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Assessment of material related embodied carbon of an office building in Sri Lanka

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ABSTRACT

Buildings, due to their significant environmental footprint, are major contributors to global energy use and carbon emission. Although buildings consume more than 50% of raw materials in the construction sector of Sri Lanka, there is a notable lack of building energy and carbon related studies based on the country. The present study assesses the embodied carbon of a commercial office building in Sri Lanka, focusing on the material production phase of the building life cycle. The embodied carbon in the material production phase was found to be 629.6 $kgCO_2/m^2$ of the gross floor area of the building. Reinforced concrete and clay bricks are the major carbon emitting materials contributing to more than 70% of the total embodied carbon. It was found that in selecting building materials, both the mass materials and high carbon emitting materials should be given special attention. The study identified several important strategies for the reduction of embodied energy and carbon of buildings in Sri Lanka. Taking a proactive approach in mitigating embodied energy and carbon impacts of buildings will lead to energy efficient and low-carbon buildings, enabling Sri Lanka to take part in overcoming the global environmental challenges in future.

1. Introduction

Climate change due to greenhouse gas (GHG) emissions from anthropogenic and natural activities is a major concern across the globe [1]. Carbon dioxide (CO_2), the most prominent GHG, contributes to about 80% of the global warming effect [2]. The construction sector is the largest consumer of materials worldwide and buildings are responsible for nearly 40% of energy consumption as well as one third of related GHG emissions [3]. As found by recent studies, buildings offer the highest opportunity for mitigating GHG emission in the short-term [2]. In the past, priority was given in reducing energy consumption and subsequent carbon emissions in the operation phase of a building. Innovations and technological advances in the area of renewable energy technologies, energy efficiency and inducements to change consumer behavior have offered promising operational emission reductions in buildings. As these measures often lead to an increase in material use and energy demand for their production, the focus was shifted to embodied energy and emissions in current environmental studies [3]. A wide range of materials are used in buildings and each material consumes energy and emits carbon throughout its life cycle. Energy and carbon emissions can be regarded as being 'embodied' within materials. Embodied energy is directly related to embodied carbon of building materials and both are viewed as equally important in the context of buildings and construction materials. With the increased attention on embodied energy and carbon emission of buildings, the pre-use phase which is directly related to the building materials has grown in significance [4].

In Sri Lanka, buildings comprise of more than 50% of value and raw material use in the construction sector [5]. According to the present energy scenario of the country, the rapidly expanding building sector consumes about 35% of national energy, thus contributing to a significant amount of carbon emissions [6]. Within the buildings sector, office buildings consume the largest share of raw materials as shown in Fig. 1. Sri Lanka has already recognized the need to focus on the building sector in identifying carbon mitigation strategies. For any improvements to take place, the assessment of the current performance in terms of carbon emission is essential. This paper presents an analysis of the embodied carbon of a commercial office building in Sri Lanka, focusing on the material production phase of the building life cycle. The study intends to accomplish two objectives; to identify the embodied carbon profile of building materials in the case study building and to compare

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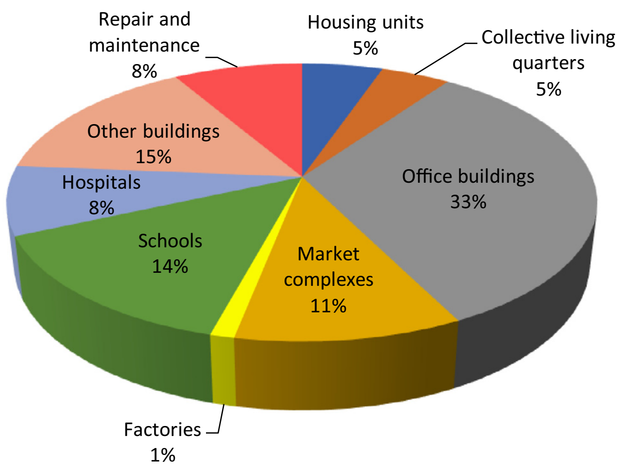

Fig. 1. Raw material consumption of building sector of Sri Lanka [5].

the contribution of each material to the overall building mass and the embodied carbon content.

The study will recommend appropriate strategies for reducing embodied carbon of buildings in the context of Sri Lanka. As there are no similar studies found in the literature based on Sri Lanka, this study will be an important milestone in the carbon emission assessment of buildings in the country. The analysis of embodied carbon in the initial design stages of a building can facilitate environmentally-friendly building material selection, thus reducing the adverse environmental impacts of buildings.

