

## **A Review of the Application of LCA for Sustainable Buildings in Asia**

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**Abstract.** The introduction of life cycle assessment (LCA) to the building industry is important due to its ability to systematically quantify every environmental impact involved in every process from cradle to grave. Within the last two decades, research on LCA has increased considerably covering from manufacturing of building materials and construction processes. However, the LCA application for buildings in Asia are limited and fragmented due to different research objectives, type of buildings and locations. This paper has attempted to collect and review the application of LCA in the building industry in Asia from the selected publications over the last 12 years, from 2001 to 2012. The result shows that most LCA research basic methodology is based on International Organization of Standardization (ISO) 14040 series but with variance. It is found that the operational phase consume highest energy and concrete responsible for the highest total embodied energy and environmental impact. It also suggested that building material with low initial embodied energy does not necessarily have low life cycle energy. Overall, findings from LCA studies can help to make informed decisions in terms of environmental impact and help realizing sustainable buildings in the future.

### **Introduction**

The term sustainable development is being described in the United Nations' Our Common Future report as the development that meets the needs of the present without compromising the ability of future generation to meet their own needs [1]. Since then, numerous campaigns were introduced by the United Nations (UN) to promote the sustainable development agenda such as the introduction of Agenda 21 plan of action in 1992 in the UN Conference on Environment and Development (UNCED) and the following World Summit on Sustainable Development in 2002 [2]. The relationship between the building industry and environmental pollution is commonly associated. Although building industry is crucial for social and economic development, the environmental impacts of the processes are significant. Recent studies also identified that buildings all over the world responsible for 30 to 40% of energy usage and 40 to 50% of world greenhouse gas emission [3]. LCA has been accepted internationally as a tool to improve processes and services environmentally and it can be implemented into a wider field, including in the building industry [4], [5].

### **Basic Concept of LCA for Buildings**

LCA is a methodology framework to estimate and evaluate the environmental impact throughout the product life cycle from cradle to grave [6] but the implementation in the building industry is fairly recent. Most LCA research in the building industry is based on the International Organization of Standardization (ISO) 14040 series which consist of four phases: goal and scope definition; inventory analysis; impact assessment and interpretation [6].

The first phase of LCA which is defining goals and scopes will determine the purpose of the study, system boundaries, selection of suitable functional units and determine the building lifespan. The second phase, which is life cycle inventory (LCI) is the data collection process of all relevant inputs and outputs of all data relevant to the building life cycle. Thirdly, the life cycle impact assessment

(LCIA) phase, the process is divided into compulsory and non-compulsory elements. In the compulsory elements, the LCI results will be assigned to the specified impact categories (classification) and subsequently, the analysis of category indicator results (characterization) will be made. The next step in LCIA is non-compulsory which consist of the normalization process, grouping and weighting. The last phase is the interpretation. In this phase, sensitivity analysis will be conducted if non-local databases were used. The result will also be validated by comparing to other published research. Finally, significant issues will be identified, results will be assessed to reach conclusions, explain the limitations and provide recommendations.

There are 3 approaches used in LCA research: 1) Process-based LCA; 2) Economic Input Output LCA (EIO-LCA); and 3) Hybrid LCA (Combination of process based and EIO-LCA). In general, process-based LCA is more complex and time consuming than EIO-LCA but the majority of the LCA research prefer the process-based method [7].

