A PRACTICAL PERSPECTIVE OF INTEGRATING LIFE CYCLE ASSESSMENT INTO LIFE CYCLE COST ANALYSIS FOR SUSTAINABLE BUILDING DESIGN

Ellen Lau¹ and Vikki Lew²

Division of Building Science and Technology,
City University of Hong Kong, Hong Kong, CHINA
¹bsellenl@cityu.edu.hk

ABSTRACT

Integrating cost and performance assessment makes the building sector a more feasible route in reducing the environmental impact in the human society. To realize this cost-benefit potential, owners and design teams need to understand sustainable design, construction, cost and environmental factors which are closely linked, and consider these factors simultaneously. Two methodologies are of particular interest. Life cycle costing has long been used as a technique in assessing the economic viability of design decisions. It provides a long-term economic perspective on asset investment, whereas life cycle assessment (LCA) evaluates environmental performance. This paper compares four applications in terms of ease-of-use and relevance to design decision-making. It concludes that a team approach should be adopted to evaluate design options to provide benefit and cost analysis that appeal to clients and stakeholders to fulfill the sustainability of our built environment.

Keywords: Life Cycle Costing, Life Cycle Assessment, Environmental Impact, Sustainable Building, Carbon Audit

1. INTRODUCTION

Life cycle costing has long been used in the 1950s but its popularity is still in question because it has not been able to address the design criteria which are important in the process of assessing its economic viability. In addition, life cycle costing application in US, UK and Europe varies because of their different design standards and this makes both design options and economic issues difficult to compare (Ashworth, 1993). While life cycle assessment has been commonly used to evaluate the environmental aspect of buildings, building components, material choices and even infrastructure works, there is a ‘missing link’ between the two methods. With an overview of how life cycle assessment is used for design decision commonly used in US in evaluating the environmental aspects of the design component, this paper puts forward a view that the technical and environment impact of design options should be considered as well when applying life cycle costing analysis to offer an integrative perspective of building life. If the design options with a life cycle perspective are not thoroughly reviewed, the associated life cycle cost analysis is meaningless as its reliability is doubtful. It is considered that only design and cost options provided in an integrative approach are viable for decision-making and that a cross-functional team approach is essential to address the economic and environmental assessment of the lifespan of buildings to fulfill the sustainability of our built environment.

2. SUSTAINABLE BUILDING DESIGN DEVELOPMENT

In building industry, life cycle costing (LCC) refers to the evaluation method of quantifying economic performance of buildings or building systems (Charette, n.d.), accounting for investment and operation...
costs from construction to building life cycle. LCC is of particular interest in validating the cost-benefit of construction investment as the building industry shifts to reduce environmental impact of the built environment worldwide. A building client should not have sole interest on the initial investment cost, and the long-term energy consumption cost should also be considered so as to produce sustainable building design. Therefore, energy and environmental impact of buildings are important in life cycle costing.

According to United Nations Environment Programme (Cheng et al., 2008) buildings are responsible for more than one-third of the total energy use and associated greenhouse gas emission worldwide. Majority of this energy consumption is for building operations, and about 10-20% is for construction and demolition. International Panel of Climate Change [IPCC] 2007 mitigation report (Levine et al., 2007) detailed that, from 1971 to 2004, building carbon emissions has grown by 2% annual rate worldwide. Environmental impact of a geographical region is also closely related to its economic activities. Data from the same 2007 IPCC report shows that in China, 45% of commercial building energy is used for space heating, 22% for water heating, 19% for lighting and space cooling. Conversely, in Hong Kong, a report from government agencies Electrical and Mechanical Services Department and Environmental Protection Department (2008) pointed out that in a service economy without major industrial activities like Hong Kong, more than 60% of greenhouse gas emission of the city originates from electricity, of which 89% is from buildings, followed by 16% emission from transport, and 12% emission from waste. To encourage businesses and institutions to voluntarily take the initiative in building carbon audit, the two agencies released "Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings in Hong Kong", outlining the framework of building environmental performance including direct and indirect emissions. The guideline references International Organization for Standardization (ISO) 14064-1 as well as Greenhouse Gas Protocol by the World Resources Institute/World Business Council on Sustainable Development (Hong Kong Government, 2009).

Reducing environmental impact of buildings is also an economic matter. According to Pacala and Socolow (2004) of Princeton Carbon Mitigation Initiative, buildings are "particularly promising" among fifteen currently available technologies which could mitigate climate change. Similarly, International Panel of Climate Change (Levine et al., 2007) refers to "green building" as the strategy that could be implemented with no extra costs. For instance, strategies such as electronic efficiency labels involve minimal investment but yield high efficiency. According to Dell'Isola and Kirk (2003), two life cycle costing experts in U.S., environmental sustainability requires using building materials and construction methods with minimal harm to the environment, and not extracting excess natural resources. Dell'Isola and Kirk specified that "unfortunately, many of these alternatives carry a high initial price tag that must be factored into the LCC considerations in selecting the best choice for a given owner or user." In U.K., Kelly and Male (1993) define LCC as "a technique for economic evaluation which accounts for all relevant costs during the investor's time horizon and adjusting for the time value of money." It takes into account the total costs for an investment during the life span of buildings, building components or materials. The cost-benefit implication for building industry is that to realize sustainable buildings, cost and environmental performance are closely linked and should be considered simultaneously.

3. LIFE CYCLE COST ANALYSIS

An essential skill quantity surveyors and cost engineers could add value to sustainable building design is life cycle cost analysis (LCCA). Ashworth & Hogg (2000) referred to LCCA as an "investment appraisal" by utilizing a "systematic approach to capital investment decisions regarding proposed projects. The technique is used to balance the associated costs of construction and maintenance with rental values and need expectations." By forecasting "cost-in-use", LCC allows building owners and design teams to make informed-decisions about building systems and materials inclusive of future economic consequences of operating the building. These future expenditures include replacement and repair, in addition to basic utility costs. Flanagan et al. (1989) further reasoned the importance of LCC in improving investment decisions on total cost, including both tangible and intangible cost and benefits.
Although difficult to quantify, intangible benefits, such as aesthetic quality, reduced disruption, increased income, are important and should be part of decision making. According to definitions in British Standards Institution BS 3811, timeframe of building life cycle begins at specification phase and ends at eventual replacement or demolition (Ashworth & Hogg, 2000). However in practice, building life and building component life vary significantly. While a building may be expected to last 100 years, engineering services components may have a lifespan of 15 years, and finishes no more than 10 years. Design decisions therefore must distinguish components with long life cycle and those require maintenance or replacement (Ashworth, 2002).

Although the basic concept of forecasting in the long-term is easily understood by client and design team, detailed consideration of LCC is not so when historic data, long term future time horizons, and asset management policy are to be considered as well. Also, because LCC intends to forecast long way ahead of time, accuracy of cost estimate is subject to future changes in user patterns, such as working practice, operation hours, new equipment, and maintenance methods (Ashworth, 2000). LCC result reliability is therefore subject to even greater variation and prone to errors than capital-cost estimates. According to studies by Ashworth and Skitmore (1986, cited in Ashworth, 2000), contractor's tender sum are estimated to have about 13% inaccuracy. HVAC system is one of the building systems more likely to be seen in LCC due to the cost of maintenance. To keep equipment effective, the cost of scheduled service checks and unscheduled support become increasingly significant through building life cycle. Ashworth (2000) suggested that as early as the planning stage, mid-life update and refurbishment has to be included in LCC and be updated over time.

There are three aspects to be considered in the LCC calculation. Firstly, the initial cost includes capital investment and construction. Secondly, the future cost refers to energy consumption, financing costs, operating, maintenance costs, replacement cost, and residual value. Thirdly, the end-of-life cost includes resale, salvage and disposal. One characteristic of LCC is the computation of time-adjusted value for validity. Taking into investment potential of money over time, value of future costs are adjusted with inflation to convert dollar amount into "present value". When accounting for sustainable design, energy-saving potential of building systems is often calculated by comparing the proposed design with a base case of "doing nothing". LCC analysis of HVAC system may compare the life cycle cost of an absorption chiller to conventional system to determine long-term saving in energy cost. At concept and design stages, LCC result could inform owner and design team of cost-effectiveness of various design options, building systems, and material choice. Despite benefits of making more informed-decisions, practice of LCC typically limited to quantity surveying instead of an integrated design process. There are a few reasons. First, design teams typically are unfamiliar with LCC (Charette, n.d.) and do not have the numerical knowledge to comprehend economic data and its implications for design. Second, linear process of evaluating economic performances of design is only possible when the design is complete together with compromised input from both the design and surveying teams where common ground could be found. Third, speculative nature of commercial development means minimal financial incentives for client to reduce tenant operation cost. Flanagan et al. (1989) pointed out that in fact, it is in the developer's best interest to take a total cost approach to provide best value for money for clients and to maintain capital market value of the building.

4. LIFE CYCLE ASSESSMENT

The terms life cycle costing (LCC) and life cycle assessment (LCA) refer to different though interrelated aspects of buildings design. LCC concerns cost of construction and operation, timeframe beginning from construction through operation (Norris, 2001). According to definition from United Nations Environmental Programme (2004), LCA concerns environmental impact of a product or service from "cradle-to-grave", accounting for environmental impact from upstream raw material extraction, manufacturing, transportation, use phase, till reuse or disposal at the end. LCC and LCA also share some similarities. First, both techniques can be applied to evaluate single building components, building systems, or whole-buildings. The life spans accounted in the studies therefore vary depends on the
purpose of the studies. Both methods are quantitative but require qualitative evaluation on the part of stakeholders. Third, both techniques are dependent on data collected from past projects to forecast future performances. Flanagan et al. (1989) pointed out that although forecasting are not exact science, it improves basis upon which decisions are made. Numerous research institutes are undertaking the intricate relation between design decision-making and sustainable goals by integrating the life cycle perspective. At Carnegie-Mellon University (Loftness, Hartkopf & Gurtekin, 2004), Building Investment Decision Support software was launched to address cost-benefits of high-performance building components and systems. The framework correlates building component to affiliate benefits, providing building owner and design team necessary information for better decision from life cycle perspective. In a capacity comparison report sponsored by U.S. Department of Energy (2005), out of twenty energy simulation applications being studied, eighteen include at least energy cost and demand charges in calculations, nine of which include equipment and component life cycle cost estimates, and seven of which include standard life cycle costing.

The relation between economic and performance of services and systems is not a new concept. In 1970s, Economic Input-Output Life Cycle Assessment (EIO-LCA) was developed by economist and Nobel Laureate Wassily Leontief in 1970s. Green Design Institute of Carnegie Mellon University (2009) hosts an online EIO-LCA tool for quantifying environmental impact across economic sectors based on an amount of dollars of services and products. In addition to the EIO-LCA tools specific to United States, the data also has an international outlook of other countries including Canada, Spain and China. According to the EIO-LCA China tool, which is based on the country's 2002 economy, $100 million economic activity in construction sector emits 538 metric tons (mt) of carbon dioxide, of which 212mt is from the commercial and institutional building sector, 119mt is from power generation and supply sector. Of relatively lesser impact, 34mt of carbon dioxide is from truck transportation sector, 27mt is from cement manufacturing sector, and 3mt from waste management and remediation sector. The input-output data offers an understanding of the relation between construction activities and the broader economy.

5. EVALUATION OF LCA TOOLS IN USE IN THE BUILDING INDUSTRY

In United States, U.S. Green Building Council (2007) formed a special working group to take charge of integrating life cycle thinking into the voluntary green building rating system “Leadership in Energy and Environmental Design” (LEED). For applying LCA in practice, the working group recommends that, design teams should approach with building structure and envelope assemblies, with environmental impact ranked according to the LEED credits, with the eventual goal to make LCA a credible part of integrated design. While LCA has the architectural potential of accounting building environmental impact to help design teams making more informed-decision in selecting building systems and avoiding trade-off, the location factors would greatly influence its effectiveness in use. Currently there are numerous tools available for life cycle environmental impact assessment, including some that have integrated life cycle costing. This paper compares four of the tools in use -- SimaPro, BEES, ATHENA Impact Estimator, HK-EMSD LCA/LCC tool, from the perspective of industry practitioners. While all four applications aim to evaluate building product life cycle, actual applications vary in terms of regional relevance, ease of use, and economic performance.

SimaPro 7, is a detailed LCA software developed by PRé Consultants based in Netherlands. The software is equipped with major databases, including Ecoinvent by Swiss Institute, which covers more than 2700 industrial processes in the database known as ETH-ESU 96 database (Goedkoop, De Schryver, Oele, & PRé Consultants, 2008). In combination, these data library covers vast data on basic chemicals, transport, agriculture, plastics, metals, construction materials. Energy supply are categorized based on fuel types, electricity production, heat production, to accommodate different energy source differs between regions. For impact assessment, the software uses Eco-indictor 99, a damage oriented method covering damages in three categories of environmental impact -- ecosystems, damages to resources, and human health (Goedkoop & Spriensma, 2001). The detailed, specific data characteristics of the SimaPro software make it highly transparent. The software is available in various languages including Chinese and
Japanese. "Compact" version is available for quick results. The "analyst" version may be too technical for most practitioners in building industry but is promising in modeling complex scenario such as innovative design. In practice, the assessment may be best performed by engineering or environmental consultants, who then interpret the data and design implications to owners and design team. In such case, design team must operate in an integrated manner to facilitate accurate information flow between teams to ensure that LCA assessment is based on accurate and most updated design information.

Second software, BEES 2.0, which stands for Building for Environmental and Economic Sustainability, is developed by U.S. National Institute of Standards and Technology, with support from U.S. Environmental Protection Agency. The tool specifically concerns generic U.S. building products and the life cycle environmental and economic performances. Economic performance is modeled using ASTM standard life-cycle cost method, accounting for initial investment, replacement, operation and maintenance (Lippiatt, 2000). Weighting between environmental and economic performance can be specified to be valued separately or in combination. Environmental impact output is coded according to the building life cycle. For instance, impact data of carpet tile indicates that major environmental impact of the product takes place during the operation stage due to its impact on indoor air quality. Current BEES database include 65 commonly used building products, including foundation, structure, cladding, interior finishes, and furniture. For purpose of design investment, the tool is most useful comparing alternative systems. Where data for specific product is not available, a similar product will nonetheless provide owners and design team an approximate understanding.

Third, ATHENA Impact Estimator for Buildings is formulated by the Athena Institute in Ontario, Canada, evaluates environmental performance from the perspectives of whole-building and building assemblies. According to the Institute's press release (2008), database in the latest version covers 90% commonly used structural and envelope systems used in residential and commercial buildings. Application of the software is based on building system selection including foundations, walls, envelope, floors and roofs where environmental impact of respective systems can also be viewed. In addressing building component life cycle, the software also distinguishes owner-occupied and rental facilities to address different level of incentives to maintain or upgrade existing facilities, making explicit the relation between owner investment and environmental performance. Function of specifying operating energy by fuel type also informs owners and design team members trade-offs between building system alternatives on life cycle energy use. Accounting for the scenario of construction waste, the software also factors in material replacement and waste material disposition based on typical life expectancy. Impact assessment simplified the U.S. EPA TRACI method into six categories of environmental impact -- embodied primary energy use, global warming potential, solid waste emission, pollutant to air, pollutant to water, weighted resource use. From costing perspective, although current version of the Estimator does not offer economic performance weighting, the quantitative data about environmental performance can be a useful reference in decision making.

Fourth, a self-developed tool EMSD & Arup (2004) is in use in Hong Kong. A consideration of applying LCA in Asia-Pacific is the regional relevancy of data, as most LCA tools are developed based on data collected in Europe and North America. In Hong Kong, the government agency Electrical and Mechanical Services Department (EMSD) developed the LCA/LCC software jointly with engineering firm Arup as consultant. The localized tool is developed by surveying twenty-eight newly constructed office buildings to assemble database indicative of Hong Kong condition. Considering most of the construction materials in Hong Kong are imported, transportation is included in the impact assessment. Tender price data by local quantity surveyors are included in the database. LCA/LCC result can be weighted among the ten categories of environmental impact and economic performance. Impact results can be viewed according to phases, including as-built stage, operating stage, and end-of-life stage. Life cycle impact assessment of the tool is developed using aforementioned SimaPro software (EMSD, 2006), based on CML 2 Baseline 2000 LCIA methodology, a midpoint impact assessment method originally developed by University of Leiden, Netherland. There are ten categories in environmental impact -- abiotic depletion, global warming, ozone layer depletion, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification, eutrophication. Current study
based on local cases indicates that the five building materials with highest environmental impact in Hong Kong are concrete, reinforcing bar, plaster, galvanized steel and tiles, and stones. Concrete in particular averages 74% of total building weight, and 31% environmental impact points (EMSD & Arup, 2006).

