Sustainable Supply Chain of Construction Products and Materials: A Case Study of Natural - Fiber Cement Wall Products

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ABSTRACT

Nowadays, poverty and deficiency of proper housing are main problems of Thailand, particularly in rural areas. A quick-fixed solution is to provide low-cost houses directly to the villagers. This study gives an alternative solution by promoting local knowledge and self-sustained concepts to the society. Local resources and agricultural wastes are used as raw materials for creating different alternative construction products and materials, such as natural-fiber cement board, natural-fiber reinforced panel, etc. Production lines are designed to suit different environments. Competitive benchmarking and Life Cycle Cost analysis are used to evaluate each product in terms of performances, cost and environment impacts. The results show high responsiveness of the villagers. Once this project is fully established, the village can be benefited in terms of both the social and economic aspects.

Key words: Recycle agricultural waste, Product and process design, Local wisdom, Natural-Fiber cement board, Appropriate technology, Alternative construction, Products and materials

INTRODUCTION

Housing is a vital factor for mankind and their quality of life. It is defined as a human-built dwelling which can provide shelter against precipitation, wind, heat, cold and intruding. Once it is occupied as a routine dwelling for human, a house is called a home. The higher the quality of homes, the better the chance of growing and surviving.

Nowadays, Thailand still confronts with the low standard of housing situation, particularly in the groups of low-income people. Historically, each society has its own local wisdom to create a peaceful community from local resources, such as wood and soil (Thiengburanathum et al., 2005).

However, after the society has been influenced by globalization and capitalism, the local wisdom and the local resources are neglected and depleted. In today's market, designer/owner and contractor are limited to selecting proper construction materials. For example, to build a wall, concrete block or common brick is typically used; to construct a structural system, reinforced concrete (RC) is normally selected, according to their economy and availability.

Low-income villagers also have limited choices in today's situation. The cheapest choice is RC structure and concrete block if they would like to build a new house. However, for the villagers who would like to repair/renovate by keeping the old structure – normally timber system, the concrete block cannot be used (see Figure 1). Wood panel is too expensive. The other panels such as cement board, laminated wood board or bamboo mat are also inappropriate or costly for the low-income people (see Figure 2).

Figure 1. Due to rare wood resource, repairing by timber is expensive for the low-income villagers.

Figure 2. Variety of construction wall materials of typical low-income housing.

A possible solution is to provide a set of appropriate technologies to the village by focusing on sustainable economic and sufficient-living concepts. Therefore, this research is introducing the idea of sustainable supply chain and developing a series of appropriate technologies in both product and process designs. Objectives of this study are summarized as follow:

• To study and develop local housing materials, combined with local wisdom, by using the left-over of agricultural wastes
• To study construction techniques from local materials in order to produce wall panel products that are more environmentally friendly with better quality of lives and cost-effective. It will include the study of product characteristic and will determine a range of design criteria
• To provide community employment and encouragement in order to become more economically self-sufficient
• To study the local living pattern and feed back after participating in the research

SUSTAINABLE SUPPLY CHAIN

The idea of sustainability may be defined differently. This study coins the definition of a sustainable system as "a dynamic system that can reliably grow in the long term and can preserve its core value in different aspects, such as economic, social, institutional and environmental." Therefore, sustainable supply chain is referred to as the sustainable system that is mapped by the definition of supply chain which is the network of flows for both physical and non-physical entities among demand and supply through the system.

The supply chain concept can be used as a modeling tool to capture the value stream of a system. The higher the value added through the supply-demand lines, the better the business opportunity (Figure 3).

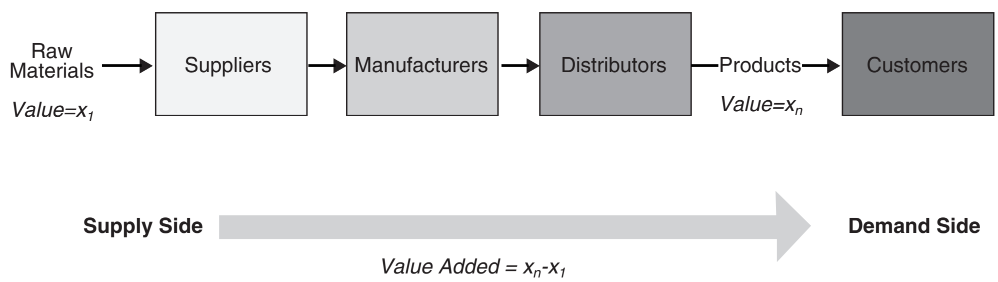

Figure 3. A typical supply chain model.

