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Statistical analysis of embodied carbon emission for building construction

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ABSTRACT

Buildings are significant contributors to the greenhouse effect through emission of considerable carbon dioxide during their life cycle. Life cycle carbon resulting from buildings consists of two components: operational carbon (OC) and embodied carbon (EC). Recent studies have shown the growing significance of EC because much effort has already been invested into reducing OC. In this context, it is important to estimate and reduce EC. Because of the variability and uncertainty contained in a range of conditions, the EC of building needs to be calculated based on probabilistic analysis. This study identifies and analyzes the statistical characteristics of EC emitted from building construction materials. It was aimed at buildings constructed of reinforced concrete and nine representative construction materials. Descriptive statistics analysis, correlation analysis, and a goodness-of-fit test were performed to describe the statistical characteristics of EC. In addition, a case study was carried out to show the difference between the deterministic and probabilistic estimations. Presenting statistical information on EC data and the differences between the deterministic and probabilistic values, the result shows the necessity and reasonability of the probabilistic method for EC estimation.

1. Introduction

1.1. Background

The Earth's climate system is influenced by greenhouse gas emission resulting from development activities of humans [1]. In particular, buildings, which are one of the major artificial structures, consume various natural resources and energy, and lead to air pollution and carbon emission [2]. In South Korea, the building sector is the secondly dominant one in terms of energy use and greenhouse gas (GHG) emissions, consuming approximately 22% of the total energy used, and thereby contributing 25% of total GHG emissions. The Korean government has forecast that this will increase to 40% in the next few years, and has set the goal of cutting GHG emissions by 26.9% by 2020, relative to the “business as usual” scenario. Accordingly, efforts are being made to reduce carbon emissions across the whole life of buildings. To obtain more specific outcomes via these efforts, it is mandatory to clearly identify the carbon emission status and establish a goal based on this status [3].

Recently, embodied carbon (EC) has become especially important for estimating the life-cycle carbon of buildings. EC refers to carbon dioxide emitted during the manufacture, transport, and construction of building materials; operational carbon (OC) refers to carbon dioxide emitted from the use of buildings including heating, cooling, and lighting. In conventional studies, the OC is mostly assumed to be larger than the EC in the building life cycle. However, OC is being continuously reduced via multipronged efforts related to technology and policy aspects, such as improvement of heating, ventilation, and air-conditioning performance, utilization of new and renewable energy, adoption of the zero-energy building design, and the introduction of green building certification policies. In accordance with green building certification in South Korea—known as G-SEED (green standard for energy and environmental design)—an increasing number of stakeholders have obtained certification. Since G-SEED was established in 2002, 4958 buildings have been certified. Because of these efforts, the proportion of EC in the life cycle is increasing [4–8], which implies that carbon reduction in the building sector cannot be successfully achieved as long as EC is ignored [8].

However, there is uncertainty in EC estimation because a single value has to be predicted from among various possible values.

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Moreover, it has variability because of the type and quantity of resources employed in a building could change depending on the design, construction type, site condition, and owner's characteristics. To deal with the uncertainty and variability, a probabilistic analysis can be adopted, such as Monte Carlo simulation, which is the most widely used method. However, in conventional studies on EC, the statistical information for the data is insufficient; in particular, the distribution type, parameters, and correlations required as input variables in Monte Carlo simulation have not been investigated yet. Acquaye et al. [9] remarked that understanding the statistical characteristics of EC would be useful in formulating an effective policy, and would facilitate environmental decision-making in the design phase by providing detailed information to architects and contractors. In other words, probabilistic analysis is necessary for a meaningful estimation of EC where uncertainty and variability are inherent, and a statistical characteristics analysis must take precedence to retain value for the input variables in simulation.

1.2. Research objectives and methodology

This study aims at analyzing the statistical characteristics of EC in buildings in terms of construction materials. Factors inducing EC of buildings were classified into the carbon caused by construction materials that buildings consist of, and the carbon caused by equipment used in transportation or on-site construction work. According to a preliminary study [10], the carbon caused by materials accounts for 90% or more, whereas the effect of the one caused by equipment is insignificant. Therefore, this study considered only construction materials as a factor for EC.

