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Life Cycle Assessment of Hempstone for Green Buildings

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Hemp is a non-psychoactive (less than 1 % tetrahydrocannabinol) variety of Cannabis sativa L. It is cultivated on hills and used mainly for textiles. Hemp requires less water and pesticides. It grows fast (3 - 4 m in 3 months) and has a high carbon sequestration rate of 1.67 kg CO_2-eq per kg of hemp fibre. The local hemp in Thailand is the Rpf3 species developed by the Highland Research and Development Institute. This study aims at exploring the potential use of hemp for eco-building materials to meet the increasing demands for green buildings by applying the upcycling design concept. Hemp stalks left after fibre harvesting were sun dried before ground into small pieces of varying sizes. Artificial stones (polyester-resin solid surface material) left over from production processes were also collected. Hemp materials and artificial stone scraps were used at different proportions to develop a new composite called Hempstone. The study found that Hempstone did not require the drying process; hemp fibers helped absorb the moisture. Hemp fibres also offered unique natural aesthetic. Quality tests were conducted to ensure that Hempstone was fit for use in construction. Life Cycle Assessment (LCA) was performed to identify the potential reduction of environmental impacts of typical artificial stone and Hempstone. The results indicated that the Hempstone sheet (0.82 x 3.04 x 0.012 m) with 10 % of hemp-stalks (6 - 10 mm size) and 7.5 % or 10 % by weight of artificial stone scraps performed best with the potential reduction of environmental impacts by 40 % on climate change, 42 % on freshwater eutrophication, 55 % on terrestrial eco-toxicity and 60 % on terrestrial eco-toxicity. With the growing pursuit of green buildings, these reductions show that the potential use of hemp in local eco-building materials to help reducing impact on the environment.

1. Introduction

Hemp was originally grown by the hill tribe in the North of Thailand, known as the Hmong; its fibres were used to produce traditional clothes for religious rites, funerals and weddings. Later on, hemp farming has been promoted as a new economic plant in Thailand especially on the high-land areas, as proposed by Thailand's National Economic and Social Development Board. Hemp plants in fact have already been grown by various royal projects, which aim at generating supplementary income for farmers. Since 2014, the Thai government has issued special permits allowing the cultivation of hemp (HRDI, 2013). This has taken a positive step forward to promote hemp farming and creating new rural jobs. Thailand has also set up royal initiatives to investigate hemp and initiated a program aiming to develop a hemp seed strain suitable for industrial uses. There were, however, limitations on growing hemp since it is categorised as a No. 5 narcotic plant in the form of marijuana although hemp is not marijuana. A plant cultivated for marijuana has a 3 - 15 % of tetrahydrocannabinol (THC) content or more, while industrial hemp generally contains 1 % or less (Pakauthai and Sringam, 2007). Thai hemp farmers must be registered to collect the hemp seeds for growing in the allowed areas for hemp farming activities. Hemp is used for wide-ranging products from durable clothing to nutritional supplies. It is refined into products such as hemp seed foods, hemp oil, wax,

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resin, rope, cloth, pulp, paper, industrial materials and fuel. Hemp fibres are long, light, strong and durable, with about 70 % cellulose and contain around 8 - 10 % lignin (EIHA, 2011). By using the hemp fibre's properties, it was mixed with foam gym to enhance the strength (Brencis, et al., 2011). The hemp fibers could also be mixed with MgO-cement which could be useful for improving the mechanical properties and thermal resistant in construction works (Cigasova, et al., 2014). Hemp is a fast-growing plant and does not need much water or pesticides (Van der Werf, 2004). It was reported that hemp could potentially absorb carbon dioxide for about 44.46 % of stem dry weight (Vosper, 2011). A high potential of hemp plant to absorb carbon dioxide makes it more appealing to be explored for eco-building materials, especially with the requirement of green building certification system on environmental product declaration of building materials based on Life Cycle Assessment (LCA) with multiple aspects with the focus on climate change. To explore an alternative and innovative use of hemp, this study focuses on solid surface material for green buildings design applications.

2. Methodology

2.1 Goal and scope

This LCA study aims at exploring a potential use of hemp stalks remaining after fibre extraction as "Hempstone" solid surface for buildings' interior applications. The scope of study covers all stages based on the cradle-to-gate approach, i.e. hemp growing, hemp-stalk material preparation, Hempstone solid surface production (experimental scale), use and final disposal including the related transports (Figure 1). The functional unit was set as a Hempstone sheet (W 0.82 x L 3.04 x H 0.012 m). Impact categories of interest were: Climate change, Freshwater eco-toxicity, Terrestrial eco-toxicity, and Freshwater eutrophication. The method of life cycle impact assessment was ReCiPe (ISO, 2006).

