible planning and building regulation challenges.

The drivers for prefabrication are quality, construction time, reduced health and safety incidences, bypassing skill shortages, and cost and time certainty, rather than lowest cost in a simplistic sense.

Tam et al (2007), looked at the potential for prefabrication by component, for four types of building work in Hong Kong. A total of 23 building components were considered and respondents were asked to assess each component for four levels of prefabrication, namely conventional (i.e. no prefab), semi-prefabrication, comprehensive prefabrication and volumetric prefabrication. **Effective levels of prefabrication were identified for structural steel frames, external cladding, concrete wall and floor panels, washroom, and internal walls, i.e. the full range of prefabrication was found to be applicable**.

In the US, a report commissioned by the National Institute of Standards and Technology (SmartMarket Report 2011) examined current usage of S&P, benefits and barriers, and expected future uptake. Between 74% and 90% of architects, engineers and contractors used some prefabrication at the time of the survey (2011). Among users, the volume of prefabrication is quite low with **only a third of users reporting a high level of prefabrication** (defined as some prefabrication on at least 50% of their projects).

The main **reason given for not using prefabrication was that the architect did not specify it**, and the latter blamed owner resistance to prefab. Current and expected future use of prefabrication had the best potential in health, education, factories/ warehousing, low-rise offices and hotels. A net 24% of respondents said prefabrication improved safety. Material use was reduced by about 4% and site waste by about 6%

using prefabrication. Project cost savings of about 6% were reported, compared to traditional construction methods.[1]

The Canada Mortgage and Housing Corporation (2006) commissioned a report in 2006 on factory-built housing. It found 7% of housing in Canada was factory-built (defined as complete house, modules, panels, pre-cut/engineered components, and log.) It appears that trusses and frames are included in pre-cut/ engineered components and the numbers of these are low at about only 1.5% of all new housing. Modular homes are higher at 3% and complete homes about 2%. Panels (mainly one side opened) are low at about 1%. The reason for the low use of prefabrication appears to be tract builders (in new developments) are uninterested. There is general lack of interest in moving beyond stick building for the large majority of builders. Prefabrication is mainly used in remote locations or where construction duration is a critical consideration for a particular project. However the local manufacturers export significant quantities of panels to the USA.

Page (2012) estimated the value of time savings associated with quicker construction in housing using prefabrication. The main results was a saving of about $1,500 per week for larger builders.

In summary, the literature indicates that:

- In the UK, **prefabrication decisions are ad-hoc** and techniques are suggested to measure the benefits of S&P in order to have better evidence for comparisons. They include use of KPIs, safety records, life-cycle costs, job turn-over data, and quality measures. More detailed items have been suggested but very few of them have been used in actual comparisons for specific projects.
- The UK house building industry has a similar distribution of firm size to that in NZ (a few large firms and most construction done by smaller firms) although numbers are larger. Use of prefabrication is low with **start-up costs and economies of scale seen as the main barriers**. Potential is seen in kitchens and modular bathrooms.
- In Hong Kong, greater use of prefabrication in commercial buildings was expected in steel frames, cladding, floor slabs, partition walls and bathrooms.
- The use of prefabrication is low in the US, with only about 30% of contractors using some prefabrication on the majority of their projects. **Cost savings of about 6% are identified** for these projects, compared to traditional construction, with much of those savings passed on through lower project budgets.
- Canadian use of frames and trusses is surprising low and modular construction in housing is more common, but overall use of prefabrication in housing is low.

This research illustrates low uptake in buildings due to the complexities that make prefabrication and standardisation uptake difficult to promote, including uncertainty about

[1] Note that these are for non-residential buildings and it is likely housing, which is more homogeneous, will potentially have larger savings in costs.

the advantages of prefabrication among designers and builders, and reluctance to change by builders.

4.2 Interviews: Prefabricators

The first prefabricator we consulted is a manufacturer of concrete products for commercial buildings. In their experience, the designer is the main decision maker with regard to concrete, steel or timber structural systems, and the **builder or main contractor decides on prefabrication or in-situ assembly**. We did not interview designers as part of the project, so could not confirm this view independently.

According to prefabricators, the builder or main contractor typically decides on prefabrication or in-situ assembly.

Prefabrication is influenced by required completion time, site conditions and the finish required. For some projects, financing is the critical item after design. Arranging finance is typically a drawn-out process and as funds have already been spent on investigation, sales and design, there is a rush to start and complete on-site construction. Often this means prefabrication is the only option to meet deadlines.

A **reduction in site skills**, e.g. block layers, is also **a factor in the choice** of concrete prefabrication. Repetition and standardisation favours the use of prefabrication. For example, the use of **common window and edge details** on concrete wall panels **enables economies** in production. Further gains are possible in **standardising panel thicknesses** to say 150 mm, 175 mm and 200mm instead of wide variety of precast concrete intervals that are typically used today.

The second prefabricator we spoke to works with structural steel. Almost all steel has some machining and/or welding on steel lengths prior to installation on-site, so **to some extent all steel is prefabricated**. However, **more intensive steel prefabrication is common**. For example, steel portal frames and floor/ roof trusses are common and are partial or completely prefabricated.

The extent of prefabrication (for all materials) is limited due to transportation issues. With steel, this is addressed by the use of steel splices on-site, and **site welding is minimised** as far as possible due to cost. Coordination between the designer, contractor and the steel prefabricator is vital. It is quite common for the pre-fabricator to “drive” the project. He discusses with the contractor how the main frame is to be erected and the fabricators advises the designer where the splices need to be. The Heavy Engineering Research Association (HERA) has a fabricator assurance scheme that endorses certain steel fabricators because they recognise the vital role that fabricators have in delivery of an efficient structural system.

Prefabrication in New Zealand is largely limited to wall frames and roof trusses.

The **exchange of electronic files** of building layouts and design details for any particular project **is common** in the industry i.e. Computer Aided Design (CAD) systems. But this does not operate as efficiently as it could. It appears steel, frame and truss fabricators have to re-produce to some extent the CAD files from the designers because they are inadequate for detailing the junctions. In addition, there are legal issues for the fabricators in that they are contractually expected to have satisfied themselves that the overall design dimensions received from the designers are correct. Sometimes, this involves a complete re-build of the electronic file in CAD. This problem can be overcome with design-build type partnerships, because legal responsibility is shared between parties which ensure cooperation at the design stage. However, most projects still follow the traditional design and then tender route. Other solutions include the Building Information Modelling (BIM) systems being used by all parties and/or a better sharing of risk between the designer and the prefabricator.

In the timber industry, prefabrication ranges from wall frames to completed transportable buildings, including:

- Wall frames typically up to 6 m long and full stud height, including lintels.
- Roof trusses of a variety of shapes and sizes
- Floor panels and semi-closed wall panels
- Completed wall panels including claddings, linings and services
- Volumetric modules, typically of bathrooms
- Small standardised rooms e.g. students accommodation, hotel accommodation
- Complete houses and bedsit units, education rooms, and some other building types.

