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Life cycle assessment of Hempstone for green buildings

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Abstract

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 (4–5 meters in 3–4 months) and has a high carbon sequestration rate of 1.36 $kgCO_2e$ per kg of hemp fiber. This study aims at exploring the potential use of hemp for construction materials. By applying the upcycling design concept, hemp stalks left after fibre harvesting were sun dried before grinding into small pieces of varying sizes. In addition, artificial stones (polyester-resin solid surface material) left over from production processes was 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 fibers also offered unique natural aesthetic. Quality tests were conducted to ensure that Hempstone was fit for use in construction. LCA (Life Cycle Assessment) was performed to identify the potential reduction of environmental impacts of typical artificial stone and Hempstone. The results indicated that the Hempstone sheet (0.82×3.04×0.012m) with 10% of hemp-stalks (5 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 ecotoxicity and 60% on terrestrial ecotoxicity. Hence, the Hempstone sheet with 10% of hemp-stalk material and 10% of artificial stone scraps complies with the UPCYCLE Carbon Footprint certification and labelling requirement of minimum scrap content of 20% by weight. With the growing pursuit of green buildings, these reductions

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show that the use of hemp in construction materials help reduce impact on the environment and offer opportunities for commercialization.
Keywords: carbon footprint, eco material, green building, hemp, Hempstone, Life Cycle Assessment, upcycling, sustainability.

1 Introduction

Sustainability now has a defined presence in the world of architecture and becoming the norm for designing the built environment. Eco-architects are seeking to minimize potential environmental impacts through the use of sustainable construction materials, particularly those that could help reducing greenhouse gas emissions associated with the material production as well as the energy performance of buildings during occupancy. With the growing pursuits of sustainable architecture by architects and designers, not having a variety of eco-building materials for diverse architectural applications and aesthetics available in the markets has become a barrier for increasing green buildings.

Hemp was originally grown by the hill tribe in the North of Thailand, known as the Hmong; its fibers 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 [2]. 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. However, there were limitations on growing hemp since it is categorized 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 [4]. 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, resin, rope, cloth, pulp, paper, industrial materials and fuel. Hemp fibers are long, light, strong and durable, with about 70% cellulose and contain around 8–10% lignin [1, 7]. The fiber diameter ranges from 16 to 50 microns and has a texture similar to linen. Hemp can be de-gummed for processing in flax or cotton machinery. It can be blended with cotton, linen, silk and wool to provide a softer feel, while adding resistance and durability to the product. In Europe and China, hemp fibers have been used to strengthen concrete, and in other composite materials for construction applications. A mixture of fiberglass, hemp fiber, kenaf, and flax has been used to make composite panels for automobiles. Hemp seeds contain a very high content of protein and are used for food and animal feed. Their leaves are used for health products. Hemp oil is used for cosmetics. Hemp stalks remaining after peeling off their fiber-rich barks were mainly used as low cost biomass. Recently, hemp stalks have been explored for building materials, e.g. fiber-cement mix, insulator, wall covering, and sound absorption.

Solid surface materials based on polymer resin is widely used as the substitute of natural stone. It offers the better quality in terms of lower water absorption, better chemical resistance, easier in forming into various shapes, and recyclability. Hemp is a fast-growing plant and does not need much water or pesticides [5, 6]. It was reported that hemp could potentially absorb carbon dioxide for about 44.46% of stem dry weight [7]. 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 or based on Carbon Footprint with the focus on climate change. To explore an alternative and innovative use of hemp, this study focuses on solid surface material for buildings' interior design applications.

2 Methodology

2.1 Goal and scope

This LCA study aims at exploring a potential use of hemp stalks remaining after fiber 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, hem-stalk material preparation, Hempstone solid surface production (experimental scale), use and final disposal including the related transports. The functional unit was set as a Hempstone sheet (W0.82 × L3.04 × H0.012 m). Impact categories of interest were: Climate change, Freshwater ecotoxicity, Terrestrial ecotoxicity, and Freshwater eutrophication. The method of impact assessment was ReCiPe [3].

2.2 Hemp-stalk material preparation

Hemp stalks left after fiber harvesting were transported from the farming site to a local laboratory for hemp-stalk material preparation. They were primarily suns dried for 2 days before grinding into small pieces by using a grinding machine. The ground hemp-stalk materials have varying sizes as follow: 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). 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.

