



A multidimensional model for green building assessment: A case study of a highest-rated project in Chongqing



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ABSTRACT

Green building is an inevitable trend in the construction industry which deeply affects the social development of the economy, environment and a series of industries. There is practical significance for the multidimensionally balanced development of green buildings. A model for multi-objective assessment of green building is developed under three dimensions: Objective, Professional and Time (OPT) according to the green building definition. The OPT coordinate system was built up based on the scoring centroid system of both the China Green Building Labelling scheme (GBL) and the Singapore Green Mark (GM) by the introduction of the Coefficient of Variation and Moment of Inertia. Both these frameworks are restructured based on a case study of a practical project in Chongqing which had achieved the highest GBL and GM awards. Results show that GBL distributes its scores more evenly while GM concentrates on energy saving with greater diversity in land supply and building operations (normalized coefficients of variation of 0.435 and 0.350). The project's compliance coefficients are 1.27 and 0.31 under GBL and GM respectively indicating its higher degree of compliance with the GM framework. The developed model provides multitarget-oriented guidelines for green building design, assessment and standard development.

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1. Introduction

Green building has become a critical measure for climate change and sustainable development and has taken responsibility for the long-term balance of economic, environmental and social health [1]. The history of green building design dates back to the late 1980s when sustainability was defined by the United Nations' World Commission on Environment and Development [2]. In the past 50 years, the concept of green building has gradually been established after intensive research and practice [3–6]. The most widely accepted definition of green building is to provide people with healthy, applicable, efficient space and natural harmonious architecture with the maximum savings on resources (energy, land, water, materials), protection for the environment and reduced pollution throughout its whole lifecycle [7–12]. The definition indicates the target requirements for green building objectives, professional skills and time. Many countries have paid great attention to the healthy

development of green building [13]. A range of green building rating systems, protocols, guidelines and standards have been developed in the past 20 years [14,15] and around 600 methods of assessment exist today [16] including Building Research Establishment Environmental Assessment Method (BREEAM) in the U.K, Leadership in Energy and Environmental Design (LEED) in the U.S, the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan, the Green Building Tool (GB-Tool) in Canada, Green Star in Australia, Green Mark (GM) in Singapore, the Hong Kong Building Environmental Assessment Method (HK-BEAM) in Hong Kong, EcoProfile in Norway, Environmental Status in Sweden and the Green Building Labelling scheme (GBL) in China. However, there is no consensus on the best evaluation standard for green building assessment tools [17] as the individual evaluation systems are based on their own regional conditions and characteristics with separate scoring systems. So a lot of related research has been done based on the application and improvement of the various green building standards.

However, most studies aimed at the development of specific standards. Azhar [18] explored the implementation of Building Information Modelling (BIM) technology to help the LEED certification process while Cheng and Ma [19] studied the relationship

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between LEED credits in order to simultaneously achieve multiple credits using one type of green building technology. On the technical aspects, Alshamrani [20] explored the possibility of integrating lifecycle assessment (LCA) techniques to achieve higher sustainability levels.

Green building standards have also been widely applied in architectural design. Castro-Lacouture [21] developed an optimization method for the selection of construction materials. Wang [22] developed an object-oriented framework that tackles specific problem areas related to green building design optimization. A methodology was developed to optimize the building shapes using genetic algorithms by the introduction of lifecycle investment and lifecycle environmental impact as two objective functions for green performance evaluation. Schiavon and Altomonte [23] studied the indirect influential factors, such as office type and building size, in the achievement of indoor environment quality (IEQ).

More and more theoretical models involving all building aspects have been developed. Günaydin and Doğan [24] developed a neural network model for 30 residential building projects to estimate cost per unit area. Kim [25] used three different prediction models: neural network, regression analysis and case-based reasoning, to predict the cost of 530 local buildings in Korea. Emsley [26] developed an ANN model to predict building cost by utilizing a project's strategic, site-related and design-related variables.

