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STRUCTURAL INSULATED PANELS: A SUSTAINABLE OPTION FOR HOUSE CONSTRUCTION IN NEW ZEALAND

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ABSTRACT

A central principle of sustainability is the recognition of the interdependence of economic, environmental, and equity issues. This interconnection is evidenced in the resurgence of sustainable housing types. However, in the sustainable housing literature most examples given are of collective housing, affordable housing, or, green-housing.

Yet there are other emerging forms of sustainable housing, which are almost unreported in the literature. This paper discusses some of the socio-cultural issues at work in sustainable housing typology. It begins by retracing the key historical moments in the sustainable housing discourse in order to position the current popularity of the aforementioned three housing types. Then through an exploration of this typology and in case studies, it questions the predominance of the techno-centric models over other sustainable housing types, such as conjoined. Finally, it argues that attention must also be given to the practice of sharing as an added method of sustainability.

Key words: Insulated panels, Sustainability, Panel System, Energy efficiency.

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Introduction

While relatively unknown in New Zealand, Structurally Insulated Panel systems (SIPs) have been in existence in some form or another since Frank Lloyd Wright used SIP-like panels in the 1930s. Interest in SIPs has grown with the introduction of more streamlined assembly technology; the reduction in construction time; the subsequent reduction in labor costs; and most recently, the 'green building' attributes of the system. The SIP industry in the US can now be considered a sustained growth industry. In 2003 SIPs contributed 1% of all new residential construction in the USA, growing by 10% in 2004 and then by 23% to 2005 *(from 8,515 to 10,485 new SIPs homes*--SIPA webpage). In the UK, Canada, Europe, Central America, Japan, and many other countries SIPs construction has seen acceptance and is growing in use with more recent press coverage on television home building programs and in magazines and journals.

In the face of growing public awareness and concern for global warming and climate change and new information regarding the impact of building on the environment, there has been a resurgence of interest in sustainability and green building. The Structural Insulation Panel Association (SIPA) promotes SIPs in its website as a 'green building product' and one that is environmentally sustainable. In addition to the sustainable qualities detailed later in this paper, the demonstrated success of SIPs in situations of natural disaster, most notably in the earthquakes in Japan (Kobe 1993) and Northridge California, recent hurricanes in southeastern USA (Hurricanes Andrew and Iniki) and performance in world record snowfalls in the Cascade and Rocky Mountains has further added to their popularity. The advantages of the reduced construction time for SIPs homes also demonstrated their added value in the face of civil emergency, most recently following Hurricane Katrina when the USA Federal Emergency Management Agency (FEMA) dispatched 25,000 Building America Structural Insulated Panel (BASIP) homes for temporary housing *(Schwind 2006).* In many respects, SIPs appear to be the ideal solution for sustainable construction for New Zealand, a country prone to earthquakes, high wind and extreme weather conditions; one with a relatively unskilled construction labor force and a desire for more sustainable housing.

Measures of Sustainability

Measures of sustainability attempt to provide some quantifiable indicator of performance to measure the sustainability of an architectural intervention. The search for sustainability measures is hot right now—many nations, states/provinces and authorities are working to develop their own. Among the numerous systems of measuring sustainable building introduced worldwide are the :

- British Research Establishment Environmental Assessment Method - BREEAM
- Building Environmental Assessment Criteria (Canada) – BEPAC.
- US Green Building Council's Leadership in Energy and Environmental Design Green Building Rating System – LEED
- Energy Performance of Buildings Directive (UK) – EPBD
- Green Builder Program (International) – GBP

Most recently, in April 2007 of this year, the Green Building Council of New Zealand announced a measurement system for New Zealand. Modeled on the Australian example, the NZ Green Building Council is relatively new and is still in the process of developing its measurement systems, but it is expected that the issues will be similar to those experienced overseas. Each of the programs has its advocates and all have their critics but all use some or all of the following broad areas as a standard for measuring sustainable building;

- Sustainable site planning
- Safeguard water and water efficiency
- Energy efficiency and renewable energy
- Conservation of materials and resources
- Material toxicity and emissions
- Waste reduction
- Indoor environmental air quality

Of these measurement systems sustainable site planning falls outside the scope of this review. Safeguard of water and water efficiency is relevant during the process of manufacturing the materials; however amounts of water used in the manufacture of timber and of SIPs are negligible. Conservation of materials and resources ensures resources are renewed and replenished and are considered in the manufacturer's claims. Materials should not be toxic to the manufacturers or the end occupants of the building or to the environment. Waste to landfills should be kept to a minimum or be recycled or reused where possible. Indoor environmental air quality must be safe and energy efficient to the occupants, which would relate to the claims of healthy occupant environments. From a survey of the measurement systems noted above, the manufacturers are deemed to have selected a reasonable set of measures.

Perhaps what is most interesting is that despite the similarity in the various programs, there is also a great deal of difference. While there is global agreement on the foundations of sustainability, there are variations by location, by country size and by culture. Some measurement systems are industry driven, others have been positioned by government; some have been structured to achieve a baseline of acceptable compliance and others seek to encourage best practice. All are sufficiently different so as that we are unable to assess sustainability relative to the rest of the world. None permit an accurate comprehensive assessment of sustainability, as sustainability encompasses more than green building or healthy building and there are serious limitations in the available data relevant to environmental sustainability. However, we are now each able to compare to the measures between buildings within our own countries.

As has been noted at a recent Green Star New Zealand briefing held by the New Zealand Green Building Council--formed to lead New Zealand's focus on green building-- sustainability issues differ by location, as do green building objectives. In order to evaluate whether the US SIPs manufacturer claims are appropriate measures of sustainability for New Zealand, we first considered the range of sustainability measures worldwide, then compared them to the sustainability priorities in New Zealand and finally compared with the 'next best available option' in New Zealand-- the light timber framed, traditionally constructed house.

Sustainability and the Status Quo

Timber has been the material of choice for house construction in New Zealand since its first inhabitation. Understandably, this early preference for timber was due to its abundance throughout the country and the building skills and experiences that the new colonizers bought from their respective origins. Currently, 90% of all new houses in New Zealand are platform timber framed construction using plantation softwood. Unlike many countries around the world, timber for light construction is produced from a renewable source in New Zealand; plantations of softwoods that are replaced in a continuous cycle--at the same or a faster rate than they are used.

To meet requirements for durability in the New Zealand climate, the timber cannot be used in its natural state. First it must be treated with the chemical cocktail Copper Chromium Arsenic (CCA) to protect the framing members from insects, fungi and fire. For health and safety reasons, CCA was phased out of use in the USA in 2004 and is to be phased out of Canada, the UK and Australia soon. However, it was reintroduced into NZ building after untreated timber was found to contribute to the recent leaky buildings. For load-bearing construction, NZ timber frames are constructed of dimensional timber. Preparation of the timber involves splitting logs into 'rough sawn' usable lengths and widths and smoothing to a plain gauged (dressed) size suitable for construction. Following the manufacture of the timber, it is then usually shipped to site in set lengths and cut to size at construction. Standard sizing allows designers to create a design using the standard size timber components or timber selected from standard (incremental) sizes.

This timber preparation process presents four major sustainability challenges for load-bearing construction. First, construction grade timber can only be manufactured from 60% of the tree, generating significant amounts of waste, which while biodegradable or recyclable, still requires transportation and/or further processing. Second, much of this timber cannot be used for load-bearing construction purposes due to the natural changes in density and imperfections such as knots and shakes (splits) which affect the load bearing capacity of the members. Again, large amount of waste is generated and the requirements for transportation to larger processing facilities which can accept the waste for development of other products. Third, the copper and chromium used to treat the timber exist naturally in our environment and are not toxic to humans in small amounts, but the arsenic is a known carcinogen. Inhalation as timber dust during sawing, or through contact with skin can induce skin, lung or bladder cancer. Finally, though the standard sizing reduces some waste in manufacturing, assembly on site contributes the significant portion of waste from this method of construction. This is due to the many small non-reusable off-cuts that contain the toxic chemicals added once the timber is dressed ready for construction use. It is rarely economical to ship large pre-constructed walls and trusses to site so it is uncommon to manufacture in the factory which would reduce waste. While the waste generated from unsuitable load bearing timber at the initial processing stage can be used toward making another product, such as paper, the majority of the waste--treated timber off-cuts become non-biogradeable waste and are sent directly to landfills rather than through disposal by other means. In New Zealand, construction waste contributes toward 30% of landfill waste (BRANZ).

For comparison with SIPs in terms of utility, timber frame construction also requires insulation, lining and at a minimum a building wrap. As a rule, framing comprises approximately 15-25% of the wall structure, the remainder filled with insulation, then sealed with an interior lining on the interior and building wrap, then cladding on the exterior. A variety of insulation materials are used, chosen for different characteristics including thermal resistance, sustainability and cost. The most common insulation choices for timber frame structures, in rough order of sales volumes are fiberglass, wool and polyester blankets or batts, recycled paper and poly foam products. Each of these products have high insulation values that can meet the minimum standards required by legislation, provided that they are properly installed, and can be chosen for their varying 'green' performances or for their cost. It is difficult to insulate timber frame to a uniform thermal resistance, or R-value, due to thermal bridging in at the framing members where the timber has less thermal resistant than the insulation placed between them, not to mention installation deficiencies (estimated at 10% - 20% less than theoretical). In addition, the air tightness of light timber framed buildings is problematic as the settlement over time creates natural drafts of up to 0.5-0.7 creating a higher natural draft than the recommended 0.2-0.25 air changes per hour.

Light timber framed load-bearing construction has not had much competition overall for the average house construction in New Zealand. Perhaps for this reason, there has been little serious challenge to its ongoing viability in terms of sustainability. The high degree of construction waste, both biodegradable and non-biodegradable, the poor track record for insulation and the resulting high energy costs for heating, the low skill levels of construction laborers and the overall high costs of housing, not to mention the poor health records of housing occupants from living in unsustainable housing, have all been identified independently as issues for New Zealand, but to date, there has been no serious contender for an alternative construction method.

Structural Insulated Panel Systems (Sips)

The term Structurally Insulated Panel systems (SIPs) refers to a simple system of interlocking monolithic panels, the panels comprising a poly foam core sandwiched between two engineered wood panels. The American based SIPs Association defines them as; "high-performance building panels for floors, walls and roofs in residential and commercial buildings. Each panel is typically made using expanded polystyrene (EPS), or polyisocyanurate rigid foam insulation sandwiched between two structural skins of oriented strand board (OSB)." The panels are manufactured in the factory, cut to the size demanded by the individual design, and then shipped to site ready for quick assembly. Onsite, the building envelope are assembled by slotting the panel components together with splines or timber blocks, and fastened with screws and nails, into which the windows and doors are then inserted. For an average house (less than $300m^2$ footprints) the envelope can be enclosed to become weather-tight within 3 days. Some internal and external claddings can be assembled in the workshop before shipment to site, or cladding systems can be constructed on site.

With the current interest in sustainability and in particular green building, SIPs manufacturers are marketing the panel systems under the banner of sustainability. All of the sustainability claims for SIPs by manufacturers and suppliers are similar. The system is claimed to be far superior to light timber framed construction by being:

- Energy efficient; the SIP system has superior thermal resistance and insulation, and it is a more airtight system, which enables the building envelope to regulate the heating, cooling and humidity using less energy to heat or cool.
- Renewable; the construction materials are made from renewable sources.
- Waste efficient during the construction process; because SIPs are manufactured in the factory, less building material is wasted during the construction process and onsite during construction.
- Healthy; the thermal and airtight qualities enhance the indoor environments by regulating the temperature close to that required by the occupants, i.e. warm in winter and cool in summer.

While several NZ companies have overseas affiliations with SIPs manufacturers, there are currently no SIPs constructed homes in New Zealand, nor were we able to find any SIPs in Australia. The product is relatively unknown to the industry and is often mistaken for metal clad panels commonly used in refrigeration containers. We imported samples and investigated two systems, one American and one from the UK, both reliably similar in their composition.

Energy Efficiency

As a result of their composition, SIPs have continuous insulation throughout the panel which is unbroken at any point. Thermal bridging appears to affect only 3% of the panel where splines and electrical chases can affect the thickness of the plastic foam. To gain a better understanding of SIPs performance for thermal resistance, a world recognized institution, the Oakridge National Laboratory (ORNL) in Tennessee, compared SIPs and light timber framed construction (*see figs 1 and 2*). The ORNL base house was equivalent to our 100x50mm light timber frame (at 600mm centers). Insulation was fiberglass Batts in the walls, roof and basement of R-1.8, and R-3.1. A 165mm thick panel wall has a thermal resistance or R-2.4, the minimum required by the New Zealand Building Code (NZBC) is R-1.8. By specifying insulation such as Pink Batts ultra 2.8W, the whole wall thermal resistance values are still less than SIPs due to the thermal bridging *(fig. 2)* across frame of the wall. This makes controlling the heat and cool of the interior more energy intensive.

