Environmental Impact Assessment for Typical and Innovative Housing Construction Materials in Thailand

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Abstract

In Thailand, the awareness of environmental issues among the architect community has become increasingly significant. Building construction has been causing many environmental problems, ranging from excessive resource depletion and global warming to human health and well-being impacts. For housing construction, building materials are a major contributor to such problems. The impact of building materials on the environment can be in many forms and is very hard to define and measure. It is therefore very important to understand and be able to assess the environmental impacts of construction materials.

This study reports the methodology and results of an environmental life cycle assessment (LCA) of typical construction materials and system assemblies that are commercially available and typically used in housing projects. The construction materials are categorized into 4 components - architectural, engineering, electrical and sanitary, and landscape - with a total of 17 subsystem assemblies. Innovative construction materials are also evaluated to demonstrate their potential as environmental friendly replacement products. The LCA is conducted using a detailed LCA software tool, SimaPro and its database. CML2001 is selected to demonstrate the impact categories, spanning resource depletion, global warming, acidification, eutrophication, ozone depletion, smog, ecotoxicity and human toxicity. To illustrate their use, the case study of a typical housing in Thailand, a two-storey house with a contemporary design, is studied. The life span of the house is 50 years. The study also assesses the materials' embodied energy over the building life span. The results show the environmental impacts are mostly caused by materials in the architectural components, coming to almost 95%: 44% on the walls, 25% on the floor, 17% on the ceiling and 9% on the windows and doors. For embodied energy, the percentage contributions to the whole building can be ranked from the highest to the lowest as follows: roof (34.37%), wall (29.34%), window (12.15%), door (11.60%), ceiling (7.68%) and floor (4.86%). For construction innovations, the potential for business development and low environmental impact comes from cement-based products groups which can reduce the environmental impact from the base-products by up to 80%. Brick and other products with sugarcane fibers or coconut fibers as replacement materials also help reduce the environmental impact from the base-products by up to 50%. The implementation in architectural project of changes to the material use and construction of buildings are also discussed.

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1. Introduction

Construction, especially housing construction, creates significant environmental impacts over the life span of a building. The impacts can range from its energy use and embodied energy, as well as its generation of pollution and green house gas (GHGs), to the effect on human health and well-being. During the last decades there has been an increasing interest and awareness within the Thai architectural community on the environmental impacts of building construction. In the pursuit of a more sustainable approach, the Thai government has directed its focus on green economy and society in one of the seven strategic plans of the draft 11th National Economic and Social Development Plan of 2012-2016 (NESDB, 2011). The promotion of the use and manufacture of environmental friendly products is strongly encouraged. However, the impact of building construction materials on environment can be in many forms and is very hard to define and measure. Therefore this research evaluates the environmental impacts of housing construction materials and innovations using the life cycle assessment (LCA) software tool for the appropriate impact categories, quantifying and assessing their environmental impacts and finally applying the findings as a design process and decision making tool for architects and designers.

2. Environmental impacts assessment

The environmental impact of a building depends on two major contributors: the construction materials and the energy consumed during the operational phase. For a housing project, especially those built with a replicate design, the construction materials selection plays an important role to the environmental impact contribution. To evaluate and reduce the impact of such materials, an assessment of the impacts of a product is needed.

2.1 Life Cycle Assessment (LCA)

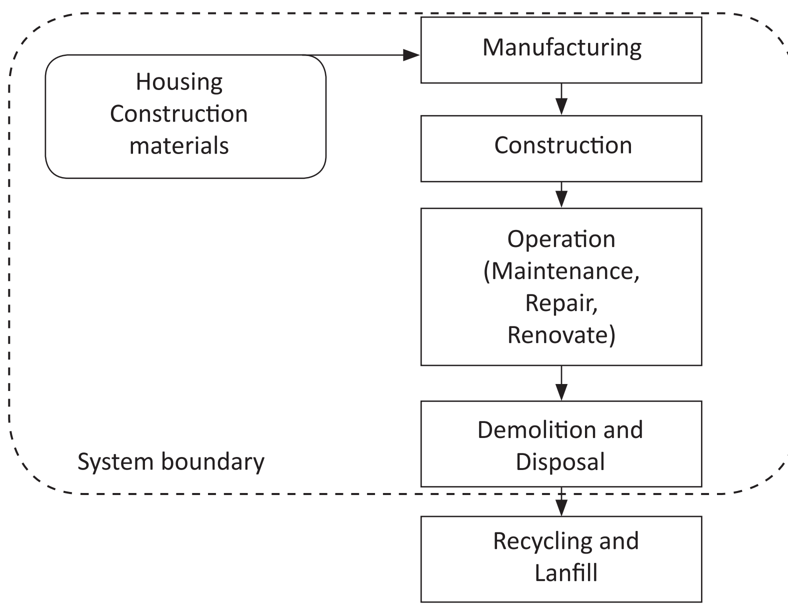
Life cycle assessment is one way to assess the environmental impacts that a product has on the natural environment. The life cycle assessment or LCA has been developed by the International Organization for Standardization (ISO) with ISO14041 that describes how to conduct an LCA (International Organization for Standardization, 1998). The LCA process evaluates the impact of products from cradle to grave; from material manufacturing and the construction process to their operation and demolition. The system boundary for LCA normally defines the scope according to the study's objectives. The system boundary of this study is shown in Figure 1.