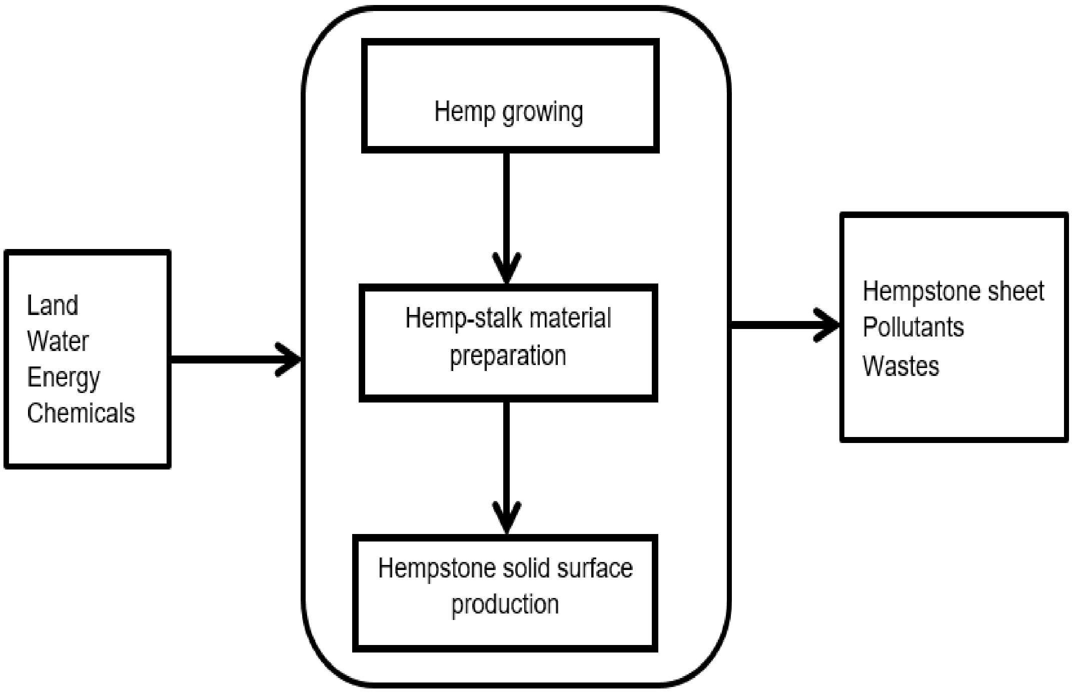

Figure 1: Scope of the LCA study

2.2 Hemp-stalk material preparation

Hemp stalks left after fibre harvesting were transported from the farming site to a local laboratory for hemp-stalk material preparation. They were primarily sun dried for 2 d before grinding into small pieces by using a grinding machine. The ground hemp-stalk materials have varying sizes as follows: lesser than 0.2 cm (number 0), 0.3 - 0.5 cm (number 0.5), 0.6 - 1.0 cm (number 1), and 1.0 - 1.5 cm (number 2), as shown in Figure 2. The number 2 size was prepared from a rough grinding. The number 1 size was obtained from the sieving of the hemp stalk after grinding, while the number 0 size was achieved by sieving the grinded hemps stalk with 2 times of grinding.

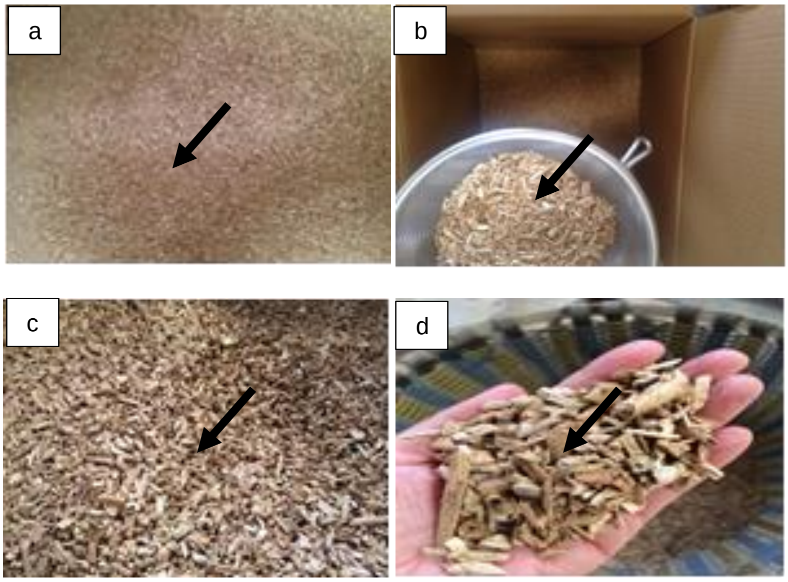

Figure 2: Hemp-stalk materials at different sizes; a) 0 cm, b) 0.5 cm, c) 1.0 cm, and d) 2.0 cm