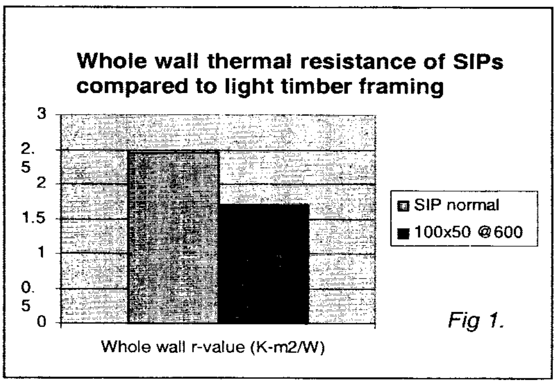

Fig 1.

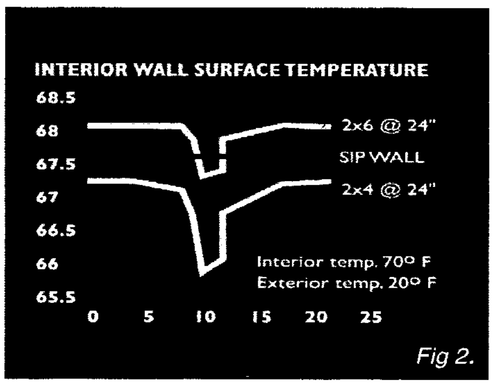

Fig 2.

The manufacturers' claims that SIPs provide a healthier environment prevail when compared to timber framed construction that requires additional heating and cooling to control extreme temperature swings. While we were unable to verify the claim that "SIP homes have repeatedly demonstrated annual energy savings of 50-60% when combined with other high performance systems (SIPs website); we did note that US homes account for 22% of energy use nationwide, and release on average 22,000 lbs of carbon dioxide into the atmosphere annually. To provide some perspective, this is roughly twice as much as the average car; wherein SIPA conclude that building a SIP home with 50% energy savings will be the same as removing one car from America's highways. Arguably in the NZ environment, this level of energy savings would be a stretch, but the evidence does support SIPs superior performance for energy efficiency.

Indoor Air Quality

In addition to thermal performance, the air tightness of SIPs is reported by the ORNL study to be less than 0.1 air changes per hour (ach). The nature of the panels means that over time settlement will not create air-gaps large enough to allow drafts at the panel connections and the openings which are set into the panels. The NZBC recommends a comfortable natural draft rate to be 0.25 ach and requires a minimum of 5% area of openable windows or other openings to remove pollutants from the air. Because SIPs are so airtight there is provision to keep a tighter control on the heating and cooling of the building, by using the windows and doors to increase or decrease ventilation as required. An added benefit of the continuous insulation is that it avoids cavity voids which are prone to mold, a leading contributor to respiratory problems and allergic reactions. However, SIPs air tightness may further require that ventilation be improved to remove toxins from the interior atmosphere through mechanical means.

Material Toxicity and Emissions

SIPs are simple in construction with only two components, engineered wood board and plastic foam. The engineered wood is then combined with wax and a polymer resin (or adhesive) for moisture resistance and to bind the timber wafers (or plies). In terms of contaminants, the resins used in the exterior wood panels are most commonly phenol formaldehyde, which is produced from methanol. Formaldehyde emission from wood composites is restricted mainly to the curing time; however, low level formaldehyde emissions can result from a breakdown of the resin as a result of hydrolysis (damp). Formaldehyde is a carcinogen and exposure may cause skin, respiratory and pulmonary complications. The plastic foam centre is made up of either Polystyrene (XPS) or Polyurethane (PUR) and its derivative polyisocyanurate (PIR) all of which are manufactured as oil by-products. The blowing agent used to expand or extrude EPS, XPS, PUR and PIR is most commonly pentane, or sometimes carbon dioxide for polystyrene. XPS is highly flammable, PUR and PIR are do not support combustion, but emit toxic fumes when subjected to constant flame.

The plastic foam interior of the panel raises other issues relating to sustainability. Because these plastics are derived from petrochemicals, they have a very high embodied energy. The extruding agent, petane affects the central nervous system and causes irritation to skin, eyes and respiratory tract on exposure. However, very little trace of the pentane is left behind after the curing time. The CO^2 used for expansion/extrusion is usually recovered from existing commercial or industrial sources so is not further contributing to the high CO^2 in the atmosphere. Once expanded, the foams contain 95% air and only 5% of the plastic, so very little of the material is actually used in the making of SIPs. When the XPS deteriorates, it releases gases under ultra-violet light, however little UV penetrates the panels once manufactured. To our knowledge, there is no foam plastic manufacturing in NZ at this time, so importing would be required.