6. IMPLICATION AND LIMITATIONS

Above comparison illustrates the potential of integrating environmental and economic considerations in life cycle thinking in the building industry. However, there remain hurdles to bring full potential of LCC and LCA in practice. The first hurdle is the least-first cost mentality (Loftness, Hartkoph & Gurtekin, 2004). Various studies have been conducted in recent years and uniformly point to the fact that green buildings require no significant increase in construction cost. Study by cost consultancy firm Davis Langdon & Seah (Matthiessen & Morris, 2007) shows that although the number of projects pursuing LEED or equivalent sustainability goals grew 20-30 percent from 2004 to 2006, the increased interest in sustainable building also reveals the preference for low-cost, low-or-moderate benefits building technologies while avoiding high-cost, high-performance systems. In quantity survey terms, it is the dilemma between cost and value. Ashworth and Hogg (2000) elaborated the concept that “it is worth while to pay a little more if he gain in value exceeds the extra costs involved.” If the total cost is accounted for, the total cost is low although the initial cost is high. Also, it is envisaged that a combination of assessment of the building components and materials may give rise to very different results as this would become so complex that even computer programs are not yet able to offer any indicative solutions. It is then only appropriate to have continuous reviews carried out to monitor building performance as a whole. Flanagan et al. (1989) pointed out that when applying life cycle techniques, decision-makers must be familiar with technical issues of building components being studied, including life expectancy, maintenance and performance characteristics. In addition, uncontrollable external factors such as the global climate change and the unpredictable issues arising from the social, economic and political changes worldwide. The design, cost and construction functions undertaken by practitioners with varied level of competence may also have an effect on the outcome of assessment. Therefore, it is recommended that the relevant education and training should be provided for better work done.

7. CONCLUSION

The tools of LCC and LCA allows for more accurate informed-decision throughout the building design, construction and operation. The availability of tools, as well as the skills and knowledge of the professionals, are only relevant if presumed. There is also motivation on the part of stakeholders in the building industry to venture beyond conventional practice for a more sustainable built environment. While the environmental benefits are attainable, the responsibility is not limited to any single party. Building owners, regulation agencies, coding officials, architects, engineers, and the affiliate professionals in the industry all play a role in reducing building environmental impact. A teamwork approach in working towards LCA seems to be the only viable solution.
### Table 1: Comparison of LCA softwares

<table>
<thead>
<tr>
<th>Developer</th>
<th>SimaPro</th>
<th>BEES 4.0</th>
<th>Athena Impact Estimator</th>
<th>EMSD LCA/LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRe Consultants, Netherland</td>
<td>National Institute of Standards &amp; Technology, U.S.</td>
<td>Athena Institute, Canada</td>
<td>Electrical and Mechanical Services Dept, Hong Kong</td>
<td></td>
</tr>
<tr>
<td>Datasource</td>
<td>Various database including Swiss EcoInvent v2, USA and Japanese Input Output</td>
<td>Manufacturers, literature, journal articles, 65 building products</td>
<td>US Life Cycle Inventory, region-alized structural/envelope databases</td>
<td>Surveying of 28 high-rise office buildings in Hong Kong</td>
</tr>
<tr>
<td>Impact assessment methods</td>
<td>Various methods: Eco-indicator (eco-system, human health,resources), CML, TRACI, IPCC ghg, etc.</td>
<td>Various methods: Eco-indicator (eco-system, human health,resources), critical volume, etc.</td>
<td>Energy use, solid waste, global warming, air/water pollution indexes, resource extraction. TRACI option.</td>
<td>Abiotic depletion, global warming, ozone layer deplet-ion, human toxicity, eco-toxicity, etc.</td>
</tr>
<tr>
<td>Strength for decision making</td>
<td>Capacity to assess complex, technical scenario, product and services.</td>
<td>Assessment by components. Economic weighting.</td>
<td>Assessment by systems and whole-building</td>
<td>Localized data. Assessment by systems and whole-building.</td>
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</tbody>
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### REFERENCES