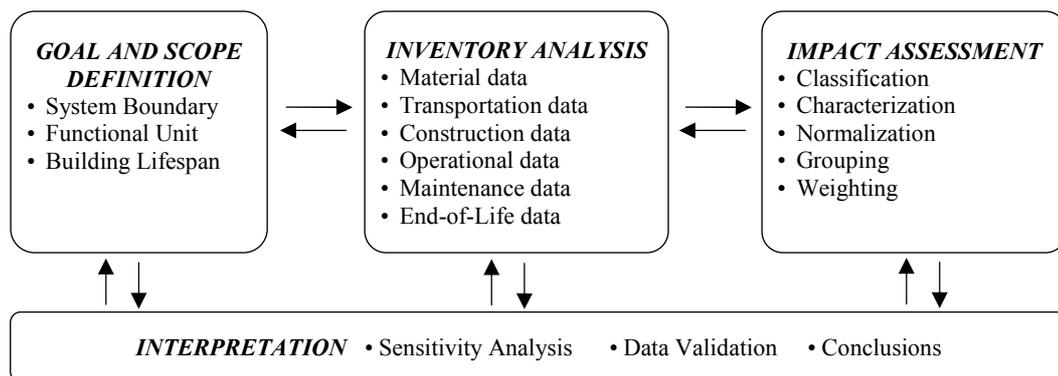


Fig. 1: LCA Framework for the Building Industry. Adapted from [6], [8–11]

### LCA Research for Buildings in Asia

In general, the application of LCA for building in Asia is quite recent. This paper has identified that the published papers were focused into two different approaches that is LCA and life cycle energy assessment (LCEA) for buildings. LCEA is part of LCA but unlike LCA, LCEA only focus on the energy consumption anticipated lifetime of the building [12].

**LCA of Buildings.** One of the earliest LCA research probably conducted by Adalberth [13] in 1997 for residential building in Sweden. In Asia, one of the first LCA research in building was conducted by Zhang et.al [14] in 2006. In this paper, building environmental performance analysis system (BEPAS) LCA framework was developed which investigated three main aspects of the building specifically building facilities, building materials and locations in China. An office buildings in Tsinghua University was analysed using BEPAS. The LCIA steps taken were consist of classification, characterization and the weighting were done to convert the results to Eco-point. It was found that 96.6% of environmental impact came from 50 years of building operation (electricity, water and coal) which represent the longest period in the building life cycle.

In the same year, Li [15] has introduced region-type life cycle impact assessment (R-LCIA) which examine the environmental impact to surrounding rather than globally. Ancillary facilities such as roads and parking lots which was not included in previous research were included in the assessment. A 9000m<sup>2</sup> store building in Taki town, Japan was analysed with 3 possible designs (Case 1-steel structure; Case 2-reinforced concrete (RC) structure with photovoltaic system; and Case 3-steel structure with a different location and shorter roads). Similar to previous research, the operational stage of the building (50 years) was identified as the largest impact in all cases although Case 2 is the lowest for the building and Case 3 for the ancillary facilities. However the demolition and disposal of the Case 2 building contributed the highest due unrecyclable concrete.

Fujita et.al [16] used LCA for carbon dioxide (CO<sub>2</sub>) analysis in Malaysian housing by using an input-output process in 2008. The aims of the research is to differentiate between housing types and building materials. The results show that the house with sharing walls and floor such as apartment or terrace houses have less CO<sub>2</sub> emission per m<sup>2</sup>. The house that use timber also have been identified

to comprise lower CO<sub>2</sub> emission than concrete buildings. In the same year, Kofoworola & Gheewala [17] conducted an LCA for a 38 storey office building in Thailand using hybrid LCA. The EIO-LCA was used only for production of material data and the rest used process-based method. The functional unit was defined as 60,000m<sup>2</sup> and only the structure and the envelope were being analysed. Similar to Zhang et.al [14] and Li [15], building lifespan is set at 50 years and the impact categories selected were global warming potential (GWP), acidification potential (AP) and photo-oxidant formation potential (POCP). The result shows the operational stage represent the largest environmental impact; 52% of total GWP, 66% of total AP and 71% of total POCP. Since concrete is the major materials used in the building, it represents the highest GWP. This study also identified that air-conditioning consume 56% of energy during operational stage, followed by lighting (18%), office equipments (17%) and others (11%).

In 2012, Pinky et.al [18] and Balasbaneh [19] has conducted an LCA for a residential building in India and prefabricated residential building in Malaysia, respectively. Similar to Zhang et.al [14] and Li [15], both research used process-based LCA. SimaPro software was used for LCA modelling for both research but Pinky et.al [18] only focus on the pre-use phase rather than the whole building life cycle. The functional unit chosen was 'one house' and the Ecoindicator 99 were used for LCIA. The results show that bricks responsible for the highest environmental impact rather than concrete as indicated in [16], [17]. Balasbaneh [19] had compared prefabricated concrete and timber frame houses for 50 years of building lifespan and Ecoindicator 99 for LCIA. The results shows that overall, timber frame have lower environmental impact than concrete frame.