To perform LCA for a commercial product, the ISO standards suggest three phases. The first phase is the selection and inventory of the inputs and outputs of a product system. Then, the life cycle impact assessment (LCIA) is assessed to define the potential impacts of those inputs and outputs. Finally, the results are analyzed and interpreted according to the objectives of the study (International Organization for Standardization, 1998).

Life cycle inventory data

The difficulty for the assessment of construction materials in Thailand lies in the limited data of construction-related products.

Figure 1. System boundary for housing life cycle assessment.



As seen in Table 1, the Green label and LCI data – both Thai-based inventories - show a very limited number of construction materials compared to databases from commercially available LCA software tool such as SimaPro (PRe' Consiltants, 2011) or GaBi (PE INTERNATIONAL AG, 2011).

A comparison between the different commercially LCA software and the available Thai databases are displayed in Table 2. For this study, the SimaPro database is selected. The LCI data and its assumptions can be found in SimaPro database (PRe' Consiltants, 2011).

Product inventory database	LCI (Thailand)	Green label (Thailand)	GaBi (Germany)	SimaPro (Netherlands)
Cement products	0	3	11	11
Earthen products	1	2	4	4
Steel/Metal	2	0	7	8
Plastic	1	7	10	19
Wood	0	0	4	4
Others	1	0	10	16
Total	5	12	46	62

Table 1. Comparison of construction materials in different inventory databases.

Name	GaBi	SimaPro
Sources	PE International (Germany, Netherland)	PRé Consultants (Netherland, Sweden, Swiss)
Version	GaBi 4.0	Sima Rro 7.2
Methods	CML 2001, TRACI, EDIP, EI95, EI99, IMPACT 2002+	CML 2001, BEES, EI99, TRACI, EPD, IPCC2007

Table 2. Comparison of commercially available LCA software.

Thailand construction materials category

This study categorizes and evaluates construction materials into 4 components and 17 subsystem assemblies, which are;

1) *Architectural components (AR)* - composed of 5 sub-system assemblies: floor, wall, window and door, ceiling, and roof.

2) *Engineering components (EG)* - composed of 3 sub-system assemblies: column, beam and floor slab.

3) *Electrical and Sanitary components (E/S)* – composed of 5 sub-system assemblies: sanitary wares, internal plumbing, septic tanks, grease traps and electrical wires.

4) *Landscape components (LA)* – composed of 4 sub-system assemblies: external floor, external pipe line, external drainage, and roadway.

Thailand construction innovations category

For construction innovations, the main reason for categorization is to promote the use of environmentally friendly products in which the product itself uses another industry's by-product or agricultural waste as a component in the construction material. These construction innovations are new environmentally-friendly products or materials that are currently not manufactured in the industrialized process, but with properties equivalent to what is commercially available in the market. The data on these products or materials is gathered from research studies from many organizations. This study categorizes them into 5 groups according to their raw materials, which are;

1) concrete 147 studies
2) brick 23 studies
3) cement products 16 studies
4) natural fiber products 8 studies
5) other materials 10 studies

Life cycle impact assessment

For life cycle impact assessment, several methods are developed in order to measure the impact on the environment. Different methods offer different but slightly similar category definitions. Category definition is the identification of impact relevant to the studied product. Table 3 displays different methods and category definitions.

For this study, the method chosen is the CML2001 (Institute of Environmental Sciences, 2001). The CML 2001 is an impact assessment method which restricts quantitative modeling to the relatively early stages in the cause-effect chain to limit uncertainties and group LCI results in so-called midpoint categories, according to themes. These themes are common mechanisms (e.g. climate

	Eco-indicator 99 (Goedkoop & Spriensma, 2001)	**TRACI** (Bare, 2002)	**CML2001** (Institute of Environmental Sciences)
Resources depletion	O	X	O
Global Warming	O	O	O
Acidification	O	O	O
Eutrophication	O	O	O
Ozone depleting	O	O	O
Photo-oxidant formation	X	O	O
Eco-toxicity	O	O	O
Human non-cancer effect	O	O	O
Human cancer effect	O	O	O

Table 3. Impact categories for three life cycle impact assessment methods.

