A Review of Quantitative Approaches to Intelligent Building Assessment

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Abstract: This paper provides a review of the assessment methods of intelligent buildings (IBs). Based on a review of rating method currently used for building assessment, 6 rating systems for IB assessment are compared according to assessment clusters such as Architecture, Engineering, Environment, Economics, Management, and Sociology. The 6 IB rating systems include the AIIB method developed by the Asian Institute of Intelligent Buildings (AIIB), Hong Kong, China; the BRE method developed by the Building Research Establishment Ltd., UK; CABA method developed by the Continental Automated Building Association (CABA), Canada & USA; the IBSK method developed by the Intelligent Building Society of Korea (IBSK), Korea; the SCC method developed by the Shanghai Construction Council (SCC), China; and the TIBA method developed by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan, China. Although the AIIB method is identified as the most comprehensive assessment system, its four weaknesses are explained. The paper concludes that an innovative building approach using analytic network process will bring advantages to IB assessment.

Key words: Intelligent building; Assessment; Methodology; Review

1. INTRODUCTION

Sustainable building design, construction and operation require innovations in both engineering and management areas at all stages of a building's life. The lifespan of buildings is composed of a series of interlocking processes, starting from initial architectural and structural design, through to actual construction, and then to maintenance and control as well as to eventual demolition or renovation of buildings. Inside this lifespan, essential requirements are generated from considerations of social, environmental, and economic issues for high-efficient energy-saving building systems in compliance with building codes and regulations. In this regard, building assessment is becoming popular in order to have a standard method to evaluate new and existing building design. For example, the U.S. Green Building Council [1] developed the LEED (Leadership in Energy and Environmental Design) Green Building Rating System as a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. The Japan Sustainable Building Consortium [2] developed the CASBEE (comprehensive assessment system for building environmental efficiency) system as a new environmental assessment system to meet both the political requirements and market needs for achiving a sustainable society. The Building Research Establishment Ltd. [3] from UK developed the BREEAM (Building Research Establishment Environmental Assessment Method) to assess the environmental performance of both new and existing buildings. Meanwhile, intelligent buildings (IBs) are also under assessment according to their IB related characteristics and actual circumstances. For example, the Asian Institute of Intelligent Buildings (AIIB) [4] from Hong Kong developed an IB Index system to specifically assess the performance of IBs; and the BRE developed a matrix tool called MATOOL for assessing the performance of intelligent buildings [5]. Although a new international benchmark of IB assessment is under developing by the Continental Automated Building Association [6] in Canada, there is not a standard sustainable or green IB assessment tool, and this leads to the research being presented in this paper.

2 BUILDING ASSESSMENT METHODS

According to the latest literature [10], an IB is one that provides a productive and cost-effective environment through optimizations based on its three basic elements – people (owners; occupants; visitors etc.); products (materials; fabric; structure; facilities; equipments; services); and processes (automation; control; systems; maintenance; performance evaluation) – and the interrelationships between them. IBs use integrated and intelligent systems to provide a rewarding experience for the building owners, property managers, occupants and visitors to achieve their goals. These goals include the lifespan high energy efficiency, the environmental-friendly built environment with substantial safety, security, well-being and convenience, a lower life-cycle cost, and long-term flexibility and marketability, which lead to achieve a high-level of buildings that have the highest social, environmental and economic values. Meanwhile, IBs use advanced information and communication technologies to develop embedded data collection and information networks through which its services systems are automatically controlled to respond using an approach similar to the sensor system of human beings, guided by predictions based upon knowledge of the past situations of the building and usage, maintained in an integrated data base. Thus, IBs should be sustainable, healthy and technologically aware, meet the needs of occupants and business, and should be flexible and adaptable to deal with change.

Practitioners use assessment methods to evaluate the design or the performance of IBs. There are three main kinds of assessment methods including building rating, computer simulation and facilities management [10]. The rating method relies on a series of factors/indicators related to the design and the performance issues together with their defined scales to rate an IB. The simulation method uses artificially settings based on real-world data from the operation of IBs. The facilities management method use experts' knowledge to achieve goals in practical IB design, construction and operation. The applications of the first two kinds of assessment methods can be at either design or operation stage of any IB under evaluation, while the third method can be applied at all stages of the IB life cycle.