2.3 Hempstone solid surface production

The production of artificial stones (solid surface) was based on polyester resin. Alumina Trihydrate (ATH) is used as the filler to provide the properties of flame retardant and smoke suppression. In this study, the first attempt was to try using the hemp-stalk materials at various sizes to replace ATH at different ratios (Table 1) and different ratios of resin, hemp-stalk materials, ATH and artificial stone scraps were investigated (Table 2). The mixed components were poured into a mould and left to air dry for 3 - 4 h.

Table 1: Ratios of resin and hemp-stalk materials at various sizes

Scenario	Ratio (%)				
	Resin	Hemp-stalk materials			
		Number 0	Number 1	Number 2	Number 3
1	90	0	0	0	10
2	90	0	0	10	0
3	90	2.5	0	7.5	0
4	90	2.5	7.5	0	0
5	90	5	5	0	0
6	90	10	0	0	0

Table 2: Ratios of resin, hemp-stalk materials, ATH and artificial stone scraps

Scenario	Ratio (%)			
	Resin	Hemp-stalk materials (Number 1)	ATH	Artificial stone wastes
7	90	10	0	0
8	87.5	12.5	0	0
9	85	15	0	0
10	80	10	10	0
11	80	12.5	7.5	0
12	80	15	5	0
13	80	10	5	5
14	75	10	7.5	7.5
15	75	10	5	10
16	75	10	2.5	12.5
17	80	10	0	10
18	75	10	0	15
19	70	10	0	20

In addition to hemp-stalk materials, artificial stone scraps left over from production processes were also used at different ratios for the development of this new hemp composite. Different ratios of resin, hemp-stalk materials, ATH and artificial stone scraps were trialled. The first attempt was aimed to achieve at least 10 % of using hemp-stalk materials (Table 1 and 2).

2.4 Quality testing

Quality tests were conducted to ensure that Hempstone sheet was fit for use in architectural applications. The quality parameters included in the test were in accordance with the American Society for Testing and Materials (ASTM) standard.

3. Environmental performance assessment

LCA (Life Cycle Assessment) was performed to identify the potential reduction of environmental impacts of typical artificial stone and Hempstone solid surface. The local hemp in Thailand is Rpf3 species developed by the Highland Research and Development Institute**.** For the hemp growing stage, the inventory data of annual production in 2015 (especially the current practice) was collected by interviewing 20 farmers in Tak province, the main hemp production sites of Thailand (more than 50 % of total production at the national level). The inventory data associated from the cradle-to-gate were identified and collected accordingly. The background data were based on the national inventory databases, supplemented by secondary data from literature and international databases where necessary.

4. Results and discussions

4.1 Carbon sequestration

Hemp can grow fast, 3 - 4 m in 3 months. Chemical fertilisers, 46-0-0 and 15-15-15, were applied at the rates of 313 and 156 kg per ha to achieve the yields ranging from 18,750 to 25,000 kg per ha. Hemp axis is left after harvesting its fibres, about 70 % by total weight. The carbon contents of root, body, branch and leave are 43.81 %, 45.46 %, 39.36 %, and 46 %. The carbon sequestration rate of hemp fibre is 1.67 kg CO_2-eq per kg, which is slightly higher than the previous study in Australia (Vosper, 2011).

4.2 Hempstone prototype

The hempstone prototype was shown in Figure 3. By varying sizes of hemp-stalk materials while using the same amount of resin, the results showed that the components could be homogenously mixed together only for the scenarios 2 and 3 (see Table 1). There was a clear separated layer between resin and hemp-stalk material in scenarios 1. The higher ratios of finer size hemp-stalk materials in scenarios 4 - 6 caused (see Table 1) a significant reduction of liquidity that led to the difficulty in mixing. By varying the ratios of all components, they could be homogenously mixed in all scenarios except for scenarios 9, 12, 16 and 19 (see Table 2). It was found that the maximum ratio of hemp- stalk material was 10 % and that of artificial stone scraps was 15 % (scenario 18).