change) or commonly accepted groupings (e.g. ecotoxicity). The CML 2001 method has also been acceptable and used by the Thailand Environment Institute (TEI): for example, in assessing the environmental impact occurring during each production process of Portland cement (unpacked) (Lohsomboon, Jirajariyavech et al., 2004). The normalization data "CML 2001" for the Netherlands, Western Europe and the world are based on the information of the Institute of Environmental Sciences, Leiden University, the Netherlands, and have been calculated for problem-oriented life cycle assessments only. From the selected LCIA methods, eight impact categories are selected to demonstrate the impact of each construction material. The impact categories, their brief descriptions and the abbreviations used in this study are as follows:

1. Resource depletion (Res. D) targets the depletion of non-renewable resources or renewable resources that cannot be renewed in one's own lifetime.
2. Global warming (GW) is the potential contribution of a substance to the greenhouse effect. This category has typically been calculated for a number of substances accumulated over 100-year periods.
3. Acidification (Acid.) is expressed relative to the acidifying effect of sulfur dioxide (SO_2) in soil, air and water. Other known acidifying substances are nitrogen oxides and ammonia. Sulfur oxide (SO_x) has also been evaluated, with the same value as SO_2. The time span is infinity and the geographical scale varies between the local and continental scales.
4. Eutrophication (Eutro.), also known as nitrification, includes all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. The time span is also infinity, and the geographical scale varies between the local and continental scales. The reference substance for CML2001 are phosphates (PO_4)
5. Ozone depletion (Ozon.) has been established mainly for hydrocarbons containing combined bromine, fluorine and chlorine, or CFCs. One of the substances (CFC-11) has been adopted as a reference. This category is output-related and evaluated at the global scale. The time span is also infinity.
6. Smog formation (Smog) or photo-oxidant formation is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and may damage crops. The interaction includes nitrogen oxide (NO_X) and volatile organic compound (VOCs) from industry and transportation. The process using Ethylene as a reference. The time span is 5 days and the geographical scale varies between local and continental scales.
7. Eco-toxicity (Eco. T) refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. The time span is also infinity. Characterization factors are expressed as 1,4-dichlorobenzene (1, 4-D). The indicator is applied at the global/continental/ regional and local scales.
8. Human-toxicity (Hu. T) concerns the effects of toxic substances on the human environment. This impact category covers human-toxicity, carcinogens and non-carcinogens using both benzene and toluene as reference substances. The geographic scope of this category can vary between local and global scales.

After the impact is defined and classified, the weighing factors are assigned or *characterized* according to a substance's relative contribution to a particular impact category. It is important to note that there is no scientific base for comparing across different impact categories (International Organization for Standardization, 1999). With ISO 14042, the LCIA intention is not to identify, measure or predict actual impacts but to lessen the environmental impacts of products or services by guiding and aiding the decision-making process. In assessing the potential impact, a weighting factor of 1 is assigned to each impact category. Then, to compare each product in their group of components and subsystems, the maximum impact category value is set at 100% and all 8 impact categories added together to get a single bar (see Figure 2). For example, the comparison of the Ecotoxicity of various cement product groups (with a maximum impact of 100% for product A) can be compared with other products in the same groups (e.g. product B, C, D, and F to this product).

3. Embodied energy

In this study, embodied energy is the sum of energy inputs to make a product from the point of extraction and refining of the materials to their marketing, disposal and re-purposing. This is another measure that needs to be considered during the lifespan of a building. The methodology and scope of this study is based on the work of the Sustainable Energy Research Team (SERT), Department of Mechanical Engineering, University of Bath, UK (Hammond & Jones, 2008).

The embodied energy can be explained in the much more simple form of a line graph overlapping on the summation of eight impact categories with 100% in each category, as seen in Figure 2. Each material is analyzed by its quantity and weight per area according to its bill of quantity (BOQ). The unit used is MJ/sq.m.

4. Building life span

During the life time of a building, many building materials need to be changed several times. The study considers the life span of selected materials: examples are shown in Figure 3. The lifespan of a building is important as the impact may or may not be different depending on the life span and renovation time. Figure 3 and 4 show the differences between two material groups: paint and wall studs. For paint, the environment of the product itself may seem not much, but over the lifespan of the building the impact can be significant (Figure 4). However, this is not true in the case of wall studs (Figure 5).