The authors are conducting an extensive literature review on conventional building assessment systems in order to grasp the progress of building rating method and develop innovative approach to IB assessment. Current building assessment systems under review include:

- Assessment Standards for Certifying Intelligent Buildings (ASCIB, by Intelligent Building Society of Korea (IBSK), Seoul, Korea) [3],
- Building Quality Assessment (BQA, by Building Economics Bureau, UK),
- Building Research Establishment Environmental Assessment Method (BREEAM, by Building Research Establishment Ltd. (BRE), UK) [3],
- Building Sustainability Assessment Tool (BSAT, by the Department of Trade and Industry, UK) [11],
- Building IQ Rating Criteria (BIQRC, by Task Force 1 - Intelligent Building Ranking System, Continental Automated Building Association (CABA), Ottawa, Canada) [6],
- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, by Japan Sustainable Building Consortium (JSBC), Japan) [2],
- Design Quality Indicator (DQI, by Construction Industry Council, UK),
- Environmental Performance Express of Buildings (Eco-Quantum, by IVAM, The Netherlands),

- Assessment Framework & Green Building Tool (GBTool, by the International Initiative for a Sustainable Built Environment (IISBE), Canada) [12],
- Green Mark for Buildings (GMB, by Building and Construction Authority, Singapore) [13],
- Hong Kong Building Environmental Assessment Method (HK-BEAM, by HK-BEAM Society, Hong Kong) [14],
- Intelligent Building Assessment (by Architecture and Building Research Institute, Ministry of the Interior, Taiwan, China) [7],
- IB Index (by Asian Institute of Intelligent Buildings (AIIB), Hong Kong, China) [4],
- IB Rating (by Shanghai Construction Council (SCC), Shanghai, China) [8],
- Leadership in Energy and Environmental Design/Green Building Rating System (LEED, by U.S. Green Building Council, USA) [1],
- A matrix tool for assessing the performance of intelligent buildings (MATOOL, by Building Research Establishment Ltd. (BRE), UK) [5],
- National Australian Built Environment Rating System (NABERS, by Department of the Environment and Heritage, Australia) [15],
- Office Scorer (Sustainable Refurbishment/Redevelopment Decision Support Tool for office buildings, Building Research Establishment Ltd. (BRE), UK) [18],
- Sustainable Project Appraisal Routine (SPeAR, by Arup, UK) [16], and
- Sustainability Checklist (Assessment of the social, environmental and economic impact of a proposed development, by the South East England Development Agency (SEEDA), UK) [17].

According to the literature review focusing on the building assessment systems, the authors noticed that there are several successful applications of rating methods for building performance assessment. For example, the LEED *Green Building Rating System*® is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings in the United States [1]. The *Environmental Assessment Method* by the Building Research Establishment Ltd. (BREEAM) is adaptable to assess the environmental performances of both new and existing buildings in the United Kingdom [3, 19]. The *Standard Assessment Procedure* (SAP) of the National Home Energy Rating (NHER) is the UK's premier energy labelling scheme recommends by the UK Government for home energy rating [20]. On the other hand, although simulation methods can provide more reliable results than rating methods using various conditions in the building lifespan based on objective and subjective settings in computer programmes; there is not a comprehensive simulation tool for practitioners to conduct IB assessment at present. On the contrary, popular simulation approaches mainly focus on only one part of building performance such as thermal environment or acoustic environment, and it is a difficult task to develop a tool for complete performance simulations of the total environment in buildings. In this regard, rating systems have been widely adopted in building performance assessments, and the simulation method is often adopted in building design.

Among these building assessment systems, there have been several rating methods designed for IB assessment, and there are some new rating systems under development as well. Table 1 gives a summary of representative methods based on current practice in IB assessment. According to the literature review, the authors identified six assessment clusters of indicators centring on Architecture, Engineering, Environment, Economics, Management, or Sociology. Among the five IB assessment systems listed in Table 1, the AIIB method, i.e. IB Index method [4] is the most comprehensive one that covers all of the seven assessment clusters, and the SCC method [8] is mostly focused on the one assessment cluster, i.e. Engineering. The CABA method [6] aims to benchmark the IB assessment in a more general way but is still under construction. And the BRE method, i.e. MATOOL [5] and the IBSK method [7] have less coverage of assessment clusters than the IB Index. Therefore, the AIIB method is currently the most comprehensive method for IB assessment.