The **large majority of timber prefabrication** work in New Zealand is on **wall frames and roof trusses**. The third prefabricator consulted is a timber frame and truss prefabricator. He, and most timber pre-fabricators have sophisticated software that analyses load paths and simplifies the sizing of members (trusses chords, lintels, plates and studs) using NZS3604 requirements. The software is not totally "glitch" free and in about 10% of cases manual calculations and adjustments to the software output are required. This software also runs the timber cutting process, and nailing of plates to studs is mainly automated.

The interviewee accepted frame prefabricators appear to have potential to add more value by progressing to open or closed panels (i.e. frames with one or both faces surfaced with cladding and or linings). He was open to the production of exterior panels, especially those with sheet material (i.e. plywood, fibre cement, steel sheet). However, the interviewee saw the potential for more value added as limited. The reasons include:

A number of obstacles to increasing prefabrication in New Zealand were identified.

- **Resistance to panels** from some builders because of **reduced work** for them.
- The **weight of panels**, meaning they may require cranes to put them in place, whereas most frames can be handled by two persons.
- **Difficulty in getting panel junctions correctly aligned**. For example, exterior wall panels need to meet another panel at right angles, to avoid in-plane junctions. Getting the junction detail weather-tight, and aesthetically attractive, is usually more difficult than if cladding is installed in-situ. This difficulty can be mitigated by a level working platform or use of a levelling compound.

- The **fixing of cladding is not easily automated** in the prefabrication process unless sheet materials are used. Brick veneer, the most common cladding, is not feasible for prefabrication. Based on current market shares only about 40% of new housing could use panels with lighter claddings (timber / fibre cement / PVC weatherboard, and plywood / steel and fibre cement sheet).
- **Risk of damage to interior wall panels** with plasterboard linings and services installed as they have to be positioned by crane before the roof trusses are placed, meaning there is risk of weather and handling damage.

The conclusion from discussions with prefabricators is that semi-closed (one-sided) panels are feasible and attractive from the prefabricator's view-point, and that the main barrier is getting builders to request them. This could be achieved by improving awareness of the benefits of S&P to builders, as we discuss later.

4.3 Interviews: Builders

Structured interviews were held with three builders of houses to assess their views on prefabrication, and in particular moving beyond prefabricated frames and trusses.

The first was a small scale builder (four houses per year) with one apprentice. Most of his houses are bespoke and in the medium to high cost range. He would consider additional prefabrication but it would need to be cost-effective for him to change i.e. items delivered as required for a realistic price. Exterior wall panels would be considered e.g. weatherboard and the joints would need to be box and scriber finish. In addition, **part-completed roofs could remove the need for safety netting thereby saving time and cost**.

A second builder (six houses per year) with two other persons is a contractor to a large group builder. Materials and sub-contractors are supplied by the group builder so he has little choice in the construction process. They already have problems in erecting larger windows and he can **foresee problems in handling cladding panels**. He suggests in two storey construction the panel detail for full height walls could be "tricky" as two single storey panels may need to be joined together. In particular, getting weatherboard spacing right may be a challenge.

The NZ Panelised joint venture announced in March 2014 plans to manufacture timber framed panelised walls, floors and roofs. The two parties are Spanbild and Mike Greer Homes, the latter of which currently builds over 500 houses per year, based in Christchurch. Initially the Christchurch and Auckland markets will be supplied. The planned capacity is up to 1,000 houses and buildings per year from a new factory in Rolleston using German fabrication equipment. The venture plans to use the panels in their own buildings and will sell off excess panels to other builders. Exterior wall panels are to have windows, linings light weight claddings (or thin sheet material for on-site brick cladding), stopping and paint finish. Conduits are provided for cabling. Interior plasterboard wall panels are also to be produced with conduits and paint finish. Full wall length panels will be possible though panel sizes will be standardised to some extent and the window range also reduced to about 12 sizes. Some degree of customisation will be possible within the standard range of panels. Advantages are foreseen in **time savings** (typically 5 week savings for a house), **reduced need for skilled labour**, and **purchase of materials and fittings directly in bulk** from manufacturers.

4.4 Current activity among panel prefabricators

There are already some panel systems in use in New Zealand, including reconstituted wood panel systems (e.g. Metra), in which wall panels include openings cut out at the factory.

Prefabricators such as Stanley in Matamata make custom panels, as well as modules (student accommodation, washroom pods, etc.) and classrooms. They emphasise the need for sufficient time to plan the complete construction process for use of prefabrication. As an example, consider the commercial building in Figure 3 where reduced on-site construction time is critical because of disruption to existing activities on the site. The example assumes the overall procurement duration is the same between traditional and prefabrication approaches.

Figure 3 Typical time lines for procurement

Small commercial building (one-off design)					
			Weeks		
	Design & Prefab panels	Consent	Lead time	On-site Construction	Total
Traditional	4	4	1	12	21
Prefabrication	13	4	1	3	21

Because prefabrication allows for such a reduction in on-site construction, the time allowed for design and prefabrication is far higher, at up to 13 weeks in our example. One reason why the time to prefabricate may be substantially less than 13 weeks is that making the panels could overlap with some of the other processes.

Objections from the builders, discussed above, can be overcome, but will require careful planning and attention to detail.

In practice, prefabrication is often chosen because of **shortened time frames**, so the period available for design is less than indicated in the example, but it is **vital to allow sufficient time for design and planning** so that on-site time is reduced as far as possible.

eHome Global produces timber framed panels at its plant in Kumeu including fully clad and lined exterior panels, and interior panels. Erection of stand-alone single storey housing on a slab is typically done in 1 or 2 days including a prefabricated roof. HNZC have contracted with eHomes for 85 houses and house extensions to be delivered over the next two years in Auckland. They also expect their panels to be used in low rise apartments, up to 4 storeys high, in the private sector.

The Home Advantage Group (Hobsonville Land Co, Auckland Council, Building and Construction Productivity Partnership, MBIE and Beacon Pathway) in February 2014 asked for proposals for an off-site housing construction pilot project.[2] The project is to be based in Christchurch and an at-scale pilot of 300 to 500 homes is planned to prove the business model. The aim is to provide affordable and sustainable housing. It is possible above code sustainable features will be included within the houses and some financial assistance may be provided to owners, though these details are yet to be announced. It is possible that some of the output from the NZ Panelised venture will be used in the pilot.

There are also other panel systems such as Autoclaved Aerated Concrete (AAC), Structural Insulated Panel (SIP), and Cross Laminated Timber (CLT) panels, and the solid wood systems (Lockwood, Touchwood and Fraemohs) which have been used for many years and involve a large amount of off-site manufacturing.

[2] The Home Advantage Group is one work-stream led by Pure Advantage.

5. POTENTIAL TO GROW S&P IN NEW ZEALAND

The previous chapter highlighted a number of opportunities and challenges to growing the use of S&P in New Zealand, with emphasis on housing. This chapter estimates the size of the S&P pie in New Zealand for all building types, if all components that could be prefabricated are put together off-site, or where standardisation is increased. This leads into the next chapter, which discusses how S&P could be encouraged in New Zealand.