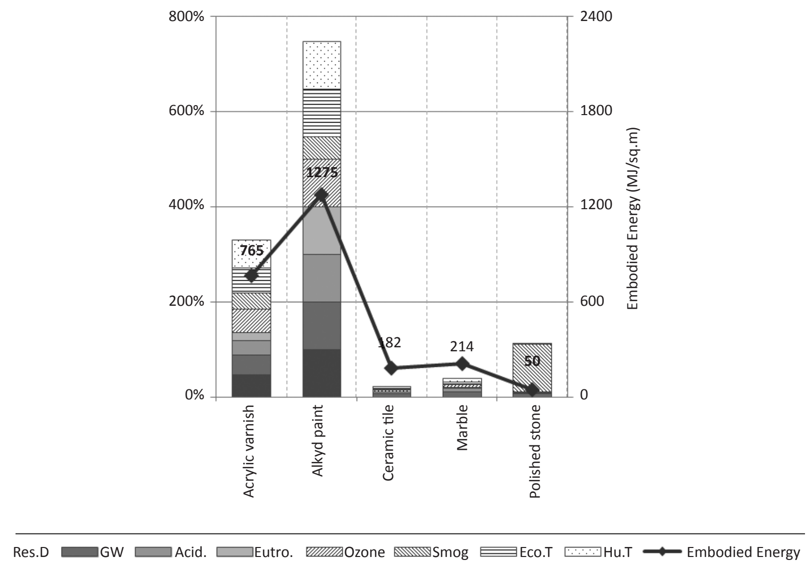


Figure 2. Example of impact category comparisons between different construction materials under the light weight wall components.

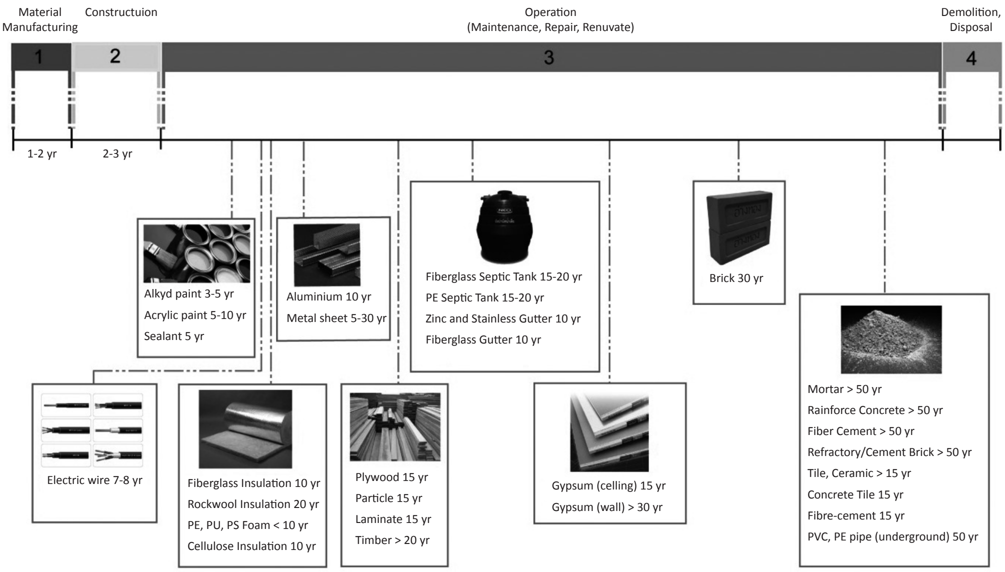
5. Life cycle interpretation

Construction materials interpretation

The evaluation and interpretation process are done by collecting and categorizing the construction materials according to the subsystems, using the weighting (kg) per area of 1 square meter (m^2). The building attributes per square meter area, including the several replacements during the building life cycle, are then analyzed. Finally, the environmental impact of these materials is assessed for both the environmental impact categories and embodied energy.

Construction innovations interpretation

The analysis of the innovative construction materials is slightly different from the typical construction materials due to insufficient



Note: Pre-operation phrase is seperated in construction and transportation, which is fixed by the distance to construction/disposal site.

Figure 3. Life span of products during the building life cycle (50 years /life cycle) .

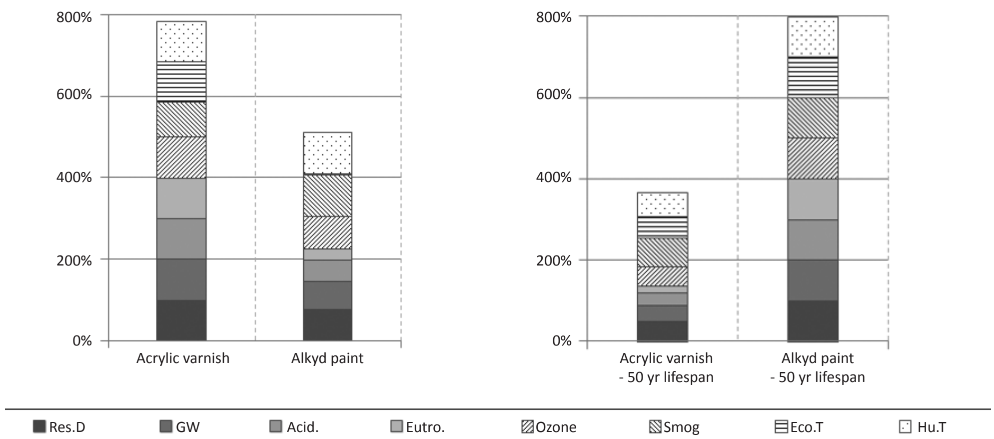


Figure 4. Life cycle assessment of 2 types of paint in a two-storey house, showing the contribution of each impact category (output from SimaPro). The data have been normalized and weighted. (Remarks: Comparison between 2 types of paint; impact of product only (left), impact during 50 yrs lifespan of a house.)

