Assessment of building environmental impacts for sustainable development

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ABSTRACT
As a main wealth of human beings, buildings impact environment significantly and thus take crucial responsibility in global sustainable development. So we must diminish the building environmental impact when we construct a benign living and working environment, in which building environmental impacts assessment occupies a crucial position. This paper gives a brief overview of the existing environmental impacts assessment methodologies for buildings and the tools that support them in advanced countries, especially the crucial issues of life cycle assessment method which are employed for buildings and their services systems, the discrepancies compared with general environmental impacts assessment, and the problems still persisting in existing methodologies. Finally, several advices about China's building environmental impacts assessment are put forward, which will lead to great improvement for building sustainable development.

INDEX TERMS
Sustainable development; Green building; Life cycle assessment; Environmental impacts

INTRODUCTION

Buildings alter the environment significantly. Building construction consumes 40% of the raw stone, gravel and sand used globally each year, and 25% of the virgin wood. Buildings also account for 40% of the energy and 16% of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage (Roodman and Lenssen, 1995). All of the above show that buildings should shoulder a significant responsibility in global sustainable development.

According the definition of sustainable development, the core aspect of building sustainable development is to diminish the building environmental impacts and natural resources depletion when we construct a benign living and working environment. Namely, it is a strong desire for building sustainable development to take account of building environmental performance throughout the buildings' life cycle and combine building environmental performance with buildings technology and economy demand simultaneously, in which BEIA (Building Environmental Impacts Assessment) occupies a crucial position.

BEIA AND LIFE CYCLE ASSESSMENT

The building environmental impacts include all kinds of physical and chemical interactions between buildings and environment throughout the buildings' life cycle, which is generally divided into resource extraction, manufacturing, on-site construction, occupancy, maintenance,

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demolition, recycling/reuse and disposal stages. There are numerous environmental impacts brought by buildings and building systems, and some of them are familiar to the public, such as global warming, ozone depletion, acid rain, indoor air pollution, noise, light pollution, etc.

Buildings and building systems commonly have long lifetimes, so they are ideally sited to the Life Cycle Assessment (LCA) method. Only by considering resource flows at each stage in a building's lifecycle is it possible to obtain an accurate perspective on the environmental impacts. Frequently the repair and running costs of building are the single highest category of impacts, however, the impacts associated with creating new building materials and transportation of building materials can also be especially significant. Presently, the LCA method is employed in several building materials environmental impacts assessments successfully (Chevalier, 1996; Jonsson *et al.*, 1997; Harris, 1999).

The BEIA process begins with a definition of the total building life cycle, which entails the sequence of all events and activities in the life of the building from site selection through construction and operation to ultimate demolition. The environmental impacts of the building and all components can be assessed in terms of the changes that occur in the environment as a result of this total sequence of activities. Included in this is an understanding of the environmental changes occurring as a result of materials or things being taken from and returned to the environment.

THE CRUCIAL ISSUES OF BEIA

Categorization of Building Environmental Impacts

An LCA starts with a systematic inventory of all emissions and the resource consumption during building's entire life cycle. The result of this inventory is a list of emissions, consumed resources and non-material impacts like land use. This table is termed the inventory result. Since usually inventory tables are very long and hard to interpret, it is common practice to sort the impacts by the impact category according certainly principles. Up to now, although there are substantive studies about environmental impacts, some impacts' effect mechanisms are still unambiguous, and there are amount of interactions among several impacts too, then, it will achieve a better effect if we employed a suitable categorization principle.

There are two categorization principles about environmental impacts: bottom-up approach and top-down approach. This way of thinking, starting with the inventory result, and then trying to interpret this is sometimes referred to as the bottom-up approach. The top-down approach starts by defining the required result of the assessment. This involves the definition of the term 'environment' and the way different environmental problems are to be weighted.

The weighting of environmental problems is usually seen as the most controversial and difficult step in an assessment, as it is usually very difficult to give meaningful values to environmental problems. With this in mind, the top-down approach is designed around the weighting procedure. The rest of the procedure is set up to accommodate the best weighting procedure.

The starting point has some important consequences for environmental assessment. For instance the environmental problems in top-down approach are defined at their endpoint level, in terms of damages to human health, ecosystem quality and resources generally. Definitions at this level are much easier to comprehend than the rather abstract definitions of greenhouse effect and acidification in bottom-up approach. As a consequence, the definition of the impact categories in the top-down approach is no longer a free choice, as is the case in the bottom-up approach. This means additional requirements have to be fulfilled in top-down approach by the modelling of effects. In the bottom-up approach, the modelling of impact categories is certainly simpler, but the weighting problem is virtually impossible to solve.

Integration of Building Environmental Impacts

After the categorization of building environmental impacts, for the building environmental impact categories having various units, the impact of a building is still unambiguously interpreted. To solve this problem an integration of building environmental impacts, followed by a weighting step, is desired (Soebarto, 2001).

There are basically two methods to determine weights in society: (1) Observation of actual behaviour. It is often referred to as revealed preference method. The core of this method is to analyse how decisions on comparable issues are taken. (2) Questioning representatives of society (a panel) on the specific issue. This method contained a ranking and a weighting procedure.

It is often hard to isolate and interpret the basic values that are underlying the decisions of society. Very often the decisions made are complex and in very few cases a single issue is at stake. For instance, policy targets set by governments are often a compromise between the need to reduce loads and the preparedness to make the necessary sacrifices. In other words, an estimate of the total expenditure society makes for broadly defined issues, such as protecting human health, ecosystem quality and resources will be very difficult to make. That all of the above make use of revealed preference is not prevailing in BEIA (Goedkoop *et al.*, 2000).

