The eco-friendliness of Bio-Structural Insulated Panels (SIPs)

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Abstract: Globally, it has been noted that construction industry uses non-regenerative materials that has significant impacts on the environment. This study is to find suitable alternative manufacturing process for structural insulated panels (SIPs). Although the conventional SIPs when compared to conventional timber framing (CTF) are eco-friendly, clean materials and energy efficiency very high. SIPs are made of two facing boards called oriental strand board (OSB) and the inner continuous insulating core of either expanded polystyrene foam (EPS) or extruded polystyrene foam (XPS) or polyurethane foam (PUR). Formaldehyde adhesive has been a common binding material for almost all furniture, building materials including OSB. EPS or XPS or PUR are non-renewable materials but by-product of fossil fuel that “present environmental impacts”. If SIPs manufacturers can consider alternative for inner core, it will increase the eco-friendly of SIPs. The research methodology is to compare the attributes of conventional SIP with biologically based structural insulated panel (Bio-SIP). Green Seal standards (criteria) is used to evaluate Bio- SIP with conventional SIPs to formulate matrix and SWOT analysis.

Keywords: Environmental impact; sustainability; conventional structural insulated panel (SIPs); biologically structural insulated panels (Bio-SIPs).

1. Introduction

The construction industry has been facing some challenges in the transition to low carbon construction due to one-way approach to the choice of building materials and technologies. Right from the choice of raw materials, processing, manufacturing to waste disposing, all contributed to the negative environmental impact. The global concern is that the building materials globally consume 30-50% of available raw resources and produce about 40% of waste to landfill in Organisation for Economic Co-operation and Development (OECD) country. Australia, as one of the countries in OECD, produced a larger quantity of carbon-dioxide (CO2) emission and solid waste especially from the built environment (Productivity Commission 2006). The awareness created world advocating for sustainable buildings which have zero or low carbon footprint. Conventional SIP has been seen as a way to achieve the goal of energy efficiency and minimizing waste, though the material components and the manufacturing

process of conventional SIP have health risk such as rash, eye irritation, headache, allergic, skin reaction, even carcinogenic to humans and production of greenhouse gases depending on the deteriorating state of SIP. The choices of replacing conventional SIP with bio-SIP is to improve and have a building that is eco-friendly. A building that uses renewable resources (plant-based materials) which can reduces carbon footprint, locally source and recycled naturally (biodegradable) can improved the quality of life of the end users. This research is to compare conventional SIP with bio-SIP products based on literature review and manufacturers' catalogues and specification. Laboratory or chemical test nor field test is beyond the scope of this research. The figures below are diagrams of conventional SIP and bio-SIP components.

2. Historical background of structural insulated panel (SIPs)

SIPs literally called sandwich panel has been dated back to the innovation of “beauty and simplicity in cost effective homes” (Morley 2000) by famous Architect Frank Lloyd Wright when he designed Usonian houses in 1930s and 1940s (Morley 2000, p.8). The earlier SIP lack adequate insulation materials but today's SIP has been greatly improvements with the additional strong and continuous inner core insulating material. The use of structural insulated system in Australia has been dated back to the past fifty years though popularly used for commercial construction known as “Insulated sandwich panel otherwise referred to ‘insulated concrete form’ (ICF) (Steinhardt, Manley & Miller 2013). Now, attention is being drawn to SIPs for residential buildings especially in Western Australia and in other developed countries such as United State of America (USA), United Kingdom (UK).
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SIPs constituted two layers of structural boards - oriented strand board (OSB), sandwiched with the new improved inner core of closed cell foams of either expanded polystyrene foam (EPS) or extruded polystyrene foam (XPS) or polyurethane foam (PUR) or composite honeycomb (HSC) (Morley 2000, p.21-26). SIPs serve as one of the “energy efficient building materials for walls, roofs and floors” (Purasinghe & Dusicka 2013) and can be placed on any foundation type. The energy efficiency of SIPs has contributed to better sealing of the building against heat loss and heat gain whereby bring about durability, indoor air quality and improvement on environmental. Moreover, the fast construction method with less labour intensive and reduction of site waste gives the edge above conventional timber framing. The insulation is inculcated to the facing boards which makes the inner-core, continuous, stable, create constant and uniform thermal reduction and minimized thermal bridging (Doan Oct 2012, p.32).