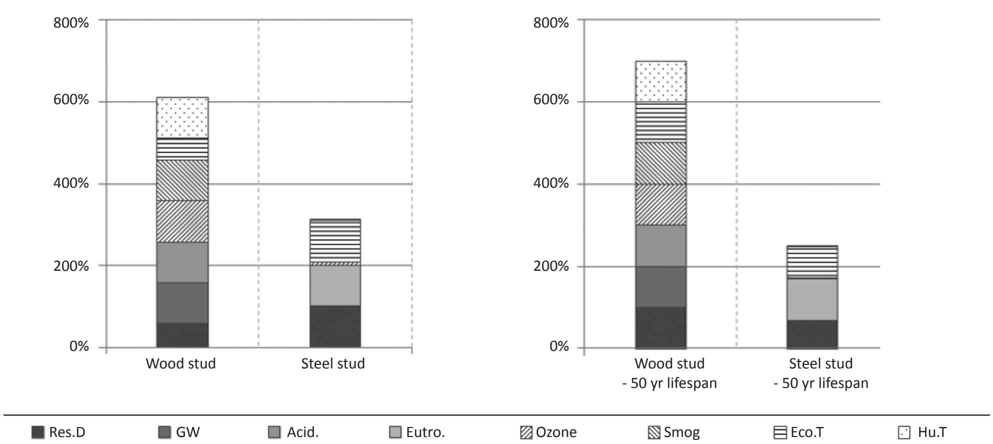


Figure 5. Life cycle assessment of 2 types of wall stud in a two-storey house, showing contribution of each impact category (output from SimaPro). The data have been normalized and weighted. (Remarks: Comparison between 2 types of paint; impact of product only (left), impact during 50 yrs lifespan of a house.)

data. This study has attempted to categorize those impacts by using the following method. The environmental impact categories of the base-products assumed to have 100% impact. Then, the impact from the preparation process of adding or replacing substances is evaluated and added to the impact. The replacement substance preparatio can be divided into 4 processes: heated process, size-reduction process, chemical process and no process. For this study, the chemical process is not included due to the unavailable reference database of SimaPro7.2. Finally, the total impact is reduced in proportion to the ratio between the replacement substance and the base-product impact. The main reason for this category is to use an industrial by-product or agricultural waste as an additive in the construction materials. The impact should remain lower than the base-product at this point. The study categorizes construction innovations into 6 groups, based on their base products: load-bearing concrete, non-load-bearing concrete, brick, cement products, natural fiber products and others. The product evaluations are based on a total 204 studies. The reference of each study can be found in the appendix of the final report of this study (Tantasawasdi, Wankanapon et al., 2011).

The evaluation can be done in a two-part process, depending on the construction innovations. The impact can be analyzed according to its subsystems using the weighting (kg) per area of 1 square meter (m^2), such as products in the group of block concretes, asphalt concrete, bricks, gypsum boards, cement boards, cement mortar, heat insulations, and ceramic tiles. The impact can also be analyzed according to the weighting (kg) per cubic meter or equivalent for materials such as precast concrete, light-weight concrete and high strength concrete. In order to create a realistic scenario, the construction materials of a typical two-storey house are used in the study. The house is based on a case study of a typical 2 million baht house designed by the National Housing Authority (NHA) with a 50-year lifespan.

6. Results and discussions

Construction materials

The results, generated according to the construction materials of a case study house, show that the impact is mostly caused by construction materials in the architectural components: almost 95%, as seen in Table 4 and Figure 6. The list of construction materials in each architectural component, together with their impact categories percentage and embodied energy results, are shown in Table 5.

Table 4. The percentage contributions of each subsystem assembly toward the overall impact of a case study house.

