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Lifecycle assessment for sustainable design options of a commercial building in Shanghai

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ABSTRACT

Buildings are long-lasting products which have huge impacts on the environment during their whole lives. The design of buildings should take into consideration long-term environmental and economic benefits. A life cycle assessment approach is developed and demonstrated in a case study—the strategic design of a Flagship Store in Shanghai. Industrial practitioners were invited to the feasibility study. Their opinions were included in the life cycle assessment for the first time. The economic analysis takes account of not only the capital costs of the design options but also the running costs during the building's economic life cycle. The methodology adopted is an integrated life cycle assessment process including life cycle costing, multi-criteria decision making and group decision making methods. The workshops are successful in terms of educational opportunity for the practitioners and have obtained good feedbacks. The top 10 sustainable design options after the life cycle assessment process were chosen by the practitioners as the compulsory design strategies in their global environmental development agenda, whilst the other 32 design options as optional design solution for the international retailer's future stores. The life cycle assessment tool demonstrated by a case study was proven to be a simple and efficient design tool in practice, and therefore it can be adopted in other projects to assist the decision makers.

1. Introduction

There are about 40 billion m^2 of buildings in China and this figure will reach 70 billion in 2020 [1]. The construction industry has a significant impact on the environment. The energy consumption relating to buildings, such as building construction and operation, in China accounts for almost 50% of the total energy each year [1]. There are about 650 million tonnes of wastes produced by the construction industry in China every year [2]. Design for sustainable buildings is an urgent task for the construction industry in China.

Sustainable building design reduces the influences of man-made buildings to the environment during the buildings' whole lives. It is vital for the investors to take into consideration the environmental influences of a building through its whole life, that is, from the initial construction process to the future operation stage of the building.

There are various sustainability assessment toolkits being implemented in different countries. The BRE Environmental Assessment Method (BREEAM) system is an integrated sustainability assessment tool used in the UK. This tool covers waste, water and energy, as well as transport, pollution, community engagement, the health and wellbeing of building occupants, the choice of material, enhancing biodiversity and building management. The BREEAM series can assess several types of buildings' design, including BREEAM Courts, Healthcare, Industrial, International, Multi-residential, Prison, Offices, Retail, Education, Communities and Bespoke. The other sustainability assessment tool for buildings is The Code for Sustainable Homes [3] to be used in residential building designs in the UK covers the following areas:

1. Energy efficiency/CO_2.
2. Water efficiency.
3. Surface water management.
4. Site waste management.
5. Household waste management.
6. Use of materials.
7. Lifetime homes (applies to Code Level 6 only).

Another well known sustainability assessment tool is Leadership in Energy & Environmental Design [4] used mainly in the US. It covers new construction, existing buildings, commercial interiors,

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core and shell, schools, retail, healthcare, homes, and neighbourhood development. The checklist scoring system includes the following main aspects:

1. Sustainable sites.
2. Water efficiency.
3. Energy and atmosphere.
4. Material and resources.
5. Indoor environmental quality.
6. Innovation and design process.

The Waste and Resources Action Programme (WRAP) recycle content toolkit is designed by the WRAP [5] in order to increase the amount of recycled content incorporated into buildings. It includes some 3000 building components' recycle content that estimates for new build and existing buildings.

In the IPCC fourth assessment report Metz [6] suggested key mitigation technologies and practices by seven sectors.

1. Energy supply—improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power.
2. Transport—more fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; bio fuels; modal shifts from road transport to rail and public transport systems; non-motorised transport; land-use and transport panning.
3. Buildings—efficient lighting and day lighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of flu orientated gases.
4. Industry—more efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions and a wide array of process-specific technologies.
5. Agriculture—improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.
6. Forestry—forestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use.
7. Waste—landfill methane recovery; waste incineration with energy recovery composting of organic waste controlled waste water treatment; recycling and waste minimisation.

Other resources for generating sustainable design solutions include BRC [7], Constructing Excellence [8], SEEDA [9], The Carbon Trust [10], UK Government Office of Government Commerce [11].

There are an enormous number of literature and sustainable design tools providing numerous sustainable design options for designers to choose; however not all of them can be implemented in practice. In the current industrial environment, the application of sustainable design solutions in a project is limited by the affordability and risks the investors willing to take in practice. The opinions of the practitioners are crucial to the final decision. Therefore a feasibility study on the design options should be included in the decision making process. Workshop is the most direct and effective way to educate the practitioners by how much their project can benefit the environment by choosing the right design options. Meanwhile, their industrial experiences can provide us with the best feasibility evaluation on the sustainable design options.

The existing sustainable design tools are designed for the general guidance of building design. These sustainable design tools for buildings mostly focus on the environmental impact of the buildings and the capital cost of the design options. However the life cycle costs and the practitioners' opinion have been neglected, even they are just as equally important as the environmental impact. Buildings are long-lasting products; the design of buildings should practically reduce the life cycle costs and improve the sustainability of the buildings.

Life cycle assessment is the best tool to combine both the long-term environmental and the economical evaluations of building designs. Tukker [12] claimed that life cycle assessment is a generic environmental evaluation framework. It should be pointed out that life cycle assessment also includes economic and risk evaluations in analysis. The key economic analysis is life cycle costing, which is a technique to estimate the overall costs of design options during the economic life of the building. In order to compare the long-term economic performance of the design options, life cycle costing should be included in strategic designs because the economic concerns drives the decision makers may be sometimes more than the other concerns. There are many cost models that have been developed to estimate life cycle costs such as NHS hospital buildings [13], running cost for building element [14], and noise barrier wall selection [15].

As a powerful environmental assessment tool, life cycle assessment has been widely used in many areas such as solar PV system [16], municipal solid waste management system [17] and chemicals [18].

The advantages and disadvantages of those sustainable design tools are listed in Table 1. The life cycle assessment tool can evaluate unlimited sustainable design options and also include the

Table 1
The advantages and disadvantages of some main sustainable assessment tools.

Assessment tools	Advantages	Disadvantages
BREEAM	Covers a wide range of design aspects	Serves the UK public non-commercial buildings. Limited sustainable design options
Code for sustainable homes	Higher standard requirements on energy efficiency. Request zero carbon for new houses on level 6	Limits to residential projects only. Limited sustainable design options
LEEDs	Covers various types of buildings	Exclude waste management. Limited sustainable design options
WRAP recycle content tool	Building breaking down into components in order to select the high recycle content building materials for projects. Suitable for all types of buildings	Focuses on only the recycle content aspect of sustainable design. Limited sustainable design options
IPCC	Includes new considerations such as industry, agriculture and forestry, etc.	Just a general guidance for sustainable design. Limited sustainable design options
Life cycle assessment tool	Combines the long-term environmental and the economical evaluations. It can include as many design criteria and options as required into assessment process	Requests a range of expertise and time consuming.