The sustainable supply chain is also a modeling concept that reviews both the value streams (supply-demand lines) and influences toward other core elements, such as environmental and human resources.

Another important concept of sustainable supply chain is *system reliability*, which consists of the reliability of flow elements and non-flow elements. The reliability of flow elements is basic concept of typical supply chain management. This is an attempt to control flow variability. For example, the business or organization cannot be truly successful if they cannot secure their supply and demand lines; then, sustainability cannot happen. On the other hand, the reliability of non-flow elements is referred to as preserving the quality of any core elements that normally support the supply chain process and generating innovation and improvement to the system. The most important core elements are environment and human resources. Once the environment is not appropriate, performance of the value stream cannot be achieved. Human resource is another crucial aspect of the system sustainability. The better the quality of human resource, the higher the chance of suitable knowledge, culture and policy that enable the system to adapt itself properly.

Sustainable supply chain allows modelers to design business process or organization activity. Figure 4 illustrates an example of the sustainable supply chain modeling. It shows the flows of physical elements (raw materials and products) and value that circulate within the society.

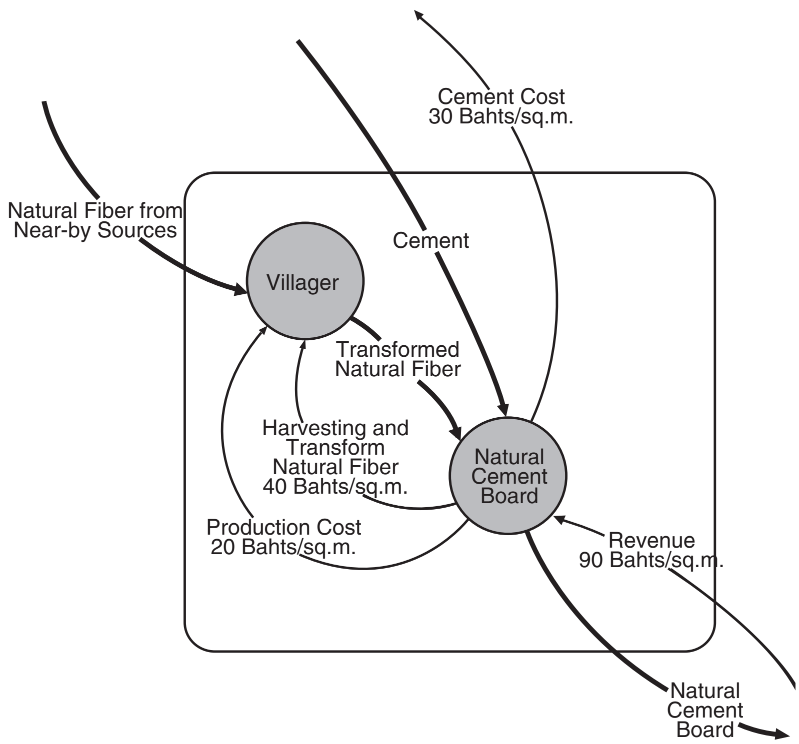

Figure 4. An example sustainable supply chain of natural cement board production system.

METHODOLOGY

The framework of research methodology consists of loop process: (1) analysis of the potential resources, such as agriculture wastes and local resources, and social value/culture, (2) product design, (3) process design, (4) implementation, and (5) social evaluation, as shown in Figure 5.

Analysis of potential resources is the first step of deciding between Go/NoGo decision in each area. Basically, each area has its own peculiarity. There are several criteria to determine the potential of successful implementation. For example, they are quantity and quality of raw materials (e.g., agriculture waste, community waste, natural resources), logistic/transportation, culture/norm, and workforce skills. Once the raw materials are confirmed, the prototype product and process are created specifically. Then, the quality of the product and process are evaluated in terms of performance (Lee and Miller, 1997; ASTM, 2000; KaKlauskas et al., 2005), economic (Deseeltumkan, 2004; Treearrayapong and Keawta, 2004), and environment. After that, this product and process are released to the implementation phase which is also evaluated again by the users.