System components	System assemblies	Percentage contributed to total impact
AR	Wall subsystem assemblies of brick-mortar walls with ceramic and marble tiles of 58 m^2, acrylic paints of 594 m^2 and timber frames with horizontal wood slabs and acrylic paints of 29 m^2	44%
	Floor sub-system of 88 m^2 of ceramic tiles, parquet 33 m^2	25%
	Roofing sub-system of 155 m^2 concrete roof tiles with metal structural frame	17%
	Subsystem assemblies of 168 m^2 gypsum ceiling tile with acrylic paints	5%
	Windows and doors subsystem assemblies of 8 plywood doors, 1 aluminum door, 15 aluminum windows	4%
LA	149 m^2 of finished concrete and 104 m concrete pipeline	3%
EG	Structural concrete of 48 m^3, reinforce concrete of 2,771 kg and precast floor plank of 165 m^2	1.5%
E/S	Electrical wire of 119 m, 1200L sanitary septic tank and 30L grease trap	1%

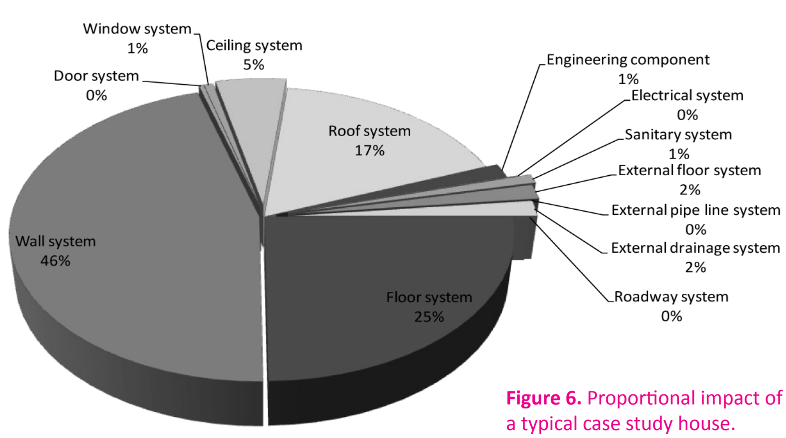


Figure 6. Proportional impact of a typical case study house.

Figure 5. Life cycle assessment of the architecture components of a two-storey house, showing the contribution of each subsystem assembly.

Subsystem assemblies	Area (sq.m.)	Embodied energy (MJ/sq.m.)	Res.D	GW	Acid.	Eutro.	Ozon.	Smog	Eco.T	Hu.T
Floor 8"x8" ceramic floor tiles/ sq.m.	1	164	1.1E-01	5.2E-02	2.1E-02	1.7E+01	1.5E-06	8.1E+00	1.0E-02	1.2E-03
Total impact	16	2624	1.8E+00	8.3E-01	3.4E-01	2.7E+02	2.4E-05	1.3E+02	1.6E-01	1.9E-02
Wall Cement block wall	1	148	5.6E-02	2.1E+01	4.1E-02	1.2E-02	8.2E-07	1.3E-03	2.0E+00	5.5E+00
Ceramic finishing wall	1	182	1.0E-01	1.7E+01	5.0E-02	2.0E-02	1.4E-06	1.3E-03	3.5E+00	7.6E+00
Total impact	48	15840	7.5E+00	1.8E+03	4.4E+00	1.5E+00	1.1E-04	1.2E-01	2.6E+02	6.3E+02
Doors Wooden door panel	1	614	4.2E-02	6.4E+00	4.0E-02	8.1E-03	5.2E-07	3.2E-03	1.1E-01	2.3E+00
	3.2	1966	1.3E-01	2.0E+01	1.3E-01	2.6E-02	1.7E-06	1.0E-02	3.4E-01	4.5E+03
Wooden frame of section 2" x 4"/ m length	1	430	2.9E-02	4.5E+00	2.8E-02	5.7E-03	3.6E-07	2.2E-03	7.4E-02	1.6E+00
	10	4300	2.9E-01	4.5E+01	2.8E-01	5.7E-02	3.6E-06	2.2E-02	7.4E-01	7.0E+03
Total impact		6265	4.3E-01	6.5E+01	4.1E-01	8.3E-02	5.3E-06	3.3E-02	1.1E+00	1.1E+04
Windows Tinted glass	1	588	1.5E-01	2.6E+01	2.3E-01	1.8E-02	2.1E-06	1.1E-03	1.7E+00	4.4E+00
	5.5	3231	8.4E-01	1.5E+02	1.2E+00	9.9E-02	1.2E-05	6.2E-03	9.5E+00	1.4E+04
Wooden window panel (sq.m.)	1	945	5.3E-01	5.6E+01	2.2E-01	3.1E-02	5.1E-06	6.7E-03	7.5E-01	1.1E+01
	1.7	1607	9.0E-01	9.4E+01	3.7E-01	5.3E-02	8.6E-06	1.1E-02	1.3E+00	1.8E+04
Wooden frame of section 2" x 4"/ m length	1	430	2.9E-02	4.5E+00	2.8E-02	5.7E-03	3.6E-07	2.2E-03	7.4E-02	1.6E+00
	4	1720	1.2E-01	1.8E+01	1.1E-01	2.3E-02	1.4E-06	9.0E-03	3.0E-01	2.8E+03
Total impact		6558	1.9E+00	2.6E+02	1.7E+00	1.8E-01	2.2E-05	2.7E-02	1.1E+01	3.5E+04
Ceiling 9 mm gypsum board	1	153	5.6E-02	8.1E+00	2.5E-02	1.1E-02	8.9E-07	6.0E-04	1.6E+00	6.9E+02
C-section metal stud for ceiling	1	22	1.4E-02	2.8E+00	1.1E-02	3.4E-03	1.1E-08	1.0E-03	1.5E+00	7.9E-02
2” Fiberglass insulation	1	84	2.8E-02	3.5E+00	8.7E-03	2.5E-03	4.0E-07	2.9E-04	5.3E-01	1.4E+00
Total impact	16	4144	1.6E+00	2.3E+02	7.2E-01	1.6E-01	2.1E-05	3.0E-02	5.8E+01	1.1E+04
Roof Fiber cement roof tiles	1	29	3.2E-02	9.2E+00	2.1E-02	8.1E-03	4.4E-07	8.6E-04	1.5E+00	4.1E+00
Square section roof metal stud	1	226	1.2E-01	2.2E+01	8.0E-02	3.0E-02	7.4E-08	9.0E-03	1.3E+01	7.2E-01
Fiber cement roof connectors	1	29	7.5E+00	2.0E+03	3.7E+00	9.5E-01	8.2E-05	1.4E-01	1.1E+02	3.6E+02
Galvanized- metal rain drainage	1	205	7.3E-02	6.4E-02	1.7E-02	1.5E+01	6.5E-08	3.7E-01	7.2E+00	5.3E-03
Total impact	37.95	18558	2.9E+02	7.7E+04	1.4E+02	6.0E+02	3.1E-03	8.4E+00	5.0E+03	1.4E+04
Total impact of AR component		51529	3.0E+02	7.9E+04	1.5E+02	6.2E+02	3.3E-03	3.8E-02	5.3E+03	7.2E+04