3. Terminologies defined

Table 1 is the definitions of the terms used in this research

<table>
<thead>
<tr>
<th>Terms</th>
<th>Definitions</th>
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<tbody>
<tr>
<td>Regenerative material</td>
<td>Regenerative material is defined according to free dictionary, as material that can reconstitute or reuse again into a better form. It can be derived from living tree, plant, animal or ecosystem. Regenerative are renewable, biodegradable, compostable, ecologically friendly and there is tendency for the regenerative materials to undergo natural recycling and reduce carbon footprint.</td>
</tr>
<tr>
<td>Biodegradable material</td>
<td>Biodegradable material can decompose by the action of biological agents especially bacteria that bring about reduction in the volume of waste into the landfill site. It is the action that takes place when microorganisms act on a material; break the components down into carbon-dioxide (CO2) and water.</td>
</tr>
<tr>
<td>Compostable materials</td>
<td>Compostable materials are the biopolymer materials that can undergo breaking down by 90% within six months through an industrial composting process.</td>
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<tr>
<td>Eco-friendly or ecological friendly</td>
<td>Eco-friendly or ecological friendly can literally refer to earth- friendly, non-toxic, recyclable and biodegradable. According to 'Longman' dictionary, eco-friendly is defined &quot;as products that are environmentally friendly that do not harm the environment when they are made or when you usethem&quot;.</td>
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4. Evaluation Criteria

As the global world is becoming aware and responsive to the large environment impacts of building materials, effort is been made to choose building materials that are eco-friendly. This can be done if the life cycle assessment is done which include production, manufacturing, distribution, maintenance and disposal of the materials. In selecting the appropriate criteria for this research, green seal criteria will be used. The key aspects of evaluation criteria of Bio-SIPs versus conventional SIPs has been based on green seal evaluation criteria to improve these products. Green seal-based evaluation criteria (steps) focus on life cycle assessment are: (1) Source of raw materials; (2) Extraction of the materials; (3)
Manufacturing process; (4) Intended Use; and (5) Disposal/recycling. According to the green seal evaluation criteria, products should have the following attributes:

- Promotion of good indoor air quality that can reduce emissions of volatile organic compound.
- Source form renewable materials such as plants that are locally available
- Require low energy consumption for production and process therefore low embodied energy and reduction in the greenhouse gas emission.
- To be recycled or are biodegradable with no risk to health.
- Promote reduction of waste.

5. Assessment of SIPs

SIPs are made of oriented strand board (OSB), sandwiched with the new improved inner core of closed cell foams of either EPS or XPS or PUR or composite honeycomb (HSC) (Morley 2000, p.21-26). SIPs are known for energy efficiency, waste minimisation, not labour intensive and reduction in cost of labour in comparison with timber framing construction. The materials components are assessed below based on literature reviews and manufacturers’ catalogue. No laboratory test was carried out which is beyond the scope of this research.

5.1. Oriented strand board (OSB) - Material components assessment

OSB is the combination of wood and adhesives strengthen the panel against deflection, delamination and warping. It is widely used by the manufacturers. 'There are currently no Australian regulations, standards or codes that specifically deal with OSB, but Suppliers are able to provide specifications on the OSB products they stock.'

5.2. EPS, XPS and PUR - Material components assessment

EPS or XPS (inner insulating core) are so suitable to be used with OSB" (Pfundstein et al. 2008, p.34) because of the closed-cell moisture resistant structure composed of millions of tiny air-filled pockets. EPS/XPS are widely used unlike PUR which are used by few manufacturers because is expensive and the blowing agent CFC is toxic (see table 2).

5.3. Biologically based structural insulated panels (Bio-SIPs)

Bio-SIPs can be referred to as biologically structural insulated panels that are made from plant-based materials. It is a natural and organic materials that may contribute positively to the environment by reducing the carbon emission and embodied energy during production, and construction. Bio-SIP can be a better option to conventional SIP because of the availability of materials, source from renewable materials and ability to undergo natural recycling that is biodegradable. In Australia, there are a lot of residue from timbers, agricultural waste, domestic and commercial waste such as paper that can be used to make Bio-SIPs without depending on the importation of the OSB and raw materials for EPS or XPS.
5.4. Bio-based board analysis - Material components assessment

Wheat straw, rice husk, flax, hemps, bamboo, cork, palm kernel tree, straw bale, reeds, sheep's wool, wood chip or pellet available in Australia that can be used to manufacture engineered boards. Australia’s hardwood plantation estate has been largely planted and managed to produce pulplogs destined for the woodchip export market. There is need to divert the timber residue to produce valuable boards (Forest Industry Advisory Council, March 2015). In this research, literature reviews were used to source for renewable, biodegradable and locally available materials that can be used for the facing board and inner-core insulation.

