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The Hong Kong Polytechnic University
The Department of Building and Real Estate

A Study on Analytic Approaches to Intelligent Buildings Assessment

Hong Ju

A thesis submitted to in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

Feb, 2006

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ABSTRACT

This dissertation presents my PhD research into a study on generic analytical approaches to intelligent buildings assessment based on a novel prototype of lifecycle information management and knowledge utilization of intelligent buildings. This research aims to overcome the weakness existed in currently used intelligent buildings rating systems such as the Intelligent Building Index (IB Index) which has been developed by the Asian Institution of Intelligent Buildings (AIIB) since 2001, and to provide more accurate and effective toolkits for practitioners to appraise intelligent buildings, which have been established based on extensive literature review and questionnaire surveys. The analytical approaches being presented in this dissertation include an Analytic Network Process (ANP) approach, an Artificial Neural Network (ANN) approach, and a Knowledge-based Information Visualization (KIV) approach. The ANP approach is conducted to support decision making in the assessment of intelligent buildings under multicriteria. The ANN approach is introduced to facilitate the adoption of ANP approach in real-world appraisals. Both of them are integrated within a Tactical Intelligent Buildings Evaluation and Renovation (TIBER) model for intelligent buildings assessment. The KIV approach is originally developed to facilitate the adoption of currently used building rating systems such as the AIBI with a knowledge management toolkit. All these analytical approaches are integrated into the prototype of lifecycle information management and knowledge utilization of intelligent buildings, which is called the Data and Knowledge Management Platform of Intelligent Buildings (DAKIB platform). Experimental case studies are conducted to demonstrate the effectiveness of those analytical approaches.

PUBLICATIONS ARISING FROM THE THESIS

Chapters in Books

1. **Ju.Hong** and Z. Chen, H. Li, Q. Xu Knowledge-oriented Information Visualization for Intelligent Building Assessment. Open Building Manufacturing: Core Concepts and Industrial Requirements. (Editor: A.S. Kazi). VTT, Finland. Under review. (2006).

2. **Ju.Hong** and Z. Chen, H. Li A case study of intelligent buildings: Manchester stadium. In Intelligent Stadia and Sports Buildings. China Architecture and Building Press. Beijing. (2005).

Refereed Journal Articles

1. **Ju Hong** and Z. Chen, H. Li, Q. Xu A Decision-making model for the Asian intelligent building index. Journal of Harbin Institute of Technology. **(**Accepted for Publication). (2006).

2. **Ju Hong** and Z. Chen, H. Li, Q. Xu. An information visualization approach to intelligent buildings assessment. Journal of Harbin Institute of Technology. (2006). **(**Accepted for Publication).

3. **Ju Hong** and Z. Chen, H. Li, Q. Xu. A multilingual web-based decision support for knowledge sharing and management in intelligent buildings assessment. In progress with Decision Support Systems, Elsevier. (2005).

4. **Ju Hong** and Z. Chen, H. Li. A knowledgebase for teaching and learning intelligent buildings for sustainable built environment. In progress with the Journal of Professional Issues in Engineering Education & Practice, ASCE. (2005).
5. **Ju Hong,** and Z. Chen, H. Li, Q. Xu. An intelligent decision support system for intelligent buildings assessment. Building and Environment, Elsevier. Accepted for Publication. (2005).
6. Z. Chen and D.J. Clements-Croome, **Ju Hong**, H. Li, Q. Xu. A multicriteria lifespan energy efficiency approach to intelligent buildings assessment. Energy and Buildings, Elsevier. 38(5), 393-409. (2005).

Refereed Conference Papers

1. **Ju Hong** and Z. Chen, H. Li, Q. Xu. A data and knowledge management system for intelligent buildings. Proceedings of the 6th International Conference for Enhanced Building Operations, 6-8/11/2006, Shenzhen, China. (2006). (Accepted for Publication).
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3. **Ju Hong** and Z. Chen, H. Li, Q. Xu. A case study on intelligent buildings: the City of Manchester Stadium. Proceedings of the 2nd International Conference on Intelligent Green and Energy Efficient Buildings, 28-30 /03/2006, Beijing, China. 383-392. (2006).

4. **Ju Hong** and Z. Chen, H. Li. A knowledge-driven multicriteria decision support system for intelligent buildings assessment. Proceedings of the International Conference on Construction and Real Estate Management. 12-13/12/2005. Penang, Malaysia. 465-469. (2005).

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Consultation Reports

1. **Ju Hong** and Z. Chen, H. Li. Technical Review on the LEED (Leadership in Energy and Environmental Design) Green Building Rating System. U.S. Green Building Council, Washington, USA. (2005).

2. **Ju Hong** and Z. Chen, H. Li. A Consultation Review of the National Management Information System of the China Real Estate Market. The Ministry of Construction, Beijing, China. (2004).

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LIST OF ABBREVIATIONS

AIBI	Asian Intelligent Building Index
ANN	Artificial Neural Network
ANP	Analytic Network Process
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standards Institution
CAC	Computer-Aided Construction
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CSI	The Construction Specifications Institute
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CABA	The Continental Automated Buildings Association
CEPB	The China Environmental Protection Bureau
CIRIA	The Construction Industry Research and Information Association
DAKIB	The Data and Knowledge Management Platform of Intelligent Buildings
DEH	Department of Environment and Heritage, Australian Government
ETI	Energy-Time consumption / use Index
FIDIC	The International Federation of Consulting Engineers
IB	Intelligent Building
IBAS	Intelligent buildings assessment System
IBSK	Intelligent Building Society of Korea
ISO	International Organization for Standardization
IT	Information Technology
KIV	Knowledge-base Information Visualization
KM	Knowledge Management
KPI	Key Performance Indicator
LCA	Life Cycle Analysis/Assessment
LEED	Leadership in Energy and Environmental Design
O&M	Operation and Maintenance
POE	Post Occupancy Evaluation
RFID	Radio Frequency Identification
SCC	Shanghai Construction Council
SEC	Score of Energy Consumption
SIBER	Strategic Intelligent Building Evaluation and Renovation
STC	Score of Time Consumption
TIBER	Tactical Intelligent Buildings Evaluation and Renovation
TLEBM	Through Life Environment Business Model
USACE	The U.S. Army Corps of Engineers
USGBC	The U.S. Green Building Council
USGSA	The U.S. General Services Administration
USNIBS	The U.S. National Institute of Building Sciences
WLAN	Wireless Local Area Network

Chapter 1

INTRODUCTION

1.1 Overview

This dissertation is prepared in partial fulfillment of the requirements for the degree of PhD so as to apply for the confirmation of the degree of PhD. Based on my Report for Confirmation of Registration as a PhD Candidate in March 2004, it was considered that good progress had been made during the previous stage in my study, starting in the February of 2003. And my PhD dissertation was therefore temporally entitled *Assessment System for Intelligent Buildings in China*. Since then, my research into intelligent buildings assessment has generated a series of generic approaches as to be presented in this dissertation. As a result, I finally entitle the dissertation as *A Study on Analytic Approaches to Intelligent Buildings Assessment*, which means that research outputs from my PhD study can be generically applied to the assessment of intelligent buildings from all geographic areas.

1.1.1 Research Background

The construction of intelligent building (IB) in China has only a history of about ten to twenty years; meanwhile the time of relevant study in the areas of technology and management is short. Therefore, the codes and standards for intelligent buildings are mostly modified from existing ones in relevant areas. Due to the lack of specific codes and standards, many intelligent building projects have been carried out without proper codes and standards. As a result, inappropriate design schemes, poor construction quality, and sub-standard after checking, and non-intelligence of the “intelligent buildings” always occur in China. However, this circumstance is changing. In recent years, a number of codes and standards of intelligent buildings have been issued. Presently, the China Ministry of Construction, the Ministry of Information, and the China National Committee of Standards have jointly drafted three construction standards about intelligent buildings, including

- *The Application of Digital Management of Buildings and Residential House Estates*,
- *The Checking and Acceptance of Digital Technology Application System in Buildings and Residential Areas*, and
- *The Application of Digital Technology Application in Operation Services of Buildings and Residential Areas*.

These three standards are under drafting and will to be released. It is believed that these standards will promote the developments and standardization of intelligent buildings in China. Moreover, these codes and standards actually make the basis of further research and establishment of an Intelligent Buildings Assessment System (IBAS) in China.

The promotion of intelligent buildings within the construction industry needs proper rules, policies, laws, standards, technologies, etc. The proposed IBAS can be used to regulate the developments of intelligent buildings; and by using code-driven assessment, the whole process of intelligent buildings, including project setting up, design, system integration and operation, etc. will become more standardized and be in good order. Thus, the development of intelligent buildings will be more rational and highly efficient. In order to support the research and development of IBAS in China, this research project aims to establish a Data and Knowledge Management Platform of Intelligent Buildings (DAKIB platform) (see Figure 2.1), which comprises several toolkits for intelligent buildings assessment. To apply DAKIB platform ant its toolkits into the practice of intelligent buildings assessment, case studies will be used to demonstrate the effectiveness of these toolkits. Particularly, the DAKIB platform and its toolkits extends the method and process of traditional building performance assessing systems in assessing intelligent buildings; it focuses on intelligent buildings assessment at pre-construction stage and decision making at post-assessment stage. The results from this research project are expected to contribute to the literature in the field and provide an efficient tool for assessing the aspects of intelligent buildings within the context of the building professions.

The proposed DAKIB platform (see Figure 2.1) and its toolkits aim to incorporate contributions from all project participants to achieve better efficiency of building intelligence. Potential users of the DAKIB platform include the end-users or occupants, clients or developers, contractor, consultants, and systems suppliers, etc. The DAKIB platform with its toolkits will collect information and data from multiple disciplines such as architectural engineering, construction engineering and management, electronic engineering, information and communication technology, etc. in order to form a generic platform for knowledge reuse for the building professions. It is expected that the proposed DAKIB platform with its toolkits can not only help developers to accomplish the integrative management of intelligent buildings through better design, effective system integration and proper facility management, but also facilitate further development of the IBAS in China.

1.1.2 Objectives of the Research

This study aims to develop the DAKIB platform and its toolkits for intelligent buildings assessment. The DAKIB is the philosophy and the physical target of the originally proposed IBAS in 2004. In order to achieve these objectives, the following specific objectives are planned:

- set up DAKIB platform, focusing on the structure of the platform and its toolkits;

- formulate the Key Performance Indicators (KPIs) of intelligent buildings, focusing on the characteristics of intelligent buildings in China;
- set up a model for intelligent buildings assessment using Analytic Network Process (ANP), focusing intelligent buildings assessment at pre-construction stage;
- set up a model to facilitate the application of ANP model using Artificial Neural Network (ANN);
- determine the scores and relative weights of KPIs;
- develop a Knowledge-based Information Visualization (KIV) approach for decision making at post-assessment stage;
- build up a quantitative model for calculating the score of an intelligent building, and
- test the DAKIB toolkits through case studies.

Overall, a system for intelligent buildings assessment within the context of the building professions will be established, which comprises the DAKIB platform and its toolkits. The context of the building professions will focus on generic information, processes and knowledge, which have been generally accepted not only in China but also in other countries. Deliverables from this study will include the DAKIB platform for comprehensive intelligent buildings assessment and its toolkits derived from the research.

1.2 Literature Review

The concept of intelligent buildings was initially advocated by the United Technology Building Systems Corporation in the United States in 1981, and became reality as the completing ceremony of Hartford Square Mansion (City Place Building) in Connecticut, USA in July 1983 (Albert and Wong, 2002; AIIB, 2005). Since then, thousands of office building, business centers, and bank in intelligent type were constructed in North

America, Europe, and Asia in the past decade. In China, intelligent buildings were gotten off the mark formally at the beginning of the 1990s. The Construction Ministry of China constituted Electric Design Specification of Civil Buildings, in which the application of Building Automation and Office Automation were put forward. At the same time, the definition of intelligent buildings was concerned. Emergency and development of intelligent buildings was paid wide attentions and some relevant academic organizations were founded. For example, American Intelligent Building Society founded at the beginning of 1985, followed by the European Intelligent Building Group, the Japan National Intelligent Building Professional Committee of Construction Department, and the Asian Intelligent Building Institute. Since 1992, intelligent buildings have been developed vigorously when the technology of AT&T synthetically laying line system introduced into China. In recent years, some large public buildings with high-level intelligence, such as Shanghai Museum, Guangzhou World Trade Center, Capital Airdrome Building, Shanghai Stock Mansion and Shanghai Jinmao Mansion, have been completed, and more and more intelligent buildings or residential district have been constructed and are being constructed.

However, the intelligent level is different with these intelligent buildings; about this issue refers to a lot of matters from different ways. Should be how scale about an intelligent building? And what is the ‘intelligence’ of an intelligent building? Up to now, there has been no universally accepted criterion for intelligent buildings (Smith, 1997); in point of fact, how intelligent building is assessed is clearly dependent on how intelligent building is defined.

1.2.1 Concept and Definition of Intelligent Buildings

The word ‘intelligent’ was first used to describe buildings and the term of ‘intelligent building’ was originated in the United States in the early 1980s (AIIB, 2005). Its emergence was stimulated by the development of information technology (Kroner 1997, Harrison, Loe and Read, 1998). The increasingly sophisticated demand for comfort living environment and requirement for increased occupant control of their own local environments (Wigginton and Harris, 2002) also motivate the development of intelligent buildings. In fact, the relationship between human activities and buildings is inseparable, Clements-Croome (1997) pointed out that the building, its services systems and management of the work process have close relationship with the well-being of people within an organization The building environment has great influence on the productivity of the human as the health, wellbeing and comfort of the workplace may affects their morale and satisfaction. Intelligent building have a vital role to play in helping to achieve this by enhancing human resources, by providing environmental systems which support the productive, creative, intellectual and spiritual capacities of people. According to Arkin (1997), the concept behind current intelligent buildings emphasizes a multidisciplinary effort to integrate and optimize the building structures, systems, services and management in order to create a productive and responsive environment for the building occupants, in a cost-effective manner.

Since the introduction of intelligent building concepts, there have been many definitions and description of intelligent buildings published in the academic and technical literature. Early definitions of intelligent building focused almost entirely on the technology related to the automation of building and did not suggest user interaction at all (Powell, 1990; Wigginton & Harris, 2002). Cardin (1983) defined intelligent building as one which has fully automated building service control systems. In 1988, the former Intelligent Building

Institution in Washington defined intelligent building as one which integrates various systems to effectively manage resources in a coordinated mode to maximize: technical performance; investment and operating cost savings; flexibility.

The early limitation of purely technological definition of intelligent buildings began to become apparent. The research carried out by architect DEGW (1985) on the interactions between organization, buildings and information technology in the context of a rapidly changing work environment, found that buildings which were unable to cope with changes in the organizations that occupy them, or in the information technology that they use, would become prematurely obsolete and would either require substantial refurbishment or demolition. Since that time, many researchers have modified the definitions of intelligent buildings to include an additional dimension of responsiveness to change. Fagan (1985), Duffy (1986), Tomano (1987), Robathan (1989), Kell (1996), Schneider and Gentz (1997), Loveday et al. (1997), Preiser and Schramm (2002) suggested that intelligent buildings must respond to user requirement. Boyd (1994) and CIB Working Group W93 (1995) defined an intelligent building as a dynamic and responsive architecture that provides every occupant with productive, cost effective and environmentally approved conditions through a continuous interaction among its four basic elements, including places, processes, people and management and the interrelation between them.

Yang and Peng (2001) regarded a true intelligent building as one building which is not only able to respond to individual, organizational and environmental requirement and to cope with the change, it should also be able to learn and adjust its performance from its occupancy and the environment. On the other hand, Wigginton and Harris (2002) thought that an intelligent building is not just a building with the ability to know its configuration, anticipate the optimum dynamic response to prevailing environmental stimuli, and actuate the appropriate physical reaction in a predictable manner, but also to expect that the system will strive to exploit the use of natural forces and minimize the need to import energy from non-renewable sources.

In addition, different countries or geographic regions differed in the understanding of intelligent building. Both the United States and the United Kingdom have difference in the interpretation of building intelligence. The Intelligent Building Institute of the United States defined an intelligent building as one which provides a productive and cost-effective environment through optimization of its four basic elements, including structures, systems, services and management and the interrelationships between them.

Whereas, the UK based European Intelligent Building Group defines an intelligent building as one building that creates the environment that maximizes the effectiveness of its occupants, while at the same time enables the efficient management of resources with minimum life-time costs of hardware and facilities. A comparison study shows that the definition of intelligent buildings in Europe is more focusing on the users' requirements other than merely on the technologies as defined in the United States.

As a matter of fact, there are many definitions to describe what an 'intelligent building' is from various researchers. So et al. (2001) reviewed many definitions for intelligent buildings around the world, and pointed out that many definitions are very subjective in nature. They stressed the importance to redefine the intelligent building in order to suit the culture of intelligent buildings in Asia. According to their new definition (AIIB, 2005) intelligent buildings are not intelligent by themselves but they can furnish the occupants with more intelligence and enable them to work more efficiently. Actually, most existing definitions of intelligent buildings around the world are to trying to ensure a building is suitable for occupants to work and live in safely, comfortably, effectively and efficiently. However, these definitions are either too vague to be useful guidance for detailed design; place an unbalanced focuses on technologies only; or do not fit that culture of Asia. It is time for Asia to adopt its own definition of intelligent buildings. Without a correct definition, new building will not be optimally designed to meet the next century.

The terminology of 'intelligent building' was then re-interpreted by So et al. (2001) and AIIB (2005) and suggested a *'two-level strategy'* to define an intelligent building which is more suitable for formalizing a generic definition in Asia. The ten 'Quality Environment Modules (QEM)' (Module 01~10) form *the first level*, or the fundamental level of the definition, they include:

- Module 01: Green;
- Module 02: Space;
- Module 03: Comfort;
- Module 04: Working Efficiency;
- Module 05: Culture;
- Module 06: High-tech Image;
- Module 07: Safety and Structure;
- Module 08: Management Practice & Security;
- Module 09: Cost Effectiveness; and
- Module 10: Health and Sanitation.

The second level includes three areas of key elements which are functional requirements, functional spaces and technologies. Each of the ten key modules mentioned above will be assigned a number of key elements in an appropriate order of priority. Hence, the AIIB

(2005) re-defined the intelligent buildings, and it is designed and constructed based on an appropriate selection of ‘Quality Environmental Modules’ to meet the user’s requirements by mapping with the appropriate building facilities to achieve long term building values.

This new definition includes two dimensions which are the needs of users and the enabling technologies. As commented by So and Wong (2002), this new definition is more appropriated and useful as it give the designers a clear direction and sufficient details to enable high quality design practice of intelligent buildings in accordance with the definition. Meanwhile, it is expected that the new definition can provide a fair platform for users to evaluate the performance of intelligent buildings.

According to the definition of intelligent buildings in China (see GB/T50314-2000), the intelligent building is taking a building as its platform, having equipment of building, office automation and communicating network system simultaneously, and an optimizing composite integrated structure, system, service, and management, and providing the environment with high-efficiency, comfort, convenience and safety to people.

Among existing definitions of intelligent buildings around the world, there still has been not a standard definition. It is found that they can more or less be categorized into two aspects, an emphasis on technologies and an emphasis on user’s requirements. However, the beauty of intelligent buildings is that they make building more efficient and effective to provide the built environment that can respond to requirements and to fit people’s expectations.

1.2.2 Existing Methodologies for Intelligent Buildings Assessment

The evaluation of building performance is crucial as failure to obtain feedback on building performance can have serious consequences (Preiser, 2001). The development of building performance evaluation can be traced back to the early works carried out by Manning (1965) and Markus et al. (1972). This was later improved by Preiser and Schramm (1997) who proposed an integrative building performance evaluation framework, which can be used to evaluate and review stance in all six major phrases of building delivery and life cycle, including planning, programming, design, construction, occupancy and recycling.

Table 1.1 summaries the hierarchical development of the methods for intelligent buildings assessment.

Since the development of intelligent buildings in early 1980s, many researchers have been trying to develop techniques for measuring the level of intelligence that a building exhibits for the sake of comparing buildings anywhere to determine the best, or most intelligent, intelligent buildings (Harrison, Loe and Read, 1998). One of the essential assessments for intelligent buildings is the ‘Building Rating Method’, which was refined by the DEGW (1995), and was based on the Intelligent Buildings Europe Work (1992) and Building Quality Assessment (1992-1994). The method employs five categories of factor which are combined to produce overall assessments of the suitability of intelligence provided by the subject building (see Table 1.1).

Table 1.1 Summary of the development of intelligent buildings assessment methods*

Year	Research agency	Details of assessment methods
1983	DEGW	Orbit 1 multi-client study in associated with Eosys and building use studies.
1985	DEGW	Orbit 2 determining the degree of matching between the buildings, the organizations occupying it and the information technology using 9 key organizations issues and 8 key information technology issues.
1988	Camegie Mellon University	Measures of quality, satisfaction and efficiency using 6 performance criteria and 5 system integration criteria.
1991	Kuala Lumpur City Hall	Development of guidelines specifying features of 6-star, 5-star and 4-star office buildings based on location, design, systems and services.
1992	Intelligent Building Research Group, (Birmingham Polytechnic)	IQ-style rating Method; Considering 10 individual user needs, 15 organizational needs, 6 local environmental needs and 5 global environmental needs (Project not completed).
1992	Intelligent Building in Europe Project	Intelligent Building Rating by key questions based on building shell characteristics, services and applications (Not published).
1992-1994	Real Estate Norm (Holland); Building Quality Assessment (New Zealand); and Serviceability Tools and Methods (Canada)	Development of three evaluation methodologies to evaluate the quality of buildings and the suitability for different tenant types.
1995	DEGW	Building Rating Method: Involving five sections (A-E) including namely seven items related to A) building site/location, 14 items related to B) building shell issues, 3 items related to C) building skin issues, 11 items related to D) organizational and work process issues; and 12 items related to E) building services and technology, where the result is an overall score by combination of all items.
1998	Harrison, et al.	Building Rating Method (Results Matrix): Based on the Building Rating Method constructed by DEGW and demonstrated its use in evaluations through the two plots of the categories (A-B/C; D-E). The categories are each dimensioned as per cent and the four quadrants of each plot are considered to indicate the building's performance.
2001 to date	Asia Institutes of Intelligent Building	Development of IB Index to quantify the performance of intelligent buildings. Based on its 3rd version, the assessment criteria of the IB Index involve Green module (M1:75 elements), Space module (M2:18 elements), Comfort module (M3:50 elements), Working Efficiency module (M4:80 elements), Culture module (M5:13 elements), High-tech Image module (M6:38 elements), Safety & Structure module (M7:31 elements), Management Practice & Security module (M8:40 elements), Cost Effectiveness module (M9:1 element), and Health & Sanitation module (M10:32 elements).

*References: So and Wong, 2002; Cho and Fellows, 2000; and AIIB, 2005.

Although there are many building rating systems, most existing assessment methods have some shortcomings in practical buildings assessment (So and Wong, 2002); however, the construction of any evaluating methodology is always fraught with problems of fairness and partially subjective assessment. To develop a practical method for intelligent buildings assessment, researchers have to consider the following issues:

- the conventional means of linear addition to arrive at a final assessment index is not consistent with human thinking;
- different types of intelligent buildings must be assessed in slightly different ways in terms of the weight or priorities of elements characterizing an intelligent building;
- important elements must receive emphasis while less important elements should not be ignored with an aim to well-balanced performance of the whole building; and a system fails to operate should be discriminated from a system that is not application to the operation of a certain intelligent building;
- the assessment method must follow a learning curve and should be able to evolve from time to time; and
- the binary approach of each rule or question is not a good practice. The mere provision of a particular facility, or system, in a building is not a conclusion of its intelligence.

On the other hand, Arkin and Paciuk (1997) developed a simple index, called MSIR, to determine the level of systems' integration in intelligent buildings which is widely adapted by other researchers (Yang and Peng, 2000). This evaluation approach applied for the evaluation and comparison of intelligent buildings according to the extent of integration among their systems, and between systems and the building's structure. As pointed out by Arkin & Paciuk (1997), the key to the effective operation of intelligent building is not related to the sophistication of the building services systems, but is the integration among the various systems, between the system and the building structure. The Magnitude of Systems' Integration (*MSI*) is used to evaluate as objective index that quantifies and summarizes the various aspects of integration. It compares various building's intelligence as related to systems' integration. A simple cumulative index is obtained by summing all the ratings ("Ri") attributed to the integration features of various systems in the building, and then dividing the sum by the number of available systems; A normalized index, i.e. *MSIR* (see Formula 1.2), is the ratio of *MSI* for a given building and MSI_{ref} for the corresponding reference building;

$$MSI = \frac{\sum_{i=1}^{NS} R_i}{NS} \tag{1.1}$$

$$MSIR = 10 \times \frac{MSI}{MSI_{ref}} \tag{1.2}$$

The *MSIR* can be considered as an index for determining the level of systems' integration in intelligent buildings. According to Arkin and Paciuk (1997), this assessment methodology can be used for evaluation and comparison of this single aspect of building's intelligence and to create a unified index for evaluation of system's integration in intelligent buildings.

Preiser (2002) constructed a Post Occupancy Evaluation (POE) process model for buildings evaluation. The system was turned out from the early works carried out by Manning (1965) and Markus et al. (1972) as mentioned previously. Preiser and Schramm (2002) applied the POE process model to intelligent building evaluations in the cross-cultural context. The POE process model can be divided into the three phases, including

- Phase 1: concept phase to develop compatible data collection instructions;
- Phase 2: application and pilot testing of evaluation instruments in field studies on intelligent office building; and
- Phase 3: comparative analysis of data collected and development of recommendations and guidelines for the utilization of the data-gathering instruments worldwide.

The advantage of the POE model is that it enhances building performance evaluation in intelligent buildings, especially if established on a long-term, continuing basis, as it permits the tracking of performance of new high-tech systems and their effects on building occupants as well as the effectiveness of these systems in general. As pointed out by Preiser and Schramm (2002), the evaluation of an building in the context of a given location, culture and building users will show the successes and failures of building's performance and will provide evidence as to whether it is a building with intelligence.

Furthermore, the Asian Institute of Intelligent Buildings (So and Wong, 2002; and AIIB, 2005) constructed a quantitative assessment method for intelligent buildings, i.e. the IB Index. The individual assessment index for this methodology was originated from the ten 'Quality Environment Modules' (M1-M10) (refer to Table 1.1, and Appendix 3) and each module possesses a score which is a real number (within the range of 1 to 100) by a conversion formula, and the building will be ranked from A to E to indicate the overall intelligent performance.

The arithmetics of IB Index (AIIB, 2005) are summaried in Formula 1.3 and Formula 1.4. The overall index or score of an intelligent building can be calculated using Formula 1.3.

$$I = M_1^{\frac{W_1}{W_1+...+W_{10}}} \quad ... \quad M_{10}^{\frac{W_{10}}{W_1+...+W_{10}}} \tag{1.3}$$

$1 \le I \ge 100; \quad 1 \le M_i \ge 100; \quad (10 \ge W_i \ge 1; i = 1,...,10)$

Where M_i is the score of the i^{th} module (e.g. M_1 =the green Index); and W_i is the i^{th} module's weight (or importance) relative to other modules, and preferably a positive integer.

To get the M_i, the Formula 1.4 is used to assess the individual module's scores:

$$M_i = X_1^{\frac{w_1}{w_1+...+w_m}} \quad ... \quad X_m^{\frac{w_m}{w_1+...+w_m}} \tag{1.4}$$

$1 \le X_j \ge 100; \quad (10 \ge w_i \ge 1; j = 1,..., m)$

Where x_j is the score of the j^{th} element and there are m elements in each module; and w_i is the j^{th} module's weight (or importance) relative to other modules.

As commented by the AIIB (2005), designers and users of buildings require a set of objective evaluation system to assess an intelligent building, the evaluation result should truly reflect the performance and justified price of intelligent buildings; a good assessment method should be able to:

- encourage well-balanced performances, emphasize important elements but, at the same time, discourage total ignorance of minor subjects;
- be consistent with human preferences while random judgments must be minimized;
- practically have the extension of the utility theory, measuring all levels of building performances, weighting as attributes and combining them systematically, to form the overall intelligent building index; and
- have learning ability, and be upgraded and modified from time to time.

However, according to further study on currently used systems for intelligent buildings assessment (see Chapter 3), the IB Index (AIIB, 2005) method actually cannot provide a satisfied assessment result due to its weaknesses including the calculation method itself. It therefore becomes visible that it is nessary to further develop a reliable method for intelligent buildings assessment.

1.2.3 New Development of Intelligent Buildings

It has been generally accepted that the development of intelligent buildings in the future can bring great benefits to both users and suppliers. On the suppliers' side, problems of co-ordination and integration must be solved. To achieve this, Harrison, Loe and Read (1998) suggested developing a number of specialist roles, including

- Project integration – co-ordination and integration the various requirements of end users and suppliers at the conceptualization phase of the project.
- Systems integration – analyzing the application and supplying additional hardware, software and customization services enable different systems to communicate and inter-operate.
- Services integration – providing complete supervision and co-ordination of building services, IT services and communication services.

Moreover, the intelligent building should be regarded as the product of a partnership between the organization, the building occupants and suppliers. The process leading to the construction and occupation of any building is often complicated and stressful for all concerned. The end result may be unsatisfactory either because client requirements have not been understood or because the sophisticated systems installed to meet these requirements do not live up to expectations. None of the participants in the development and construction process can be said to be blameless. There are lessons to be learned, however, in bringing together the intelligent buildings team. According to Harrison, Loe and Read (1998), an intelligent building does not have to involve high levels of technology. A simple adaptable building form, combined with appropriately specified building services and technologies should still be able to result in a high-quality business value intelligent building. At the building site and shell level the 'intelligence' of the building can largely be judged independently of the current occupants as the key issues are accessibility and adaptability.

1.3 Research Methodology

In this study, a number of research methodologies are used depending on the characteristics of various problems. These research methodologies will be elaborated in details in various chapters. Generally speaking, research methods adopted in this study include extensive literature review, indicator evaluation, analytic network process, building rating, artificial neural network process, system analysis and development, and case study, etc. All these research methods will be adopted in accordance with the specific objectives of each chapter. A general view of research methodology is given below.

1.3.1 KPIs

In this step, the research efforts have been made to identify and formulate Key Performance Indicators (KPIs) of intelligent buildings. There are considerations about characteristics of intelligent buildings in China as well. Based on literatures reviewed, including the IB Index (AIIB, 2005), *Intelligent Skin* (Wigginton and Harris, 2002), *Hughes Electrical and Electronic Technology* (Hughes, et al., 2002), and *Intelligent Buildings in South East Asia* (Harrison, Loe and Read, 1998), etc., it has been noticed that there are a number of literatures which provide various types of KPIs for intelligent buildings. Although they are valuable to finalize KPIs for this study, the limititation in the lack of theory for a system of classification actually makes their categories too subjective to be reasonable. For example, the Policy Study Centre of the Ministry of Construction has generated a set of criteria for evaluating intelligent buildings in China (PSC, 2003). According to this regulation, indicators for intelligent buildings evaluation can be classified into the following five groups, including

- building element (such as architecture, structure, plumbing, ventilation, lighting, fire prevention facilities, safety measures, and passages),
- intelligence system (such as communication, GCS, auto office, facility monitoring system, etc.),
- environment (energy sources, pollution, energy consumption, space utilization, comfortableness, efficiency, and culture),
- service (property management, operation and maintenance), and
- cost-benefit (such as cost-efficiency, which is considered one of the five major indicators indicating the intelligence value of a building. The construction and operating costs of a building should be compatible to its rental income (AIIB，2005)).

It is obvious that there is no consideration about architectural design of intelligent buildings according to the classification provided by the PSC (2003).

Based on extensive literature review, a proposed structure of KPIs for intelligent buildings assessment is illustrated in Figure 1.1. Regarding how to select KPIs, Chapter 3 introduces a novel quantitative approach called Energy-Time consumption Index (ETI).

Figure 1.1 actually is a generic description of the structure of KPIs. For instance, the IB Index proposed by the AIIB (2005) provides a quantitative method to conduct composite evaluation of intelligent buildings based on 10 clusters of KPIs with total 378 nodes (see Appendix 3). KPI clusters and their nodes are summarized in Table 1.2. A detailed list of IB indicators adopted by the IB Index (AIIB, 2005) is summarized in Appendix 3.

However, despite of the large number of IB Index (AIIB, 2005), it will definitely consume time in assessment, further research will also concentrate on the criteria of classification, which can finally lead to a group of crack indicators exactly for intelligent buildings assessment. In this study, such a group of KPIs is defined based on the IB Index (AIIB, 2005), because the IB Index has the most comprehensive group of KIPs for intelligent buildings assessment. Detailes about how to finalize a group of KIPs and how to use them in intelligent buildings assessment are described in Chapter 3 to 6.

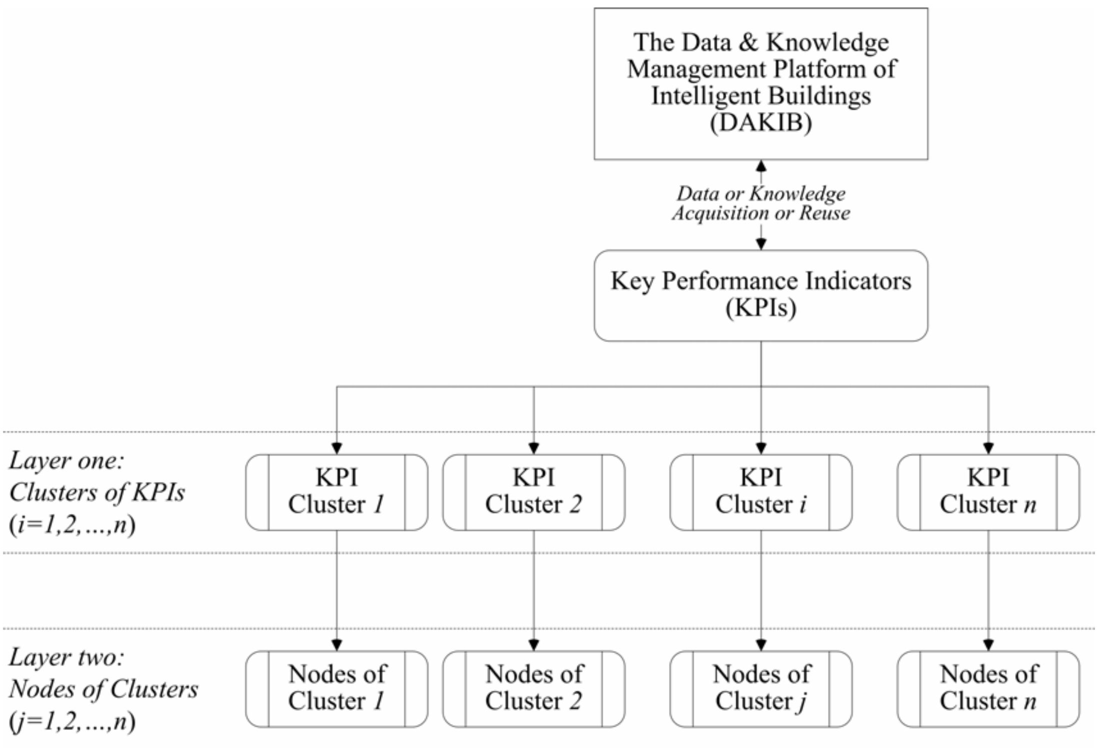


Figure 1.1 The structure of KPIs for intelligent buildings

Table 1.2 The structure of the KPIs of the IB Index (AIIB, 2005)

	Nodes/Indicators	
KPI Clusters	**Code**	**Number**
Cluster 01: Green Index (GRI)	GRI 01~ 75	75
Cluster 02: Space Index (SPI)	SPI 01~ 18	18
Cluster 03: Comfort Index (CFI)	CFI 01~ 50	50
Cluster 04: Working Efficiency Index (WEI)	WEI 01~ 80	80
Cluster 05: Culture Index (CLI)	CLI 01~ 13	13
Cluster 06: High-tech Image Index (HTI)	HTI 01~ 38	38
Cluster 07: Safety and Structure Index (SSI)	SSI 01~ 31	31
Cluster 08: Management Practice & Security (MPS)	MPS 01~ 40	40
Cluster 09: Cost Effectiveness Index (CEI)	CEI 01	1
Cluster 10: Health & Sanitation Index (HSI)	HIS 01~ 32	32
Total		378

1.3.2 The Theory of Assessment

It is regarded that KPIs can influence the result of assessment. Therefore, the selection of KPIs and the definition of relative weightings between paired KPIs are essential for intelligent buildings assessment. In order to set up a system of KPIs, both qualitative and quantitative analysis will be conduced to understand the function and characteristics of individual elements which affect KPIs.

The qualitative analysis of KPIs is to finalize a group of indicators for intelligent buildings assessment. The analysis on the functions and characteristics of relevant indicators will be conducted, in particular, by referring to the following standards and regulations issued by the relevant authorities, such as *Design Criteria for Intelligent Buildings (GB/T50314-2000)* by the Standard and Normans Bureau of the Ministry of Construction (MoC) (SNB, 2001); *Digitalization in Managing Residential Buildings* by MoC (GB-1, 2004). Meanwhile, attentions will also paid to the following six rating approaches specially designed for intelligent buildings assessment, including

- AIIB method (AIIB, 2005) developed by the Asian Institute of Intelligent Buildings (AIIB), Hong Kong, China,
- BRE method (Rassi, 2005) developed by the Building Research Establishment Ltd., UK,
- CABA method (CABA, 2004) developed by the Continental Automated Building Association (CABA), Canada & USA,
- IBSK method (IBSK, 2002) developed by the Intelligent Building Society of Korea (IBSK), Korea,
- SCC method (SCC, 2002) developed by the Shanghai Construction Council (SCC), China, and
- TIBA method (Wen, 2003) developed by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan, China.

After finalizing the group of KPIs, a questionnaire survey will be conducted to collect experts' knowledge and opinions for quantitative analysis in the assessment of intelligent buildings. Questionnaire will be designed to distribute to professionals to consolidate their views and judgments. The target professionals will mainly include client, designers, building developers, systems integrator and facility property management professionals.

The survey will be conducted within the Chinese mainland construction industry. Interviews will also be arranged to collect relevant data.

1.3.3 The Score of Intelligent Buildings

In this step, a quantitative method for calculating the intelligence value or the score of intelligent buildings is to be established. The existing model Cobb-Douglas utility function (AIIB, 2005) provides a useful tool for building up this model; however, there are several limitions that make it unreasonable for further application. A new rating method, i.e. the score of intelligent buildings, is described in Equation 1.5.:

$$IB_{Score} = \sum_{i=1}^{n} w_i \times S_{KPI_I} \qquad (1.5)$$

Where IB_{Score} is the score of an intelligent building under assessment, w_i is the weight of the i^{th} KPI, S_{KPI_i} is the score of the i^{th} KPI ($0 \le S_{KPI_i} \le 100$), n is the number of KPIs. Chapter 3 and Chapter 4 give detailes about how to select KPI for the DAKIB assessment system, and how IB_{Score} can be exactly calculated and applied.

1.3.4 An Assessment System

Based on the quantitative model established in the previous step, a system for assessing intelligent buildings will then be established. As it is built on the DAKIB platform, it is called DAKIB system. The relation of DAKIB approaches for assessment and decision-making at pre-construction stage and post-construction stage is illustrated in Figure 1.2.

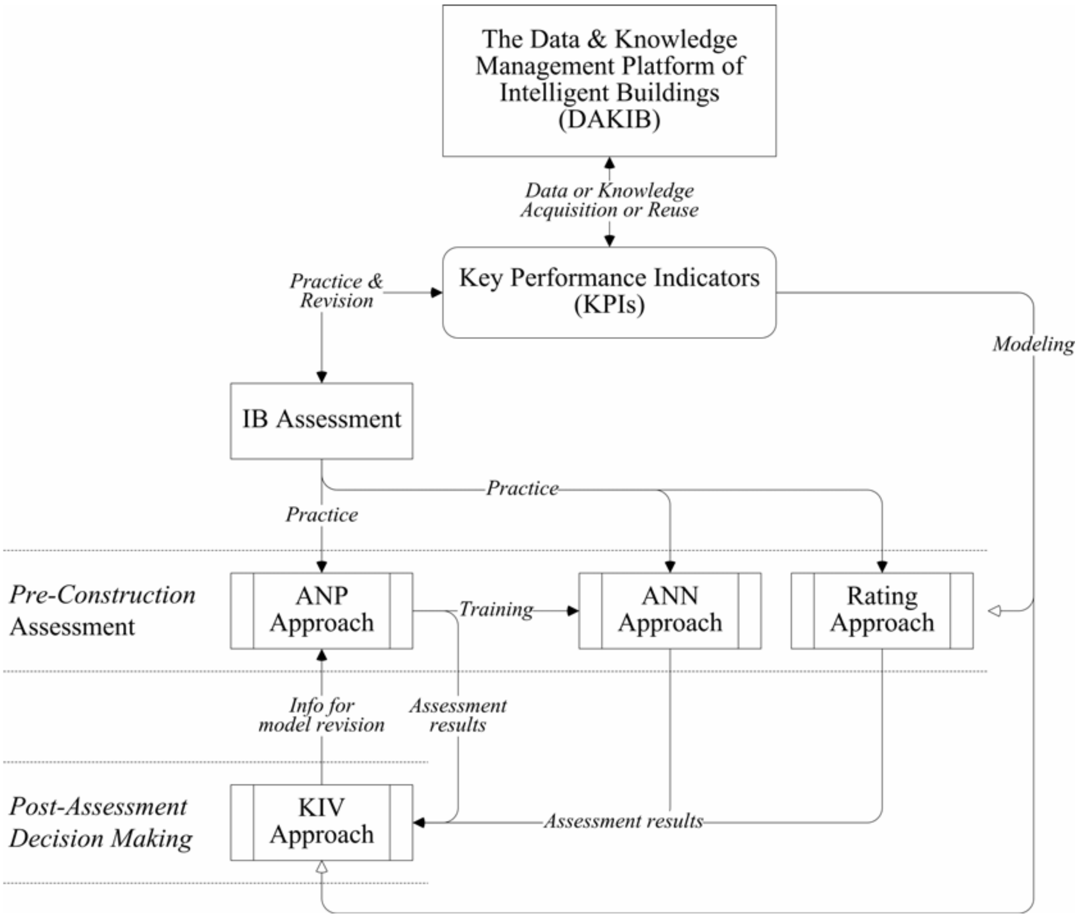


Figure 1.2 Relation of DAKIB approaches in assessment and decision-making

Traditionally, the assessment is mainly given to built ones. However, this study proposes a two-stage assessment system, including intelligent buildings assessment at pre-construction stage and intelligent buildings assessment at post-construction stage. The pre-construction assessment mainly concerns project feasibility study and design, which can have major influence on the layout of building and materials application. The post-construction assessment concerns mainly the operation, maintenance and management of a building, which can provide effective and efficient supports to decision-making on building and facilities management.

1.3.4.1 Decision-making at Pre-construction Stage

The preconstruction assessment concerns the functions and adequacy of various building elements including type of building, building function, environmental issue, and investment. The KPIs used for intelligent buildings assessment are multiple, including building type, system integration, function demand, time, and investment, etc. These KPIs are used to indicate the appropriate plan of building design, providing information for achieving optimal design.

1.3.4.2 Decision-making at Post-construction Stage

The assessment at post-construction stage or POE concerns similar elements such as the building type, building function, environmental issue, and investment. According to the fact of buildings' existence, the focus of POE will be given to provide relevant decision support for buildings maintainence and renovation. Moreover, the POE will also provide relevant information and data for knowledge reuse for the building professionals via the DAKIB system.

1.3.5 Applications

Case studies will be used to demostrate how to use the DAKIB system and its toolkits in the assessment of intelligent buildings, which have been built in previous research stages. It is planned to select three kinds of intelligent buildings as samples, including public building, office building, and residential building. In this dissertation, intelligent buildings selected mainly include

- The City of Manchester Stadium, Manchester, UK
- The Hong Kong International Finance Centre, Hong Kong, China
- Hong Kong Science & Technology Park (HKST Park), Hong Kong, China

However, as the purpose of this study is partially focusing on intelligent buildings assessment in China, more studies regarding the three types of buildings will be conducted respectively for cases from China.

1.4 Organization of the Dissertation

This dissertation consists of six chapters. All these chapters are organized according to their relationships with the objectives of the research. To start with the introduction to the integrative analytical approach to assessing intelligent buildings, the need for an integrative analytical approach is presented based on extensive literature review and questionnaire survey focusing on the development of intelligent buildings. After introducing an integrative methodology called the Data and Knowledge Management Platform of Intelligent Buildings (entitled DAKIB platform) (see Figure 2.1) for the knowledge-driven assessment of intelligent buildings, three practical toolkits, which are integrated in the DAKIB platform for assessment at different stages inside building lifecycle, are elaborated individually. Finally, case studies are conducted to demonstrate how to apply these analytic approaches in intelligent buildings assessment. Brief descriptions for each chapter are given below:

1.4.1 Chapter 2: An Integrative Methodology

This chapter describes a novel prototype of lifecycle information management and knowledge utilization of intelligent buildings and their assessment. There is a comprehensive summary of the types of information and knowledge of intelligent buildings in their lifecycle based on literature review and professional experience. Based on this prototype, this chapter originally introduces the concept of lifecycle information management and knowledge utilization of intelligent buildings. The lifecycle of intelligent buildings is divided into four stages, including architectural and structural design, examination and verification of building project, construction, and property management. The concept is then developed to an integrated model for web-based information supply and share, and some key points of the construction of an information platform and a knowledge system portal are discussed. It is expected that the integrated model can not only effectively support the information management and knowledge utilization of intelligent buildings, but also supply necessary data to a digital cities.

1.4.2 Chapter 3: An Analytic Network Process Approach

This chapter presents a multicriteria decision-making model for lifespan energy efficiency assessment of intelligent buildings. The decision-making model called IBAssessor is developed using an Analytic Network Process (ANP) method and a set of lifespan performance indicators for intelligent buildings selected by a new quantitative approach called Energy-Time consumption Index (ETI). In order to improve the quality of decision-making, this chapter will make use of previous research achievements including a lifespan sustainable business model, the IB Index (AIIB, 2005), and a number of relevant publications. Practitioners can use the IBAssessor ANP model at different stages of an IB lifespan for either engineering or business oriented assessments. Finally, this chapter presents an experimental case study to demonstrate how to use IBAssessor ANP model to solve real-world design tasks.

1.4.3 Chapter 4: An Intelligent Decision Support System Approach

This chapter presents a novel prototype of intelligent decision support system for intelligent buildings assessment. The prototype is called Tactical Intelligent Buildings Evaluation and Renovation (TIBER) model, which is developed to integrate an Artificial Neural Network (ANN) process with the IBAssessor ANP model in order to facilitate the adoptions of ANP approach in intelligent buildings assessment. In addition to the novel integration of ANP and ANN, a KPI based rating approach to intelligent buildings assessment is also introduced to further the impletation of DAKIB system.

1.4.4 Chapter 5: A Knowledge-based Information Visualization Approach

This chapter presents a Knowledge-based Information Visualization (KIV) approach to facilitating the implementation of building rating systems such as the IB Index (AIIB, 2005). A spreadsheet and a casebase of intelligent buildings have been developed to support the KIV process in intelligent buildings assessment.

1.4.5 Chapter 6: A Case Studies

This chapter presents several real case studies by using the analytical approaches developed in this dissertation. First of all, the City of Manchester Stadium is used to demonstrate the ANP approach in selecting the most appropriate alternative during building design stage. After that, the Kadoorie Biological Sciences Building (KBS Building) and the Hong Kong Science & Technology Park (HKST Park) are used to further demonstrate how to apply KIV approach for decision making in the post-assessment of intelligent buildings.

1.4.6 Chapter 7: Conclusions and Recommendations

An integrative analytical approach to intelligent buildings assessment has been developed in this study. The DAKIB platform (refer to Figure 2.1) comprises four analytical approaches including

- ANP approach,
- ANN approach,
- KIV approach, and

- Rating approach.

They are involved in two functional patterns, i.e. DAKIB Analysis and DAKIB Synthesis. The DAKIB Analysis pattern consists of the first two analytical approaches including ANP approach and ANN approach, whilst the DAKIB Synthesis consists of the last two analytical approaches including KIV approach and Rating approach. According to experimental case studies for applying these approaches, both DAKIB Analysis and DAKIB Synthesis can work together in an information pervasive environment for integrative assessment of intelligent buildings, and it is thus expected to provide a knowledge-based system for intelligent building design, construction, utilization, and education in the future development to assist all participants to effectively, efficiently and economically enhance the performances of intelligent buildings.

Chapter 2

AN INTEGRATIVE METHODOLOGY

2.1 Introduction

This chapter describes a novel system prototype of lifecycle information management and knowledge utilization of intelligent buildings. Based on the descriptions in Chapter 1, the proposed prototype is called DAKIB system. There is a comprehensive summary of the types of information and knowledge of intelligent buildings in their lifecycles based on literature review and professional experience. The system prototype originally introduces the concept of lifecycle information management and knowledge utilization about intelligent buildings. The lifecycle of intelligent buildings is divided into several joint stages, including architectural and structural design, project examination & verification, construction, and property management. The concept is then developed to an integrated model for web-based information supply and share, and some key points of the construction of an information platform and a knowledge system portal are discussed. In order to clarify the feasibility of applying the proposed DAKIB system in China, a questionnaire survey has been conducted to the Chinese construction sector. It is expected that the DAKIB system can not only effectively support the information management and knowledge utilization of intelligent buildings, but also supply necessary data to frameworks and entities of digital cities.

2.2 Background

It is the development and application of modern technologies in the areas of information, communication, materials, and machinery in the construction industry that facilitate intelligent buildings emerging and growing into fashion with high efficient devices and systems. The intelligent building is an organic integration of evolving architectural system, structural system, and facilities system of buildings. According to the extensive literature review, key technologies that support intelligent buildings include sustainable architecture, building structure control, building facility control, computer and network, information and communication, safety and security control, multimedia application, and structured cabling and comprehensive electrical system, etc. (Zhang, 1996; Yang, 2002; and Clements-Croome, 2004), which involve many subjects such as architecture, material, structure, construction, mechanization, computer and network, information and communication, and electrification, etc. throughout the lifycycle of intelligent buildings.

Accompanying the development of these modern technologies as mentioned above, the information management of intelligent buildings has been being paid high attention to. Turk (1988) put forward the concept of life-cycle information system for intelligent buildings, and made an information model for intelligent buildings which can be used for information management at four stages of intelligent buildings including planning, design, construction and utilization. In the middle of the 1990s, the Lawrence Berkeley National Laboratory, operated by the University of California for the U.S. Department of Energy, put forward the conception of life-cycle information management system for building performance assurance (Hitchcock, et al., 1997). However, this concept hasn't been put into practice to follow up the fast development of information and communication technology. As mentioned by Boyd (1994) Intelligent buildings aim to provide the most efficient utilization for occupants by means of using the most effective lifecycle resource management of buildings, most research into Intelligent buildings info management have focused on how to enhance levels of informationlization and automation at the utilization stage of buildings (So and Chan, 1999), and how to manage information at separated life-cycle stages of Intelligent buildings (Rojas and Songer, 1999; Hegazy, et al., 2001; Peña-Mora and Tanaka, 2002). For example, the Building Information System developed by the New York City Department of Buildings can only provide limited information (Lancaster, 2002). Based on an extensive literature, there is still no research into an integrated life-cycle information management of intelligent buildings. It is the initiative of my research to put forward an integrated methodology for lifecycle information management and knowledge utilization of intelligent buildings. Information here comprises both relevant data and knowledge. The methodology will be described by using a novel prototype based on a comprehensive summary of the information of intelligent buildings. The lifecycle of intelligent buildings is divided into three main stages, including design, construction, and utilization. The concept could be further developed into an integrated model for web-based information supply and share. It is expected that the integrated model can not only effectively support the information management and knowledge utilization of intelligent buildings, but also supply necessary data to frameworks and entities of digital cities.

2.3 An Integrated Prototype

2.3.1 DAKIB platform

The relevant information of intelligent buildings, hereafter called IB info, comprises all data and knowledge that can be collected from various stages of intelligent buildings such as design, construction, operation, and deconstruction etc. during their lifespan. Generally speaking, IB info is separately managed by various sectors in the construction industry. For example, architects may possess design information of intelligent buildings; contractors may maintain construction information of intelligent buildings, while facilities managers may hold operation information of intelligent buildings. In fact, it may take much effort to retrieve useful information for specified purposes such as intelligent buildings assessment from various sources if there is not an information pervasive platform to effectively and efficiently coordinate different ways of data or knowledge acquisition and reuse. In this regard, the concept of an integrated IB info management system is presented in Figure 2.1.

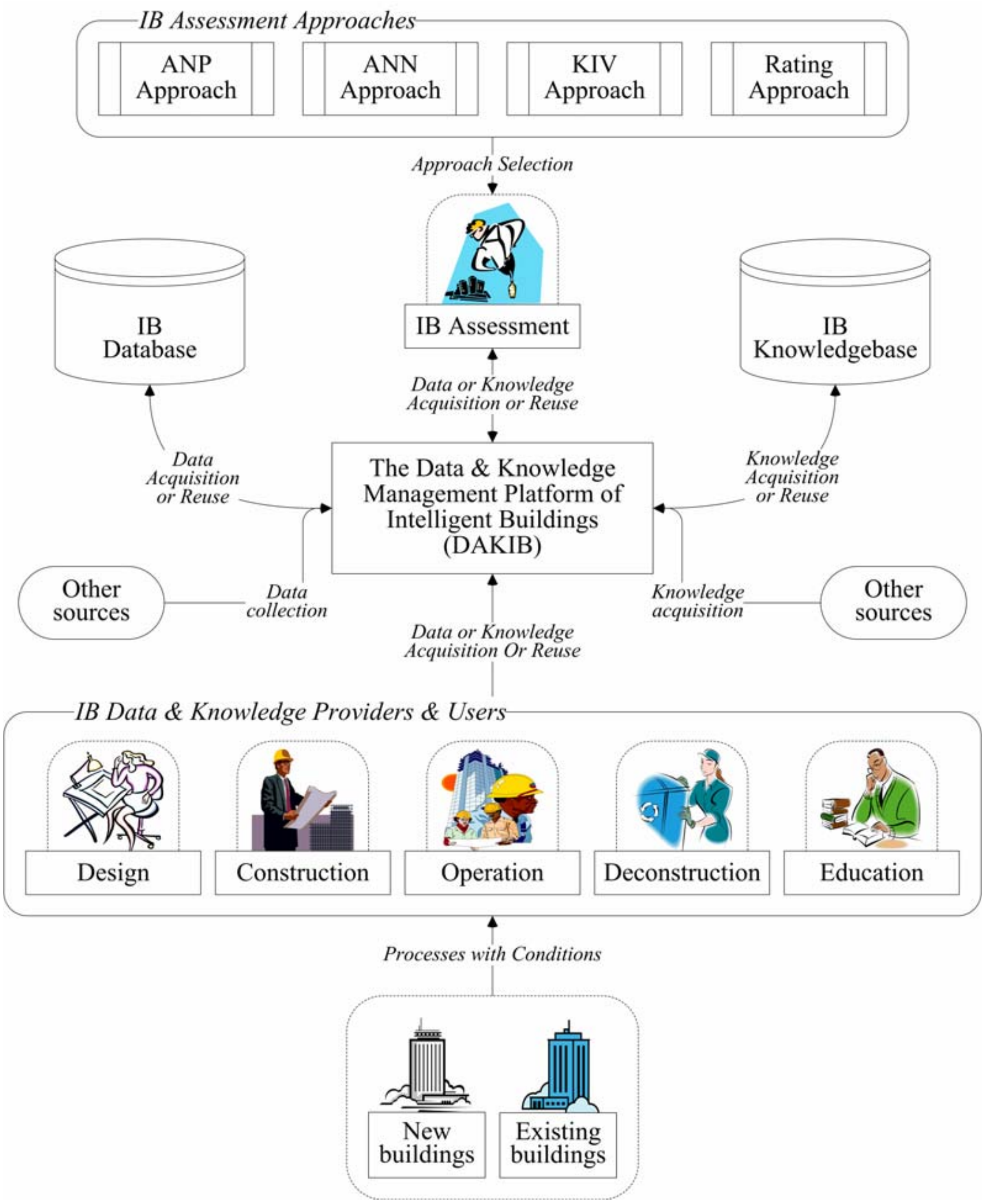


Figure 2.1 The prototype of knowledge-driven assessment of intelligent buildings

There are two purposes for introduce the integrated IB info management system prototype (see Figure 2.1). First of all, this model provides a conceptual design or an architectural plan for information management of intelligent buildings. In the meanwhile, it regulates the process of intelligent buildings assessment by using various approaches including the Analytic Network Process (ANP) approach (Saaty, 1996), the Artificial Neural Network (ANN) approach (Haykin, 1999), the Knowledge-based Information Visualization (KIV) approach (Spence, 2001), and commonly used building rating approaches, etc. As a result, all information relating to Intelligent buildings can be shared on the data and knowledge management platform, i.e. DAKIB platform supported by an IB database and an IB knowledgebase which are ultimately sustained by information acquired by knowledge workers from IB data and knowledge providers or users whose daily work focus on their design, construction, facilities management or study etc.

The intelligent buildings assessment requires effective tools to facilitate its process. As mentioned above, there are four intelligent buildings assessment approaches including ANP approach, ANN approach, KIV approach, and rating approach (see Figure 2.1, see further descriptions in Figure 5.1). Details about these tools are introduced below.

2.3.2 Rating Approach

The rating approach, generally called building rating method, relies on a series of factors/indicators related to the design and the performance issues together with their defined scales to rate intelligent buildings. Based on literature review, there are about six rating approaches specially designed for intelligent buildings assessment, including

- AIIB method (AIIB, 2005) developed by the Asian Institute of Intelligent Buildings (AIIB), Hong Kong, China,
- BRE method (Bassi, 2005) developed by the Building Research Establishment (BRE)

Ltd., UK,

- CABA method (CABA, 2004) developed by the Continental Automated Building Association (CABA), Canada,
- IBSK method (IBSK, 2002) developed by the Intelligent Building Society of Korea (IBSK), Korea,
- SCC method (SCC, 2002) developed by the Shanghai Construction Council (SCC), China, and
- TIBA method (Wen, 2003) developed by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan, China.

Among these six intelligent buildings assessment methods, there are six commonly used assessment clusters of indicators centring on Architecture, Engineering, Environment, Economics, Management, or Sociology. It has been further identified that the AIIB method, i.e. the IB Index (AIIB, 2005) is the most comprehensive one that covers all of the six assessment clusters, and the SCC method (SCC, 2002) is mostly focused on the one assessment cluster, i.e. Engineering. The CABA method (CABA, 2004) aims to benchmark the intelligent buildings assessment in a more general way but is still under construction. And the BRE method, i.e. MATOOL (Bassi, 2005) and the IBSK method (IBSK, 2002) have less coverage of assessment clusters than the IB Index. Therefore, the AIIB method is currently the most comprehensive method for intelligent buildings assessment. Other proposed intelligent buildings assessment approaches, i.e. the ANP approach (Saaty, 1996), the ANN approach (Haykin, 1999), and the KIV approach (Spence, 2001) will adopt indicators from the IB Index (AIIB, 2005).

2.3.3 ANP Approach

The ANP approach will employ a multicriteria decision-making model for intelligent buildings assessment in their lifespan. The decision-making model called IBAssessor is developed using an analytic network process (ANP) method (Saaty, 1996) and a set of key performance indicators of intelligent buildings selected by a novel quantitative approach called Energy-Time consumption Index (ETI) (Chen, Clements-Croome, Hong, Li, and Xu, 2006). As mentioned above, this Chapter make use of previous research achievements including the IB Index (AIIB, 2005), and a number of relevant publications in order to improve the quality of decision-making. Practitioners can use the IBAssessor ANP model at different stages of intelligent buildings lifespan for either engineering or management oriented intelligent buildings assessment. Case studies to demonstrate how to use IBAssessor ANP model to solve real-world design tasks will be conducted in other papers.

2.3.4 ANN Approach

The ANN approach will employ a novel prototype of intelligent decision support system for intelligent buildings assessment. The prototype is called Tactical Intelligent Buildings Evaluation and Renovation (TIBER) model (see Figure 3.2 and Figure 4.1), which is developed to integrate an Artificial Neural Network (ANN) process (Haykin, 1999) with the IBAssessor ANP model in order to facilitate the adoptions of ANP approach in intelligent buildings assessment. The ANN model will adopt the same group of key performance indicators adopted by the ANP model, and will be trained by using assessment results from ANP approach. Based on this agreement, the ANN approach can actually facilitate the application of ANP approach, which is too complex to be used by practitioners directly, but assessment results are more convinced than rating approach due to its consideration of interrelations among each two indicators.

2.3.5 KIV Approach

The KIV approach is to employ a Knowledge-based Information Visualization (KIV) (Spence, 2001) toolkit to facilitate the implementation of rating approach such as the IB Index (AIIB, 2005). A spreadsheet and a knowledgebase of intelligent buildings will be developed to support the KIV process in intelligent buildings assessment. The spreadsheet use Microsoft Excel with its figure function to visually show status of an intelligent building with respect to each of ten modules adopted by the IB Index (AIIB, 2005) including Green Index module, Space Index module, Comfort Index module, Working Efficiency Index module, Culture Index module, High-tech Image Index module, Safety and Structure Index module, Management Practice and Security Index module, Cost Effectiveness Index module, and Health & Sanitation Index module. The spreadsheet aims to establish correlations among an intelligent building with each of these ten modules based on its scores measured by the IB Index (AIIB, 2005). To further support cased based knowledge acquisition and reuse about intelligent buildings, all IB nodes on the spreadsheet will be linked to relevant cases inside an IB knowledgebase.

As a summary, the interrelations among these intelligent buildings assessment approaches can be summarized as followings:

- The ANP approach will use ETI to select a group key performance indicators from all indicators adopted by the IB Index (AIIB, 2005);
- The ANN approach will use the same group of key performance indicators adopted by the ANP model, and will be trained by using results from ANP approach;
- The KIV approach will use ten modules adopted by the IB Index (AIIB, 2005) as ten measurement dimensions for intelligent buildings assessment. Hyperlinks will be set up to link each IB node on the diagram of ten dimensions to an IB knowledgebase, where results from either ANP approach or ANN approach will be verified.

As illustrated in Figure 2.1, the DAKIB model is an integrative prototype based on these intelligent buildings assessment approaches, and it can be used to evaluate new designs or existing buildings. Moreover, it provides a platform for sharing information and knowledge among academics and professionals. It therefore summarys research tasks to be undertaken in this study, including research focuses on these assessment approaches and their relevant information and knowledge.

2.4 The Relevant Information of Intelligent Buildings

As mentioned above, the information of intelligent buildings including all relevant data and knowledge, are generally separately managed by various sectors in the construction industry. It will take much effort to collect enough information for intelligent buildings assessment regarding many indicators adopted by various assessment approaches. In addition, relevant information required for intelligent buildings assessment are generally in different ways of representations, and this will take much effort as well to regulate information with an uniform format for further use in intelligent buildings assessment. The adoption of the Data and Knowledge Management Platform of Intelligent Buildings (DAKIB platform) (see Figure 2.1) can definitely streamline the process of information acquisition and reuse in intelligent buildings assessment as well as IB info share across various sectors in the construction industry. Further to these particular applications, the DAKIB platform also has its potentials to provide reliable information to digital platforms and their entities for city management and urban development. Therefore, it is necessary to make a classification criterion about IB info management so as to facilitate the process of information acquisition and reuse in intelligent buildings assessment and other applications. According to the variety of information yield and reuse, IB info can be divided into the following three main types, including design information, construction information, and operation information, etc. Details about these three types of information are given below from Section 2.4.1 to 2.4.3.

2.4.1 Design Information

The design information of intelligent buildings comprises all sorts of information based on various design documents such as design contracts, blueprints, CAD files, and instruction booklet of designs, etc. which are yielded during the design stage of intelligent buildings but can be potentially useful and reusable in other building designs and building studies. Table 2.1 gives a description about the proposed standard classification of design information of intelligent buildings.

2.4.2 Construction Information

The construction information of intelligent buildings comprises all sorts of information based on various construction documentations such as construction contracts, official documents, bidding documents, assurance contracts, loan agreements, briefings of management team, sub-contracting teams and labor teams, construction diary or minutes, blueprints and CAD documents with alterations for new construction, order forms or bills of materials and equipments for construction, instruction booklets of processes, materials or equipments, and bills of resource consumptions during building construction, etc. which are yielded during the construction stage of intelligent buildings but can be potentially useful and reusable in other building construction and building studies. Table 2.1 gives a description about the proposed standard classification of construction information of intelligent buildings.

2.4.3 Utilization Information

The utilization information of intelligent buildings comprises all sorts of information based on various property management documentations such as property management contracts, official documents, bidding documents, assurance contracts, loan agreements, briefings of property management team, sub-contracting teams and labor teams, property management diary or minutes, blueprints and CAD documents with alterations for renovations, order forms or bills of materials and equipments for building renovation, instruction booklets of processes, materials or equipments, and bills of resource consumptions during building utilization, etc. which are yielded during the property management stage of Intelligent buildings but can be potentially useful and reusable in other building property management and building studies. Table 2.1 gives a description about the proposed standard classification of utilization information of intelligent buildings.

The standard classification and possible data format are discussed above with Table 2.1. All these discussions will be reviewed during system analysis and development. However, this is beyond the scope of this chapter. Regarding IB info acquisition, sharing and maintenance across the DAKIB platform (see Figure 2.1), further descriptions are provided below from Section 2.4.4 to 2.4.6.

Table 2.1 A standard classification about lifecycle information of intelligent buildings

Cluster	Sub-clusters	Elements
Design Info	**Code (D(i,0))**	**Code (D(i,j))**
	Geographical info	Address, etc.
	Geological info	Geological parameters, blueprints, and CAD files, etc.
	Foundation info	Blueprints, alterations, and CAD files, etc.
	Structure info	Blueprints, alterations, and CAD files, etc.
	Decoration info	Blueprints, alterations, and CAD files, etc.
	Water supply & draining info	Blueprints, alterations, and CAD files, etc.
	Heating & ventilating info	Blueprints, alterations, and CAD files, etc.
	Air supply info	Blueprints, alterations, and CAD files, etc.
	Electrical info	Blueprints, alterations, and CAD files, etc.
	Facilities info	Blueprints, alterations, and CAD files, etc.
	Design contractor info	Contracts, details about designers, etc.
	Other relevant info	To be confirmed.
Construction Info	**Code (C(i,0))**	**Code (C(i,j))**
	Design info	Blueprints and CAD files with alterations
	Official info	Environmental assessment report, commencement instructions, etc.
	Assurance info	Assurance contracts, bid bonds, etc.
	Loan info	Loan agreements, mortgage agreements, bid guarantees, etc.
	Bidding info	Bidding documents, book of tender, etc.
	Documentation info	Construction plans, progress reports, etc.
	Diary info	Parameters such as geometrical measurements, and Intensity target, etc.
	Material info	Parameters such as name, model, quantity, manufacturer, and wastage, etc.
	Equipment info	Parameters such as name, model, quantity, manufacturer, and depreciation, etc.
	Resource info	Water, electricity, labors, etc.
	Completion approval info	Completion report, sub-work reports, etc.
	Sub-contracting info	Sub-work contracts and other relevant documentations.
	Other relevant info	To be confirmed.
Property management Info	**Code (P(i,0))**	**Code (P(i,j))**
	Resource consumption info	Consumption parameters and bills to all consumptions.
	Waste discharge info	Quantities of life and office trash, sewage, and the places of discharge, etc.
	Renovation design info	Blueprints and CAD documents with alterations, etc.
	Renovation construction info	All relevant info in building renovation construction.
	Management info	Small personnel files for property management including building occupants.
	Other relevant info	To be confirmed.

Note: i is the number of sub-clusters, j is the number of elements from each sub-cluster.

2.4.4 Information Release

The information release will be undertaken by authorized information providers via the DAKIB platform (see Figure 2.1). Potential IB info providers are from various building sectors including Building Designers, Construction Contractors, Property Managers, Recyclers or Manufacturers, and Academic Educators, etc. An authorized information provider can use a unified web-based form to release relevant information within the scope of contents committed to DAKIB users' agreement. The agreement can ensure the DAKIB platform have unified formats of information which can help both information providers and information users to read and save their data and knowledge at their conveniences. As documents provided by different IB info providers may be in different formats, the DAKIB platform should have ability to transfer all uploaded files into agreed formats. In addition, the DAKIB platform should provide enough storage for IB info providers to save and manage their documents. Meanwhile, updated information will be transferred into the integrated database of DAKIB platform and be selectively put online for sharing in the real-time network environment.

2.4.5 Information Acquisition and Sharing

The information acquisition aims to collect data or knowledge from each life-cycle stage of intelligent buildings. The DAKIB platform, as described in Figure 2.1 and further developed in Figure 5.1, will be used as an open information system by its users potentially including Building Designers, Construction Contractors, Property Managers, Manufacturers, Recyclers, and Educators, etc. when they have new data or knowledge to share with the community or their peers. The users of the DAKIB platform are not only information providers but also information seekers or retrievers. For example, a Building Designer may use the platform to describe his/her design of an intelligent building; in the mean time, he or she may want to know more to improve a building design based on data and knowledge from other Designers, Construction Contractors, Property Managers, or even Educators. In this regard, the DAKIB platform will definitely provide effective, efficient and economical support. In fact, the function of information acquisition and sharing from the DAKIB platform can provide huge potential for us to manage IB info.

The information sharing of DAKIB platform is realized by allowing authorized users to search and retrieval relevant information. Generally speaking, the DAKIB platform will lead all potential participants from each life-cycle stage of intelligent buildings to release and to share relevant data and knowledge via Internet; and the process of information acquisition will follow an established agreement between the DAKIB platform and its users regarding the appropriate levels of users' rights in online information acquisition and sharing. This agreement can ensure the DAKIB platform have enough security and prevent contingent abuse. Therefore, the DAKIB platform is designed to provide five channels for information sharing, including design info channel, auditing info channel, construction info channel, property management info channel, and general info channel. Users can visit different info channels according to the level of their authorizations. In addition, the DAKIB platform will provide document menegement services for users too. The document management services include document storage and email etc. for each registrated user.

2.4.6 Information Maintenance

The information maintenance of DAKIB platform is undertaken by system administrators. System administrators will undertake maintenance work at both system level and content level, which means that the DAKIB platform will be operated by the system administrators who have sound knowledge and techniques about IT system maintenance and IB info acquisition and storage. As mentioned in Section 2.4.4, the unified formats of information are adopted by the DAKIB platform. In other word, the system will only accept multimedia IB info in unified formats, including text files, image files, video files, and audio files, etc. Users are required to adopt the unified formats in their daily work, or at least to upload their documents in unified format so as to reduce maintenance work and facilitate information sharing; meanwhile, system administrators will assist users to transfer uploaded documents from nontype formats into unified formats.

2.5 A Study into the IB Market in China

As this research project is partly funded by the China Electronic Standardization Institute, which focuses on an assessment system for intelligent buildings in China, it is therefore necessary to further investigate the market of intelligent buildings in China so as to further proof the feasibility of the DAKIB platform and its practical tools.

2.5.1 The Actuality of the Constriction and Real Estate Market

China has entered a fast developing epoch that's never been seen before. The nation's economy is increasing rapidly, along with huge improvements of people's living standard. Yet living situations are still expected to be improved in order to meet people's daily advancing requirements. Under this circumstance, the construction sector and the real estate sector are gradually becoming two supporting sectors in the Chinese national economy. According to the Chinese Department of Statistic, the construction and real estate sectirs have been developing fast and sound, and the real estate sector has undoubtedly become a supporting industry in China's economical development. According to the latest statistic data (China DoS, 2005), the investments to the Chinese real estate market was CNY1,010.6 billion in 2003, approximately 8.66% out of the national GDP (Gross Domestic Product) (CNY 11,660.32 billion) in the same year;

meanwhile, the Chinese construction industry has contributed CNY5,600 billion to the national GDP in the same year. Among the contributions from the Chinese construction industry in 2003, CNY2,300 billion was put into the nationwide infrastructure construction, about 20% of the GDP. The construction industry is also a fast developing industry with an increasing rate of more than 20% in 2003. On the other hand, all provinces and directly administered cities in China have regarded the real estate sector as their supporting industry for further development. According to the latest statistic data (China DoS, 2005), the investments to the real estate sector in Liaoning Province was CNY48.62 billion in 2003, about 8.10% of its local GDP (CNY600.25 billion); in Guangdong Province, it was CNY120.99 billion, about 9.00% of its local GDP (CNY1344.99 billion); in Beijing, it was CNY69.24 billion, about 19.17% of its local GDP (CNY361.19 billion); and in Shanghai, it was CNY72.02 billion, about 13.17% of its local GDP (CNY546.88 billion). To achieve these significant developments, there have been more than 60,000 construction enterprises and more than 10,000 survey and design companies in the Chinese construction and real estate industry.

However, a huge amount of construction projects across the country has also brought about the problem of over developing in China. Both central and regional governments have taken actions to deal with the proble. Some regional governments have provided affordable houses to decrease the prices of houses, and the central government has provided new rate of interest for individual's house purchasing loan, also restricted the developers' loan for commercial houses. These kinds of policies aim to keep the development of real estate industry in a favorable circumstance and the development seems sound as a whole. The Ministry of Construction of China has estimated that in the near future, the nationwide completed housing area will reach 5.7 billion square meters, which indicates that China has a bright future and a huge stage for building intelligentization. The building intelligentization market is swiftly developing thanks to the large amount of construction projects around the country, providing people with more comfortable working and living places. It promises a brilliant future with the promotion and supports from the central and local governments, including the Minitry of Construction, the Department of Science and Technology, and the Department of Information Industry.

2.5.2 Analysis of Housing Intelligentization Market

2.5.2.1 Size

According to the national authoritative Technology Bureau of the Ministry of Construction, the market of building intelligentization in recent years is advancing at a very high speed, above 20% every year. The market scale was CNY10.23 billion in 2002, CNY12.56 billion in 2003, and CNY16.01 billion in 2004. The Technology Bureau of the Ministry of Construction has estimated in 2005 that in the coming few years, with the fast development of the construction industry and the gradually improvement of people's living standard, the market of building intelligentization will continue developing quickly.

2.5.2.2 Intelligent Systems

The intelligentization of domestic buildings can mainly be divided in to the following three systems, including security system, intelligent control system, and adminiatration system. A detailed classification is given below:

- Security System
    - Administration of in and out
    - Public monitoring
    - Perimeter exceeding-proof
    - Electronic patrol over the night

- Electronic map for security
- House security
- Visible interphone
- Unit gate security

- Intelligent Control System
    - Emergency broadcasting and background music
    - Lighting control
    - Facility monitoring
    - Administration in parking lots
- Administration System
    - Community administration
    - Information service
    - One-stop expenditure balancing
    - Electronic inquiry

Survey reveals that among the more than 190 projects completed by Xidong Company and other companies in the Chinese market, the Security System is regarded as the most acceptable Intelligent System by both clients and developers, which takes up 79.3% of the total number of intelligent systems installed in residential communities, followed by the Intelligent Control System (15.1%) and the Administration System (4.6%).

2.5.2.3 Mass Observation

Based on the *2004 Questionnaire Survey on Community and House Intelligentization* (China ASD, 2004) released by the national authoritative Association of Survey and Design in China, which focused on the investment situation in intelligent community, function collocating, products choosing and other hot issues, a questionnaire survey was conducted (see Appendix 2). This questionnaire objectively reflects the present situation of intelligent buildings in China. 435 questionnaires were distributed and 429 of them are valid. As the questionnaire survey is supported by the Association of Survey and Design, the survey has got a high response rate, i.e. 98.6%. Respondents mainly come from design units, real estate companies, system integration companies, construction companies, consulting units, and community administration units, etc. from total 302 enterprises. The following data shows the result of this mass observation. Table 2.2 describes a profile of respondents to this questionnaire survey.

Table 2.2 The number of respondents to questionnaire survey (refer to Appendix 2)

Unit	No. of Units	Percent (%)	No. of People	Percent (%)
Designer	190	44	156	36
Developer	43	10	43	10
Contractor	59	13	65	15
System Supplier	36	8	43	10
Consultant	12	3	17	4
Manufacturer	82	19	96	22
Property Manager	10	2	10	2
Others	3	1	5	1
Total	435	100	435	100

2.5.2.4 Concerns from the Central Government

According to the literature review, it reveals that the central government has many concerns about the building industry in China. For example, the Ministry of Construction released *Brief on Demonstrating Projects of Intelligent Systems in Residential Communities in China* in April 1999; the

Construction Main Points and Technology Instruction of Demonstrating Projects of Intelligent Systems in Residential Communities in China was established in October 1999; the setup of seven sample residential communities, including the *Huijingxincheng* in Guangzhou, and the *Yihai Garden* in Shanghai to domestically demonstrate communities using Intelligent Systems was approved in March 2003; the *Construction Main Points and Technology Instruction of Intelligent Systems in Residential Communities* was released on 17 March 2003. From then on, most intelligent residential communities around the country are designed, built, and operated according to these governmental instructions. Meanwhile the intelligent residential community is basically becoming more and more mature, although there are still huge spaces for further development. Anywise, it has become the trend for developing new residential communities in China. Table 2.3 indicates that most intelligent residential communities in China have been just completed in the past one to three years, i.e. after 2001, which indicates that it is becoming prevalent recently. This prevalence also suggests that the intelligent industry needs gradually to be transformed to be more normative and promising, which will finally benefit the consumers of the intelligent residential communities.

Table 2.3 The history of intelligent residential districts in Shanghai

Status	More than 3 years old	Between 1 to 3 years old	Less than 1 year old	Under construction	All of these
Percent (%)	8.8	15.2	40.0	20.0	16.0

2.5.2.5 Recognitions

During the questionnaire survey, some developers expressed that owners could hardly understand the importance of intelligent systems to a modern residential community in 2000, but they finally found out the comforts that intelligent systems had brought to them, along with real economical benefits. As a result, owners have begun to pay more attention on intelligent systems for their homes, and it is believed that more and more people will be keen to intelligent systems integrated inside residential communities (see Table 2.4).

Table 2.4 The acceptance of intelligent residential districts from clients

Attitudes	High attention	Care	Notice	Don't mind
Percent (%)	11.4	49.6	32.5	6.5

According the questionnaire survey, 60% of people care or pay high attention to intelligent systems for domestic utilization. Regarding changes to intelligent systems, 24% of people thought "more and more investment has been put into it", which is a result of the exaltation of acceptance from the clients (see Table 2.5). Most people agreed to "more professional", which indicates that developers need to care advanced technologies, and the government need to control the market effectively and efficiently.

Table 2.5 The development of intelligent systems for residential buildings from clients

Status	More functions	More investment	More standardization	More market potential	No significant development	Others
Percent (%)	21.6	24.0	31.0	21.1	1.7	0.6

Regarding the size of investments that have been put into intelligent residential communities with integrated intelligent systems in China, the questionnaire survey provides some reference data. Table 2.6 summaries the size of total investment put into intelligent resisential communities; while Table 2.7 gives the proportion of investment put into intelligent systems comparing with total investments. Although data from the whole market might vary, these survey results actually provide reference data for understanding the overall situation of investments put into intelligent residential communities in China. It has been noticed that the amount of investments varies according to the size of projects, the level of standards, and the brand of facilities, etc.; in addition, less than 12% of total investments have been put into intelligent systems in more than 90% projects, which reveals that developers are actually prudent in developing intelligent residential buildings in China. According to literature review, the selling price of intelligent buildings is CNY8,000~20,000 per square meters, which is much higher than ordinary buildings, in big cities such as Shanghai, Beijing and Shenzhen. The reason why intelligent buildings were welcome on the market is because buyers believe that these buildings can improve their residential conditions. However, data analysis about standards of facilities adopted in intelligent buildings indicates that there are only 5.7% buildings have higher-standard intelligent facilities, and most buildings (94.3%) actually use medium or low-standard ones. In this regard, developers have to care the developing stream of intelligent buildings to provide more comfortable residential environment; currently, most developers adopt low-level products (see Table 6 and Table 7) and put them into small residential projects to gain short-term profits.

Table 2.6 The investments to intelligent residential communities

Investment (1 Million CNY)	>1,000	800~1,000	500~800	300~500	<300	Others
Percent (%)	2.7	3.6	10.7	31.2	42.0	9.8

Table 2.7 The investments to intelligent systems in residential communities

Percentage of the cost of intelligent systems (%)	1~4	4~8	8~12	12~18	18~22	Others
Percent (%)	29.2	42.5	18.6	3.5	1.8	4.4

Regarding the recognition of intelligent systems used for residential communities, Table2.8 provides a summary based on the questionnaire survey. It actually clarifies the diversity of clients' requirements. As intelligent buildings aim to provide people a safe, comfortable and convenient living space, so a powerful function of security is required (see Table 2.8).

Table 2.8 The attractions of intelligent systems in residential communities

Rank	Item	Percent (%)
1	House Alarm Equipment	14.2
2	Broadband Entrance	12.2
3	Interphone for Visitors	10.8
4	Wired TV	10.6
5	Exceeding-proofing Equipment	9.0
6	Automatic Registering and Recording Equipment	6.5
7	In-and-out-vehicle and Parking Managing	6.5
8	Cable TV	6.3
9	Equipment Monitoring	4.7
10	Community Managing	4.5
11	Broadcast and Background Music	4.3
12	Telephone System	4.3
13	Electronic Patrol over the night	3.7
14	Others	2.4

2.5.2.6 Market sharing

Data analysis reveals that 78.4% intelligent residential communities have been built by system integration providers, and only 21.6% intelligent residential communities have been set up by developers themselves. Regarding facilities adopted in those intelligent residential buildings, 77.3% of them are individual facilities, others are systematically integrated. In China, the most important system integration providers are Shenyang West-East, Tsinghua Tongfang, Tsingtao Haier, and Shenzhen Jiaoda Technology, etc. These companies rely on universities and research institutions so that they have higher ability of techniques and knowledge, and actually power upon the development of intelligent residential communities in China.

2.5.2.7 Several Problems

There are several problems emerged from the literature review and the questionnaire survey, including the problem of integrative design, the problem of high cost, and the problem of intelligent products, etc. All these problems are discussed below.

The first problem is that there are not enough considerations regarding the integrated implementation of intelligent systems to buildings or communities, most designers currently pay attention to separated intelligent equipments or facilities only. To achieve the final objective of intelligent buildings, the integrative design of intelligent systems is essential; however current intelligent buildings in China are mostly designed as simple combinations of the products and functions of electronic, automatic and communicating technology, without the consideration for the houses' basic structures, materials, equipment maintaining, and the environment. As a result, it is difficult to show what real intelligent buildings are and what they can bring for people to have more advantages. Moreover, digital cities are under construction in China, which require high-level integration of building systems. In this regard, the integrative design of intelligent buildings is very important in China. Currently, few Chinese domestic companies in the area of intelligent buildings followed up the concept of digital city to go for basic platforms of digitalized community, which is essential for digital cities. The WestEast Company in Shenyang is among these pioneers with strong confidence in designing intelligent communities using digital technology to provide services in integrative design and construction.

The second problem is that the costs of the construction and the maintenance of intelligent domestic buildings are high. This problem is relevant to the lack of integrative considerations in buildings design. Each of the sub-systems inside the community has different product quality, operation platform and different degree of operation difficulty, which results in maintaining difficulties and rising of the basic cost (see Formula 2.1).

$$IB_{Cost} = C_{Initial} + C_{Use} + C_{Maintenance} + C_{Renovation} - S_{Lifecycle} \qquad (2.1)$$

Where IB_{Cost} represents the cost of an intelligent building or an intelligent residential community, $C_{Initial}$ represents the total initial investment input to the intelligent building or the intelligent community, C_{Use} represents the running cost required for the building or the community during the period of occupancy and utilization, $C_{Maintenance}$ represents the expenses for maintaining the building or the community during the period of occupancy and utilization, $C_{Renovation}$ represents the expenses for renovating the building or the community during the period of occupancy and utilization, and $S_{Lifecycle}$ represents all kinds of actual cost savings, profits, or benefits that can be achieved due to utilizing the building or the community.

Regarding the development of intelligent buildings, basic cost calculation is most important. Houses are built for their consumers, and consumers may pay much more attentions to the basic quality of their houses other than their additional functions. Therefore, if the cost of additional functions is too high, these functions will be given up.

The third problem is that products currently used in intelligent buildings in China are still monotone and very complicated to operate. Presently, products that are used in house management mainly consist of data collecting modules, security modules, and household appliances controlling modules, and communicating network modules. These controlling equipments have a lot of inconsistency with the products that are to be controlled. However, now there are only a minimum number of manufacturers who can make products and their controlling equipments with exactly the same consistency. Now the intelligent products' compatibility and their ability to be upgraded are very limited. These all make the products complicated to operate.

2.5.3 Investigation on Domestic Market and Manufacturers

2.5.3.1 Situation of Domestic Interphone Manufacturers

In the domestic intelligent market, most of the products are made by manufacturers who first begun with the interphone business. According to an online investigation by the national security and products Web, these kinds of products have occupied 31.6% of the market. Their manufacturers are the several hundred leading enterprises of intelligent product making in our country. Some of these companies have enlarged their sizes and occupied high percents of the market. For example, companies such as Shide'an, Lilin, Anjubao, and Zhenwei are all have capabilities to produce 500,000 visual and un-visual interphones per year, which worth about CNY150~200 million. These leading companies have better bases and stronger capability of product inventing. However, their products often lack innovation because they are usually limited by their history of interphone making.

Table 2.9 The market of intelligent systems for residential buildings

Rank	Supplier	Percent (%)
1	Intercom products	31.6
2	System integration	23.7
3	ITC services	16.3
4	Domestic electric appliances	13.6
5	Foreign profucts	7.9
6	Others	6.9

2.5.3.2 Situation of Domestic System Integration Companies

There are also system-integration companies who do mainly system integration business, and when the technology is mature enough, they develop to invent products. The WestEast Company in Shenyang has its products already occupying 23.7% of the market. This kind of company is a new stream who've made good use of its advanced technology and quickly developed into a big-in-size enterprise. These companies have a very clear cognition of the industry that they are in, and are good at technology because most of them have strong capability doing projects. So their products meet the market's demand better than others. However, the products still need further quality promoting for the manufacturers are not industrial enough. Besides, domestic enterprises of IT business such as Tsinghua Tongfang and Shenzhen Jiaoda Technology stand for a stream, who have advantages in strong ability of technology and inventing. Their techniques stick to the latest market trend but still need improving. These companies have occupied 16.3% of the product market.

2.5.3.3 Situation of Enterprises of Domestic Household Electronic Appliances

Some civil leading enterprises such as TCL and Haier have also realized the big market of intelligent houses. So they've also produced their own household intelligent appliances. However, because they are doing business which is not their specialty, they are not devoted enough into the market. They only occupy 13.6% of the market. But the economical strength and selling networks of these companies should never be despised.

2.5.3.4 Situation of Overseas Enterprises

Several overseas enterprises such as Samsung of Korea, DSC of Canada, and CK of Israel have had their products imported into China's domestic market since as early as 1990s. Their products have excellent functions and good stability. But the products' high prices make the companies popular and leading only in middle and higher leveled market. They occupied 7.9% of the market, others occupy 6.9%. Presently most of China's manufacturers of intelligent products are developing at a very high speed, and the intelligent market is quickly extending. Under the good situation of the fast and sound growth of China's economy, the intelligent product market will enter a overall fast growing stage in the coming few years.

Regarding technology platforms used for domestic intelligent products, manufacturers mainly use three kinds of technology platforms, including RS485 (72%), TCP/IP (23%), and LONWOER (5%). Now RS485 is the mainstream and most products are realized using this platform. It is regarded that TCP/IP represents the springing new technology and new trend; moreover, professionals have to pay much attention to technology used in future higher standard products, such as Bluetooth technology, super broadband UVW and so on.

2.5.4 High-Standard (Top-Grade) Products

Besides broadband connection that relates to most people's working and living, security systems are also highly concerned by people (see Table 2.8). Compared to living comforts and individual functions, security issues attract much more attention from the consumers in China. Most Chinese people will not pay much attention to any additional function unless their security is promised and they have enough money. However, this does not mean that top-grade products have no market in China. In recent years in the market of intelligent community, we can see that in big cities whose economy is better developed; top-grade villa communities and higher standard department communities have adopted top-grade intelligent residential products (including some world famous brands like Samsung and AB). But the use of higher standard products differs a lot in different regions. The main reason is that now China's economy is developing without balance. Cities along the coastline and the directly administered cities have developed better than cities in middle and western China.

Based on the investigation on these products, it has been found that family intelligent wire installation is the foundation of setting up household network, which not only connects people's homes with the broadband network, but also can be settled down at any place according to your individual plan. It in company with the household network barrier and the 3 kinds of networks (broadband network, household internet and household controlling network) compose the intelligent house. As summaried in Table 2.10, it is easy to see that people's need for some top-graded functions. Nowadays China's market of top-graded products occupy about 5% of the whole market, which is about CNY800~1,000 million, with a growth of 30~40% per year. As the 2008 Beijing Olympic Game and the 2010 Shanghai World Exposition Conference are approaching, a huge number of higher standard real estate projects are being and going to be finished. So the high-standard intelligent products market actually has a bright future. It is believed that the market of top-graded products will enter its fast growing period very soon and till 2010, it will have expanded to worth CNY6~7 billion.

Table 2.10 The attention to top-grade intelligent systems for residential buildings

Rank	Products	Percent (%)
1	Visible interphone and gate controlling	26.4
2	Household intelligent wire installation	24.9
3	Household security network	23.8
4	Intelligent long-distant recording	10.3
5	Residents' information collection	8.1
6	Intelligent remote controllers to household electronic appliances	6.5

Table 2.11 shows different degrees of acceptance to the costs of intelligent household controlling systems. It has been noticed that up to 3.8% of people accept the cost of more than CNY5,000. This table basically reflects the present domestic acceptance for the systems; in other word, the affordability of intelligent systems is still a question need to be concerned.

Table 2.11 The acceptance to intelligent system for residential buildings

Rank	Cost (CNY1,000)	Percent (%)
1	1~3	53.7
2	3~5	25.9
3	<1	16.6
4	5~10	1.9
5	>10	1.9

Table 2.12 shows different degrees of concerns on the functions of household intelligent systems. It has been noticed that most people pay attention to the family guard, namely the security and alarm function. Household electronic appliances controlling also attracts much attention. According to this result, there might be a huge market for household electronic appliances to have controlling connecting-port integrated.

Table 2.12 The attention to the functions of intelligent system for residential buildings

Rank	Items	Percent (%)
1	Family guard (Security Alarm)	36.1
2	Family nurse (Monitoring the elderly and the young)	17.2
3	Long-distance monitoring	14.4
4	Remote controlling to household electronic appliances	13.5
5	Promulgating short messages	9.8
6	Designing and controlling of the lighting mode	9.0

Table 2.13 provides a summary about opinions on the potentials of intelligent systems. Table 2.14 provides a summary about opinions on the potentials of applying wireless technology in intelligent household products. Table 2.15 shows different proportions of application software used in intelligent systems. Based on these survey results, it has been noticed that Chinese domestical products still have imperfections in their compatibility, product diversity and function diversity. As people pay much attention to energy saving, there are hugh potentials for developing new intelligent products.

Table 2.13 The potentials of intelligent systems for residential buildings

Rank	Items	Percent (%)
1	Safety guard	33.9
2	Energy saving	29.2
3	Family well-being	26.8
4	Lighting	10.1
5	Others	0.0

Table 2.14 The potentials of wireless intelligent systems for residential buildings

Rank	Items	Percent (%)
1	Bluetooth	36.3
2	WLAN	29.4
3	UVW	27.4
4	Zigbee	3.9
5	HomeRF	2.0
6	Others	1.0

Table 2.15 The applications used in intelligent systems for residential buildings

Rank	Applications	Percent (%)
1	Microsoft Windows	81.0
2	Linux	15.0
3	Others	4.0

Based on above analyses on the situation relevant to the development of intelligent buildings in China, it could be concluded that the market is growing fast, and customers also have a wide range of requirements such as top-grade intelligent sustems and affordable products. As a matter of fact, a huge potential of developing intelligent buildings exists in China; where governmental departments are making regulations to control the market, developers are keen for new intelligent buildings, suppliers are keen to make innovative and high-standard systems, and consumers are keen to find satisfied new homes. Under this circumstance, a realiable system for intelligent buildings assessment is becoming necessary in order to make a general measurement for each participant to be able to evaluate intelligent building products and make their decisions.

2.6 Conclusions

This chapter presents a novel prototype of life-cycle information management of intelligent buildings. The research has been conducted based on an extensive literature review and solid professional experience of experts'. The usefulness of this model and standard format of information has been discussed. This model can be further used in system analysis and development of a web-based DAKIB platform, and to support effective intelligent buildings assessment.

In addition, the questionnaire survey conducted to the Chinese construction industry gives background information regarding further analysis and development of the DAKIB platform and its toolkits, as the DAKIB system will be used to evaluate intelligent buildings in China too. Based on the literature review, it has been noticed that currently used building rating systems have limitions in KPIs description; for example, they do not allow users to measure interrelation between two indicators; and in building scoring, which are mostly based on subjective judgements by single auditor. Detailes about these limitations will be discussed in Chapter 3. The questionnaire survey indicates that the intelligent buildings assessment need to overcome these limitations because the the circumstance of intelligent buildings are too complex to be accurately measured by a single subjective assessment. In this regard, a DAKIB-driven total intelligent buildings assessment is expected to be more effective and efficient to support decision-making for all participants from each relevant stage, including design, construction, operation, deconstruction, and education.

Chapter 3

AN ANALYTIC NETWORK PROCESS APPROACH

3.1 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 (USGBC, 2005) 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 (JSBC, 2004) 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. (Anderson, Shiers, and Sinclair, 2002) 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 are also under assessment according to their related characteristics and actual circumstances. For example, the Asian Institute of Intelligent

Buildings (AIIB) (AIIB, 2005) from Hong Kong developed an IB Index system to specifically assess the performance of intelligent buildings; and the BRE developed a matrix tool called MATOOL for assessing the performance of intelligent buildings (Bassi, 2005). Although a new international benchmark of intelligent buildings assessment is under developing by the Continental Automated Building Association (CABA, 2004) in Canada, there is not a standard sustainable IB assessment tool, and this leads to the research being presented in this chapter.

Based on current practice in building assessment, this chapter presents a multicriteria decision-making model using the analytic network process (ANP) (Saaty, 1996-2001) to evaluate the lifespan energy efficiency of intelligent buildings. To undertake this task, this chapter firstly reviews building assessment systems currently adopted in Australia, Canada, Hong Kong, Japan, Korea, mainland China, Netherlands, the United Kingdom and the United States. A quantitative indicator selection approach to energy-time consumption during building lifespan is proposed based on a Strategic Intelligent Building Evaluation and Renovation (SIBER) model, which is a development of the *Through Life Environment Business Model* developed by the University of Reading for lifecycle assessment (Clements-Croome, 2004). Under the SIBER model, this chapter further developed a Tactical Intelligent Buildings Evaluation and Renovation (TIBER) model, and from which an ANP model named IBAssessor is then structured based on a group of key performance indicators (ABS, 2004), which are selected through a proposed quantitative approach called energy-time consumption index (*ETI*). In order to further exam the effectiveness of IBAssessor, an experimental case study is finally conducted with detailed calculation and evaluation procedures. The paper concludes that auditors can use the IBAssessor when it is necessary to evaluate the lifespan energy efficiency of intelligent buildings and therefore select the most appropriate building.

The significant contributions of this chapter include a quantitative approach to KPI selection based on energy-time analysis, a set of criteria applied to intelligent buildings assessment regarding their lifespan performances of energy efficiencies, and an ANP model for lifespan energy efficiency assessment in intelligent buildings design, construction and operation. Meanwhile, the evidence to be presented in this chapter include the SIBER model for building lifespan performance management; the TIBER model for intelligent buildings assessment; the energy-time analysis based quantitative approach to KPI selection; the ANP model for selecting the most appropriate IB alternative based on lifespan energy-time consumption analysis; and an experimental case study. It is my expectation that practitioners including managers and auditors can use the proposed IBAssessor for energy efficiency assessment in intelligent buildings design, construction and operation.

3.2 Assessment Methods

According to the latest literature (Clements-Croome, 2004), an intelligent building 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. Intelligent buildings 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, intelligent buildings 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, intelligent buildings 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 intelligent buildings. There are three main kinds of assessment methods including building rating, computer simulation and facilities management (Clements-Croome, 2004). 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 intelligent buildings. The simulation method uses artificially settings based on real-world data from the operation of intelligent buildings. The facilities management method use experts' knowledge to achieve goals in practical intelligent buildings design, construction and operation. The applications of the first two kinds of assessment methods can be at either design or operation stage of any intelligent buildings under evaluation, while the third method can be applied at all stages of the life cycle of intelligent buildings.

This chapter conducts an extensive literature review on conventional building assessment systems in order to extract a group of indicators for the proposed ANP model. Current building assessment systems under review include:

- Assessment Standards for Certifying Intelligent Buildings (ASCIB, by Intelligent Building Society of Korea (IBSK), Seoul, Korea) (IBSK, 2002),
- Building Quality Assessment (BQA, by Building Economics Bureau, UK),
- Building Research Establishment Environmental Assessment Method (BREEAM, by Building Research Establishment Ltd. (BRE), UK) (Anderson, Shiers, and Sinclair, 2002),
- Building Sustainability Assessment Tool (BSAT, by the Department of Trade and Industry, UK) (Sayce, Walker, and McIntosh, 2004),
- Building IQ Rating Criteria (BIQRC, by Task Force 1 - Intelligent Building Ranking System, Continental Automated Building Association (CABA), Ottawa, Canada) (CABA, 2004),
- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, by Japan Sustainable Building Consortium (JSBC), Japan) (JSBC, 2004),
- Design Quality Indicator (DQI, by Construction Industry Council, UK),
- Environmental Performance Express of Buildings (Eco-Quantum, by IVAM, Netherlands),
- Assessment Framework & Green Building Tool (GBTool, by the International Initiative for a Sustainable Built Environment (IISBE), Canada) (Cole, 2002),
- Green Mark for Buildings (GMB, by Building and Construction Authority, Singapore) (GMB, 2005),
- Hong Kong Building Environmental Assessment Method (HK-BEAM, by HK-BEAM Society, Hong Kong) (HK-BEAM Society, 2004),
- IB Index (by Asian Institute of Intelligent Buildings (AIIB), Hong Kong) (AIIB, 2005),

- IB Rating (by Shanghai Construction Council (SCC), Shanghai, China) (SCC, 2002),
- Leadership in Energy and Environmental Design/Green Building Rating System (LEED, by U.S. Green Building Council, USA) (USGBC, 2005),
- A matrix tool for assessing the performance of intelligent buildings (MATOOL, by Building Research Establishment Ltd. (BRE), UK) (Bassi, 2005),
- National Australian Built Environment Rating System (NABERS, by Department of the Environment and Heritage, Australia) (DEH, 2004),
- Office Scorer (Sustainable Refurbishment/Redevelopment Decision Support Tool for office buildings, Building Research Establishment Ltd. (BRE), UK) (Anderson and Mills, 2002),
- Sustainable Project Appraisal Routine (SPeAR, by Arup, UK) (Arup, 2002), and
- Sustainability Checklist (Assessment of the social, environmental and economic impact of a proposed development, by the South East England Development Agency (SEEDA), UK) (Amato, 1996).

According to the literature review focusing on the building assessment systems, it has been 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 (USGBC, 2005). 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 (Anderson, Shiers, and Sinclair, 2002; Dickie, and Howard, 2000).

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 (NHER, 2004). 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 intelligent buildings 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 intelligent buildings assessment, and there are some new rating systems under development as well. Table 3.1 gives a summary of representative methods based on current practice in intelligent buildings assessment. According to the literature review, it has been identified that there are seven assessment clusters of indicators which focus on Architecture, Engineering, Environment, Economics, Management, or Sociology. Among the six intelligent buildings assessment systems listed in Table 3.1, the AIIB method, i.e. IB Index method (AIIB, 2005) is the most comprehensive one that covers all of the seven assessment clusters, and the SCC method (SCC, 2002) is mostly focused on the one assessment cluster, i.e. Engineering. The CABA method (CABA, 2004) aims to benchmark the assessment of intelligent buildings in a more general way but is still under construction. And the BRE method, i.e. MATOOL (Bassi, 2005) and the IBSK method (IBSK, 2002) have less coverage of assessment clusters than the IB Index. Therefore, the

AIIB method is currently the most comprehensive method for intelligent buildings assessment.

Table 3.1 The main categories of criteria adopted in rating methods for IB assessment

Assessment clusters	Main modules by each assessment system					
	AIIB method (AIIB, 2005) (Hong Kong, China)	**BRE method** (Bassi, 2005) (UK)	**CABA method** (CABA, 2004) (Canada/USA)	**IBSK method** (IBSK, 2002) (Korea)	**SCC method** (SCC, 2002) (Shanghai, China)	**TIBA method** (Wen, 2003) (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	-	-	-	-	-

3.3 Limitations of Current Building Rating Methods

One problem of current 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 intelligent buildings. For example, AIIB method adopts 29 sub-indicators to assess the performance of lift and escalators (AIIB, 2005); however, there is not a practical guide regarding how to compare two designs for one intelligent building project if one uses a lift but another does not. 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 (IBSK, 2002) uses *occupation area for one person* (occupation density) as one indicator to assess the *Architectural Design* of intelligent buildings, and the building with larger occupation area (a low occupation density) will get a higher score. Buildings are classed according to their patterns of use at the design stage. For example, *The Town and Country Planning (Use Classes) Order* (ODPM, 1987) 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 (Adler, 1999). *The NYC Building Classification Codes* (Profiles, 2004), on the other hand, provides a complete, comprehensive list of each Building Classification Code, and has been officially used to classify all properties from private homes to amusement parks by the City of New York. The lack of flexibility in current rating methods for intelligent buildings 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 Intelligent buildings.

Another problem of current building rating methods for intelligent buildings 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 (AIIB, 2005) aims to provide a quantitative composite approach to intelligent buildings assessment using 10 indicator clusters based on the Cobb-Douglas utility function (Schotter, 2001). However, the recommended method for the IB Index calculation is not 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 are given below:

3.3.1 Non-determinism

The non-determinism led by the criteria of the AIIB method means that the assessment criteria and the final scores from the evaluation criteria have 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 intelligent buildings 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*, *Comfort*, *Working 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.

3.3.2 Non-sequitur

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 (AIIB, 2005). 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 (Meyer, 2005; Vargas, Schreiner, Tembo and Marcouiller, 2005). 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 I 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 (Arrow, Chenery, Minhas and Solow, 1961; Cobb and Doughlas, 1928; Heathfield and Wibe, 1986; Qi, 2002; Yin, 2001). 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) (Osborne, 1997) cannot be of the Cobb-Douglas type (Islam, 1985). 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.