Construction innovations

The results below describe products that have potential for development into environmentally friendly products for industrialization. The products are assessed by comparing their impact with the base products' impact. For load bearing concrete blocks, the impact is 22.67% less than the base products. The non-load bearing concrete showed 79% less impact than the base products. This is due to the replacement materials having lower impact than the original products such as mixed foam waste, mixed rice husk and mixed coal ash waste. These replacements are added in higher quantities since the products do not require much strength and load bearing. Foam waste mixed into non-load bearing concrete block can reduce the impact by 79.61% compared to its base product. The impact can be reduced by 54.23% for rice husk mixed in low mass concrete blocks, 72.48% for foam waste mixed in low mass concrete and 61.71% for coal ash waste mixed in concrete. Brick products reduce the impact by 50% by adding metal dust waste, coal ash, gypsum waste, and rice husk mixed in common brick, by 67.51% for soil sediment (having undergone a water treatment process) mixed in earth bricks and by 30-60% for industrial waste, black rice hush, and sugar cane fiber mixed in common bricks. Cement-based products reduced the impact by 34% by adding black physic nut wood and wood tissue to cement board, by 25% for sea shell mixed in cement mortar and by 60.77% for sugar cane or coconut fiber in gypsum board. Natural fiber tile products reduced the impact by 80.23% compared to the base products. Soil cement roof tiles and ceramic tiles reduced the impact by 50% by adding water-treated soil sediment, granite waste, oil palm fiber, para wood ash, ceramic waste, tinted glass waste and ceramic alumina and by 63.50% for water-treated soil sediment mixed with soil ceramic tiles. When the impacts for each construction innovation category are ranked, the innovative material with natural fiber replacement is shown to be the most environmentally friendly product and should be developed further in the future, as shown in Figure 7. The list of construction innovations with natural fiber replacement materials are shown in Table 5.

Construction innovations	Weight (kg/m^2)	Replacement quantity (kg/m^2)	Raw material preparation		
			heated	resized	Chemical processed
1. Rockwool	2.36	0.00	X	X	X
2. Water hyacinth, bagasse and rice strew mixed	6.81	4.30	X	X	X
3. Bagasse mixed	4.08	2.73	O	O	X
4. Rice straw mixed	3.89	3.42	X	O	X
5. Fiber of Phrynium parviflorum Roxb. mixed (family: MARANTACEAE)	9.47	7.96	O	O	X
6. Vetiver grass fiber and natural rubber latex mixed	2.75	2.06	O	O	X
7. Water hyacinth fiber and natural rubber latex mixed	3.00	0.75	O	O	X
8. Cassava mixed	2.00	1.80	O	O	X

Table 6. Replacement materials and its preparation process use in analyzing construction innovations impact.

