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A tool for assessing life cycle CO_2 emissions of buildings in Sri Lanka

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ABSTRACT

The critical role of buildings in overcoming global environmental challenges is evident from their high contribution to global energy use and carbon dioxide (CO_2) emission. This study was aimed at developing a life cycle CO_2 emission estimator tool for buildings in Sri Lanka. First, system requirements and system boundary were identified. Then CO_2 emission calculation method for each life cycle stage was established, which was followed by development of building life cycle CO_2 emission database and program. The applicability of developed tool was evaluated by a case study of a multi-storey building in Sri Lanka. In the case study, operation and maintenance stage contributed to 55.47% of life cycle CO_2 emission, which was followed by material production stage (42.09%). Ready-mixed concrete, reinforcement steel, cement and clay bricks contributed to nearly 90% of CO_2 emission at material production stage. To the best of our knowledge, this study is the first-ever attempt at developing a building life cycle CO_2 emission estimator tool for Sri Lanka. The limited availability of local data for some life cycle stages was the main challenge faced by researchers, as national data inventories for building life cycle CO_2 emissions are still not fully developed in Sri Lanka. The tool can be used to compare life cycle CO_2 emissions of different buildings as well as providing means of assessing compliance of life cycle CO_2 emissions of buildings to CO_2 emission standards specified by green building certification bodies in Sri Lanka, thus promoting sustainable construction practices in the country.

1. Introduction

As stated in a recent report of Intergovernmental Panel on Climate Change [1], buildings account for 32% of global energy use and 19% of energy related CO_2 emissions as well as 57% of global electricity consumption. Therefore the importance of their role in overcoming global environmental challenges is evident. The energy use and associated CO_2 emissions are expected to rise significantly in future due to key global trends such as population growth, migration to cities, household size changes and increasing level of wealth and lifestyle changes [1]. If the targets for reducing CO_2 emissions are to be met, decision makers need to pay attention to buildings and buildings must be the focus of every national climate change mitigation strategy [2]. On the other hand, buildings offer immediately available, cost-effective opportunities to reduce energy consumption and CO_2 emissions [1]. With proven and commercially available technologies, energy consumption in both new and existing buildings can be reduced by an estimated 30–50% without significant increase of investment cost [3]. According to the energy sector scenario 2050 forecasted by International Energy Agency [4], CO_2 emissions of buildings are expected to be reduced by two-thirds through low-carbon electricity, energy efficiency and the shift to low and zero carbon technologies.

In order to identify mitigation strategies, it is essential to evaluate the current building performance in terms of energy consumption and CO_2 emissions. As CO_2 emission is a process which takes place throughout the whole life cycle of a building, life cycle assessment (LCA) is considered to be the best approach in evaluating impacts of CO_2 emissions. Researchers and organizations, mainly in developed countries, have introduced a number of building life cycle CO_2 emission assessment systems. In developing these, various data sources such as existing databases, standards, codes and reports of the country concerned were used. Although these systems can be applied to any country, they have limited validity outside the specific country or region due to climatic, geographical, technological, economic and socio-cultural differences between countries [5].

Similar to other developing countries, Sri Lanka is currently facing many environmental challenges. Construction is one of the major industries and buildings contribute to more than half of value and raw material usage in the construction sector [6]. According to the current energy scenario of the country, rapidly expanding building sector consumes about 35% of national energy, thus contributing to a significant portion of CO_2 emissions [7]. Although buildings are identified

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as a priority sector in reducing energy use and CO_2 emissions, national data inventories and systems needed for the assessment of energy and CO_2 emissions are currently lacking in the country.

This study was aimed at developing a building life cycle CO_2 emission estimator tool in the context of Sri Lanka, which includes a CO_2 emission estimator program and an integrated life cycle database. The applicability of the developed CO_2 emission estimator tool was evaluated using a case study of a multi-storey building in a Sri Lankan university. With predictions of increasing energy use and rise of CO_2 emissions in the building sector of Sri Lanka in future, this type of tool will be highly useful in assessing life cycle CO_2 emissions of buildings and identifying appropriate strategies for mitigating CO_2 emissions throughout building life cycle.

2. Literature review

Life cycle CO_2 emission assessment (LCCO2A) is a technique to quantitatively assess CO_2 emissions associated with all stages of building life cycle [8] which include material production, transportation, construction, operation, maintenance and end-of-life. Many countries have been developing systems to evaluate life cycle CO_2 emissions of buildings that incorporate the unique characteristics of their construction industries [5]. Table 1 outlines some of these systems with their specific evaluation features.