5.5. Bio-based adhesive/binder - Material components assessment

Bio-based adhesive is an engineered bio-based binder system from a renewable material that can replace the formaldehyde-based resin of the conventional SIP. This product is non-toxic, and the process does not utilize solvent and does not produce toxic by-products. The bio-based binder can perform better than synthetic binder because it possesses the ability to bind efficiently, resistance to moisture, eliminate or reduction of volatile organic chemical (VOC) and involved renewable manufacturing processes which either minimize or eliminate non-renewable ingredients. According to Ireland et al of EcoSynthetix stated "replacing urea formaldehyde-based resins with engineered biopolymer binder will results in a 33 percent reduction in carbon footprint based on chemistry comparison. Greater sustainability of process and product, compared to formaldehyde-based resin, is expected when energy efficient processing and more effective transportation are taken into consideration".

5.6. Bio-based or biopolymer inner-core insulation-Material components assessment

Biopolymer is a new technology which has captured the attention of materialist scientists though natural polymer has been in existence before the emergence of synthetic polymer from fossil fuel in twenty century. The attention being shifted from synthetic polymer (non-renewable materials) to biopolymer or bio-based (renewable materials) are due to global warming, depletion of ozone and all other environmental issues associated with synthetic polymer. The use of biopolymer to replace EPS /XPS/PUR in SIPs can improve the eco-friendly of SIP. Biopolymer is known to have higher specific heat capacity and denser than conventional EPS. 'Biopolymer are biodegradable and compostable plastics whose components are derived entire or in part from renewable raw materials. Biopolymer can be derive from plant oils, polysaccharides (mainly cellulose and starch), sugars, wood and others synthetic material. (Meier, Metzger & Schbert 2007, p. 7).

6.0 Analysis of bio-SIPs versus convention SIPs:

A recent article on Sustainable brand focus on "trending: fossil fuel divestment enters primetime" written by Brynn W. McNally on May 8, 2015. The article was on behavioural change toward the use of fossil fuel. Even there was a projection that "greenhouse gas will grow to two hundred and eighty million tonne (280Mt) by 2050 an increase of 110% on 2005 emissions" (Property Council of Australia nd). So, there are variety of materials that are available locally that can be used to manufacture Bio-SIP.
to replace conventional SIP. The range of bio-based boards and insulations has be discussed above. This section focusses on the Bio-SIPs versus Conventional SIPs as the research look at the strength, weaknesses, opportunity and treats (SWOT) as per Australia context, the benefits and drawbacks of both products. The information is based on literature review and manufacturers’ catalogue, no laboratory test. Below are the SWOT analysis bio-SIP and evaluation of bio-SIP versus conventional SIP.