Figure 3: Hempstone prototype example (scenario 18)

4.3 Quality performances

The quality results were proved to meet the quality standard (Table 3). Compared to other hemp materials, it was revealed that the hemp-stalk material has an ability to increase the bending strength 4 times higher than ordinary artificial stones, and perform better in terms of impact resistance. This study showed the positive results as previously reported by Awwad et al. (2012) that hemp fibers could be mixed with concrete at the rates of 0.5 %. 0.75 %, and 1 % to reduce the ratios of rough-mix components for 10 %, 20 % and 30 %.

Table 3: Quality test results

Quality parameters	Method (Standard values)	Results
Flexural	ASTM D790 (> 25 kg/cm^2)	79 kg/cm^2
Compression	ASTM D790 (> 180 kg/cm^2)	410 kg/cm^2
High-Pressure Decorative Laminates	NEMA LD 3 (> 100 times)	115 times
Rockwell hardness	ASTM D785 (> 50 Shore D)	69 Shore D
Water absorption	ASTM D570 (< 1 %)	0.92 %

4.4 Environmental performances

The comparative environmental performances of artificial stone and Hempstone with hemp-stalk materials and artificial stone scraps at different ratios were shown in Figure 4. The results indicated that the Hempstone sheet (W 0.82 x L 3.04 x H 0.012 m) with 10 % of hemp-stalk material (6 - 10 mm size) and 7.5 % or 10 % of artificial stone scraps by weight performed the best with the potential reduction of environmental impacts by 40 % on climate change, by 42 % on freshwater eutrophication, by 55 % on terrestrial eco-toxicity and by 60 % on terrestrial eco-toxicity. Adding more artificial stone scraps into the composite, to reach the scrap ratio of 25 % (hemp-stalk material 10 % and artificial stone scraps 15 %), the potential environmental impacts on climate change, freshwater eutrophication and freshwater eco-toxicity was increased due to higher amount of polyester resin and their associated impacts.

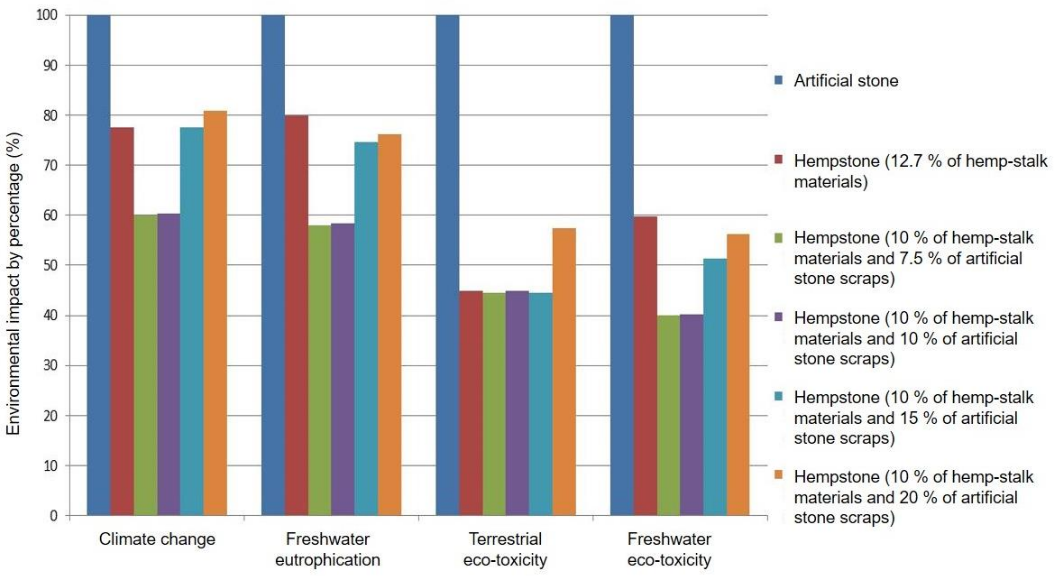

Figure 4: Comparative environmental performances of artificial stone and Hempstone with hemp stalk materials and artificial stone scraps at different ratios

5. Conclusions

Hempstone is a new composite made of hemp stalks and artificial stone scraps in polyester-resin matrix. It is an upcycled material with over 20 % reclaimed scrap content, offering a measurable potential to help reduce environmental impacts in construction. Unexpectedly, adding more scraps into the composite did not yield lower environmental impact as anticipated earlier. The reclaimed bio-based content seems to provide a greater opportunity for the reduction of environmental impact. With the growing pursuit of green buildings, Hempstone could offer opportunities for architects and designers who seek novel eco-building materials such as table top and furniture (Figure 5).

(a) (b)

Figure 5: Table top (a) and furniture (b) made from Hempstone

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