5.1 Potential for increasing prefabrication

There are two stages in looking at the potential for prefabrication. First, the potential for prefabrication of each component in a building is assessed by building type. Second, this potential is multiplied by the dollar value of annual consents to estimate the dollar value of the prefabrication opportunity.

The proportion of the cost of each building type that each component represents can be obtained from Rawlinsons (2012). This enables the calculation of the total potential percentage of a building that can be prefabricated. For example, the frame of a hotel building is 5.2% of the total value of the building and most can be prefabricated. The same analysis is done for each element of the building, and a judgement is made as to whether prefabrication is likely to be cost effective and practically feasible. Those components that are feasible are added together giving the percentage of the total cost for that type of building that can potentially be prefabricated.

Consents are almost an exact record of what is built (a small number of consents do not proceed), so they are used to scale up to get the potential size of the prefabrication market.[3]

The potential for prefabrication is the proportion of the build value of each building type that can be prefabricated, multiplied by the total value of each building type put in place in a given year.

Figure 4 shows the prefabrication potential for all of the building types used by Statistics New Zealand. Rawlinsons data was used to find the percentage of the total value for each building component that makes up each building type. Each building component was then assessed to determine whether it could be prefabricated, could be partly prefabricated, or could not be prefabricated. The percentages for the elements that could be prefabricated were added together to show the potential for prefabrication of each building type (by percentage of total building cost). For example, 45% of the total cost of stand-alone houses are judged to be suitable for prefabrication.

We used 2013 calendar year consents data to estimate the potential total value of building components that could be prefabricated in a year (appreciating that the mix of different building types produced in any year can vary significantly, especially for non-residential building types).

[3] See the appendix in the back for the detailed analysis of prefabrication potential by building component.

Figure 4 indicates that two types of building have potential for high percentage of prefabrication content. The first are utilitarian buildings without much finish, e.g. warehouses, factories and prisons. The second type are fairly high-spec buildings which have some repetition in their spaces e.g., apartments, education buildings, supermarkets hospitals, and fast-food restaurant chains.

Figure 4 Prefabrication potential by percentage, 2013 consent values

Potential for prefabrication Statistics NZ types and coding	Potential Prefab %	Prefab $M
101 House - not attached to other	49%	$2,773
103 Apartment block - attached vertically (10 or more units)	75%	$243
770 Office and administration	63%	$234
551 Warehouse	73%	$177
352 School facility	73%	$170
102 Unit/Flat/Townhouse/Studio - attached & unattached horizontally	51%	$157
601 Factory	70%	$152
204 Prison dormitory	71%	$118
103 Apartment block - attached vertically (0-9 Units)	60%	$103
751 Retail outlet - shop, hairdresser, travel agent, real estate	46%	$86
569 Other storage buildings	73%	$84
301 Hospital	74%	$83
753 Supermarket	72%	$69
519 Other entertainment, recreational and cultural building	64%	$65
719 Other farm building	40%	$56
354 University	73%	$49
154 Garage	55%	$34
701 Milking shed	40%	$30
353 Tertiary facility - polyt, college of education	73%	$25
302 Rest home - convalescence	34%	$24
605 Workshop - eg. Electrical or vehicle repairs	51%	$23
507 Cinema, theater	64%	$21
619 Other factory and industrial building	68%	$18
219 Other long term accommodation	43%	$17
169 Other outbuildings of residential building	39%	$17
602 Industrial	68%	$16
451 Religious buildings	48%	$13
407 Creche	49%	$13
752 Restaurant, bar, tavern and cafeteria	46%	$12
402 Airport terminal, rail station	50%	$11
501 Museum, art gallery	54%	$11
862 Sewage and drainage system (treatment plant)	59%	$11
251 Hotel	74%	$11

Potential for prefabrication (Continued)		
Building type	Prefab %	$M
304 Medical centre, consulting room, surgery	30%	$10
754 Service station	50%	$10
504 Sports facility, eg. Stadium	54%	$8.9
319 Other health building	36%	$8.8
554 Parking building	66%	$8.5
552 Cool store	62%	$7.3
201 Hostel (school, uni hostel, nurses, etc.)	43%	$7.2
502 Library	54%	$6.4
408 Police station, court house	52%	$6.2
704 Tunnel/glasshouse	40%	$6.1
269 Other short term accommodation	49%	$5.8
705 Covered yards	40%	$3.9
706 Implement shed	40%	$3.9
252 Motel	46%	$3.8
409 Fire station, ambulance station	48%	$3.3
152 Carport - boatshed, car deck	65%	$3.3
351 Kindergarten, playcentre	49%	$3.3
505 Clubroom	40%	$3.3
151 Sleepout	39%	$2.9
506 Gymnasium, fitness centre	52%	$2.9
405 Public toilets	40%	$2.8
759 Funeral parlour, crematorium	53%	$1.8
369 Other educational building	45%	$1.5
606 Research laboratory	36%	$1.4
104 Granny Flat - unattached	50%	$1.4
253 Motor camp facility	35%	$1.4
757 Vet surgery	30%	$1.3
556 Wool store	73%	$1.3
555 Hangar	30%	$1.2
603 Sawmill	39%	$1.1
355 Training building	45%	$1.1
206 Workers quarters	34%	$1.1
604 Freezing works and abattoir and other structures, eg. Covere	35%	$0.9
758 Studio - artist and photographer	34%	$0.7
Total		$5,059
Total excluding houses, apartments and units		$1,784

In total, more than $5 billion worth of prefabrication could have been undertaken in 2013 if all components that are relatively easily prefabricated were. Yet our earlier analysis, in Figure 10, suggests that at present, only around $2.95 billion of prefabrication was undertaken in 2013. In other words, we could conservatively estimate, based on the current mix of residential and non-residential building, an additional $2.1

Based on the current mix of building projects, a further $2.1 billion of prefabrication per year is possible, spread across residential and non-residential projects.

billion in prefabrication is possible today. This $2.1 billion is spread across residential ($760 million) and non-residential ($1.34 billion) construction.

5.2 Potential for standardisation

The same analysis was carried out for potential value of standardisation as was done above for prefabrication. The results are in Figure 3. The individual percentages are lower for each building type, compared to prefabrication. Also the dollar values are lower, as expected, because while standard components can generally all be pre-fabricated, prefabricated components are not necessarily standardised within each category. Even so, the ranking of building types is similar in Figure 4 and Figure 5.

The larger percentages of standardisation potential in the table are for apartments, schools, service stations and flats, and already we see some use of standard components in these building types. In apartments, the standardisation potential is within a building and it is not suggested that the buildings need to look the same, but use of standard components such as common kitchen and bathroom modules is feasible.

Note that these values (of up to $2.7 billion) form a sub-set of the estimate of potential for prefabrication set out in Figure 4.

