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# Title: What are 'Structural Insulated Panels' and are they the sustainable solution to standard light framing load-bearing wall construction?

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# What are ‘Structural Insulated Panels’ and are they the sustainable solution to standard light framing load-bearing wall construction?

## Abstract

A relatively recent innovation in building component systems, Structural Insulated Panels systems (SIPs) are fast gaining popularity in North America and Europe. Hailed as ‘green building product’ and promoted as environmentally sustainable, the Structural Insulation Panel Association claims in its website that SIPs create a ‘green building’ through:

- Energy efficiency and renewable energy
- Waste reduction during the construction process
- Creation of healthy indoor environments

But is this claim true, and what are the measures of sustainability? This paper serves first to define a structural insulated panel, then to consider appropriate measures with which to test its ‘sustainability’ claims and finally to compare its performance as a wall component relative to standard NZ wall construction methods.

## Introduction

The term Structurally Insulated Panel systems (SIPs) refers to a simple system of interlocking monolithic 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).”[1] 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 a small house (less than 300m² footprint) 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.

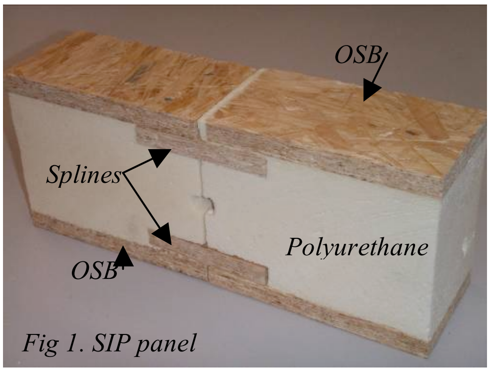

*Fig 1. SIP panel*

A variation of SIPS have been in existence since Frank Lloyd Wright used SIP-like panels in the 1930s (though Alden B. Dow, son of the founder of Dow Chemical Co., is recognised as designing the first SIP homes in 1932 with plywood and Styrofoam). Interest in SIPs has grown with the introduction of more streamlined assembly technology and the demonstrated success of SIPs constructed buildings still standing after the 1993 Kobe earthquake and the recent hurricanes in southeastern USA.

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[1] http://www.sips.org/portal/tabid__3914/DesktopDefault.aspx?tabid=3914 18/10/2006

In 2003 SIPs contributed 1% of all new residential construction in the USA (ref), and their use are growing in popularity in the US by 11% per year (ref). In the UK, Europe, China, Japan, and many other countries it has seen acceptance and is growing in use with more recent press coverage on television home building programs and in magazines and Journals.

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.

But are these appropriate measures of sustainability for New Zealand? Have all aspects of sustainable construction been considered, or have only those convenient for the purposes of promotional literature been considered? In order to address these questions and evaluate SIPs (assess these claims) in the New Zealand context, a comparison of the 'green' SIPs properties is undertaken with the New Zealand benchmark building system of light timber framed platform construction. Furthermore, a review of sustainability measures is also conducted to also consider other measures that attempt to evaluate sustainability, to better understand the growing demand for SIPs

## Measures of Sustainability

Numerous systems of measuring sustainable building have been introduced worldwide including:

- 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

to name but a few. Each of the programs has its advocates and its 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 is considered in the manufacturers claims. The material 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 and has been considered. 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; however we still question if these are all the measures of sustainability that should be used when considering the New Zealand context, for reasons that we discuss below.

## New Zealand light timber frame house construction

Currently, 90% of all new houses in New Zealand are platform timber framed construction using plantation softwood – a renewable resource (BRANZ). Timber has been the material of choice for small 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 colonisers bought from their respective origins.

*Fig 2. Light timber framed construction with Batt insulation*

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. For load-bearing construction, 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. 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. The chemical treatment of timber with Copper Chromium Arsenic (CCA) was phased out of 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 building disaster. 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 plan using the standard size increments.

This process presents a number of challenges for sustainable load-bearing construction. First, construction grade timber can only be manufactured from 60% of the tree. 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. The implications for sustainable construction relate to the large amount of waste generated and the requirements for either transportation of waste, or 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 in safe amounts, but the arsenic is toxic. The copper and chromium portions of the CCA are not toxic to humans in small amounts, but the arsenic is a known carcinogenic. Inhalation as timber dust during sawing, or through contact with skin could induce skin, lung or bladder cancer[2]. 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 offcuts become non-biogradeable waste and are sent directly to landfills rather than through disposal by other means. Construction waste contributes toward 30% of landfill waste (BRANZ).

For comparison with SIPs, timber frame construction also requires insulation. As a rule, framing comprises 15-25% of the wall structure, the remainder filled with insulation, then sealed with an interior lining on the interior and building paper, then cladding on the exterior. A variety of insulation materials are used, chosen for different characteristics including thermal resistance, sustainability and cost. As is evidenced by Fig 2, 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. 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[3] creating a higher natural draft than the recommended 0.2-0.25 air changes per hour.

The insulation choices for timber frame; fibreglass, wool and polyester blankets or batts, recycled paper and poly foam products. Each of these products have high insulation values than can meet the minimum standards required by legislation, but each can be chosen for their varying ‘green’ performances or for the costs.

**Structural Insulated Panels systems**

While several NZ companies have overseas affiliations with SIPs manufacturers, there are currently no SIPs constructed homes in New Zealand. The product is relatively unknown to the industry and is often mistaken for metal clad panels

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[2] However, once the timber is enclosed in the wall, it is unlikely to leach out unless wet.

[3] Reid 1998

commonly used in refrigeration containers. We investigated two sample systems, one American and one from the UK, both reliably similar in their composition.

Both SIPs are simple in construction with only two components, engineered wood panels 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). The resin used in New Zealand is most commonly phenol-formaldehyde (PF). 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 less flammable, but emit toxic fumes when burnt.

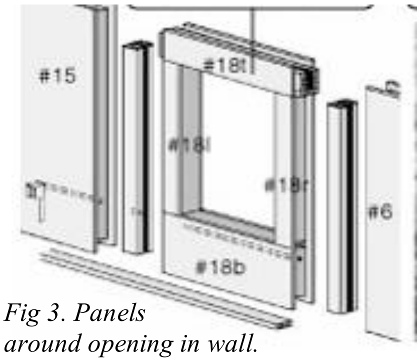

*Fig 3. Panels around opening in wall.*

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.

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 affect the thickness of the plastic foam. To gain a better understanding of SIPs performance for thermal resistance, world recognised institution, the Oakridge National Laboratory (ORNL) in Tennessee, compared SIPs and light timber framed construction. (*see figs 4 and 5*). 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.

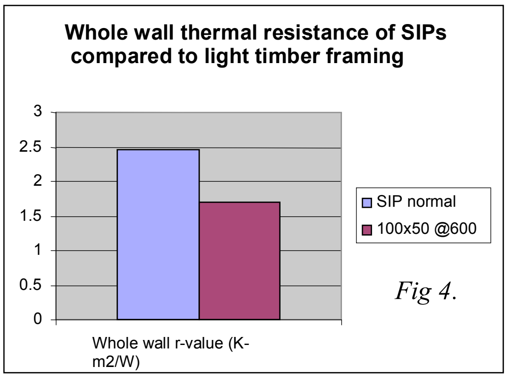

*Fig 4.*

In fig 5, the thermal bridging in light timber frame construction is represented in this graph by ORNL comparing the internal wall temperature of the insulated timber frame wall with the SIPs wall.

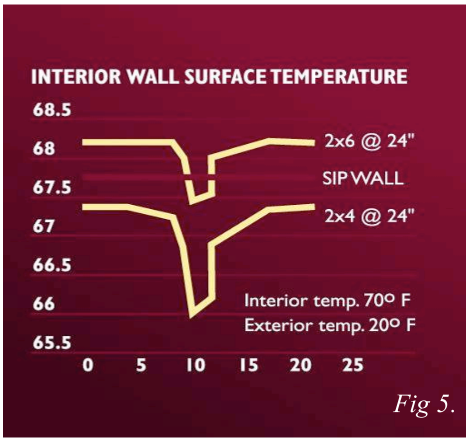

*Fig 5.*

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. SIPs airtightness may further require that ventilation be improved to remove toxins from the interior atmosphere through mechanical means.

The ORNL base house was equivalent to our 100x50mm light timber frame (at 600mm centres). Insulation was fibreglass Batts in the walls, roof and basement of r-1.8, and r-3.1. 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. 4)* across frame of the wall. This makes controlling the heat and cool of the interior more energy intensive. The manufacturers' claims that SIPs provide a healthier environment prevail when compared to timber framed construction that will require heating and cooling to control extreme temperature swings.

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 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.

To minimise 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 appear to be the superior product. The 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.