2. Literature review

Many researchers identified material selection as one of the key success factors in achieving carbon neutral buildings and emphasized the importance of design and construction phases on carbon mitigation [7,8]. Knight and Addis [9] demonstrated the use of embodied carbon estimations as a design tool to develop structural options with reference to the West Kowloon terminus in Hong Kong. Gonzalez and Navarro [10] identified the possibility of reducing the CO_2 emissions up to 30% in the construction phase of buildings through a careful selection of materials with low environmental impacts. Lee et al. [11] recognized two distinct stages of the design process where the choice of materials takes place; project appraisal stage and working plan stage. Hakkinen et al. [12] emphasised the importance of early design stages in achieving low carbon buildings and identified the need for integrating the roles and responsibilities of the relevant stakeholders necessary for ensuring carbon efficiency. It was identified that building materials having high embodied energy could result in more carbon emissions than would materials with low embodied energy [10,13]. Embodied carbon can account for between 2% and 80% of life cycle carbon emissions and the exact proportion depends on a number of characteristics including building use, location, type of materials used and the assumptions made about the service life and future energy supply [3]. Much effort has been given recently to document the environmental impacts of materials including embodied energy and carbon which are incorporated in commercial software, handbooks, websites and tools [1].

In order to evaluate the embodied energy and carbon of buildings, numerous studies have been conducted, mainly based on case studies from developed countries. Many studies compared the carbon emissions of buildings constructed with different materials [14–17]. Some researchers explored the possibility of achieving low-carbon houses using traditional and locally available materials [18–22]. The carbon emissions of pre-fabricated and conventionally constructed buildings were compared and the advantages of pre-fabricated buildings in terms of carbon emissions were emphasized [23-26]. The importance of the main structural materials such as concrete and steel in embodied carbon assessment of buildings was identified in a number of studies [8,24–29]. Atmaca and Atmaca [30] pointed out that material selection, durability, local availability and recycling facilities are important considerations for a building to perform efficiently in terms of energy and carbon emissions. Brown et al. [31] evaluated the importance of embodied GHG emissions for refurbishment of Swedish residential building stock and estimated the total embodied GHG emission to achieve 50% reduction of operational energy by considering a range of structures.

In the contemporary research literature on the environmental impacts of buildings, a significant gap is observed with regards to developing countries. The number of building energy and carbon related studies based on these countries are highly limited [24,32–37] and reliable data are nearly non-existent. Ruuska [38] identified the transition from traditional materials to modern materials as one of the parameters which need special focus in applying current research findings to developing and tropical countries. The author analyzed case studies from Indonesia, Thailand and India, which gave evidence that the move from traditional to modern materials may result in increased embodied energy and carbon emission.

In the recent years, Sri Lanka has taken a number of initiatives in promoting environmentally-friendly buildings in the country. Green Building Council of Sri Lanka introduced GREEN SL® Rating System for Built Environment in 2015. Benchmarked with leading green building certification systems such as Leadership in Energy and Environmental Design (LEED), GREEN SL® Rating System incorporates several evaluation criteria which reflect the unique requirements of the country. A comparison of the main features of GREEN SL® and LEED rating systems is given in Table 1.

Fig. 2. illustrates the percentage weights assigned for the key evaluation criteria in the two systems. Although GREEN SL® Rating System awards points for material recycling and reuse, renewable energy sources, rapidly renewable materials and use of local materials under the key evaluation criteria, there are no direct provisions to account for embodied carbon emissions.

3. Materials and methods

This study analyzed the embodied carbon of a commercial office building located in Gampaha, Sri Lanka. The main materials used for the building structure, envelope and the finishes were considered in the study. The details required to calculate the material quantities were obtained from building drawings, bill of quantities and technical specifications. Due to the unavailability of carbon emission data in the Sri Lankan context, internationally recognized databases such as Inventory of Carbon and Energy (ICE) developed by University of Bath, UK and recent research literature were referred in identifying embodied carbon coefficient values of building materials.

3.1. Estimation of embodied carbon emission

The carbon emission coefficient method was used in estimating the embodied carbon content of materials which was carried out by using Eqs. (1) and (2) [42].

$$\mathbf{CO}_{2,\boldsymbol{embodied}} = \sum_{1}^{\boldsymbol{i}} \mathbf{CO}_{2,\boldsymbol{embodied},\boldsymbol{i}} \tag{1}$$

where $CO_{2,embodied,i}$ and $CO_{2,embodied}$ are the amounts of embodied carbon of the ith type of building material and the building (in