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An LCA-based environmental impact assessment model for construction processes

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ABSTRACT

A quantitative assessment of the environmental impact of construction activities can help decision-makers identify major environmental impact factors and make environmentally friendly construction plans in the early stages of construction. This paper presents an integrated life cycle environmental impact assessment model that is applicable to construction phase studies, where impact factors are examined according to two aspects of a typical construction process: construction equipment and ancillary materials. Environmental impacts are categorized into three safeguard subjects: ecosystems, natural resources and human health. A disability adjusted life year (DALY) model for assessing human health damage due to construction dust is developed. In addition, the environmental impact of earthwork construction is assessed as a case study to demonstrate the application of the proposed model. Results indicate that the proposed model can effectively quantify the environmental impacts of construction processes, and can potentially be used as a tool for contractors to select environmentally friendly construction plans.

1. Introduction

Construction is not an environmentally friendly process by nature. A recent study [1] shows that construction is the third largest industry sector in terms of contributions to greenhouse gas emissions in the United States. Construction-related environmental pollution has been increasing in China because of the country's fast-paced urban development since the early 1980s. Compared to the operation phase of a building facility, Yang [2] suggests that the environmental impact of the construction phase is much less. Others argue that this subject is not well studied and that quantifying such impact is necessary to remedy this [3]. In addition, the impact of the construction phase may be more intensive because the construction duration of a building facility is usually much shorter than the operational life span of the facility. Given that there are a massive number of ongoing construction projects every year in China, the cumulative environmental impact from the projects becomes a serious problem that can cause significant damage, not only to ecosystems but also to the health and well-being of field workers and nearby residents of those projects. For example, to improve the air quality of Beijing during the 2008 Summer Olympic Games, the organization committee had to impose a ban on construction activities before and during the Games to control construction dust.

With the rising demand from policymakers to achieve a sustainable society in China, there has been an increasing interest in the sustainability of buildings. Therefore, the environmental impact of buildings and construction has become an important and relevant issue. Presently, several models and systems for assessing environmental impacts of buildings have been developed in China. However, most of the models, such as the Evaluation System for Eco-buildings in China (ESEB) [4] and the Green Olympic Buildings Assessment System (GOBAS) [5], are based on qualitative scoring methods. The scoring system is easy to use, but is sometimes subjective, which makes it difficult to provide in-depth and comparable results. In addition, they often serve as a post-construction evaluation tool for determining the acceptance of completed work, rather than as a pre-construction evaluation tool to support decision-making.

Thus, quantitative methods, such as life cycle assessment (LCA), are desirable. There are a few LCA tools available in China, among which the Building Environmental Performance Analysis System (BEPAS) is a premium system funded by the Ministry of Construction of China [6]. At present, the BEPAS only analyzes the environmental impact of the manufacturing and building operating phases. Construction processes are not yet taken into account.

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Therefore, BEPAS cannot be used directly to analyze the environmental impact of the construction phase [2].

This paper discusses the development of an environmental impact assessment (EIA) model for construction processes based on LCA principles. The model is intended to serve as an assessment tool to support contractors and other decision-makers in identifying major environmental impact factors, as well as optimizing construction plans during pre-construction to promote green construction. A case study, earthwork construction, is applied to demonstrate how the model works.

2. Work breakdown and scope definition

2.1. Work breakdown

A typical construction process involves the use of various construction equipment and natural resources and generates many pollutants. To ensure that a variety of important environmental factors are identified and considered in the EIA of a construction process, it is necessary to break down the construction process systematically into smaller unit processes, allowing the application of the LCA methodology. From a systems perspective, a complex construction process can be viewed as an assembly of dynamic and interdependent work items, such as earthwork, foundation, concrete, masonry, metals and finishes. Each work item can be further broken down into an ordered set of unit processes with spatial, temporal and technical requirements that are specified in the construction plans. In general, at the unit process level, specific equipment and materials required by and emissions generated from a particular unit process can be clearly identified. Such a breakdown meets the requirements for inventory analysis and provides a basis for further assessment. In this paper, a construction unit process is defined as a basic EIA unit, and its duration is the complete life span of the unit process. In this way, it is feasible to apply LCA methodology to the environmental impact assessment of a construction process.