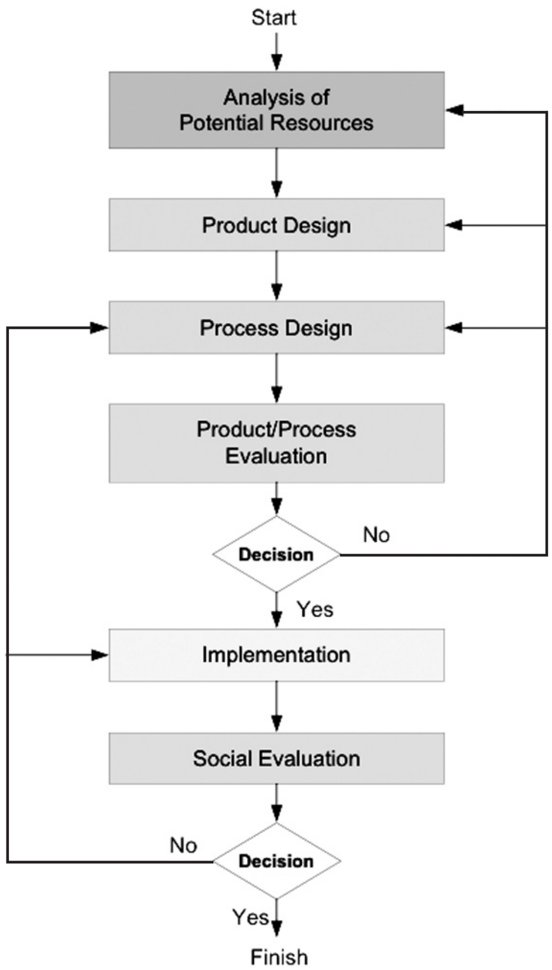

Figure 5. The framework of research methodology.

NATURAL- FIBER CEMENT BOARD

Natural-fiber cement board is made of mixture between cement, water and sand and fermented fiber, which is fiber from giant grass plants. The board is 2.5-cm thick, for the prototype model. There is an adding technique to increase compaction (Reinhardt and Naaman, 1992; Ramakrishna and Sundararajan 2005; Thiengburanathum et al., 2005).

The process starts with cutting and peeling giant grass plant. Let it dry, and then slice and grind into small pieces at 3- to 5-cm length. Put them in lime solution for 7 days until becoming fermented. Then, mix these fibers with water, cement and sand in a certain amount until it becomes homogeneous. Pour the mixture into a wooden mold of 120 x 60 square centimeters, at about 2.5-cm thick. Then, pour the mixture at the same thickness to cover up on top.

After pouring the mixture into a mold and smoothing its surface, vibrate underneath the mold evenly around 5 minutes until air bubbles are released above the surface. Leave it for 24 hours to set before disassembling from its mold. Next step is curing cement by frequently watering the board for 1-2 weeks to keep its moisture. Concrete will cure and build up its strength. After that, dry the board in normal weather condition for 1-2 weeks before it becomes ready to use. Figure 6 (a) and (b) shows the overall process of fiber cement board production.