### 6.1. Bio-SIPs versus Conventional SIPs on Literature Review and Manufacturers’ catalogue

The comparison of conventional SIP with bio-SIP boards are based on literature reviews and manufacturers’ catalogue. The green labelling criteria is explored to compare these two products. There are about fifty green labelling programs among which are LEED, Energy star, green globe and Green seal and each group are administered by different organizations though tend to direct their effort toward different goals but in different ways. The green seal criteria were used in this research to assess material components of these products though actual chemistry or laboratory or field test are not carried out. Green seal tends to look at the environmental and/or health attributes of products.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Conventional SIPs</th>
<th>Bio-SIPs</th>
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<tbody>
<tr>
<td><strong>Indoor air quality (IAQ)</strong></td>
<td>High IAQ, low off-gassing on exposure to moisture</td>
<td>High IAQ, low off-gassing on exposure to moisture</td>
</tr>
<tr>
<td><strong>Durability and strength</strong></td>
<td>Structurally sound and long-life span</td>
<td>Structurally sound and long-life span depend on the materials components</td>
</tr>
<tr>
<td><strong>Recycle content</strong></td>
<td>Low recycle content</td>
<td>High recycle content</td>
</tr>
<tr>
<td><strong>Renewable resources &amp; Availability</strong></td>
<td>Renewable and non-renewable materials. Not available locally, overseas raw materials.</td>
<td>Renewable materials. Locally available</td>
</tr>
<tr>
<td><strong>Toxicity</strong></td>
<td>High or low toxic depending on the materials used by the manufacturers for fire retardant, blowing agent and adhesive.</td>
<td>No or low toxic depending on the materials used by the manufacturers for fire retardant, blowing agent and adhesive.</td>
</tr>
<tr>
<td><strong>Sustainability and biodegradable</strong></td>
<td>Biodegradable - NO</td>
<td>Biodegradable – YES</td>
</tr>
<tr>
<td><strong>Waste minimization</strong></td>
<td>Low to medium waste minimization (timber wastes and residues for the board)</td>
<td>Medium to high waste minimization (agricultural and timber wastes for the boards &amp; inner core insulation)</td>
</tr>
<tr>
<td><strong>Disposal and recycling</strong></td>
<td>Undamaged SIP can be reused but recycling is very hard but end up in landfill</td>
<td>Undamaged bio-SIP can be reused. Easily disposable because it is biodegradable</td>
</tr>
<tr>
<td><strong>Resistant to fire, moisture and insects</strong></td>
<td>Resistant to fire is low unless treated with fire retardant. Insect resistant depending on the type and resistant to moisture is high if not exposed to moisture.</td>
<td>Resistant to fire, moisture and insect naturally. Though some Bio-SIPs need additional retardant and moisture protection to function as or exceed conventional SIP</td>
</tr>
<tr>
<td><strong>Energy efficiency and use</strong></td>
<td>The thermal performance is high therefore energy efficiency is high.</td>
<td>The thermal performance is high therefore energy efficiency is high.</td>
</tr>
</tbody>
</table>
6.1. Benefits and Drawbacks of Conversional SIPs versus Bio-SIP

A lot has been said about the components of Conversional SIPs and bio-SIP, the tables below summarised the benefits that can be derived and the drawbacks in the context of Australia. The table 3 summarised the eco-friendliness of conventional SIP and the need for regenerative SIP.

![Figure 5: Benefits and drawbacks of conventional SIP](image-url)
Figure 6: Benefits and drawbacks of conventional Bio-SIPs

**Benefits**
- Minimised waste & reuse of agricultural waste to produce valuable products.
- Boost Agricultural Economy
- Less environmental pollution
- Renewable, Biodegradable & sustainable materials
- Non toxic
- Low embodied energy
- Easy to handle i.e. lighter

**Drawback**
- Shifting to new technology rather than the old traditional timber framing.
- Low resistant to insects and moisture if not properly guide against.
- Cost of production may be high.
- Initial cost may be high
7.0 Discussion

Based on the facts gathered about bio-SIP, it has a great potential and possess attributes which can make it suitable to replace conventional SIP. Bio-SIPs components are locally sourced and renewable materials which has no VOCs, and it is biodegradable. The structural ability and resistant to moisture need improvement to meet up or exceed the conventional SIP. Oriented bamboo strand panel board is worth exploring by seeking alternative bio-based adhesive to replace the Polymeric diphenylmethane diisocyanate (pMDI). Also, the initial cost of producing bio-SIP will be high and technical know-how may not be available too. Further research can be done to verify the laboratory or chemistry test of these materials and the energy efficiency of Bio-SIP. Also, it requires to further test the integrated of bio-SIP with other building component and suitability for Australia climate. The conventional SIP cannot be recycled though little waste are generated in the cost of production and construction, but the replacement of the inner insulation core is very important to avoid dependence on fossil fuel and increasing of greenhouse gases.

8.0 Conclusion

In this paper, Bio-SIP will reduce dependence on non-renewable, none locally available materials and reduce environmental impacts (embodied energy, pollution). Bio-SIP are biodegradable and will generate economic opportunities to the agricultural sector. The use of bio-SIP will reduce energy consumption during production and cost of maintenance. Although cost bio-SIP will be higher initially than conventional SIP, so more research needs to be done in reducing the cost of developing bio-SIP. For effective implementation of sustainability development in construction industry, the use of agricultural products and waste including timber residue can bring about reduction of energy consumption and turning of waste to valuable materials.

References

Purasinghe, R & Dusicka, P 2013, 'Use of energy efficient wood structural insulation panels in seismic regions', University of Moratuwa.
Steinhardt, DA, Manley, K & Miller, W 2013, 'Profiling the nature and context of the Australian prefabricated housing industry', Queensland University of Technology.