3.3.3 Non-unique

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 (2005), 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 3.2). The AIIB method cannot provide a unique result, as different auditors may make different conclusions, which definitely cause complexity and variance in intelligent buildings assessment.

Table 3.2 An experimental verification of the IB Index method (AIIB, 2005)

Buildings	**Scores**		**IB Index**			
	Module x	Module y	w_x:w_y=2:1	Rank of Intelligence	w_x:w_y=3:1	Rank of Intelligence
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

3.3.4 Non-organization

Regarding the non-organization assessment procedure adopted in current building rating systems, I 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 3.1, 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 intelligent buildings assessment. It is thus required to provide an alternative method to evaluate the characteristics of intelligent buildings, under objective and real life conditions, in which all indicators are taken into account, not only their values but also their interrelationships. In this respect, an alternative measure for intelligent buildings assessment is put forward by means of analytic network process (ANP) (Saaty, 1996-2001). In a test drive using the IB Index, it has been also noticed that 32 indicators (refer to Table 3.5) can be extracted from an integration of its 378 elements of 10 modules by using a quantitative indicator selection approach to be introduced below in Section 3.4. In fact, this integrative 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 IB indicators, from which a most appropriate group of indicators can be selected for the ANP based assessment. In terms of the selection of indicators for assessing the lifespan energy efficiency of intelligent buildings, a quantitative evaluation approach will be put forward under the criteria of energy consumptions over time in which people, processes, and products are involved. To overcome the shortcomings that exist in the current IB Index method, the proposed IBAssessor can provide an innovative evaluation approach of intelligent buildings, in which both the value of indicators and their interrelations are taken into account.

3.4 Quantitative selection of indicators

3.4.1 SIBER model

Lifespan of buildings include successive process stages in design, construction and operation relevant to their structural and services systems. The life cycle analysis/assessment (LCA) method is a formal quantitative approach to assess load magnitude in both natural and built environments in different patterns attributable to various influential factors at each stage of building systems (ISO, 2003). The LCA method was introduced to the construction industry in 1970s (Bickley, 1974; Tufty, 1976) in both structural engineering and project management. In the past thirty years, it has developed another main stream of assessment theory in the building and construction industry (Adeli and Sarma, 2005; Alhazmi and McCaffer, 2000; Amato, 1996; Blanchard and Reppe, 1998; Blanchard and Reppe, 1998; Brown, Ashleigh, Riley and Shaw, 2001; Chen, Li and Wong, 2000; Chen, 2004; Chua and Li, 2000; Eaton and Amato, 1998;

Flanagan and Norman, 1983; Flanagan, Norman, Meadows and Robinson, 1989; Hampton, 1994; Hetherington, 1997; . Jablonski, Klempous and Licznerski, 2004; . Jakob and Madlener, 2004; Kirk and Dell'Isola, 1995; Kotaji, Schuurmans and Edwards, 2003; Kumar, Garg and Kaushik, 2005; Li, 1998; Li, Chen, Wong and Love, 2002; Lo, Chao, Hadavi and Krizek, 1998; Myerson, 2005; NAHB, 2001-2002; Owens, 1990; Palaneeswaran and Kumaraswamy, 2000; PMI, 2004; Raymond and Cunliffe, 1997; Roaf, 1992-2005; SEEDA, 2004; Smith, 2000; USACE, 1997; USGSA, 1999; USNIBS, 1998-2005; Wigginton and Harris, 2002; Wong, So and Yu, 2001; Wong, So and Leung, 2001; Wong, Li and Wang, 2005; Zachariah, Kennedy and Pressnail, 2002; Amato, L. Brimacombe, N. Howard, 1996). For implementing the concept of LCA in project management, one essential is to benchmark construction processes; significant research and development progress have been achieved already. For example, the CSI (1997) in the USA made a close loop of project cycle that describes five phases for construction projects including Planning and Pre-design Activities, Design Activities, Bidding Activities, Construction Activities, and Post-Construction Activities. Kagioglou et al. (Kagioglou, Cooper, Aouad, Hinks, Sexton and Sheath, 1998) in the UK developed a general *Process protocol* that describes ten phases for construction projects including Demonstrating the Need, Conception of Need, Outline Feasibility, Substantive Feasibility Study and Outline Financial Authority, Outline Conceptual Design, Full Conceptual Design, Co-ordinated Design, Procurement and Full Financial Authority, Production Information, Construction, and Operation and Maintenance. Smith (2000) in the USA developed a knowledgebase support prototype for the *Total Life-cycle Cost* that describes ten phases for construction projects including Requirements, Plan, Program, Design, Construction, Operation, Maintenance, Evaluation, Revitalization, and Disposal. The U.S. Army Corps of Engineers (USACE) conducted a series LCA research in 1990s [83-88] including the *Guide for Project Partners* and the *Facility Composer*. The *Guide for*

Project Partners describes six basic phases of a civil works project including Reconnaissance, Feasibility, Pre-construction engineering and design, Real estate acquisition, Construction, and Operations and maintenance; and the *Facility Composer* is a suite of criteria/requirement-based facility modeling tools that integrate customer-specific criteria with a life-cycle facility model and commercial tools (Teicholz, 2001). The Australian Building Codes Board (ABCB, 2005) introduced energy efficiency performance standards into the *Building Code of Australia* in 2003 (SEDO, 2004), in which *Life Cycle House Energy Estimator* (Drogemuller, 2004) is adopted. Literature reviews indicate the process oriented LCA has been widely recognized and adopted in the building and construction industry, and become the basic view and starting point of construction management.

On the other hand, standards for quality assurance in business have been developed since late 1950s (Seddon, 2001). After the ISO (1994-2004) issued ISO 9000:1994 series of quality management standards and replaced with ISO 9000:2000, life-cycle business management has become a new development of LCA in construction management. For example, the USNIBS (1998) put forward a *Total Life-cycle Cost Model* for facilities managers to conduct the comparative evaluation of all costs, including productivity of function and impacts on the enterprise, health and the environment throughout the facilities life (Smith, 2000). The FIDIC [33] introduced a *Business Integrity Management System* to set out why consultants should apply business integrity management in all of their work, and should introduce initiating the business integrity management process into their firms. Moreover, the USACE (USACE, 2001) developed a *Project Management Business Process* model to deliver quality projects. The model reflects the USACE corporate commitment to provide inclusive, seamless, flexible, effective, and efficient customer services, and embodies communication, leadership, systematic and coordinated management, teamwork, partnering, effective balancing of competing demands, and primary accountability for the life cycle of a project. Based on these LCA-based process benchmarks, Clements-Croome et al. (2003) put forward the *Through Life Environment Business Model (TLEBM)* that concentrates upon six consistent phases for the business management of construction projects including *Client Brief*, *Design*, *Construction &Commission (C2)*, *Operation & Maintenance (O&M)*, *Post Occupancy Evaluation (POE)*, and *Reuse/Recycle/Disposal*. In order to select the most appropriate indicators for intelligent building performance assessment, a *Building Assessment* entity is integrated with decision processes (decision-making options) into the *TLEBM* (refer to Figure 3.1). There are three decision processes involved in the proposed decision-making model including a *Design Review* between the *Design* phase and the *C2* phase; a *C2 Review* between the *C2* phase and the *O&M* phase; and an *O&M Review* between the *O&M* phase and the *Disposal/Reuse/Recycle* phase, which is integrated with the *POE* phase. The new evolving process, which is a *TLEBM* based prototype for the lifespan performance assessment of buildings, is entitled SIBER, which means Strategic Intelligent Building Evaluation and Renovation.

In addition to the review of current rating systems, a generic platform of intelligent buildings assessment under the SIBER model is also planned. In this chapter, the SIBER model will be used to effectively control a process in which a group of assessment indicators is quantitatively selected (refer to Figure 3.2).

The SIBER model regulated assessment process requires a group of indicators; this will include quality of life factors, which can effectively signify the sustainable lifespan performance of buildings for peoples. In this regard, three indicator clusters (Bahaj, Clements-Croome, Gann, Jones, and Riffat, 2002) are adopted to cover the whole range of indicators including the cluster for *People*, the cluster for *Products*, and the cluster for *Processes*; and all possible indicators are evaluated under restraining criteria of natural and social environmental factors before they can flow into the *Indicator Cluster* (refer to Figure 3.1). In order to find the most appropriate indicators for the *Building Assessment* entity of the SIBER model under the restraining criteria, a quantitative energy-time based indicator evaluation approach is created as described below.

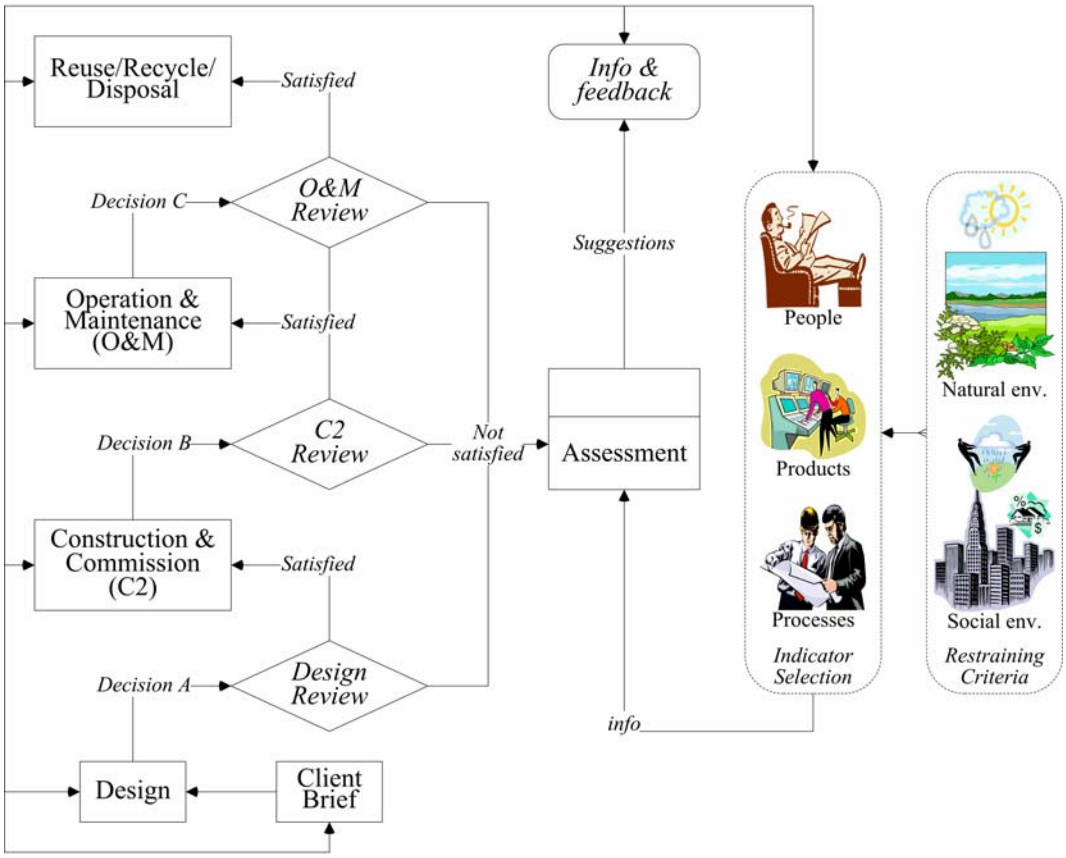


Figure 3.1 The SIBER model

3.4.2 An Energy-Time Consumption Index

It is generally accepted that both energy and time consumptions exist in each process, in term of *Products* and *Processes*, for any building component or building system to fulfill all kinds of requirements for *People*. Regarding the energy consumption, embodied energy is one important measurement. Embodied energy is the energy consumed by all of the procedures associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions (CMIT, 2002). Previous research that focus on the LCA of cost and environmental impacts of construction projects include the embodied energy of products such as material, component, equipment and building (Berge, 2000; Blanchard and Reppe, 1998; Blanchard and Reppe, 1998; Treloar, Fay and Tucker, 1998; Treloar, Fay, Love and Iyer-Raniga, 2000; BRE, 1994); and the processes such as construction, installation and maintenance (Cole, 1999; Hendrickson and Horvath, 2000; Rowings and Walker, 1984; Oka, Suzuki and Konnya, 1993). Although the time factor features in project management, the speed of energy consumption is disregarded in previous LCA research based on the embodied energy. However, it is important to measure the velocity of energy consumptions in producing and processing in accordance with the performance of intelligent buildings as required by people. Because the environment itself has power but needs time to eliminate pollutants (Stephens, 2005; Ricoh, 2005), and a high-energy consumption in a long lifespan may not be more adverse to the environment than a relatively low energy consumption over a short period. In this regard, a quantitative measurement for selecting indicators, called energy-time consumption index (*ETI*) is put forward by means of an embodied energy consumption rate (see Equation 3.4 & 3.5). This reflects the idea of energy intensity being important.

$$F_{ETI} = f(e,t) \tag{3.4}$$

$$ETI_i = \frac{\partial F_{ETI_i}}{\partial t} \tag{3.5}$$

Equation 3.4 gives a normal expression of *ETI* function (F_{ETI}) consisting of two variables including energy (*e*) and time (*t*); Equation 3.5 gives a normal calculation method of the *ETI* for whichever indicator *i*, and is a partial time derivative of Equation 3.4. The application of Equation 3.5 depends on a specific function to describe the dependent relation with energy and time variables for the *ETI*. As there is not enough statistical data to mine and formulate such a function at this moment, an alternative simplified approach to calculate the *ETI* (refer to Equation 3.6 in Equations) is proposed.

$$ETI_i = \sum_{j=1}^{2} SEC_{i,j} \Big/ \sum_{j=1}^{2} STC_{i,j} \tag{3.6}$$

In Equation 3.6, ETI_i is the *ETI* of indicator *i*; $SEC_{i,j}$ is the score of energy consumption (*SEC*) of indicator *i* relevant to *Indicator Cluster j* (*j=1 or 2*, corresponding to the two *Indicator Cluster* which include *Products Cluster* (*j=1*) and *Processes Cluster* (*j=2*)); $STC_{i,j}$ is the score of time consumption (*STC*) of indicator *i* relevant to *Indicator Cluster j*. The set of $SEC_{i,j}$ is based on consideration that the energy embodied into a product covers a period of time during a process. To further regulate the selection of indicators, fundamental scales are subjectively defined, as given in Table 3.3, which are in accordance with the values of $SEC_{i,j}$ and $STC_{i,j}$.

Based on the fundamental scale of the scores of energy and time consumptions given in Table 3.3, the *ETI* score of each indicator, i.e. *Indicator i*, can have its value regarding energy and time consumptions in a scoring form (see Table 3.4). Generally, the $ETI_{i,max}$ =1000 and the $ETI_{i,min}$ =20 (refer to Table 3.3 and Table 3.6).

Table 3.3 Fundamental scales of the sores and descriptions of energy/time consumptions

Scales for scoring		***Products*** (Embodied Energy/Time Pattern)	***Processes*** (Operational Energy/Time Pattern)
Score of Energy Consumption ($SEC_{i,j}$)		Embodied energy of products in manufacture, construction, and installation.	Energy required in operation processes depend on People' occupancy requirements.
1 = Extremely low	6 = High		
2 = Very strongly low	7 = Moderately high		
3 = Strongly low	8 = Strongly high		
4 = Moderately low	9 = Very strongly high		
5 = Low	10 = Extremely high		
Score of Time Consumption ($STC_{i,j}$)		Time requirements in product making in manufacture, construction, and installation.	Time required in operation processes depend on People' occupancy requirements.
1 = (0, 1 day]	4 = (1 month, 1 year]		
2 = (1 day, 1 week]	5 = >1 year		
3 = (1 week, 1 month]			

Table 3.4 The scoring form of indicator regarding its energy and time consumptions

	Products	**Processes**	**Subtotal**	**Total**
Score of Energy Consumption (SEC)	($SEC_{i,1}$)	($SEC_{i,2}$)	(SEC_i)	(ETI_i)
Score of Time Consumption (STC)	($STC_{i,1}$)	($STC_{i,2}$)	(STC_i)	

As mentioned in Section 3.2, the IB Index has a comprehensive category of indicators for assessing intelligent buildings. In this regard, it is chosen as a model for scoring *ETI*, and therefore chose a group of *ETI*-scored indicators for the proposed IBAssessor ANP model. Because the *ETI* is a general approach to selecting indicators under the criteria of building sustainability, it is suggested that a further complete evaluation of IB indicators is made for the IBAssessor ANP model based on current building rating systems as mentioned in Section 3.2. This chapter only demonstrates the usability of *ETI* and the

IBAssessor ANP model. Table 3.5 gives a result from *ETI*-scored indicator evaluation based on the IB Index. At Reading University and HK Polytechnic University, further development of this model is taking place.