**LCEA of Buildings.** Seo & Hwang [20] was probably the first LCEA and LCA research for buildings in Asia in 2001. This paper chooses to used EIO-LCA method and focus on the CO<sub>2</sub> emission in Korea. The functional unit was '10m<sup>2</sup> of floor area' and the lifespan of the building is 22.4 years. The input-output data were used to estimate CO<sub>2</sub> emission in construction stage; questionnaires were used for data collection for operational stage; and literature data were used for end-of-life stage. Similar to other research, operational stage was identified that produced highest CO<sub>2</sub> emission. Utama & Gheewala had conducted LCEA research in Indonesia for single landed houses in 2008 [21] and high rise buildings in 2009 [22]. The process-based analysis was used and the lifespan of the buildings is set at 40 years. The life cycle energy was normalized in MJ/m<sup>2</sup>. For single landed houses, the results shows that buildings with cement based wall and roof materials have higher initial embodied energy but lower throughout the building life cycle than clay bricks and roof materials. The high rise residential buildings case studies focus on different type of walls namely double wall (clay bricks outside, gypsum board inside with air gap in between) and single brick walls. The results shows that the double wall have higher initial embodied energy but lower life cycle energy. The findings from these research conclude that the materials with higher initial embodied energy do not necessarily means that it will have high life cycle energy.

Similar to [20], Shu-hua et.al [23] employed EIO-LCA model but to an urban residential buildings in China in 2010. The result showed that with 50 years building lifespan, the operational stage responsible for 76.5% of total life cycle energy and energy during construction and end-of-life stage were the lowest with 1% and 0.8% respectively. The most recent LCEA research by Wu et.al [24] used process-based LCA to analyse energy consumption and CO<sub>2</sub> emission for an office building in China in 2012. The lifespan of the buildings is 50 years and only the major building materials were assessed. The other minor materials such as aluminium, copper, tile, rubber and paint were omitted due to lack of data. The results show that the operational stage consumed the largest amount of energy and produce the highest CO<sub>2</sub> emission. The heating and cooling system also being identified as the main contributor during the operational stage. Similar to previous findings, concrete was identified as the main source of energy consumption and CO<sub>2</sub> emission due to the large amounts that have been used in the building.

## Discussion and Conclusions

This review compiles published papers on LCA for buildings in Asia for the last 12 years, from 2001 to 2012. It manages to identify that several LCA researchers were focused on the pre-use phase of buildings and energy rather than the whole building life cycle. The method used was various but most research applied process-based LCA, even though the EIO-LCA method is more common in LCEA research. Despite the various assumptions of building lifespan, '50 years' was commonly used which is similar to most LCA research for buildings worldwide. The functional unit selected also varies but most LCA research for buildings worldwide used 1m<sup>2</sup> of floor area. With reference to the LCA methodology, most research basically based on ISO guidelines, but with some alteration to suit its research objectives. Most LCA and LCEA results shows the operational stage contributed the largest environmental impact and consumed the highest energy. With the variety of building materials used, concrete has been identified as having the greatest impact due to large quantities used. Alternatively, timber and steel buildings perform better than concrete buildings. The findings suggested that in a hot and humid area, clay based products work much better than cement based products throughout the whole building life cycle. It also suggested that building material with low initial embodied energy does not necessarily have low life cycle energy.

There is a need to set an agreed method of LCA in the building industry such as a consistent building lifespan, a standardize functional unit, a proper LCI procedure and a suitable LCIA method. This agreed method will therefore promote transparency in the comparison and validation of the LCA results. The findings of the study will further use to build a robust database which will enable decision makers to make more practical decisions to support the development of a more sustainable buildings in the future.

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