The research was performed according to the flowchart in Fig. 1. First, the scope for sampling was determined. In a survey of the current building status of Suwon city, Korea, the major building structural type was selected for sampling in accordance with the gross floor area (GFA) priority for each type. Further, several representative materials that contribute to considerable EC were determined through literature reviews. Next, a bill of quantities (BOQs) of buildings suitable for the sample scope was collected and the EC of the representative materials was calculated to generate the sample dataset. Next, the statistical characteristics of EC for each representative material were analyzed based on the generated dataset. To highlight differences between application and non-application of the statistical characteristic information, a case study for deterministic and probabilistic EC estimation was carried out.

Along with the statistical characteristics analysis, a descriptive statistics analysis, correlation analysis, and goodness-of-fit test were performed. The descriptive statistics analysis described the representative value and degree or type of data spread using several statistics. In the correlation analysis, the correlation with EC was investigated between all representative materials. In addition, the probability distribution types fitted in the sample dataset were derived in the goodness-of-fit test. Using the investigated statistical characteristics, case studies of Monte Carlo simulation were carried out for the probabilistic estimation of EC. Monte Carlo simulation is a problem-solving technique used to approximate the probability of certain outcomes by running multiple trial runs (simulations), especially using random variables. Here, random variables were generated in accordance with the defined probabilistic distribution using a random number from zero to one.

2. Scope for sampling

2.1. Structural type

The type and quantity of construction materials may vary depending on the structure and finishing type of the buildings. Because the building structure affects the type and quantity of the main materials, it could be said that the structure is a key factor for determining the EC. In South Korea, various structural types have been adopted in buildings, such as reinforced concrete, steel, steel-reinforced concrete, and lightweight steel. In this study, the major structure types chosen for analysis were from these types. Accordingly, the percentage of structural types were analyzed by collecting the building register information of 3048 buildings that were constructed during the period 2009–2013 in the Suwon city in South Korea.

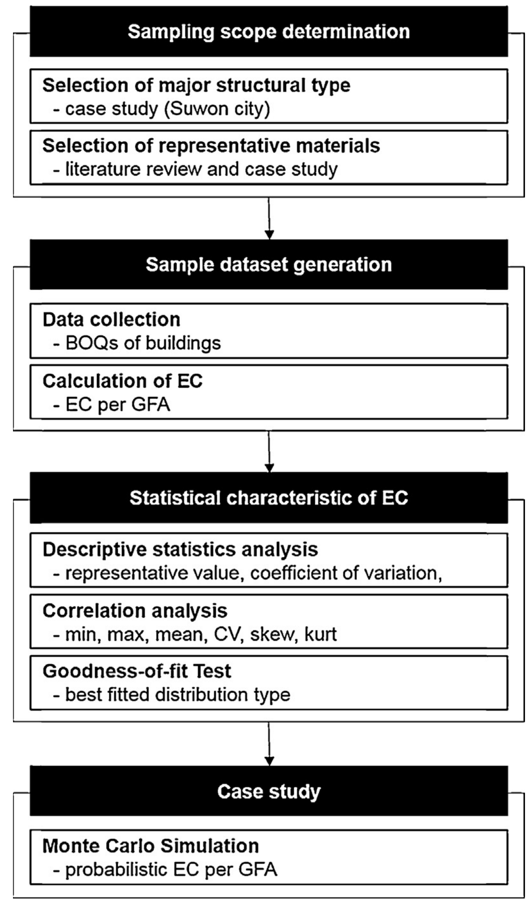

Fig. 1. Research process and methodology.

The gross floor area (GFA) percentage of each structural type investigated is presented in Table 1, including the various building-use types. Of approximately 6.02 million square meters of GFA, 97.49% was found to belong to the reinforced concrete structure type. Steel structures accounted for 1.73%; steel-reinforced concrete structures, 0.43%; and lightweight steel structures, 0.26%. With respect to the use types, reinforced concrete structures accounted for 97.48% in detached houses, 99.97% in apartments, 94.33% in public offices, 100% in commercial buildings, 97.16% in educational or research buildings, and 83.64% in community facilities. Since the reinforced concrete structure has the highest proportion, this structure was selected as the major structural type.

2.2. Representative materials

In most conventional studies related to the estimation of embodied energy or carbon, researchers did not deal with the total construction materials adopted, but limited their work to several materials. To choose the materials of study, researchers generally considered that the materials that were used in large quantities were the cause of large emissions, or determined certain