Figure 5 Standardisation potential by percentage, 2013 consent values

Potential for standardisation	Potential standardisation	
Statistics NZ types and coding	%	$M
101 House - not attached to other	23%	$1,318
103 Apartment block - attached vertically (10 or more units)	73%	$235
770 Office and administration	56%	$208
102 Unit/Flat/Townhouse/Studio - attached & unattached horizontally	56%	$174
352 School facility	64%	$148
551 Warehouse	47%	$114
601 Factory	42%	$91
103 Apartment block - attached vertically (0-9 Units)	53%	$90
204 Prison dormitory	48%	$79
753 Supermarket	45%	$43
701 Milking shed	47%	$35
154 Garage	55%	$34
719 Other farm building	15%	$20
569 Other storage buildings	15%	$17
353 Tertiary facility - polyt, college of education	46%	$16
301 Hospital	14%	$15
302 Rest home - convalescence	20%	$14
754 Service station	60%	$11
354 University	14%	$10
602 Industrial	40%	$9.4
169 Other outbuildings of residential building	21%	$9.0
251 Hotel	47%	$6.7
219 Other long term accommodation	16%	$6.4
407 Creche	23%	$6.2
408 Police station, court house	49%	$5.9
451 Religious buildings	18%	$5.1
705 Covered yards	47%	$4.6
706 Implement shed	47%	$4.6
151 Sleepout	53%	$4.0
752 Restaurant, bar, tavern and cafeteria	13%	$3.5
201 Hostel (school, uni hostel, nurses, etc.)	16%	$2.7
704 Tunnel/glasshouse	15%	$2.2
104 Granny Flat - unattached	70%	$2.0
552 Cool store	16%	$1.9
505 Clubroom	22%	$1.8
554 Parking building	13%	$1.7
152 Carport - boatshed, car deck	33%	$1.7
252 Motel	18%	$1.5
Total		$2,754
Total excluding houses, apartments and units		$937

6. ENCOURAGING PREFABRICATION

Barriers to uptake of prefabrication have been mentioned in the literature review. These include high initial cost, uncertainty about continuing supply and whether the market is large enough to support prefabrication, the joining of components on-site, risk of damage to interior walls and linings, and planning and building regulations. Some literature further cites owner and designer resistance to prefabrication.

Perhaps the greatest challenge, however, is a lack of expertise and knowledge of the merits of prefabrication among those who provide advice to people wanting to build, as highlighted in the earlier literature review. Quantity surveyors are often the main cost advisor and their expertise is mainly in costing building elements using historic data. They do not always understand the quality and time advantages of prefabrication.

Further, all prefabricators stress the need for early involvement of the various players to get the best out of prefabrication, i.e. client, designers, fabricators and constructors.

6.1 Who benefits most from prefabrication?

Perhaps the key question to encouraging uptake is to better understand who benefits most from the prefabrication process. Our earlier analysis has suggested that prefabrication is not always cheaper in a simplistic sense (lowest cost upfront). However, benefits do include quality, construction time, and time certainty, reduced health and safety incidences, bypassing skill shortages, and cost certainty. By examining who within the value (and supply) chain is most likely to benefit from these advantages, we can better understand who is most likely to drive S&P and/or where education and awareness may need to be targeted to improve uptake.

We consider the various players in the prefabrication supply and value chain, starting with the home buyer, and working back to the manufacturer or prefabricator. Specifically, we consider in a qualitative sense, the pros and cons of prefabrication for each of the following:

- The home building buyer (rather than a buyer of a spec-built home)
- The large-scale building company that runs several projects at one time
- The small-scale building company or sub-contractor that undertakes work directly on site, probably one job at a time
- The existing prefabricator
- The existing manufacturer that may consider a move into prefabrication.

We note that attendance by designers at the recent PrefabNZ conference indicates that interest in S&P among designers is relatively strong. Designers may have a role in encouraging uptake by outlining the benefits of S&P to their clients. More S&P will enable them to be better assured of quality and on occasion offer wider design options. For those designers who also project manage construction, it may also allow more project completions per year. Nevertheless, the overall monetary benefits to designers are expected to be relatively small compared to the benefits to others in the value chain.

Figure 6 presents a summary of the potential benefits and costs for each player in the supply chain, including a view based on discussions with the industry as to the relative scale of the benefits and costs, using a five point scale.

Figure 6 Benefits, costs and risks of an increase in quality prefabrication

Risks/Cost Scale					Benefit/Risk/Cost	Benefit Scale				
-5	-4	-3	-2	-1	Size of the benefit, risk or cost	1	2	3	4	5
		-3			**Existing materials manufacturer**			9		
					Opportunity to move up the value chain				4	
					Higher turnover and profits					5
			-2		More storage space required					
				-1	Increased pre-delivery damage risk					
		-3			**Existing prefabricator**			5		
					Higher turnover and profits					5
			-2		More storage space required					
				-1	Increased pre-delivery damage risk					
		-12			**Large scale builder**			21		
					Less labour required on-site			3		
					Shorter build time				4	
					Simplified work schedules	1				
					Lower risk of accidents / cost of compliance		2			
					Reduced waste		2			
					Fewer managed supplier contracts	1				
					Fewer defects			3		
					Quicker weatherproofing and lower weather dependence			3		
					Increased profits on materials		2			
		-3			Challenges in alignment of panels on-site					
		-3			Risk of damage to interior walls					
	-4				Cranes required to put panels in place					
			-2		Loss of control: reliance on quality of prefabricated work					
		-15			**Small scale builder / sub-contractor**			18		
	-4				Less labour required on-site					
					Shorter build time			3		
					Simplified work schedules	1				
					Lower risk of accidents / cost of compliance		2			
					Reduced waste		2			
					Fewer managed supplier contracts		2			
					Fewer defects			3		
					Quicker weatherproofing and lower weather dependence			3		
					Increased profits on materials				4	
		-3			Challenges in alignment of panels on-site					
		-3			Risk of damage to interior walls					
		-3			Cranes required to put panels in place					
			-2		Loss of control: reliance on quality of prefabricated work					
		-9			**Home buyer**			15		
					Time certainty				4	
					Cost certainty				4	
					Fewer defects			3		
					Quality / value for money				4	
-5					Higher price?					
			-2		Reduced flexibility for variations					
			-2		Negative connotations					

BRANZ analysis

The discussion that follows specifically addresses the following question:

What are the benefits and costs to each of players in the supply chain should there be a significant increase in high standard prefabrication in the residential building sector?

Two points to note from this specific question are that:

- The discussion that follows assumes a successful prefabrication industry that produces a quality product, as is the case in European prefabrication. The assumption underlying the discussion is that the prefabrication being considered is not of the lowest possible cost with a commensurate decline in quality. Instead, the assumption is that the prefabrication envisaged will successfully apply best practice processes and quality management to produce quality prefabricated housing components within a manufacturing environment.
- Our discussion uses the residential sector as a practical example, but there is no reason why "home buyer" could not be replaced with "prefabricated construction services buyer". As this report highlights, there is potential for prefabrication in schools, prisons, hospitals, and even bridge- and road-building.

6.1.1 The home buyer

This discussion assumes a house incorporating more prefabrication is being built specifically for a home buyer, whether it is a one-off design or an off-the-plan build (with or without changes to that plan).

The home buyer, like the purchaser of any service, wants a quality product delivered on time and within budget. An increase in prefabrication would support these objectives by:

- **Reducing the time taken to build a house**: One of the key benefits of prefabrication is that more work is done undercover in a factory environment, so less work is done on-site, where weather interrupts work, and where there are often delays between different trades or materials arriving on site to complete the next stage of work.

  Benefits of prefabrication for the home building buyer are mostly related to time savings and quality improvements.

  This benefit has tangible and intangible value to the house buyer. If they are currently renting or paying a mortgage on another home, it has the tangible benefit of reducing the time they spend paying for two properties. Intangible benefits include seeing the dream of building their own house realised more quickly.

- **Improving time certainty**: While many building companies offer guarantees of some sort, they are usually subject to weather, and almost never include a penalty clause for failure to complete on time. Once again, by more work being done off-site where weather is not a factor, and where all the relevant trades work together under one roof, there is far more likelihood that the build will be finished on time.

  Again, this increased certainty of completion date has direct tangible and intangible benefits for the home buyer through potential cost savings and the reduced uncertainty associated with a more drawn-out build process.

- **Reducing defects**: Another premise of prefabrication is that because it is done in a factory environment adopting process methodologies, defects are likely to be fewer, even if a factory produces large volumes of one-off designs.

  The BRANZ New House Owners' Survey (2014) highlights the fact that defects, and the fixing of defects, are a major challenge in the industry, with 73% of new house owners needing to call back their builders in 2013. An approach that reduces defects will be a major improvement for home buyers.

- **Increasing value for money**: Internationally, prefabrication has not necessarily decreased the cost to the home buyer. However, through fewer defects, and the use of best practice processes, it has produced better quality products at competitive prices (although not necessarily cheaper).
- **Increasing cost certainty**: In the case that a home buyer signs a contract that is time and expense based, or does not have a fixed contract price, the home buyer is exposed to significant cost blow-out risks. A prefabrication process that reduces wastage and eliminates much of the time wastage due to weather and timing delays with other trades and materials may improve cost certainty for these home buyers.

Potential risks and costs for the home buyer include:

- **Higher costs (reduced affordability)**: As already highlighted, prefabrication is not necessarily lowest cost, with the focus on quality.
- **Reduced timeframe to introduce variations**: On-site construction allows greater flexibility for the home buyer to change their minds about positions of internal walls, widths of doorways, positioning of a built-in fireplace etc. Prefabrication means once the order has been placed, there is less scope for last-minute changes.
- **Negative connotations**: It is possible that in New Zealand, where awareness of what prefabrication has done for Germany and other European economies is generally poor, that prefabrication may be associated with "cheap" production. Even though this is unfounded, it may affect public perceptions at least until the approach is more mainstream. This may discourage uptake as home buyers may be nervous they may not get the resale value they would like on their home.

6.1.2 The building company / sub-contractor

Benefits and costs for the large builder and the small builder or sub-contractor are largely similar, but with some important differences. Most notably, the impact of doing less work on the building site may affect these two types of business differently.

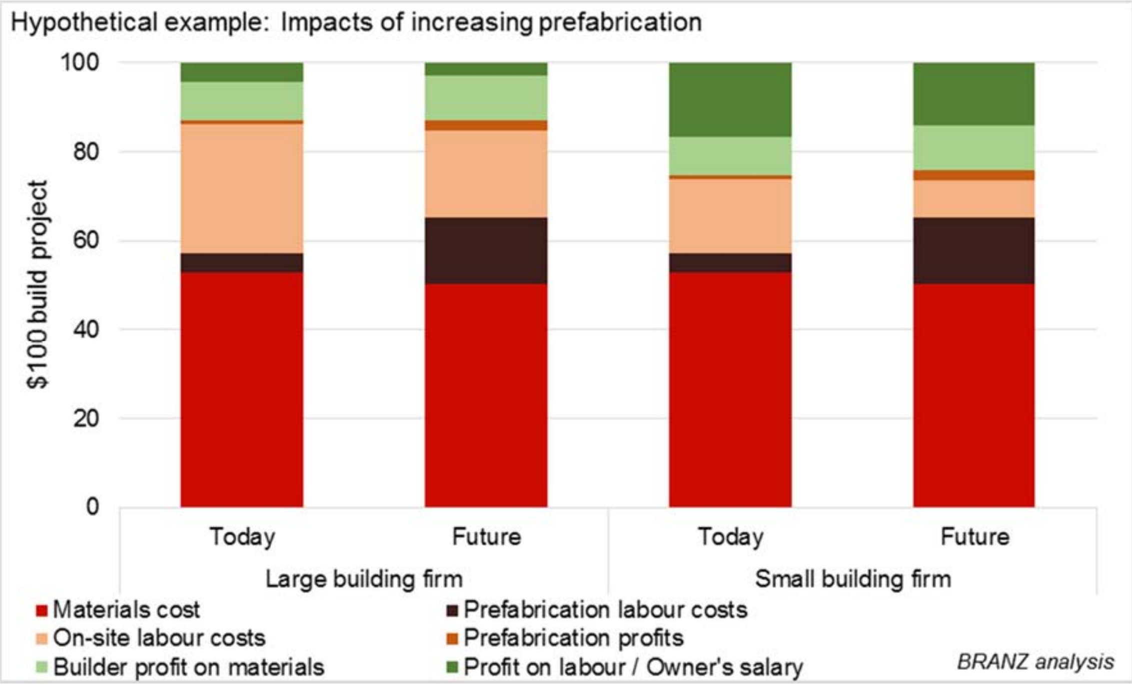
Prefabrication does not need to reduce profits and owner salaries for the building firm, and offers a number of other potential benefits.

Larger builders, running several projects at any one time, would likely see a **reduction in the amount of work to be done on site as a positive**. They could either take on more work (in areas where demand is particularly high and builders do not have the capability to take on more projects) or maintain a smaller team. The smaller team on site, with greater prefabrication, would mean fewer HR challenges.

On the other hand, **smaller builders** tend to do much of the physical on-site work themselves. Their income from running a building firm is often predominantly the value of their own building work done on-site (whether paid through a salary or through firm profits). Reducing the amount of work done on-site will **reduce the amount of money earned by the builder directly on-site**.

However, it is hard to say whether the reduction in earnings on-site would yield a net negative financial result for the builder as they will be able to offset this with higher profits on the materials which will be more expensive due to higher levels of completion. The differences between outcomes for different scale builders and prefabricators is explained by an illustrative hypothetical example in Figure 7.

Figure 7 Hypothetical example of the impacts of increasing prefabrication



The example examines the hypothetical costs to build a $100 house. Key assumptions include:

- The cost of the house is kept at the same delivery price in the "Future" scenario where far more prefabrication is undertaken due to pressure to avoid increasing house prices
- Transport, electricity, equipment costs and the like are kept the same across scenarios, and are therefore excluded from the analysis. We acknowledge that some proponents argue for significant benefits in transport costs from increased prefabrication.
- The cost to build a house and mix between material and labour costs between smaller and larger builders is the same. This is because o**ur intention is to contrast the situation today with the potential situation in future**, rather than to compare smaller and larger builders.

6.1.2.1 Today's world

In the example, the large scale builder in today's world buys materials, some of which are prefabricated already (mostly trusses and wall framing). In total, these costs are around $58, made up of the red, brown and orange components in the figure. These **costs are assumed to be identical for the small builder** (i.e. we ignore bulk buying power and the like).

The **large builder**, who has many projects on the go, makes a profit by adding a mark-up (assumed to be 15%) to the cost of materials and to labour costs, or $4.30 on labour costs. This yields **profits** (the two shades of green) **of $13.00** on the $100 project.

The **small builder** does a lot of the physical work on site. He perhaps employs a couple of workers to help him, but a large share of the firm's profits are in fact the work he has undertaken and been paid for on-site. It is assumed 50% of the labour costs and profits on labour that the large firm would charge are instead profits and salaries for the small builder, after paying his own workers. This yields **salaries and profits** for the small builder (the two shades of green) **of $25.40**. This is significantly higher than for the large builder but again it must be stressed that much of this is the value of the labour provided by the builder himself.

6.1.2.2 The future world

In the future world:

- Prefabrication leads to reduced wastage, and a resultant 5% decline in raw materials required
- More prefabrication is done before the building products are delivered to site. As a result, the cost of materials delivered to site is $67.50 rather than $58 in today's world.

The **large builder** continues to add a 15% mark-up to materials, yielding $10.10 rather than the $8.70 in today's world. But he requires far less labour on-site. In fact, to continue to enjoy similar profits to before, the large builder in this scenario **must cut on-site labour costs** by about one third, as less work and time is required on-site. Given that one of the main benefits of prefabrication is to cut on-site labour costs, this is probably not unrealistic. Overall, **profits for the large builder remain about the same, at $13.00** on the $100 project.

This hypothetical example suggests that overall, both large and small builders will probably be about as well off financially from a project, but will benefit from increased time and cost certainty, and shorter build times.

The small builder also benefits from increased mark-ups on materials. But as with the large builder, far less labour must be used on site for him to produce a house for a similar price. But because he does much of the on-site work himself, this may begin to impact his own take-home salary. In our hypothetical example, we assume he requires one less worker than before (as the labour requirement is assumed to be cut by one third). The profit on labour and owner's salary falls slightly from today's world, to $14.10 from $16.70. Overall, in this hypothetical example, the **smaller builder's profits and salary falls slightly, to $24.20 from $25.40**.

Given this potential change, one outcome may be that more small builders (and excess labour at large builders) would seek employment at prefabricators, where they would do similar work to what they did on-site, but in a weatherproof environment alongside a number of other trades.

Yet simultaneously, the time taken to build a house falls in the future world, meaning that builders **can complete more houses in the same time** in times of high demand or that they may have more downtime. Thus while small builders' profits and salaries may fall slightly, **there are intangible benefits to them** that may make the switch worthwhile. Smaller builders in particular, who have indicated in previous BRANZ surveys that they like the flexibility to take time off when they want to, may benefit from completing building projects in less time as long as their earnings do not fall too far.

Given the dominance of the small builder in the New Zealand residential construction sector, we recommend a more comprehensive analysis of the real changes in cost and profit structures a change to greater prefabrication may bring about to better understand the tangible financial benefits (if any) for builders.

6.1.2.3 Other benefits and risks to builders from increased prefabrication

As Figure 6 points out, there are several other benefits and potential risks to builders that are less easily expressed in dollar terms. On the benefits side:

- Work schedules can be simplified
- Fewer supply contracts are required to be managed (possibly a greater benefit to small builders who do not have dedicated staff members to deal with these)
- Fewer defects mean fewer call backs with associated costs
- Waste and associated costs and reduced (as suggested in the hypothetical example above)
- The risk of accidents is reduced.

There are also a number of additional costs and risks for the builder associated with a switch to more prefabrication although this study contends the benefits are probably greater than the potential risks:

- Challenges in correctly aligning and joining panels and other components on-site
- Risk of damage to interior prefabricated walls
- Heavy machinery including cranes required to put walls in place
- Loss of control over the work completed by the prefabricator, meaning a loss of flexibility due to last minute plan adjustments.

6.1.3 The existing prefabricator

The existing prefabricator understandably stands to gain a lot from increased prefabrication. Benefits include:

- **Higher turnover and profits**: A larger share of the work currently done on-site by construction workers can be captured.
- **Potential to further improve efficiency through scale**: One of the main benefits of prefabrication is that it is an efficient, process-oriented approach to building. With increased demand, prefabricators will be able to invest in more automation, and the study and adoption of international best practices, to improve efficiency even further.

The prefabricator stands to gain from an increased workload, as long as risks associated with upscaling are managed.

There are no significant risks to the prefabricator other than the scale risks associated with upscaling, such as the need for a larger storage and manufacturing area (where previously much of this storage was "free" on the building site). Risks of damage to components prior to and during delivery would also likely increase commensurate with the scale of the operation.

In reality, however, these risks and costs are likely to be accounted for in the firm's overall cost structures as a cost of doing business.

6.1.4 The existing (non-prefabricating) manufacturer

These manufacturers could include those already producing materials for the building industry, and who move up the value chain to assemble those materials (and possibly others) at their premises. It could also include businesses that already manufacture (even significantly) different products, but who have the processes and access to building industry advice and skills to enter the prefabrication market.

The key benefit to the manufacturer is the opportunity to move up the value chain, growing turnover and profits by producing a higher value product.

The risks and costs would be the same as for existing prefabricators – the requirement for more storage space and the risk of damage to products before delivery, but as with existing prefabricators, these costs will be absorbed as part of the firm's overall cost structures.

6.2 Why is prefabrication not more popular in New Zealand today?

Given the apparent advantages of prefabrication discussed in this report, and evident where it is used overseas, the immediate question is why it has not been adopted more in New Zealand.

Our interviews with builders suggests they are certainly not opposed to the idea of more prefabrication and some larger builders are actively embracing it. Clearly prefabricators are unlikely to be opposed to the idea, so why is there not a greater shift toward prefabrication? There are probably a number of market failures involved, which are discussed below:

- **Imperfect information**: The international literature and our discussions with industry players in New Zealand suggests that there is a gap in awareness and knowledge of the benefits and risks of prefabrication. Along with some of the misconceptions discussed previously, there may be an incorrect understanding of the amount of investment required to begin more prefabrication. The scale of building operations required may also be misunderstood, and there may be a shortage of people with the right skills to implement best practice processes t o make large-scale prefabrication cost-effective and popular.
- **Coordination failure**: A key question (briefly introduced below) is who should take the lead in introducing more prefabrication. Should it be led by the prefabricator, existing (non-prefabricating) materials manufacturers, designers or builders? There may be a coordination failure in linking willing producers and willing builders. This may require representative bodies like PrefabNZ to play an education and coordination role in linking prefabricators to those who could benefit from using their services.