3 THE LIMITATIONS OF BUILDING RATING METHOD

One problem of currently used building rating methods is that they actually pay less attention to functional variation in different types of buildings, which influence not only the emotional as well as the physical well-being of human beings, but also the design and the management of buildings. In other words, each assessment procedure conducted under each rating method actually uses a generic platform of indicators applied to all kinds of buildings therefore do not differentiate one building from another regarding their various features. As a consequence, assessment results of different kinds of buildings actually lack the power of comparability regarding the features of IBs. For example, AIIB method adopts 29 sub-indicators to assess the performance of lift and escalators [4]; however, there is not a practical guide regarding how to compare two designs for one IB project if one uses a lift but another does not. In fact, it is not sensible to say buildings with a lift are more intelligent than buildings without them but a common generic platform will ensure all buildings have consideration given to aesthetics, function, convenience, flexibility, adaptability, reliability and health. In addition, the IBSK method [7] uses occupation density (occupation area for one person) as one indicator to assess *Architectural Design* of IBs, and the building with larger occupation area (a low occupation density) will get a higher score; however, one cannot say easily that a supermarket is much more intelligent than an office building because occupation area in supermarket is larger than that in an office building. In fact, buildings are classed according to their patterns of use at the design stage or management stage. For example, *The Town and Country Planning (Use Classes) Order* [21] regulates building class into four main categories with 16 classes depending on the purposes of building utilization in town and country planning and has been widely adopted in building design in the UK [4]. *The NYC Building Classification Codes* [22], on the other hand, provides a complete, comprehensive list of each Building Classification Code, and has been officially used to classify all properties and parcels from private homes to amusement parks by the City of New York. The lack of flexibility in current rating methods for IB assessment and the preference of classification in building design, construction and management indicate that innovations are required to develop flexible techniques for more objective assessment results of IBs.

Another problem of current building rating methods for IB assessment is that their calculation processes are not convincing enough to provide a reasonable assessment result. For example, the AIIB method, i.e. IB Index [4] aims to provide a quantitative composite approach to IB assessment using 10 indicator clusters based on the Cobb-Douglas utility function [23]. However, the recommended method for the IB Index calculation (see Equation 1 and 2 in Equations in Appendix) is not actually reliable due to the following four reasons:

- the criteria of the AIIB method lead to non-determinism,
- the calculation method of the AIIB method is a non-sequitur,
- the calculation results from the AIIB method are non-unique, and
- the assessment procedure is based on non-organization principle/judgment.

Brief explanations to these reasons are given below: The non-determinism led by the criteria of the AIIB method means that the assessment scores for each IB result from the evaluation criteria has questionable validity. As assessment results from each rating method depend upon a set of criteria denoted with a group of IB indicators, it is important to select the most appropriate group of indicators that, are able to stand the test, and indicators adopted in a rating method that have less relevance to the IB will reduce the accuracy in assessments. For example, *Special feature(s) recommended by the auditor* is adopted in the AIIB method as an IB indicator in all most every category including *Green*, *Space*, *ComfortWorking efficiency*, *High-tech image*, *Safety and Structure*, and *Practice & Security*. It is clear that different auditors will give different scores to these indicators even though all auditors deal with the same building because of their knowledge and their various understanding of the fuzzy definition during assessment. Based on this consideration, evaluations of IB indicators are of necessity required.

Tab. 1 The main categories of criteria adopted in rating methods for IB assessment

Assessment clusters	Main modules by each assessment system					
	AIIB method [4] (Hong Kong, China)	BRE method [5] (UK)	CABA method [6] (Canada/USA)	IBSK method [7] (Korea)	SCC method [8] (Shanghai, China)	TIBA method [9] (Taiwan, China)
Architecture	Comfort	Built Environment	-	Archit. Design	-	Health & Sanitation
	Health & Sanitation	-	-	-	-	-
	Space	-	-	-	-	-
Engineering	High-tech Image	Functionality	Automation	Electrical System	Communication	Info & Comms
	Safety & Structure	Responsiveness	Comms	Info & Comms	Earthing	Safety & Security
	Working Efficiency	Suitability	Security	Mechanical System	Facility Control	Structured Cabling
	-	-	Structure	System Integration	Fire Accident Control	System Integration
	-	-	Systems	-	Int. Integration	-
	-	-	-	-	Office Automation	-
	-	-	-	-	Power Supply	-
	-	-	-	-	Security	-
	-	-	-	-	Structured Cabling	-
Environment	Green	-	-	Environment	Environment	Energy Consumption
Economics	Cost Effectiveness	Economic Issues	-	-	-	-
Management	Practice & Security	-	Property	Facility	Property	Facilities
Sociology	Culture	-	-	-	-	-