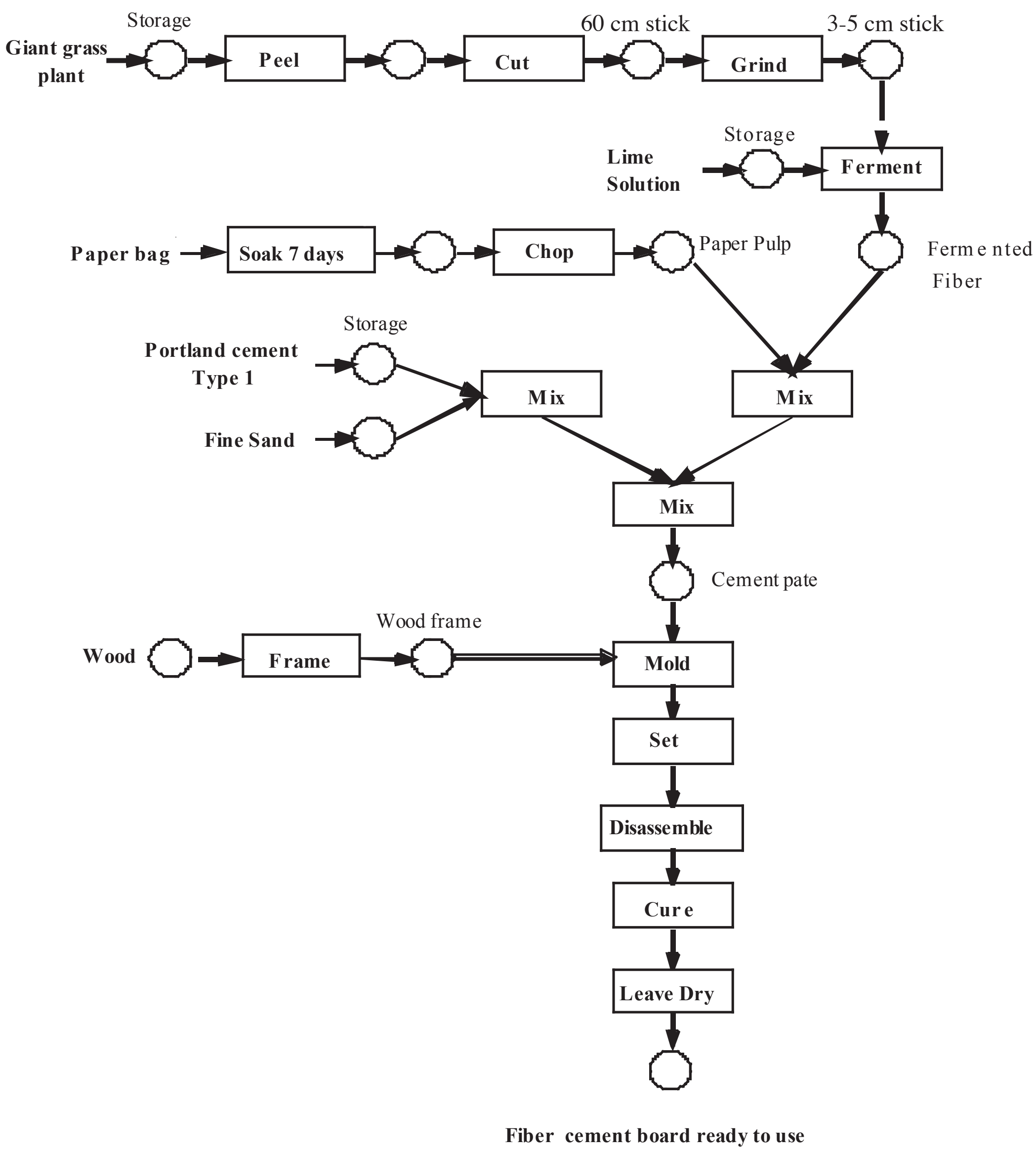

Figure 6 (a). Natural-fiber cement board production flow chart

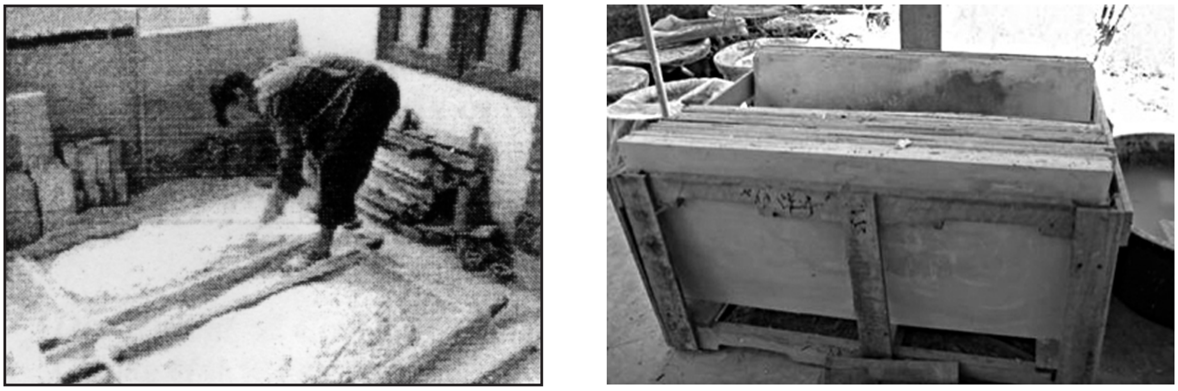

Figure 6 (b). Processes of natural-fiber cement board production

RESULTS

Tables 1 and 2 show that fiber cement board is slightly heavier than Viva board and timber. Meanwhile, modulus of rupture of the research's product, at trial run, is less than that of the market product whereas none of the boards are comparable to timber. In addition, coefficient of thermal conductivity of the research's product is slightly higher due to the mixing formula.