A range of market failures may be preventing greater uptake of prefabrication.

- **Positive externalities**: Given that this approach would shift more work off the building site into the factory, builders may feel that the benefits accrue mostly to the prefabricator through increased work in the factory (positive externalities). Because they can't capture all the benefits of a shift, it reduces incentive to them to switch to greater prefabrication.

6.3 How are benefits promoted today?

As the ones most likely to benefit from a customer preference switch to prefabrication, the question arises as to what prefabricators are doing to overcome barriers, most notably the lack of knowledge of benefits in the industry and among potential house purchasers.

An examination of a range of prefabrication suppliers' marketing information, introduced below, provides some insights.

6.3.1 Two examples

Built Smart (PLB Construction Group, 2013) is a transportable home manufacturer based in Huntly. Their brochure states that "From the time you place your order with Built Smart Advanced Transportable Homes, you can have delivery of your new house in as little as 4 weeks!". This highlights the time advantage that off-site complete building prefabrication has over traditional methods.

After presenting their house plans, they state their aim "to provide an affordable housing solution that does not compromise on quality". They then go on to claim that they "can save our customers up to 40% in labour costs alone" and "Building under cover also allows us to achieve a higher standard of quality control for the entire building process".

In other words, Built Smart is promoting:

- Timeliness of the build process

- Cost savings
- Quality.

As their client is likely to be the eventual owner of the house, issues such as cost, quality and timeliness are likely to be the among the key considerations.

Keith Hay Homes is another manufacturer of transportable homes. The benefits they advertise include quality control, minimal disruption, smaller carbon footprint, cost efficiency, and quick build times.

The solid wood systems also feature time savings of on-site construction and additionally promote the quality wood finishes of their products.

6.4 The value case and the individual decision-maker: Costs and intangibles

Yet as the earlier literature review, discussion with industry, and table on “who benefits most” highlighted, many of the benefits of S&P are hard to express in dollar terms. In many cases, a judgement will need to be made by the designer, new house owner, independent builder or building group as to which factors to consider in deciding whether or not to use prefabrication.

Nevertheless, some factors are relatively easy to quantify or measure in dollar terms, such as:

- Design (prefab and traditional design costs may differ)
- Labour (including the skills mix)
- Materials and prefab items
- Transport (including merchant to site)
- Commissioning
- Inspections

Some of the intangibles or hard-to-quantify aspects include:

- Health and safety
- Quality of the building
- Environment impacts such as waste and choice of materials.
- Eventual demolition is easier with prefab.
- Life cycle costs – Traditional and prefabricated designs should have equal performance characteristics (for a fair comparison). If their on-going costs or durability differ then a Life Cycle Cost (LCC) assessment should be done.
- Overheads – Supervision. On-site learning costs?
- Logistical – Site preparation and preliminaries may differ between traditional and prefab construction.

The ultimate decision will therefore need to be made based on the mix of quantified and intangible factors that the decision-maker values most.

6.4.1 Including intangibles in the decision process

This mix of quantified and intangible factors means in many cases, a more nuanced approach to deciding if prefabrication is the best choice may need to be made.

We know that there are various options available for constructing a building. Assume we have a layout and the question is what amount of prefabrication should be used. We consider the cost of the various options but we also want to include "hard-to-quantify" aspects of each option. How do we do this? One method is to use the weighted evaluation process. In the example shown in Figure 8, developed by BRANZ to illustrate the process, there are four options and four decision criteria (from the far longer list set out above) for a new house.

The options are:

- a traditional site-built house
- a house with some prefabricated components
- a house with prefabricated panels
- a house build from volumetric modules.

Four decision criteria were selected from the above list:

- initial cost
- health and safety issues during construction
- quality of the finished house
- environmental impact for the various construction options.

Figure 8 Example of weighted evaluation – large emphasis on cost.

Weighted evaluation method				**New house**		
Current choices			**Scoring**	(5= good, 1 =bad)		
		Opt1	**Opt2**	**Opt3**	**Opt4**	
Criteria		Traditional	Components	Panels	Modules	Weight
Quantifiable costs		4	5	3	2	75%
H&S		3	3	4	5	5%
Quality		2	3	4	5	15%
Environmental		1	2	4	5	5%
		Weighted scores				100%
Quantifiable costs		3	3.75	2.3	1.5	
H&S		0.15	0.15	0.2	0.25	
Quality		0.3	0.45	0.6	0.75	
Environmental		0.05	0.1	0.2	0.25	
	Total	3.5	4.45	3.25	2.8	
Ranking		2	1	3	4	

The method gives the best score to the component option. However, if we give more weight to quality and environmental aspects and less to cost then other options become more attractive, as in Figure 9 where the panels and modules options score well.

There is no “right” answer for particular buildings because the outcome depends on the priorities of the client, which are reflected in the weights he/she applies to the various criteria. Figure 9 provides an alternative ranking based on different priorities.

Figure 9 Example of weighted evaluation – less emphasis on cost, more on quality.

Weighted evaluation method				**New house**		
Aspirational			**Scoring**	(5= good, 1 =bad)		
		Opt1	**Opt2**	**Opt3**	**Opt4**	
Criteria		Traditional	Components	Panels	Modules	Weight
Quantifiable costs		4	5	4	3	50%
H&S		3	3	4	5	10%
Quality		2	3	4	5	25%
Environmental		1	2	4	5	15%
		Weighted scores				100%
Quantifiable costs		2	2.5	2.0	1.5	
H&S		0.3	0.3	0.4	0.5	
Quality		0.5	0.75	1	1.25	
Environmental		0.15	0.3	0.6	0.75	
	Total	2.95	3.85	4.00	4.00	
Ranking		4	3	1=	1=	

6.5 A strategy for boosting prefabrication and standardisation industry-wide

Yet at the same time as the individual makes a decision about using S&P, the industry as a whole must decide whether to tend toward more S&P or not. The earlier examples illustrate the complexities that make S&P uptake difficult. Various documents such as PrefabNZ’s *Prefab roadmap: A way forward for prefabrication in New Zealand, 2013–2018* have suggested approaches to encouraging greater use of S&P. These approaches tackle at least four focus areas: process, procurement, learning/ benchmarking, and training.

- **Process**: Builders can introduce prefab gradually with a mix of off-site and on-site technologies. In parallel to this firms, can move toward more standardisation with much reduced design portfolios. This means suppliers need to be involved early on in the process of the larger projects, and that clients need to complete all changes before manufacture begins.
- **Procurement**: This involves early involvement of client, designers and suppliers. However, other stakeholders such as lenders, insurers, planning and building control authorities need more involvement.
- **Benchmarking**: There is disagreement about which innovations matter most, and about how innovation impacts can be measured when there is no agreed criteria to assess performance beyond costs. For example, the benefits of time, quality, health and safety, and sustainability are often hidden and not fully realised by the industry. Promotion of trials is needed to better understand these benefits, and

could be assisted by increasing interest in S&P among quantity surveyors and valuers.

- **Training**: This is needed because, contrary to general belief, prefabrication will not necessarily compensate for lack of skills. An understanding of the techniques and precision involved in prefabrication is essential both off-site and on-site. There is a need to train staff on the longer-term benefits of prefabrication and to reduce staff turnover by promoting a holistic approach to innovation.

At the same time, our discussions with prefabricators and builders, as well as our review of the international literature, indicates that there is a further problem of a **lack of knowledge**. The designer, the builder, and the home buyer in New Zealand do not have a full appreciation of the potential benefits for them from S&P. For instance, as our analysis has shown, a switch to prefabrication does not necessarily mean job losses, but may mean a shift in production from the construction site to a weathertight location.

A holistic approach is needed that tackles the challenges across all four focus areas listed, as well as the challenge of education, and across the full range of stakeholders considered to have a role in uptake of S&P.

At the project and task (rather than firm) level, there is considerable further research on prefabrication. Tam et al (2007) identified four broad categories of buildings (general building, public housing, private housing, commercial), and found that prefabrication was appropriate for structural steel frames, external cladding, precast concrete slab, modular washrooms, and internal walls. This provides a starting point for the components of the building process that could be targeted first.

6.5.1 Who could make the first move?

It is worth undertaking a comprehensive study to develop a range of models for implementing S&P more in New Zealand. However, this section briefly introduces a few options for increase in the use of prefabrication.

A number of models could be adopted to boost uptake of prefabrication, but these need to be explored in far greater detail.

- **Manufacturer-led growth**: To many, this would appear the most logical way to grow the market. Existing materials manufacturers or prefabricators point out the benefits of S&P to builders and develop traditional partnership arrangements.
- **Large builder-led growth**: Some of the larger independent and franchise builders in New Zealand build dozens or even hundreds of houses each year. There is potential for one or more of the franchise brands to take an approach whereby they appoint one or more prefabricating firms strategically located across New Zealand to produce prefabricated panels and other components for all their house builds in New Zealand.
- **Vertically-integrated builder**: A final option may be for a large builder or franchise to vertically integrate, producing prefabricated components for their build projects. This would mean moving some of the building site workers into the factory, thereby

capturing the profits that accrue to the prefabricator as well as those that accrue to the builder.

The NZ Panelised announcement appears to be using this approach for most of the houses they build. It is understood their investment in plant and buildings is about $14 million and at this level of expenditure the partners will have decided the business case is strong and sustainable. It is to be hoped that this venture becomes a catalyst for a major uptake of prefabrication of small buildings in New Zealand.

APPENDIX A   REFERENCES

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APPENDIX B MISCELLANEOUS

This appendix contains two tables. The first has the details of the calculation of the current percentage of prefabrication in new buildings. The second table has the 16 factors that Blismas believes should have been used when comparing traditional construction with prefabrication in the six projects he examined.

Figure 10 Current prefabrication estimate details

Prefabrication by component Year ending December 2013	Component as % of total value of bldg (1)	Percent of bldgs with prefab component (2)	Total consent values $M/yr (3)	Prefab $M/yr
New residential			$6,476	
Component				
Wall frame prefab	17%	94%		$1,038
Windows	7%	90%		$408
Roof trusses	6%	95%		$369
Joinery	7%	80%		$363
Wall clad (AAC panels)	9%	4.8%		$28
Solid wood house	85%	1.7%		$94
Transportables (4)	92%	1.3%		$77
Metra panel houses	40%	0.4%		$10
Light steel frame	15%	2.6%		$25
Modules (5)	50%	0.1%		$4
			New residential total =	$2,416
			New housing prefabrication share=	37%
Housing A&A			$1,275	
Wall frame prefab	9%	33%		$38
Windows	3%	90%		$34
Roof trusses (6)	3%	70%		$27
			Residential A&A =	$99
			HousingA&A prefabrication share=	8%
Non-residential bldgs		% of total cost of bldg that		
		is prefabricated (2)	$M	
Hostel		18%	$255	$45
Motel/hotel		15%	$90	$13
Health		26%	$290	$76
Education		6.1%	$549	$33
Social/cult		5.3%	$394	$21
Retail		9.4%	$558	$52
Office		10%	$843	$88
Warehouse		16%	$429	$68
Factory		1.8%	$450	$8
Farm		6.6%	$262	$17
Miscell		29%	$29	$8
			$4,149	$431
Modules (eg education, hotels) (5)		0.2%		$8
		Total non-res bldgs =	$4,149	$439
			Non-residential bldgs prefabrication share=	10.6%
		All bldgs total	**$11,899**	**$2,954**
			Pre-fabrication as a % of all buildings value =	25%

(1) Source: Rawlinson Construction Cost Handbook.
(2) Source: BRANZ Materials Survey
(3) Consents values for the year ending Dec 2013. Statistics NZ.
(4) From an analysis of a few months of Whats-On datasets
(5) Modules share for residential and non-residential is a BRANZ estimate and is very approximate.
(6) BRANZ estimate of percent of bldgs with prefab component

Figure 11 Factors to include when comparing prefabrication with traditional construction.

Cross-case comparisons - items that were considered		Labour costs	Material costs	Plant/equip costs	Transport/install costs	Commissioning/ tests	Design/planning costs	Process management	H&S	Rework	Quality	Overheads	Package/ storage costs	Life-cycle costs	Human resource admin	Environmental impact	Logistical issues	Total ✓
Project 1	Traditional	✓	✓	✓	✓	×	×	×	×	×	×	✓	×	×	×	×	×	5
	Prefab	✓	✓	×	✓	✓	✓	✓	×	×	×	✓	×	×	×	×	×	7
Project 2	Traditional	✓	✓	✓	×	×	×	×	×	×	×	✓	×	×	×	×	×	4
	Prefab	✓	✓	✓	×	×	×	M	M	M	M	✓	×	×	×	×	×	4
Project 3	Traditional	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	7
	Prefab	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	7
Project 5	Traditional	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	2
	Prefab	✓	✓	×	✓	×	✓	×	×	×	×	✓	M	×	×	×	×	5
Project 6	Traditional	✓	✓	M	M	×	×	×	×	×	×	✓	M	×	×	×	×	3
	Prefab	✓	✓	M	✓	×	×	×	×	×	×	✓	M	×	×	×	×	4

✓ =explicitly specified in cost comparison

× = apparently excluded from cost comparison

M = mentioned in documentation

Source: Blismas, Pasquire & Gibb CME 24:2 2006