Tab.2: An experimental verification of the AIIB IB Index method

Buildings	Scores		IB Index			
	Module x	Module y	w_x:w_y=2:1	Rank of Int.	w_x:w_y=3:1	Rank of Int.
A. Smart Tower	70	50	63	1	64	2
B. Balanced Building	60	60	60	2	60	3
C. Mechanical Plant	100	20	59	3	69	1
D. Tree House	20	100	34	4	30	4

On the other hand, the AIIB method adopts, from the field of economics, the celebrated Cobb-Douglas utility function as its calculation method in the process of assessment [4]. The Cobb-Douglas utility function is a standard utility function applied to describe matching output to input in a production processes and it is used commonly in both macro and micro economics [24, 25]. However, there is no clear information to support concerns about the application of the Cobb-Douglas utility function to the rating procedure according to personal discussions between the authors and other researchers in either the Cobb-Douglas utility function or rating procedure fields. In fact, the AIIB did not provide a reasonable explanation of reasons to adopt the Cobb-Douglas utility function in the calculation of a 10-module IB Index algorithm. Although the Cobb-Douglas utility function is one of the most widely applied utility functions in microeconomics, its major drawbacks such as the limited scope of effective regions and the harsh constraint terms to parameters definitely affect its utility in applications [26-30]. It is actually hard to define a physical model to describe this 10-module IB Index algorithm beyond the Cobb-Douglas utility function. Moreover, according to the second law of thermodynamics, which requires that any process that takes place at non-zero speeds must consume a minimum finite amount of exergy (the quality of energy), so production isoquants (combinations of inputs that yield the same output) [31] cannot be of the Cobb-Douglas type [32]. In these cases, the necessary and the sufficient conditions of applying the Cobb-Douglas utility function to the 10-module IB Index algorithm therefore require more study.

In addition, the AIIB method allows subjective weights of different building modules but this can lead to confusion about the interpretation of the assessment results. Table 2 recalls an example by the AIIB [4], in which the rate of weight comparison between two building modules are set as w_x:w_y=2:1, and the results of IB Index for each kind of building and the rank of their intelligence are in accordance with common intuition as to which kind of building is more intelligent. However, the function adopted in the IB Index calculation (refer to Equation 3) does not always lead to a sensible result. For example, let w_x:w_y=3:1, the IB Index values for each building are then different from the ones under w_x:w_y=2:1, and the sequence of building intelligence also changes (see Table 2). The AIIB method cannot provide a unique result, as different auditors may make different conclusions, which definitely cause complexity and variance in IB assessment.

Regarding the non-organization assessment procedure adopted in current building rating systems, the authors find that it is difficult to recognize *Organization* factors from current systems besides the *Management* cluster, in which only property management issues are concerned. Based on the summary in Table 1, the non-organization principle/judgment existed in current building rating systems can definitely lead to partial assessments in which evaluators will miss their chance to study the culture, the structure and the occupants of all factors, which influence the performance of the building.

Theoretically speaking, logical defects in the currently used building rating methods, such as the IB Index method, may lead to an invalid IB assessment. It is thus required to provide an alternative method to evaluate the characteristics of IB, under objective and real life conditions, in which all indicators are taken into account, not only their values but also their interrelationships.

4 FURTHER DEVELOPMENT

Based on this review, the authors propose an alternative approach to IB assessment by means of analytic network process (ANP) [33]. In a test drive using the ANP, the authors also noticed that 43 indicators can be extracted from 378 elements of IB Index by using a quantitative indicator selection approach. In fact, this extraction also indicates that most elements adopted in the IB Index are repeated and need simplification. As mentioned above, the IB Index has a comprehensive classification of indicators; therefore a most appropriate group of indicators can be selected from it for the ANP based assessment. To overcome the shortcomings that exist in the current IB Index method, the proposed ANP approach will provide an innovative way for IB assessment, in which both the value of indicators and their interrelations are taken into account.

5 CONCLUSIONS

This paper provides a review of various systems for building assessment focusing on intelligent buildings. Based on comparison among currently used IB assessment systems, it has been identified that rating method has its limitations in the assessment of IBs. In this regards, the authors propose an innovative approach for IB assessment using analytic network process, in which both scores and interrelations of indicators can be included.

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