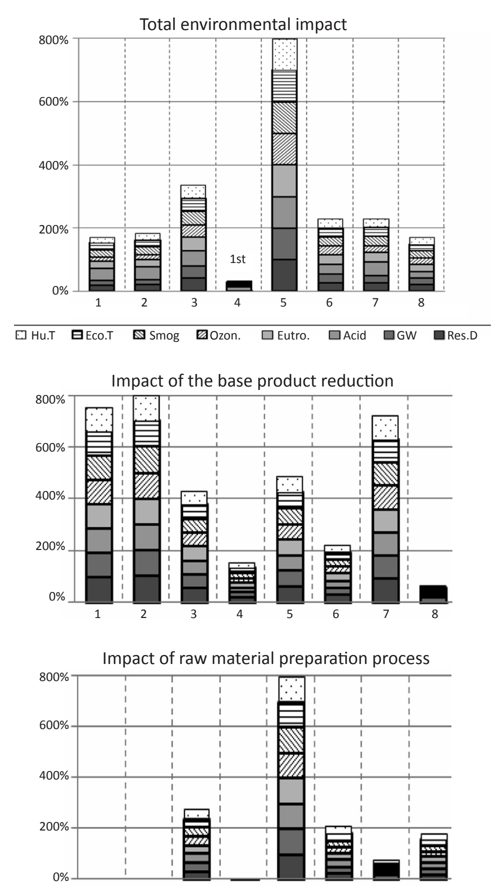


Figure 7. Environmental impact of sample natural fiber products.

Embodied energy

For embodied energy, the results for the architectural components of a case study house are shown in Figure 8. The highest embodied energy is of the roof subsystem assemblies (18,558 MJ/sq.m.), followed by the wall subsystem (15,840 MJ/sq.m.), window (6,558 MJ/sq.m.), door (6,265 MJ/sq.m), ceiling (4,144 MJ/sq.) and floor (2,624 MJ/sq.m.). The percentages of embodied energy contributing to the whole building can be ranked from the highest to the lowest as follows: roof (34.37%), wall (29.34%), window (12.15%), door (11.60%), ceiling (7.68%) and floor (4.86%).

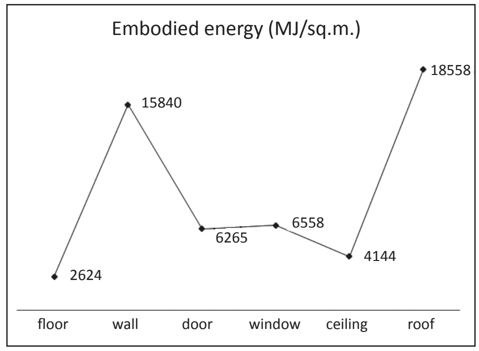


Figure 8. Embodied energy results for architectural components of a case study house.

7. Conclusions and discussions

For construction materials, it is important for designers to consider the hierarchical importance of materials for each subsystem. When selecting an architectural component (AR), designers should pay attention to construction materials with the highest environmental impact proportional to the percentage contributions of the total building impact and embodied energy first. These subsystem assemblies are the wall and floor, roof, ceiling and doors and windows consecutively. It is interesting to note that about 61-76% of major construction materials with a high impact are cement-based products. Other groups of components do not show much significant difference in the magnitude of their overall impact. The selection can be made as follows: landscape components (LA), engineering components (EG) and electrical and sanitary components (E/S) consecutively.

The detailed results show that gypsum products have less impact to the environment and can be used as replacement products in many subsystems such as walls and ceilings. For wood products, the results show a lower environmental impact in certain applications such as windows and doors. However, due to the deforestation problem in Thailand, using wood products may not guarantee a lower impact on the environment at this point in time. Other considerations should be made, including fast growing and sustainable forestry products such as Forest Stewardship Council (FSC) certified wood products. Metal products are shown to have less environmental impact when used in small amounts and in composite with other subsystems such as reinforcement bars, metal frames, wall studs, floor and ceiling subsystems. However, metal products have a greater environmental impact than concrete-based products when used in a much larger area, such as a metal sheet floor structure. High environmental impact products include artificial wood products, paints, door/window aluminum frames and fiberglass insulation. The decision also should be made based on the detailed impact categories according to the project's objective. Low environmental impact products with a low lifespan such as acrylic paints in low mass wall sub-system, natural fiber in wall and ceiling sub-system and zinc-coated metal stud frames in ceiling sub-systems can exert a considerable environmental impact when used over the course of a building's lifespan. The use should be limited to building types with a low lifespan (less than 50 years) or temporary use. For innovations, low environmental impact construction products include non-load bearing concrete, bricks, cement products, rice husk insulation, soil cement roof tiles and ceramic tiles. These products show high potential for development into environmentally friendly products for industrialization. Other factors such as energy efficiency and product longevity should be included into consideration, along with the use of an environmentally friendly database.

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