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A BIM-integrated Fuzzy Multi-criteria Decision Making Model for Selecting Low-carbon Building Measures

L. Chen[a],* and W. Pan[a]

[a]*Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong*

Abstract

Low-carbon building (LCB) has been regarded as an innovative and practical approach to reducing building carbon emissions. The design decision-making for LCBs should consider various criteria which however are often associated with uncertain information. Little research has examined multi-criteria decision making (MCDM) in selecting LCB measures, particularly in high-density subtropical urban environments. That selection process is inhibited by the lack of consensus on assessing the performance of LCB options and of an efficient decision support system. The aim of this paper is to develop a BIM-integrated fuzzy MCDM model for selecting LCB measures. The paper identifies the key criteria and alternatives to systematically assess LCB measures. Five criteria and nine alternatives were identified within the context of high-rise commercial buildings in Hong Kong, which are centralized on technical, economic and environmental aspects of building performance. With the use of BIM and eQUEST, a MCDM model based on Fuzzy PROMETHEE is developed. The developed model is validated utilizing a real project case in Hong Kong. The results will provide design decision-makers with a consolidated tool for selecting LCB measures.

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Keywords: Low-carbon building measures; Building information modeling; Fuzzy PROMETHEE; Decision-making.

1. Introduction

Recently, there has been a transition towards a low carbon built environment and increasing attention to the use of low carbon technologies [1,2]. The construction industry is a key sector expected to support achieving carbon

* Corresponding author. Tel.: +852-6255-2664.
E-mail address: dragoncl@hku.hk

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emission reductions, as 33% of greenhouse gas (GHG) emissions, 40% of energy consumption and 36% of energy related carbon emissions are concerned with buildings [3]. Also, GHG discharged from buildings in cities is even more serious due to high urban density [1]. For instance, in high-density subtropical urban environments of Hong Kong, buildings' contributions to electricity consumption and GHG emissions are around 90% and 60% respectively [4].

Acknowledging that the rapid development of the construction industry has caused essential impacts on the environment, stakeholders involved have been striving to achieve LCBs within the budget. Thus the approach of LCB has been prompted in many countries and regions. However, the take-up of LCB measures in general is still low, and the full benefits of LCB measures are not realized in many practices. A risk-averse culture often appears in the construction industry and decision-makers trend to reduce financial risks associated with making an early commitment to using innovative LCB measures or technologies. However, an arguably more essential cause is the inability of decision-makers to compare many conflicting building performance factors and achieve trade-offs among multiple decision criteria, which are attributed to a lack of consensus on criteria for assessing the performance of building design options and a paucity of systematic tools to support LCB decision making.

This paper aims to address this knowledge gap by developing a BIM-integrated fuzzy MCDM model for selecting LCB measures. Building information modeling (BIM) was adopted into this research to improve interoperability in the construction industry [5], and aid seamless data exchange and sharing at the software level among diverse applications in the LCB delivery process. LCB measures in this paper encompass all LCB technologies, products and systems, with a focus on applied innovative ones. A digital systematic assessment approach was advocated for value-based comparison among different LCB measures, rather than evaluation ending up as a cost-comparison exercise [6]. A newly method based on fuzzy logic and the PROMETHEE method was adopted, which requires less and straightforward information from customers and makes fuller use of information input to be more objective and efficient to apply [7,8]. The research was carried out with commercial buildings in Hong Kong. As the EMSD [4] reported, commercial buildings account for 65% of the overall energy consumption in Hong Kong, having more possibilities to adopt LCB measures for improving building energy performance due to their straightforward energy using pattern [9] and commercial returns. This paper develops a model of BIM-integrated decision making model using BIM, eQUEST and MCDM applets. The model is then validated utilizing a real-life case of low carbon commercial building in Hong Kong. The implications of the results are discussed, which leads to discussions and conclusions about LCB measures selection.

2. Literature review

2.1. LCB measures

LCB measures are current primary approaches adopted to improve buildings' energy performance and reduce buildings' carbon emissions. The delivery process of LCBs can be simplified into three phases, namely planning, designing, and managing and retrofitting [3]. Previous research has identified and categorized LCB measures. For example, Tymkow et al. [10] divided LCB measures into four groups, including passive design, active design, supply energy efficiency and renewable energy. Heating and cooling demand reduction technologies and renewable energy technologies were also mentioned by Ma et al. [11]. Energy-efficient lighting was added into LCB measures by Malatji et al. [12]. Based on the framework of Malatji et al. and Zhang et al. [3,12], 26 LCB measures in five groups were identified for commercial buildings in Hong Kong as an example of hot and humid subtropical climate.

2.2. The PROMETHEE and Fuzzy PROMETHEE

The PROMETHEE is a type of MCDM outranking methods developed in the 1980s by Brans and others [15]. It is applied to rank a set of alternatives by considering a set of criteria. There are 6 different types of preference functions. The alternatives are ordered based on the size of their net flows. Considering the underlying structure for MCDM problems, the consideration of fuzzy logic combined with MCDM seems to be nearly self-evident [16]. Fuzzy set theory, first developed by Zadeh [13], was used to solve problems with subjective, vague and imprecise information. Literature review reveals that several attempts to integrate fuzzy logic with MCDM are being discussed