Conservation of Materials and Resources

To minimize the impact on the environment, there have been recent initiatives in the US, Australia and NZ to use recycled polystyrene. Both PUR and PIR can be recycled through melting and regrinding. Currently, most PU waste goes to landfill where it is non-biodegradable. PIR is stronger and more stable than PUR, but is also the most expensive, so used less often. It is unclear how much recycled foam is used by manufacturers as it appears the majority of manufacturers use new foam plastics.

In comparing the level of contaminants between SIPs and standard construction timbers, SIP's would still appear to be the superior product. Relatively low amounts of plastics are used in the SIPs and the amount of formaldehyde in the engineered panels is of a similar amount to many other household items, though it is still a concern. Of larger concern is the arsenic in the chemical treatment of timber which can be of greatest toxicity during manufacture and assembly.

Waste Reduction

With respect to waste generated from construction, engineered wood panels such as the OSB and plywood used in SIPs are comprised from of 90% of the tree. While the remaining portion of the tree can be used for other materials such as paper and cellulose insulation this generally requires transporting the material and other inefficiencies. This is superior in terms of efficiency to waste generated during primary processing of standard construction timber, load bearing or otherwise. SIPs are manufactured in the workshop to a specific design, so arrive on-site ready to assemble without further modification and with the timber block in-fills and splines ready to fit. Once manufactured into sandwich panels, the waste OSB or plywood cannot be reused or recycled, but there is likely to be very little waste as panels can be designed around openings. SIPs off cuts cannot be easily recycled so end up in landfill, but the amounts are minimal. Waste plastic foam can be recycled back into the panels, but this is dependent on the foam being returned to the manufacture. If the foam is land-filled it does not biodegrade.

Discussion

The selection of the four criteria set out in the promotional literature for SIPs when advocating sustainability; namely natural resource conservation, minimization of material toxicity and emissions, energy efficiency and the creation of healthy indoor environments, were largely aligned with the international measures deemed to define sustainability. Since the initial promotion, SIPA have added a fifth and sixth sustainable benefit; namely durability and safety. Noting 'resistance to air infiltration and moisture intrusion increases the life of a home, and building longevity is a key component in environmentally sustainable building' (SIPA website). However, two components of sustainability; economics and the 'equity' or social aspects (other than healthy environment) were not well discussed in the literature as the focus of the measurement systems was primarily environmental/ecological with some balance for health. For example, internally, timber framing requires some form of lining to meet code, while SIPs will only require an intumescent paint for fire protection (if the engineered wood has less than 10 minutes fire resistance). But is painted engineered wood a socially acceptable interior finish? Obtaining a true 'apple to apple' comparison between the two systems is challenged by these types of issues.

In terms of performance against the criteria, the comparison of the claims made for SIPs with the properties of light timber frame construction revealed that the performance of SIPs stand up to most of the claims in that they are as energy efficient, conserve less resources, are less toxic, less wasteful, and are beneficial in creating a healthier indoor environment. Buildings use 30% of all energy and 60% of all electricity and are responsible for much of the emissions to the air. The SIP system has a more airtight system enabling the building envelope to better regulate the heating, cooling and humidity of the interior, also using less energy to heat in winter and cool in summer. The thermal bridging and inferior air tightness of the timber frame construction requires a more energy intensive heating and cooling. Timber buildings have been reported to have a natural draft rate of 0.25 ach up to an excessive 0.7 ach. This much draft can bring cold and damp into to the building allowing mould and other health retarding problems. A healthy indoor environment is one that provides protection from outdoor environment of extreme heat and cold and removes impurities in the air imparted by; cooking fumes and odors, moisture from laundering, dishwashing and bathing, airborne particles, bacteria, viruses and other pathogens. The manufacturers claim that SIPs provide a healthier environment is true when compared to timber framed construction that has been allowed to settle with too many air gaps.