Table 1: Product Performance Benchmarking.

Point of consideration	*Details*	*Fiber cement board*	*Viva board*	** Timber*
Performance	Density (g/cm^3)	1.45	1.1 - 1.3	1.07
	Moisture content (%)	12.3	12$\pm$3	n/a
	Modulus of rupture (Mpa.) at 28 days	3.6	9.0-12.0	90.6
	Coefficient of Thermal Conductivity (W/m^{o}c)	0.145	< 0.130	0.138
	Compressive strength (Mpa.)	188.72	n/a	18.04
	Absorption (24 hrs) (%)	14.9	n/a	n/a
	Average swelling (%)	1.4	< 2.0%	n/a
	Size (cm)	60x120x1	120x240x1	250x15x1
	Weight (Kg/m^2)	14.1	13.0	10.7
	Compressive bending stiffness (Kg/m^2)	2.629x10^7	n/a	n/a

** Biological name :Siamese Sal*

Total cost of a fiber cement board is around 35% cheaper than the market products at the same thickness. Furthermore, if the whole system is considered, the society will pay only for cement cost which is about 30 Bahts per sq.m, while other values will run within the society as mentioned earlier (Figure 4).

Table 2: Product Cost Benchmarking.

Point of consideration	*Details*	*Fiber cement board*	*Viva board*	*Timber*
Cost	Material cost (Baht/ sqm)	71		
	Production cost (Baht/ sqm)	23	145	480
	Total cost (Baht/ sqm)	95		
	Construction cost (Baht/ sqm)	207	207	207
	Usage cost (Baht/ sqm)	490	435	481
	Demolition cost (Baht/ sqm)	100	100	100

Figures 7 and 8 illustrate the final outcome of the research. As a result, villagers can see the opportunity to use these alternative materials for their home improvement and repairing. Furthermore, it can be another income source for their community.

Figure 7. Villagers apply the cement board to their home.

Figure 8. Repaired houses by this natural-fiber cement board technology.

DISCUSSION AND CONCLUSION

The idea of sustainable supply chain can help us capture the different perspective beyond the traditional value stream mapping. It allows us to visualize the value that generates back to the system. Natural-fiber cement is an example that applies this system concept. Although the performance of this natural-fiber cement board is lower than the manufacturing-based cement board and timber, the product cost is tentatively below the cement board and timber in the market.

The idea of using local supplies to produce construction materials is another key successful factor. It is aimed to substitute the use of industrial materials. Nowadays, any changes that occur to the local environment are quite threatening and likely to cause adverse impacts. The products are proved to be a great alternative to people in rural area. The processes are simplified and cost-effective. Not only will it be environmentally friendly, but also it will bring a better quality of lives to local people. The processes and products, as a result of this research, have been gradually developed through the period of time. The changes have been and will be made under circumstances of seasonal agricultural materials, new product and process designs, and also quality development. The most fortunate thing that contributes to the achievement of this research is community participation that has added hints to the processes and hence made the processes become practical and feasible.

The innovation of local materials will ease of the future researches on the invention of new alternative materials. Therefore, it should be continued, not to be held under any particular study or laboratory. The products should be tested on site, validated and continually reviewed in many different aspects to fulfill the objective of comfort living.

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REFERENCES

American Society for Testing and Materials (ASTM). 2000. Standard methods of conducting strength tests of panels for building construction, E 72-98. , ASTM, West Conshohocken, PA.

Lee, Y.K., and T.H., Miller. 1997. Final report on composite wall tests. Department of Civil Engineering, Oregon State University, Corvallis, Oregon, USA.

KaKlauskas, A.T., E.M. Kazimieras, and S.L. Raslanas. 2005. Multivariate design and multiple criteria analysis of building refurbishments. Energy and Buildings Vol. 37: 361-372.

Ramakrishna, G., and T. Sundararajan. 2005. Studies on the durability of natural and the effect of corroded fibers on the strength of mortar. Cement and Concrete Composites Vol. 27: 575-582.

Reinhardt, H.W., and A.E. Naaman. 1992. High performance fiber reinforced cement composites : Workshop summary, evaluation, and recommendations. London : E & FN Spon,.

Thiengburanathum, P., V. Lieorungruang, and A. Bhromsiri. 2005. Sustainable local housing project. Chiang Mai University, Thailand.

Treearrayapong, S., and S. Keawta. 2004. Process design and life cycle evaluation of wall materials. Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand.