Emery-based Sustainability Rating System for Canadian Construction Projects

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ABSTRACT

Building and construction industry significantly contributes to global environmental problems as it accounts for 30-40% of energy and material consumption of the society and around 30% of the greenhouse gas emissions. Considering growing population, resource scarcity and environmental effects of building industry on earth, there is an urgent need for paradigm shift toward sustainability and green buildings. However, studies shows that 28-35% of current certified green buildings actually use more energy than conventional buildings.

This paper targets to address weaknesses in current green building rating systems in Canada, by implementing emery accounting to assess environmental and associated socioeconomic impacts of the construction projects. The main objective of this paper is to outline an emery-based sustainability rating system (Em-Green) for construction projects by considering complete lifecycle of structures (cradle to grave). Emery measure provides a holistic method to estimates the value of environmental resources and services, in units of solar energy that was previously used to generate a product. Em-Green sustainability rating system for buildings is a user-friendly framework customized for Canadian construction industry.

INTRODUCTION

Building and Construction Industry in Canada

The banging hammers and swinging cranes at construction sites across Canada are indicators of economic and social trends in this country. Construction is very active all over Canada. Low interest rates have encouraged more Canadians to invest on buildings and mega construction projects (Statistics Canada, 2011b). Construction is one of Canada’s largest industries that provide both infrastructure and employment for the nation. Construction industry consists of residential, commercial and industrial components. Figure 1 shows the construction activities for Canada from 1995 to 2009. During this period, construction contributed around 6% each year to Canada’s GDP. In 2009, its contribution was more than $69 billion, making construction industry one of the most important sectors after oil and gas. New opportunities in construction began to draw people from other industries, such as farming, manufacturing, and accommodation and food services (Statistics Canada, 2011a).

During economic recessions in 2009, construction sector was hit similar to all other sectors in Canada. After the recession in 2009, construction industry is still recovering. More jobs are being created in this sector as demand for construction and new housing is uprising, especially in the western provinces. According to Statistics Canada, population of Canada is increasing at a steep slope and estimated to reach more than 42 million by 2050. This is more than 23% increase from 2012 (Statistics Canada, 2011c).
As the population increases, need for all types of infrastructure, including buildings increases exponentially. After food, a shelter or home is the most basic need of every human. The building industry consumes large portion of limited reserves in the world. It accounts for 30-40% of all natural resources used in developed countries. This includes almost 40% of all material, 30% of energy, and 70% electricity consumption in the world (Roodman and Lenssen, 1995). This is just part of the problem; buildings do not only consume limited resources, but also create pollutions to the environment. According to United States Green Building Council (USGBC 2007), building sector accounts for 30% of all greenhouse gas emissions and 45-60% of land filled waste. Considering growing population, resource scarcity and environmental effects of the building industry on Earth, there is an urgent need for paradigm shift toward sustainability and green buildings.

There are various indicators applied to buildings to evaluate its’ sustainability performance. Buildings are categorized as “green” by meeting sustainability criteria defined by assessment tools/frameworks. Among all of building sustainability grading systems, Leadership in Energy and Environmental Design(LEED) developed by United States Green Building Council (USGBC) in 2000 is the current leading system in the North America, mainly due to its simplicity to use. Although LEED is the most common building rating system, it has many drawbacks. First is ‘point hunting’, where a building can achieve required points for certification without addressing crucial points of energy efficiency. Secondly, points are lost for credits that are outside the scope of a certain project (Chew and Das, 2007). Moreover, Newsham et al. (2009) studied 100 LEED-certified buildings on energy use and discovered that 28-35% of LEED-certified buildings actually use more energy than conventional buildings. Authors also found a weak relationship between the energy performance of LEED-certified buildings and received energy points from the rating system. They concluded that these weaknesses question the credibility of current green building rating systems and believe there is a need for a stronger sustainability rating system. Due to the above pointed weaknesses in current sustainability rating systems, the construction industry needs a more comprehensive method that covers lifecycle of building materials and provides a better estimation of building’s environmental impact. The solution outlined in this paper is an emergy-based building rating system that is localized for Canadian building industry.

**Introduction to Emergy**

By definition, emergy is the available energy of one kind that has been used up directly and indirectly to make a product or service (Odum, 1971, 1983, 1996). Emergy assessment considers systems as a network of energy fluxes. It assigns a value to natural and economic products and services.
by converting them into equivalents of one form of energy, with reference to the theory of energy hierarchy in systems ecology (Pulselli et al., 2007b). The most common method is transforming all resources to solar energy (called solar emergy joule, solar emjoule or ‘sej’) since solar energy is one of the three largest but most dispersed energy input to the earth (Brown and Ulgiati, 2004).

The emergy of different products is calculated by multiplying mass (g) or energy quantities (J) by specific emergy or transformity, which is transformation coefficients. Transformity or specific emergy is the solar emergy required, directly or indirectly, to make one joule or one gram of a product or service.

By definition, the solar energy $B_k$ of the flow $k$ coming from a given process is:

$$B_k = \sum_{i=1}^{n} Tr_i E_i$$ (1)

Where, $E_i$ is the actual energy content of the $i^{th}$ independent input flow to the process and $Tr_i$ is the solar transformity of the $i^{th}$ input flow (Pulselli et al., 2007a).

For convenience, it is very common to use transformity values derived from other studies and avoid calculating emergy in products and services every time it is assessed, by assuming they are still valid under minor different conditions such as place and/or time (Meillaud et al., 2005). Moreover, there is no single transformity for most products and a range of transformities available depending on its production process (Pulselli et al., 2008).

In reference to buildings and construction, Pulselli et al. (2007a) performed emergy analysis to evaluate a typical residential/commercial building in central Italy during its construction, maintenance and use phases. The authors used emergy analysis as a form of sustainability indicator, while common building evaluation methods, such as LEED, follow state-pressure environmental indicators. Also, Meillaud and Brown (2005) applied emergy analysis to evaluate an educational building located in Institute of Technology of Lausanne in Switzerland. Analysis result was expressed in three forms of unit emergy values: transformity, specific emergy, and emergy per unit money. Authors’ major conclusion was that information has the highest emergy inputs to the building, followed by human services and operating energies.

Research Objective

The objective of this paper is to discuss an emergy-based sustainability rating system for Canadian construction projects: i.e. Em-Green sustainability rating system. This sustainability measure for building has following features:

- It is based on emergy methodology.
- It covers triple bottom line of sustainability- i.e.: environmental, social, and economical.
- It considers complete life-cycle (Cradle-to-Cradle) of buildings from resource extraction, manufacturing, transportation, on-site construction, operation and maintenance to demolition (landfill and/or recycle).
- It is a user-friendly framework customized for Canadian construction industry.

METHODOLOGY

In this section, methodology used to develop the emergy-based sustainability rating system for Canadian construction projects is outlined, as shown in Figure 2.

Initially, comprehensive literature review of building rating systems, sustainability assessment tools for the built environment and emergy methodology was conducted and objectives of research were defined. Then, necessary data were collected from various sources, such as construction project documents, field observation and statistical data for Canada.

To develop emergy-based sustainability rating system, it is necessary to create an emergy database for major constructional materials in Canada. Also, it is essential to perform emergy accounting for Canada and its provinces to get emergy indices and indicators, such as emergy to money ratio (Em$) of Canada for the analysis.
Figure 2. Research methodology outline.
Figure 3 illustrates the energy system diagram for the Em-Green building rating system. It covers complete lifecycle of a building from cradle (material formation and extraction) to grave (landfill of structure) or back to cradle (recycle of building components). The system diagram consists of major flows contributing at different stages of building lifecycle, which are resource extraction, manufacturing of materials, construction, operation and maintenance and demolition. Considered flows have different forms of energy, material (natural resources), human work, machinery, money and transportation. The green dashed-line shows the recycle scenario at the end of building lifecycle. Flows of money in the system are illustrated as dashed line with $ sign. The energy system diagram is drawn based on the symbols of the energy systems language given by H.T. Odum (1971, 1983, 1996).

Impact of buildings on environment, society and economy is not only limited to construction phase. A comprehensive building rating system should cover all life stages of building for sustainability assessment. This point lacks in current leading rating systems in Canada.

In Em-Green sustainability rating system, fluxes in each stage of building lifecycle is transformed into emergy equivalent and considered in sustainability assessment. Each stage is described in detail.

**Resource extraction and material manufacturing stages**

Athena impact estimator and SimaPro software are used to perform lifecycle analysis for major construction materials and structural systems in Canada. Athena impact estimator is a tool that is capable of evaluating more than 95% of the building stock in North America based on Life Cycle Assessment (LCA) methodology (Athena Institute, 2011). LCA provides quantity and quality of all materials and energy forms that have been used in extraction, manufacturing and transportation of construction materials. It also evaluates environmental impacts associated with these stages.

Having raw quantities (gram and joule) for emergy table, emergy analysis is performed to calculate specific emergy (sej/g) of each construction material and assemblies using transformity values in the literature. Emergy calculation is performed for major construction materials in Canadian construction industry and an emergy database is created.

**Transportation to construction site**

SimaPro is used to perform lifecycle analysis for different types of transportation for construction materials to construction site. Result of LCA is transformed to emergy values using transformity functions from literature and emergy per unit of traveled distance (sej/km) is calculated.

**Construction**

Construction is a major phase of building that covers tasks from different disciplines, including management, engineering, construction, machinery and materials. Besides flows of material, energy and transportation to the system, human work is a major flux in construction projects.

Human works done by engineering, management and construction team are measured by dollar value in the construction industry. These dollar values are transformed to emergy, using emergy/money ratio of Canada in 2011, as estimated from Emergy accounting of Canada from previous step.

Similarly, machinery cost ($) and land cost ($) are transformed to emergy values using the corresponding Em$ ratio of Canada or the province. Emergy of construction materials is already calculated from resource extraction and manufacturing stage.
Operation and Maintenance (O&M)

Consideration of post-construction phases in sustainability assessment lacks in current major building rating systems in Canada. The main focus of point-based building grading systems is on construction and material use, while building operation and maintenance is the longest stage of a building lifecycle and has highest interaction with the occupants.

In Em-Green sustainability rating system, occupants’ productivity and health over life span of building is considered as an important factor of social sustainability. In addition, operation energy from both non-renewable and renewable sources used for building operation, electricity generation, heating and cooling is captured in the assessment framework. Also, water consumption over life-span of building for different purposes such as washing, toilet and irrigation is included in the building rating system.

Productivity increase and health benefits of green buildings occupants are measured based on time and money saved compare to conventional buildings. For example, a 1% increase in productivity is equal to about 5 minutes per working-day that is equal to $600 to $700 per employee per year, or $3/ft² per year (Kats, 2003). Dollar values are converted to energy using corresponding Em$ ratio for Canada in 2011.

LCA is performed for various energy types used in Canadian buildings, including electricity, natural gas, oil, wood, propane and other fossil fuels. Results of material and energy consumptions are transformed to energy via specific emergy and transformity functions in the literature (Sej/J). The analysis is perfumed based on building life-span.
Demolition of building and recycle/disposal (end of life scenarios)

Evaluation of emergy used in demolition, recycle and disposal is based on Brown and Buranakarn (2003). Emergy per unit of area (Sej/m²) of demolition, recycling and landfilling is calculated for the building and considered in the analysis.

Based on emergy values calculated from each stage of building lifecycle, total emergy, and emergy per unit area (Sej/m²) is calculated for the building under study. The building’s sustainability is assessed by comparing its sej/m² to three levels of sustainability of Em-Green rating system. These three classes of sustainability are calculated based on case studies performed on number of green buildings in Canada, including LEED certified buildings.

Moreover, a user-friendly emergy-based decision support tool for Construction projects is developed based on Em-Green sustainability rating system.

RESEARCH DELIVERABLES

Following are the deliverables of this research study:
- An emergy database for major Canadian construction materials and structural systems.
- Emergy Accounting of Canada and its provinces by calculating emergy indicators, indices and emergy maps for the region.
- An emergy-based building rating system that covers triple bottom lines of sustainability: i.e. Em-Green Sustainability rating system
- A user-friendly building assessment tool based on the emergy database and the developed rating system (decision support tool).

CONCLUSION

Building and construction industry significantly contributes to global environmental problems as it accounts for 30-40% of energy and material consumption of the society and around 30% of the greenhouse gas emissions. Considering growing population, resource scarcity and environmental effects of the building industry on Earth, there is an urgent need for paradigm shift toward sustainability and green buildings. There are various sustainability rating systems for building industry, but these point-based rating systems have many weaknesses and do not measure true sustainability performance of buildings through their life span. Studies shows that 28-35% of LEED certified green buildings actually use more energy than conventional buildings.

In this paper, weaknesses in current green building rating systems are pointed out and methodology used to develop the emergy-based (Em-Green) sustainability rating system for Canadian construction projects is outlined. Em-Green is based on emergy methodology and covers triple bottom line of sustainability. It also considers complete life-cycle (Cradle-to-Cradle) of buildings. Em-Green sustainability rating system for buildings is a user-friendly framework customized for Canadian construction industry.
REFERENCES