One weakness in the noted international systems for measuring sustainability became apparent when trying to compare the material toxicity and emissions of the two construction systems. While they enabled comparison between two similar products or the overall output performance (such as thermal performance) of two systems, they did not provide a means to effectively compare issues such as material toxicity and emissions between systems of construction when the materials and methods of assembly were different. Without some form of scale or comparison system, we were unable to make accurate evaluations of materials toxicity and emissions from which to compare light timber frame construction with SIPs construction. More specifically, we were unable to determine if 5% of product A was worse than 30% of product B and had only the perceived health risks associated with various materials from which to compare. We are concerned about the severity of the health risks without having any means of assessing the relationship of the quantity of the material, the conditions for its risk and the likelihood of their occurrence. The literature was insufficient for any meaningful comparison.

Where the manufacturers' claims do not appear to completely stack up are when it comes to resource renewability/conservation. Renewable is defined as energy or a product derived from resources that can be regenerated at regular intervals and does not deplete fossil fuels. Perhaps understandably, the SIPs manufacturers do not mention that their 'green buildings' contain toxins and use some non-renewable resources. For this reason, it appears that SIPs do not perform as well as timber as a building product due to the low renewable energy of plastic foams which are produced from fossil fuels. The use of recycled plastics could address this shortfall; however, current recycling practices are still considered marginal. When we reduce energy use, reduce the use of non-renewable materials, and reduce the pollution caused by the manufacture of materials we can minimize the impact of the 'building footprint' on the environment.

Approximately 30% of landfill is from building waste. The choices in our selections of materials, building systems and equipment can reduce the effect of construction on that environment. SIPs outperform light frame timber construction in terms of waste reduction directly due to their manufacturing and assembly processes which are custom designed to minimize end waste. The assembly of the timber frame on site creates a lot of waste timber with chemical treatment which makes it toxic in the landfill and means it cannot be recycled. Although landfill ground leachate and gasses are better managed than ever before, it is imperative for the environment to reduce this source of toxic waste.

Conclusion

Further research into SIPs in terms of their long term sustainability is required on a number of levels to obtain realistic comparison. Sustainability is more than simply green. Currently none of the component parts of the SIPs studied are currently manufactured in New Zealand. Research is currently underway to find suitable alternatives for the ideal KiwiSips; however, there are many issues to be resolved prior to acceptance. Issues include the costs of importing plastic foams, the sustainability of recycling plastics in NZ for this type of product, opportunites for OSB manufacture or other suitable wood product for the exterior panels and opportunities for reuse and final disposition. The subject also requires further study with respect to manufacturing and transporting on the small NZ scale.

SIPs were developed in the American context of large markets, high labor cost, shortages of skilled labour, demand for reduced construction time, extensive petrochemical manufacturing industries, timber shortages and efficient land transport systems. Housing is typically mass produced, lending itself to prefabricated processes. These same conditions hold for most of the countries reporting an increase use of SIPs. Furthermore, since their initial development, other demands such as increased government requirements for high energy performance and new performance measures for sustainability have made them an easy solution. An example of this is the recent introduction to the Building Regulations for England & Wales of Part L: Sustainability which has made SIPs the simplest option for conformity. These conditions either do not exist to the same degree in New Zealand or are only in their earliest forms of development.

Perhaps the silver lining in the cloud of increased extreme weather conditions, improved reporting of natural disaster and the damage and destruction of housing is a greater public awareness of the importance of sustainable housing solutions. Overseas, SIPs have grown in popularity for their structural performance in high wind and earthquake conditions. For example, in 1995, after the 7.2 magnitude earthquake near Kobe, Japan, 6 SIPs homes were investigated and found to be still standing in good condition where other new buildings subject to strict earthquake proof standards were severely damaged. In addition, as noted previously for disaster recovery, rapid deployment opportunities and SIPs short construction times have also brought them to the attention of governments, builders and developers.

From our research, we conclude that in the majority of claims, SIPs are a 'greener' solution and potentially healthier solution for housing construction than the current practice of standard light framed load-bearing wall construction. However, we further note that sustainability measures are more than simply green, or even healthy, they are cultural constructs and vary by country and local conditions. There are currently considerable barriers to SIPs development and acceptance in New Zealand. These range from the general issues associated with difficulties of undertaking SIPs research in the NZ environment through to overall market size and the structure of competitor product manufacturers, through to national attitudes of risk-taking with structural building components and the recent history of housing failures. More specifically, there are the issues of designing and manufacturing a 'KiwiSIP' that can match the sustainability attributes of the overseas product while maintaining the building economics. On a final and more positive note, Kiwi's have a long tradition of flourishing in conditions of adversity and we are confident that sustainable SIPs housing is in New Zealand's not too distant future.

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