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. However, that remaining portion of the tree can be used for other materials such as paper and cellulose insulation. This is superior in terms of efficiency to waste generated during primary processing of standard construction timber, load bearing or otherwise. 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 (fig 3). Off cuts of OSB and ply cannot be 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, minimisation 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. 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 cladding to meet code, while SIPs will only require an in tumescent paint, or gypsum board cladding for fire protection (if the engineered wood has less than 10 minutes fire resistance). But is painted engineered wood an acceptable interior finish? Obtaining a true 'apples to apples' comparison between the two systems was challenged by these types of issues.

In terms of performance against the four 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, less wasteful, and beneficial in creating a healthier environment. Buildings use 30% of all energy and 60% of all electricity and are responsible for a much of the emissions to the air. 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 minimise 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 this to be waste to be reduced as timber can create a lot of waste that is toxic when land filled.

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 were able to compare 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 were 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.

A healthy indoor environment is one that provides protection form outdoor environment of extreme heat and cold and removes impurities in the air imparted by; cooking fumes and odours, moisture from laundering, dishwashing and bathing, airborne particles, bacteria, viruses and other pathogens. The SIP system have 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 airtightness of the timber frame 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. 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.

Where the manufacturers' claims do not appear to completely stack up are when it comes to resource renewability. Renewable is defined as energy or a product derived from resources that can be regenerated at regular intervals and does not deplete fossil fuels. The SIPs manufacturers do not mention that their 'green buildings' contain toxins and uses 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 would 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.

Further research into SIPs in terms of their long term sustainability is required on a number of levels to obtain realistic, apples to apples comparison. Issues such as the costs of importing plastic foams, the sustainability of recycling plastics in NZ for this type of product, flexibility for change, opportunities for reuse and final disposition of the SIPs all require further study, not to mention issues relating to manufacturing and transporting on the small NZ scale require further study.

## Conclusion

SIPs were developed in the American context of high labour 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 it the recent introduction to the Building Regulations for England & Wales of Part L: Sustainability.

At the same time, with the increase in extreme weather conditions related to global warming and the resultant damage and destruction of housing, 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[4]. In addition, for disaster recovery, SIPs short construction times have also brought them to the attention of governments, builders and developers. Most recently following Hurricane Katrina the USA Federal Emergency Management Agency (FEMA) dispatched 25,000 Building America Structural Insulated Panel (BASIP) homes for temporary housing *(Schwind 2006).*

This paper concludes that in most claims, SIPS are a sustainable solution to standard light framing load-bearing wall construction. Sustainability measures while seeming global in their structure must consider all aspects of sustainability, not solely the environmental/ecological and be modified for the context of the country for which they are to be used. While the factors necessary for SIPs to gain support in the New Zealand environment currently do not exist sufficiently so as to warrant their manufacture here, in these writers opinion, it is only a matter of time.

## References

Kay, J.J. 2002. 'On Complexity Theory, Exergy and Industrial Ecology: Some Implications for Construction Ecology.' in Kibert C., Sendzimir, J., Guy, B. (eds), *Construction ecology: Nature as the basis for green buildings*, Spon press, pp.72-107

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[4] R-Control Building Systems press release 'Kobe earthquake' 2001

Schwind, C. Florida Solar Energy Center Specifies SIPs for FEMA Manufactured Homes Structural insulated Panel Association Press Release 06-22. 2006

Energy Savings From Small Near-Zero-Energy Houses; Integration Of Whole-House Construction Technologies In Small, Affordable, Super Efficient Houses. Oak Ridge National Laboratory, Tennessee, USA. 2006

Green by Green: Renewable, Desirable, Sustainable wood. Canadian wood council and Forest products Association of Canada.

Bill Wachtler, innovative home Magazine (pp98)

Ministry for the Environment. 'Construction and Demolition Waste' http://www.mfe.govt.nz/issues/waste/construction-demo/ 18/10/2006

Reid, E. *Understanding Buildings; A Multidisciplinary Approach,* Cambridge Massachusetts; MIT Press, 1998

Resins used in the production of Oriented Strand Board, 2005/14; http://tecotested.com

SIPs Outperform Stick & Batt in Oak Ridge National Labs R-Value Test Structural Insulated Panel Association; http://www.sips.org 17/10/2006

R-Control Building Systems press release 'Kobe earthquake' 2001 http://www.r-control.com/downloads/literature/kobe.pdf 18/10/2006

http://www.sips.org

**Figures**

Fig 1: Authors own picture from FischerSIPs sample
Fig 2: http://www.greenspec.co.uk/images.jpg
Fig 3&4: Created from data in 'SIPs Outperform Stick & Batt in Oak Ridge National Labs R-Value Test' Structural Insulated Panel Association**.** http://www.sips.org
Fig 5: http://www.msbuilder.com