Green building adoptions have been largely explored. Reith et al. [27] compared five assessment systems including CASBEE-UD, the 2009 and 2012 versions of the BREEAM Communities, LEED-ND, and DGNB-UD and provide information about the similarities, differences, and working methods of the systems, and guidance in choosing a proper assessment system for a specific development. Kennedy et al. [28] developed an artificial neural network model (generic 7-6-4 neurons layered architecture) in predicting indices, based on certain social conditions, on the choice of certain low carbon technologies. Shin et al. [29] developed a method to assess the amount of carbon dioxide (CO₂) emitted during the production of construction materials, and arose a system for evaluating the environmental load of construction during architectural planning and basic design phases. Zhao et al. [30] analyzed the social problems of green buildings from the humanistic needs to social acceptance. Lee et al. [31] provide the green template focusing on an embodied environmental impact for lifecycle assessment of buildings based on building information modeling.

Meanwhile, researchers began to look into the limitations in the historical process of the green building development. Dean et al. [32] find that major real-estate developers of business parks around the world have made environmental responsibility a priority in building design, construction, and operation, so they promoted the EBOM model to help companies gauge the goal of environmental stewardship. Zhang et al. [33] find that there is lack of a systematic review of this large number of studies that is critical for the future endeavor. It is found that the existing studies mainly focus on the environmental aspect of green building while other dimensions of sustainability of green building, especially the social sustainability is largely overlooked. Their study also announced future research opportunities were identified such as the innovation of evaluation systems, integration of planning and design frameworks, management mechanisms and financing modes, and future proofing [33].

In conclusion, the current studies for green buildings mainly concentrate on energy efficiency, technical analysis, economic analysis, productivity, satisfaction, health and thermal comfort, but rarely involve the inner balanced evaluation [18–23]. This results in a phenomenon whereby projects are pursuing the final score as the only motivation rather than seeking to achieve a comprehensive green design. It is common that construction projects are driven by the purpose of increasing the rating scores during the green building assessment without investigation on the resource

effectiveness and environmental performance. Therefore, a holistic assessment system is desired to provide technical support for the judicious decision on the measures taken in order to achieve the green building assessment target.

The aim of this research is to develop a holistic method with a horizontal and vertical dimensional framework for the green building assessment. The method should be able to reflect the inner-relationship of dimensions in order to balance the Objective; Professional and Time dimensions (OPT) of the Green Building.

2. Research methodology

The research design has three aspects:

- (1) to investigate the specific characteristics and balance of the assessment criteria of the two Green Building Assessment methods through a case study. A real project in Chongqing is selected which has won the highest rate of both GBL and GM. The reasons of the choices of this project are: 1) the project attempted to achieve the highest level in both standards with implementations of a large number of green technologies. The application of the wide range of technologies will eliminate random errors of potential scoring difference due to the insufficient coverage of green technologies; and 2) different green building assessment methods have their own characteristics due to many factors such as policy, economic development, geographical environment, climate conditions, natural resources structures, technology availability and so on. The same building using different assessment methods could lead to different building design and performance. This real project has been awarded the highest ratings, namely a Platinum Award of the Singapore GM and a 3-Star Award of the China GBL, which offers an excellent opportunity for comparative studies in order to test their inner balance in OPT dimensions;
- (2) to analyse the score distribution of the OPT dimensions based on the green building definition as set out in the original targets; and
- (3) to develop a method of evaluating a green project's comprehensive compliance level with a specific green building standard.

2.1. Evaluation process of green building by GBL & GM

Evaluation of green building using GBL is divided into two phases, namely the design and operation phases. Operation stage evaluation is to be carried out one year after the building has begun to be used. The GM evaluation process is not divided into different phases and projects in the design stage can also apply for certification under a pre-assessment procedure. GM sets mandatory on-site examination requirements after project completion to ensure the implementation of the indicators and designs described in the pre-assessment process. The detailed assessment processes of GBL and GM are shown in Fig. 1.

A project applying for China GBL is required to have a self-assessment before delivering all the certificate materials and technical reports to the China Green Building Council. The China Green Building Council arranges the meeting for the project to examine the supporting documents. Building engineering experts will be invited to meet together with the project owners, the construction side, the designer and consultants, etc. A final score will be achieved and the project is required to supply extra materials after the meeting in response to the experts' questions. Projects applying for GM are also required to have self-assessment and complete the official forms of the Singapore Building and Construction Authority (BCA). A presentation has to be made to the expert committee and

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