It is clearly not easy to get relevant information from a panel too. The basic questions on the importance of impact categorizes are abstract. Many ordinary citizens will not be able to understand these questions, let alone answer them. The exact phrasing of questions is very important, as they can influence the perception of the questions. The number of weights is also a crucial factor. It is clear that assigning too many weights at the same time can give serious cognitive stress for those who are asked to give such weights.

Uncertainty of BEIA

In the assessment of building environmental impacts, there are several types of uncertainty to be considered, namely fundamental uncertainty and operational uncertainty. The fundamental uncertainty is the reflection of the doubt on the correctness of choices made in the development of the BEIA methodology. The choice of a concept implies that the assumptions that are the basis of this concept are fixed. This uncertainty cannot be quantified in an easy way. Operational uncertainty is the variation in the result of the calculations, caused by the variation of the parameters involved. This uncertainty can be quantified (Hofstetter, 1998).

In some BEIA with employed top-down approach, a third type of uncertainty must be added. This is the uncertainty whether the model includes all important damages that fall under the definition. It is found that some impact categories that are probably relevant, but for these an adequate damage model or sufficient data may not be found. Also within some impact categories it has been found that there are more damage types than we are able to describe. For instance, in climate change we can only model a limited set of all the health problems that can probably be related to this impact category.

This means there are three fundamentally different types of uncertainty in BEIA: (1) data, or Operational uncertainty, which deals with technical uncertainties in the data. Such uncertainties are relatively simple to document by adding the information on the statistical distribution (e.g. standard deviation). (2) Fundamental, or model uncertainties are caused by unavoidable ethical and thus value-based choices. Adding a standard deviation or a range on the calculated figures cannot cover this type of uncertainty. (3) Uncertainty on the completeness cannot be documented at all, except for providing a specification of possibly important, but not included damages.

SPECIALTIES OF BEIA

Compared with general environmental impact assessment, there are some obvious specialties with BEIA due of the characters of buildings.

Numerous impacts: Throughout buildings' life cycle, there are numerous environmental impacts, which include almost all kind of environmental impacts existing in the earth. It is a desire to introduce the concept of systems engineering into BEIA, which consider not only chemical but also physical environmental impacts in difference phases of the building as design, construction, operation and demolition.

Great difficulty and hardships: Generally speaking, the number of people influenced by a common environmental impact is limited to a certain area, which leads to a simple and convenient assessment. On the contrary, in modern society the building environmental impacts influence those people who are still alive everyday. It brings great difficulty and hardships to BEIA.

Significant uncertainty: The longevities of buildings are often more than 50–100 years, and the disparity of longevity among buildings frequently are significant too. For instance, some buildings have persisted in this world for several hundred years, but a few of buildings only existed one decade or even shorter. This status always brings a great uncertainty to BEIA.

Closely related with humans: In modern society, the average time spent in a room by humans is more than 80%, and this ratio is still increasing with the progress of modernization. Some building environmental impacts, such as indoor air pollution, noise, etc., are related with humans living closely and have a strong influence on human health.

Differences among regions: The energy consumed in building operation occupies a crucial position in BEIA. Because of diverse climates, the energy consumed by unit building area during operation is distinct sharply. Then, a main content of BEIA is to calculate the building operation energy, which requires a great demand in building simulation.

PROBLEMS IN EXISTING METHODOLOGIES

BEIA originated at the end of the 20th century, and has made rapid development in the past decade. Up to now, there are a series of BEIA methodologies that have been developed by a number of countries and areas, in which some methodologies, such as BREEAM (Baldwin *et al.*, 1993), GBTool (Zimmerman, 2000) and LEED (U.S. Green Building Council, 2001) are employed widely.

After more than 10 years of development, environmental impacts assessment methodologies for buildings, and the tools that support them, are evolving rapidly, but are not yet fully mature and robust. Compared with the desire of building sustainable development, these methodologies still have such obvious shortcomings:

Without a uniform standard: There is no uniform assessment standard presently. The assessment items, benchmarks and weights included by various BEIA methodologies are significantly different. These methodologies pertain to those located only in one country or area. With the acceleration of globalization, the cooperation among countries is enhanced, and a uniform standard for BEIA needs to be established.

Lack of a comprehensive database: The LCA of building for sustainable development lacks a comprehensive database, which contains all costs and performances of building during its life cycle. Due to various reasons, especial in construction industry, which is complicated and congested with competition, sometimes even with hostility, the realization of such database is too difficult, and those judgments or decisions based on these databases will probably be erroneous.

No suitable optimization method: Another function of BEIA is to optimize the buildings in its design stage with alternative design schemes. The optimization methods applied in existing methodologies all are enumeration, which cannot optimize the design automatically and globally, so the effect of existing BEIA methodologies will be hurt to a certain degree.

No combination with economy: Due to various reasons, there is no combination with building economic performance in BEIA methodologies presently. As a market-oriented society, no designer or owner can ignore the economic benefit of a building, and this defect will hinder the application of existing BEIA methodologies strongly.

CONCLUSION

The assessment of building environmental impact is a key content of building sustainable development. Compared with the desire of building sustainable development, existing BEIA methodologies still have serious shortcomings. Then, starting from the desire of sustainable development, combining building environmental and economic performance, establishing a uniform assessment standard and database, and improving the practicability of methodology continuously, must be the direction of the BEIA methodologies improvement and this will give a strongly support to building sustainable development.

China is a great nation and a developing country, and its desire of building is extraordinarily strong. Due to various reasons, the research on building environmental impact in China is still poor, and results in a poor building environmental performance compared with developed countries. Such researches, which combine building environment and economic performance will show more significance in China. As building occupies a critical position in sustainable development, with the realization of building sustainable development, the speed of sustainable development of China will be accelerated.

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