Based on environmental impact factors, such as CO_2, NO_x and construction waste, which are identified at the unit process level, environmental profiles at the work item level can be obtained by aggregating data of the same environmental impact factors across different unit processes. Similarly, the environmental profiles at the project level can be derived. Finally, according to the three-step impact analysis procedure of a typical LCA framework, i.e., classification, characterization and valuation, the environmental impact of a construction process at the unit process level, work item level and project level can be assessed.

2.2. Scope definition

The purpose of scope definition is to provide a specific boundary of the environmental impact considerations. As mentioned above, the model is intended to provide contractors with a reference for selecting environmentally friendly construction plans. Thus, the boundary of the environmental impact considerations in relation to construction processes should be limited to the scope that is executed by contractors.

The environmental impact considerations are related to the procurement method of a project because the scope of a contractor may vary depending on different procurement methods. So far, the traditional design-bid-build procurement method is still very common in the Chinese construction industry, although some alternate procurement methods, such as design-build, have emerged [7]. In design-bid-build projects, there is a clear division of responsibilities between the designer and the contractor. As shown in Fig. 1, the designer's responsibilities are to translate and develop the owner's specifications and prepare the design documents accordingly. Once the design of a building is completed, the major types of building materials are well defined in design documents. Thus, it is the designer, rather than the contractor, who should be responsible for the environmental impact of the manufacturing processes of those materials. The contractor, on the other hand, does not enter the process until a design is completed. The contractor usually prepares a pre-construction plan of a project, which specifies construction methods. Often, the construction methods involve equipment and ancillary materials that can potentially impact the environment. Because this study is focused on construction processes, the environmental impact assessment model for construction processes is limited to the analysis of construction equipment and ancillary materials.

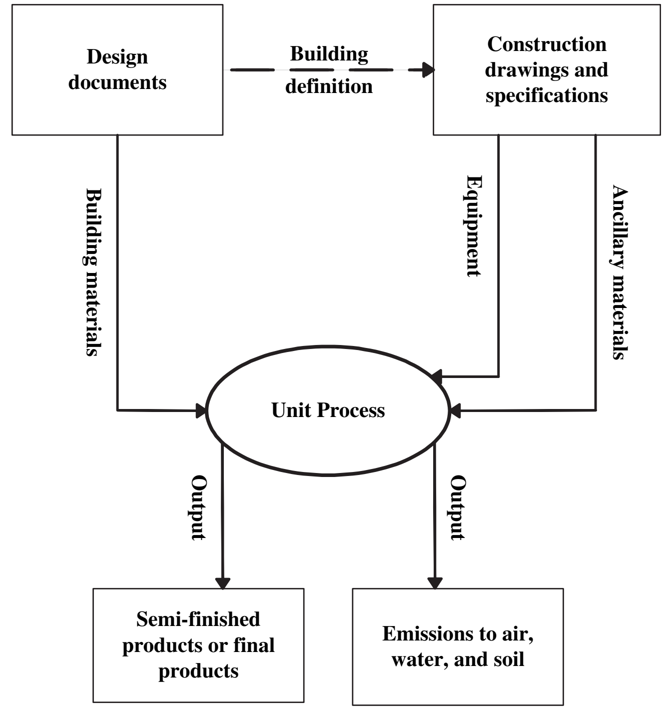

Fig. 1. The scope of EIA of construction processes.

2.2.1. Construction equipment

Many construction processes involve the use of construction equipment, e.g., rollers, scrapers and excavators for earthwork, cranes for material hoist, and hammers for pile driving. To a certain extent, environmental impact in relation to a construction phase is the result of equipment operations, which usually consume electricity and/or diesel fuel. Consequently, a great number of pollutants are generated, and a large volume of natural resources are consumed in the production of electricity and petroleum. Thus, the environmental impact of equipment operation is indirectly determined by energy consumption.

Yang [2] has developed a database that supports the analysis of the environmental impact of various types of energy production. In the database, basic environmental profiles of production per unit of electricity and diesel fuel are available. The average consumption of energy per unit time and the equipment running time for a particular unit process can be obtained by specifying the relevant equipment or field investigations. Multiplying the average energy consumption per unit of time by the running time of equipment, the electricity or fuel consumption by the equipment can be obtained. Then, the total consumption can be determined by