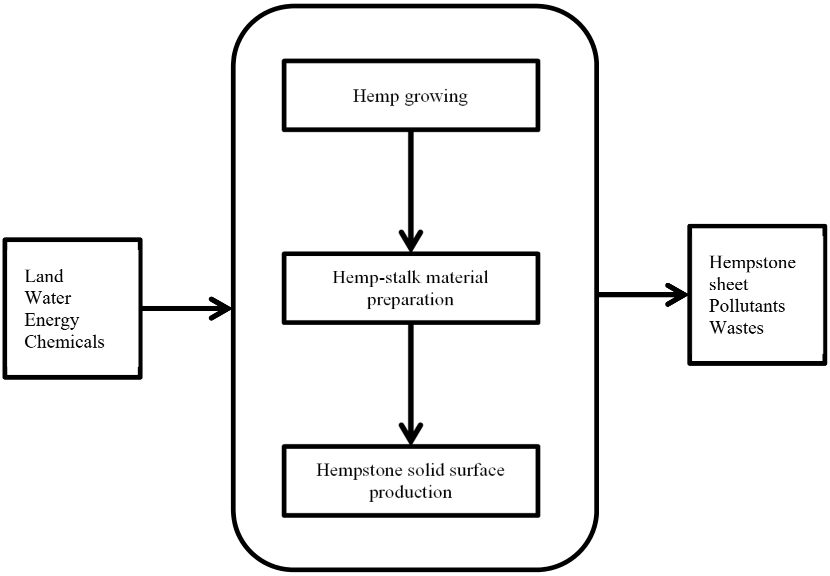

Figure 1: Scope of the LCA study.


(i) Number 0


(ii) Number 0.5


(iii) Number 1.0


(iv) Number 2.0

Figure 2: Hemp-stalk materials at different sizes.

2.3 Hempstone solid surface production

The production of artificial stones (solid surface) was based on polyester resin. Aluminum Trihydrateh (ATH) is used as the filler to provide the properties of flame retardant and smoke suppression. In this study, it was the first attempt to try using the hemp-stalk materials at various sizes to replace ATH. The components of Hempstone solid surface indicated in different scenarios (Table 1) were weighed and mixed using a mixer. The mixed components were poured into a mold and left to air dry for 3–4 hours.

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

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 (Table 2).

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

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 (Table 3).

Table 3: Quality test parameters and the related ASTM standards.

Series	Parameters	Standards
1	Flexural strength	ASTM D790
2	Compressive strength	ASTM D695
3	IZOD impact resistance	ASTM D256
4	Rockwell hardness	ASTM D2240, ASTM D785
5	Density test (Specific gravity)	ASTM D792
6	Water absorption	ASTM C373
7	Impact resistance	MEMA LD 3-3-3 (1/2 lb. Ball)

2.5 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 inventory data associated from the cradle-to-gate were identified and collected accordingly. For the hemp growing stage, the inventory data of annual production in 2015 (especially the current practice) was collected by interviewing 7 farmers in Tak province, the main hemp production sites of Thailand (more than 50% of total production at the national level). The background data were based on the national inventory databases, supplemented by secondary data from literature and international databases where necessary.

3 Results and discussion

3.1 Hempstone prototype

By varying sizes of hem-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.

3.2 Quality testing

The quality testing indicated 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. During the bending test, when the sheet was cracked the hemp-stalk still hold the test strips together not broken into pieces; this showed the reinforcement qualities of hemp-stalk material. The elasticity of Hempstone solid surface materials could facilitate the ease of forming into different shapes. Moreover, Hempstone offered a much lighter weight composite for construction.

3.3 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 (W0.82 × L3.04 × H0.012m) with 10% of hemp-stalk material (5-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 ecotoxicity and by 60% on terrestrial ecotoxicity. 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. However, the Hempstone sheet with 10% of hemp-stalk material and 10% of artificial stone scraps would comply with the UPCYCLE Carbon Footprint certification and labelling requirement of using scraps at a minimum of 20% by weight.

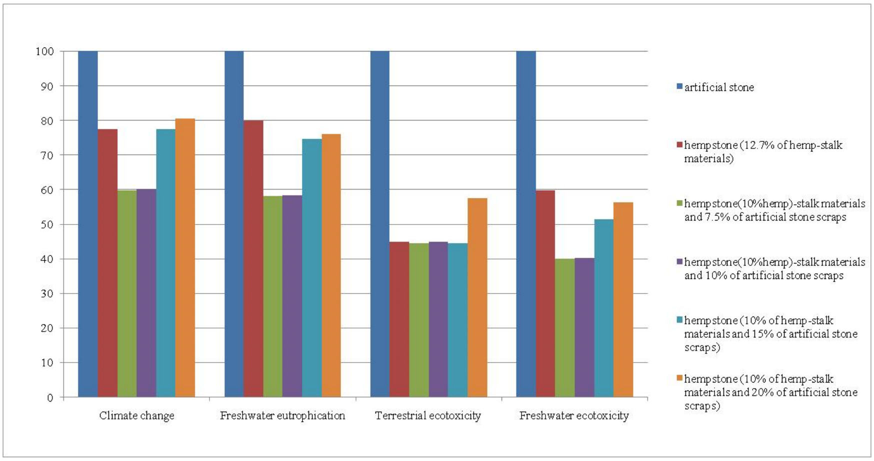

Figure 4: Comparative environmental performances of artificial stone and Hempstone with hemp-stalk materials and artificial stone scraps at different ratios.

4 Conclusions and outlook

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 earlier anticipated. 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-materials. Optimizing environmental performance, cost, material quality and design aesthetic would be the key to economic viability and ultimately commercialization in construction and interior design industry. The use of scrap at least 20% is also in compliance with the UPCYCLE Carbon Footprint scheme; the UPCYCLE Carbon Footprint label could potentially be used as a product declaration and marketing tool for Hempstone to support green building development.

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