Apart from the above national and organization-based life cycle CO_2 emission assessment systems, researchers around the globe have been developing and modifying similar systems based on building certification systems, life cycle databases, standards and codes of the respective countries in order to achieve optimum representation of existing conditions of their construction industries.

Roh et al. [9] developed a design program (SUSB-OPTIMUM) to assess life cycle CO_2 emission of an apartment house in South Korea, which included a database of CO_2 reducing performance and costs of environmentally-friendly construction technologies, an interpretation program based on a simplified technique for assessing life cycle CO_2 emissions and unit costs based on inter-industry relation table. A Building materials Embodied GHG Assessment criteria and System (BEGAS) for newly revised Korea Green Building Certification System (G-SEED) was established [14]. Li et al. [15] developed an automated estimator of life cycle carbon emission for residential buildings in China. The Building Life cycle Carbon Emission Assessment Program (BEGAS 2.0) that evaluates carbon emission quantity in Korea's Green Building Index Certification System (GBI Certification System) was developed by Roh et al. [16]. Lee et al. [17] established an integrated building LCA model that allows an interlinked application of LCA results of building materials, components and the whole building. They proposed a method for stepwise application of the integrated building LCA model to Green Standard for Energy and Environmental Design (G-SEED), a Korean green building certification system. A LCA tool for buildings which was integrated in TRNSYS environment and has the ability to perform 'cradle to cradle' LCA studies was presented by Cellura et al. [18]. The authors developed a database including the specific impacts due to Global Energy Requirement (GER) and Global Warming potential (GWP) of building materials, energy carriers, transport and end-of-life processes.

Roh and Tae [19] developed a web-based integrated assessment system to periodically evaluate and manage life cycle CO_2 emissions of a building. It included models for simple assessment (SAM), detailed assessment (DAM), construction site assessment (CAM) and results analysis (RAM). In a similar study, the same authors developed a Building Simplified LCCO2 emissions Assessment Tool (B-SCAT) for the application in the early design phase of low-carbon buildings in South Korea [20]. Dong and Ng [21] developed a LCA model, namely the Environmental Model of Construction (EMoC) to help decision makers assess environmental performance of building construction projects in Hong Kong. Li et al. [22] developed a dynamic model for calculating

Table 1
Building life cycle CO_2 emission assessment systems [5,9–13].

System	Country developed	Organization	Year	Features
SUSB-LCA	Korea	Sustainable Building Research Center, Hanyang University	2007	Assesses life cycle energy consumption, CO_2 emission and cost. The system update is relatively easy.
AIJ-LCA	Japan	Japan Architectural Society	2003	Composed of Excel worksheet type. Assesses building life cycle CO_2, NO_x, SO_x emissions, energy use and cost. Wide assessment range with industry specific analysis method.
GEM-21P	Japan	Shimizu construction	2008	Uses statistical data to assess life cycle CO_2 and estimates energy input per unit area. CO_2 unit data of Japan Architectural Society is used. Users can review alternatives for saving energy.
Carbon Navigator	Japan	Daisei construction	2009	Composed of 5 software; PAL-navi, ERR-navi, aurora, CarbonCalc and PAL-auto calculation. Interlinked with BIM, it can assess each life cycle stage and promotes efficient assessment by simulation of CO_2 reduction measures.
LISA	Australia	BHP Research Center and University of New Castle	2003	Composed of simple design interface and processes data in checklist form. Provides efficient material production analysis using life cycle inventory database.
BeCost	Finland	VTT Research Center	2003	Web based assessment offers easy access to users. Assessment and analysis of results are conducted in stages. Processes various data such as structure type, materials, land type and endurance period.
ENVEST2	UK	Building Research Establishment (BRE)	2003	Assesses building life cycle CO_2 and cost. Offers high accessibility through web based assessment. Uses Eco Point, the unique indicator of the system.
LCA-MCDM	USA	International Energy Agency (IEA)	1999	Reflects weighted value on standard proposals through general designing assessment program.
Eco-Quantum	The Netherlands	W/E Sustainable Building	1996	The first computer program based on building LCA. Capable of assessing various conditions such as effects of energy consumption through building life cycle.
K-LCA	Korea	Korea Institute of Construction Technology	2004	Uses CO_2 emission rates per basic unit on the basis of inter-industry analysis table.