Table 3.5 Selected indicators using ETI based on the IB Index

Indicator	**IB Index code**	$SEC_{i,1}$	$SEC_{i,2}$	SEC_i	$STC_{i,1}$	$STC_{i,2}$	STC_i	ETI_i
Electricity & Electrical services	multiple	7	5	12	1	5	6	200
Heating services	multiple	7	9	16	3	5	8	200
Ventilation & air-conditioning	multiple	6	9	15	3	5	8	188
Building services automation system	multiple	9	7	16	4	5	9	178
Construction materials	multiple	8	8	16	4	5	9	178
IT&C facilities and services	multiple	8	6	14	3	5	8	175
Thermal comfort & indoor air quality	multiple	5	8	13	3	5	8	163
Lifts/escalators and controls	multiple	5	8	13	3	5	8	163
Security and safety control	multiple	6	5	11	3	5	8	138
Flushing water system	multiple	6	4	10	3	5	8	125
External & internal decoration	multiple	5	6	11	4	5	9	122
Building architectural design	multiple	4	2	6	4	1	5	120
Lavatory accommodation	multiple	4	5	9	3	5	8	113
Refuse collection	multiple	5	4	9	3	5	8	113
Circulation for the disabled	multiple	5	5	10	4	5	9	111
CAD/CAM/CAC	multiple	2	8	10	4	5	9	111
Flexibility for renovation	multiple	4	3	7	2	5	7	100
Structural monitoring & control	multiple	4	4	8	3	5	8	100
Potable water system	multiple	5	3	8	3	5	8	100

Fire detection and resistance	multiple	4	3	7	4	4	8	88
Cleanliness	multiple	4	3	7	3	5	8	88
Property management	multiple	1	5	6	2	5	7	86
Car-park/transportation facilities	multiple	2	3	5	2	5	7	71
Entertainment facilities	multiple	1	4	5	2	5	7	71
External landscape	multiple	2	3	5	2	5	7	71
Extensive use of AI	multiple	4	2	6	4	5	9	67
Environmental friendliness	multiple	1	2	3	1	5	6	50
Conference and meeting facilities	multiple	1	3	4	3	5	8	50
Access sign and directory	multiple	1	1	2	1	5	6	33
Maintainability	multiple	1	1	2	1	5	6	33
Usable areas	multiple	1	1	2	2	5	7	29
Means of escape	multiple	1	1	2	3	5	8	25

Note:

1. Green Index (GRI), Space Index (SPI), Comfort Index (CFI), Working Efficiency Index (WEI), Culture Index (CLI), High-tech Image Index (HTI), Safety and Structure Index (SSI), Management Practice and Security (MPS), Cost Effectiveness Index (CEI), Health & Sanitation Index (HSI).

2. Computer Aided Design, Manufacturing, Construction/installation (CAD/CAM/CAC).

3. Artificial Intelligence (AI)

4. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

3.4.3 Key Performance Indicators

There are 378 elements under 10 modules of the IB Index, including a Green Index (GRI) module, a Space Index (SPI) module, a Comfort Index (CFI) module, a Working Efficiency Index (WEI) module, a Culture Index (CLI) module, a High-tech Image Index

(HTI) module, a Safety and Structure Index (SSI) module, a Management Practice and Security Index (MPS) module, a Cost Effectiveness Index (CEI), and a Health & Sanitation Index (HSI) module. As summarized in Table 3.5, 43 indicators emerge from these 378 indicators following the ETI based identification. To finally select a group of key performance indicators for the ANP model, the scope of ETI is further estimated, i.e. $ETI_{i,max}$ = 1000 and the $ETI_{i,min}$ = 20, based on Gann's *Square of Nine* (Mikula, 2003) (refer to Table 3.6). The purpose of this study is to explain concisely but in detail simple mathematical and graphical techniques for applying Gann's *Square of Nine* to KPI selection.

The Gann's *Square of Nine* (Mikula, 2003) for KPI selection is constructed using a grid of numbers that begins in the centre with number 20 in accordance with the value of $ETI_{i,min}$. The number 30 goes to the box to the right of the number 20. Moving up and round anticlockwise, 10 is added to the previous number and the resulting number goes to the box. This is repeated in a spiral around the centre. There are two crosses in the developed grid, including a Cardinal Cross and a Fixed Cross. The Cardinal Cross is composed of the vertical and horizontal rows that intersect at the middle of the square; the line extending at 45 degrees constitutes the Fixed Cross. The Cardinal Cross and Fixed Cross are used to determine likely points of *ETI* related to KPIs. Table 3.6 gives the results of the *Square of Nine* for KPI identification.

Table 3.6 Gann's square of nine (Mikula, 2003) for KPIs identification

		1000	990	980	**970**	960	950	940	930	**920**	
	660	650	640	630	**620**	610	600	590	**580**	910	
	670	**380**	370	360	**350**	340	330	**320**	570	900	
	680	390	**180**	170	**160**	150	**140**	310	560	890	
	690	400	190	**60**	**50**	**40**	130	300	550	880	
	700	**410**	**200**	**70**	**20**	**30**	**120**	**290**	**540**	**870**	
	710	420	210	**80**	**90**	**100**	110	280	530	860	
	720	430	**220**	230	**240**	250	**260**	270	520	950	
	730	**440**	450	460	**470**	480	490	**500**	510	840	
	740	750	760	770	**780**	790	800	810	**820**	830	

Based on these results, KPIs for intelligent buildings assessment are finally divided into five *ETI* aggregations, i.e. [20, 100], (100, 260], (260, 500], (500, 820], and (820, 1000]. In accordance with this scenario, five groups of KPIs, i.e. KPI Group *t* (t=1, 2, 3, 4, 5) can be defined. This can further be used to classify all 32 indicators extracted from the IB Index as described in Table 3.5. Among these 32 indicators verified in Table 3.5, 16 indicators are designated to KPI Group 1 with their *ETI* scores all above 100 but below 260, i.e. $260 \geq ETI_i > 100$; meanwhile, another 16 indicators are allocated to KPI Group 2 with their ETI scores below 100 but including 100, i.e. $100 \geq ETI_i > 0$. The *ETI* scores presented in Table 3.5 are calculated using Equation 3.6 and the score of energy/time consumption (*SEC/STC*), which can be compared with experts' opinions. As a result, two groups of KPIs for the proposed IBAssessor model are identified based on the IB Index (refer to Table 3.7).

Table 3.7 also describes how the 32 proposed KPIs are actually relevant to the ten modules of the IB Index (AIIB, 2005). For example, the first indicator in Group 1, i.e. Electricity & Electrical services equals to multiple relevant indicators from three modules including Green Index (GRI), High-tech Image Index (HTI), and Safety and Structure Index (SSI). There are two main benefits for these comparisons. Firstly, it effectively reduces the number of KPIs from 378 to 32, therefore assessment process may take hours instead of days. Secondly, the comparison makes it possible to define each of these 32 indicators matching relevant indicators' specifications of the IB Index, and this can ensure maximum utilization of the IB Index, which gives the most comprehensive coverage of indicators in intelligent buildings assessment. As a result, specifications to each of these 32 indicators is required based on the IB index, and it is given in Appendix 3.

Table 3.7 Relations between selected indicators and the IB Index

Indicator	Codes of the IB Index	Modules of the IB Index									
		Green	Space	Comfort	Working Efficiency	Culture	High-tech Image	Safety & Structure	Management Practice & Security	Cost Effectiveness	Health & Sanitation
Group 1											
Electricity & Electrical services	multiple	✓	✓	✓	✓		✓	✓	✓		
Heating services	multiple	✓									
Ventilation & air-conditioning	multiple	✓	✓	✓	✓						✓
Building services automation system	multiple				✓		✓		✓		
Construction materials	multiple	✓					✓				
IT&C facilities and services	multiple				✓		✓				
Thermal comfort & indoor air quality	multiple	✓		✓	✓			✓	✓		✓
Lifts/escalators and controls	multiple	✓		✓	✓		✓		✓		✳
Security and safety control	multiple		✓		✓		✓	✓	✓		
Flushing water system & drainage	multiple	✓		✓					✓		✓
External & internal decoration	multiple		✓		✓						✓
Building architectural design	multiple	✓			✓	✓	✓				
Lavatory accommodation	multiple	✓		✓	✓						
Refuse collection & disposal	multiple	✓							✓		✓
Circulation for the disabled	multiple		✓						✓		
CAD/CAM/CAC	multiple	✓					✓				
Group 2											
Flexibility for renovation	multiple		✓								
Structural monitoring & control	multiple							✓	✓		
Potable water system	multiple								✓		✓
Fire detection and resistance	multiple				✓			✓			
Cleanliness	multiple	✓		✓	✓						✓
Property management	multiple	✓	✓		✓		✓	✓	✓	✓	✓
Carpark/transportation facilities	multiple		✓		✓		✓		✓		✓
Entertainment facilities	multiple			✓	✓	✓					
External landscape	multiple	✓				✓					
Extensive use of AI	multiple				✓		✓				
Environmental friendliness	multiple	✓							✓		
Conference and meeting facilities	multiple				✓		✓				
Access sign and directory	multiple				✓		✓	✓			
Maintainability	multiple				✓				✓		
Usable areas	multiple		✓	✓	✓						
Means of escape	multiple							✓	✓		

Note:
1. Green Index (GRI), Space Index (SPI), Comfort Index (CFI), Working Efficiency Index (WEI), Culture Index (CLI), High-tech Image Index (HTI), Safety & Structure Index (SSI), Management Practice & Security (MPS), Cost Effectiveness Index (CEI), Health & Sanitation Index (HSI).
2. Computer Aided Design, Manufacturing, Construction/installation (CAD/CAM/CAC).
3. Artificial Intelligence (AI)
4. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.
5. ✓ denotes the indicator is recognized by the IB Index in such module/cluster; ✳ denotes recommended feature.

3.5 IBAssessor Approach

Developed by Saaty (1996), the ANP is a general theory of relative measurement used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interact with respect to control criteria. An ANP model consists of two parts including a network of interrelationships among each two nodes or clusters, and a control network of criteria/sub-criteria that control interactions based on interdependencies and feedback. In order to conduct decision-making process, a control hierarchy is generally employed to build an ANP model. The control hierarchy is a hierarchy of criteria and sub-criteria for which priorities are derived in the usual way with respect to the goal of a system being considered. The criteria are used to compare the clusters of an ANP model, and the sub-criteria are used to compare the nodes of a cluster. Regarding how to conduct intelligent buildings assessment by using ANP, Figure 3.2 illustrates a four-step ANP procedure, in which the SIBER model (refer to Figure 3.1) based *ETI* supported indicator selection process is integrated, and the ANP based intelligent buildings assessment model presented in Figure 3.2 is called TIBER model.

There are four general steps in ANP based multicriteria decision-making process: model construction; paired comparisons between each two clusters or nodes; supermatrix calculation based on results from paired comparisons; and result analysis for the assessment. As a frame of reference, Figure 3.2 also summaries a four-step procedure for AIIB method, which is regarded as one important source of indicators for intelligent buildings assessment to support building an ANP model. For users who want to conduct intelligent buildings assessment, Figure 3.2 provides two options to either use ANP method or other rating methods. Based on their evaluation theory, the rating methods such as the AIIB method can only be used to evaluate one IB each time, whilst the ANP method can be used to evaluate either one IB or several ones. To evaluate several intelligent buildings together each time, information of a reference IB such as a standard IB in a particular building class or alternative building plans for the same IB has to be added to the ANP model. To achieve this, Figure 3.2 also illustrates how the ANP method retrieves information from other rating methods and rating systems to collect information for intelligent buildings assessment. As all other rating methods such as AIIB method (AIIB, 2005) and IBSK method [39] have their own developed IB indicators, it is therefore useful and important for ANP model construction. In addition to the parallel assessment procedures between the rating method and the ANP method, Figure 3.2 proposes an assessment database, which is essential for an ANP model development loop including processes of model construction, model evaluation, model revision and model reuse. The proposed IB database can also provide information of a standard IB when the ANP model is used to assess a building comparing with a standard building in the same building class; otherwise, an alternative of the building has to be presented to support the assessment. However, this chapter will not discuss how to develop such an IB database to support ANP-based assessment, and will focus on the procedure of intelligent buildings assessment using ANP method and the group of indicators collected from the *ETI* based selection.

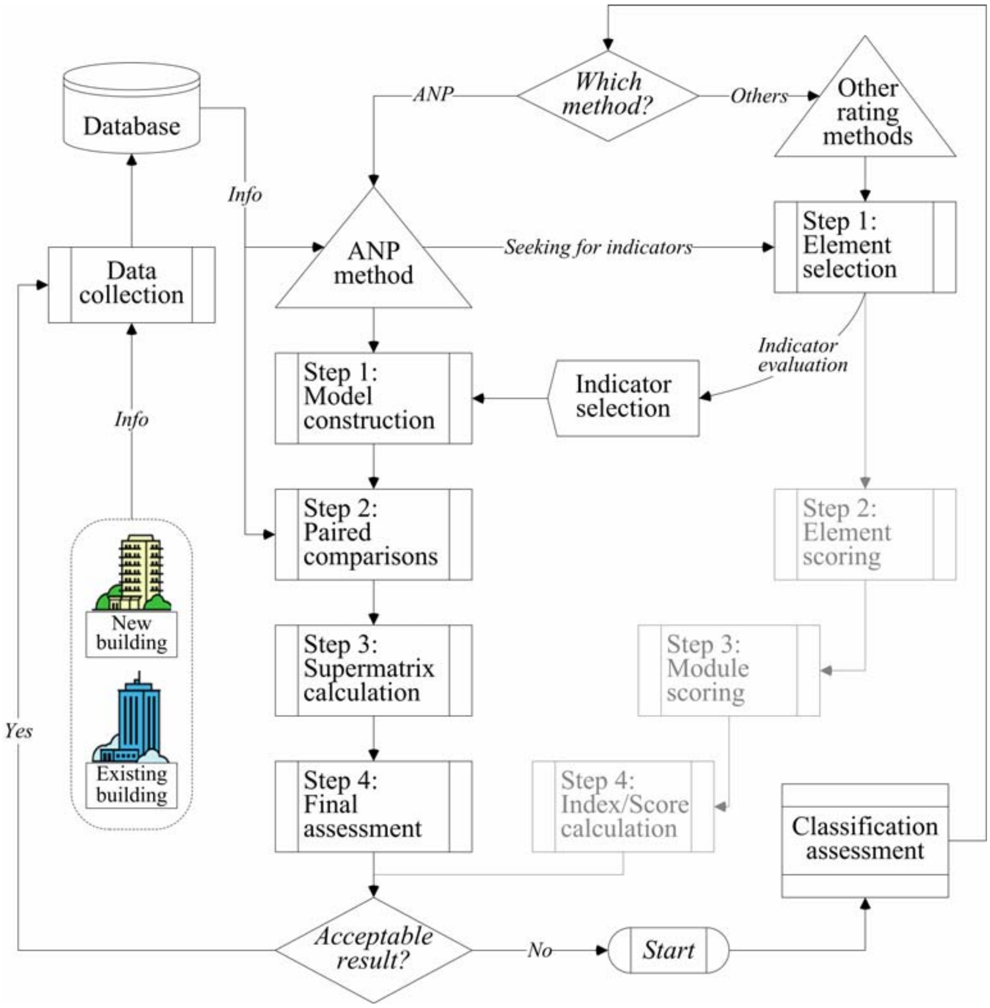


Figure 3.2 The TIBER model

3.5.1 Step A: ANP Model Construction

The objective of Step A is to build an ANP model for intelligent buildings assessment. The ANP model is built based on determining the control hierarchies, as well as the corresponding criteria for comparing the clusters, including sub-clusters, of the model and sub-criteria for comparing the nodes inside each cluster and each sub-cluster, together with a determination of clusters and sub-clusters with their nodes for each control criteria or sub-criteria. Before finalizing an ANP model, a set of indicators for the model construction has to be defined. As the purpose of this chapter is to provide an alternative approach for intelligent buildings assessment based on the IB Index (AIIB, 2005), the group of KPIs identified in Section 3.4 is therefore selected for the proposed ANP model. Figure 3.3 gives an outline of the proposed IBAssessor ANP model.

There are two clusters inside the IBAssessor model, including one Criteria cluster and one Alternatives cluster. The goal of the IBAssessor model is to select the most appropriate IB from several alternatives in the process of evaluation or to make a comparison between a proposed IB and a standard IB in a same catalogue in the process of assessment. In correspondence with this goal, the cluster of Alternatives (denoted as $C_{selection}$) consists of two nodes in this chapter including Building A and Building B, which are two IB candidates to be evaluated by the IBAssessor. On the other hand, the Criteria cluster contains two Subnets including the sub-cluster of KPI Group *t* (t=1,2) (denoted as C_{KPIGt}). Inside these two sub-clusters, the KPI Group 2 sub-cluster consists of 19 nodes (i.e. KPI *i* (i=1,2,…,16)) in accordance with the 16 indicators of KPI Group 2, and the KPI Group 1 sub-cluster consists of 16 nodes (i.e. KPI *j* (j=1,2,…,16)) in accordance with the 16 indicators of KPI Group 1. All these KPIs involved in the Criteria cluster are collected based on the *ETI* evaluation of the IB Index (AIIB, 2005) (refer to Table 3.5 and Table 3.9).

In accordance with these two clusters and their total 32 nodes, the IBAssessor ANP model is thus set up with interrelation connectivity between each two clusters and their nodes. Connections inside the two clusters finally generate a network with interrelations among clusters, sub-clusters and nodes (refer to Table 3.10) including the Alternatives cluster (with 2 nodes), the KPI Group 1 sub-cluster (with 16 nodes), and the KPI Group 2 sub-cluster (with 16 nodes). The network connections are modelled by using one-way or two-way arrows and looped arrows to describe the interdependences that exist between each two clusters or sub-clusters and each two nodes (refer to Figure 3.3).

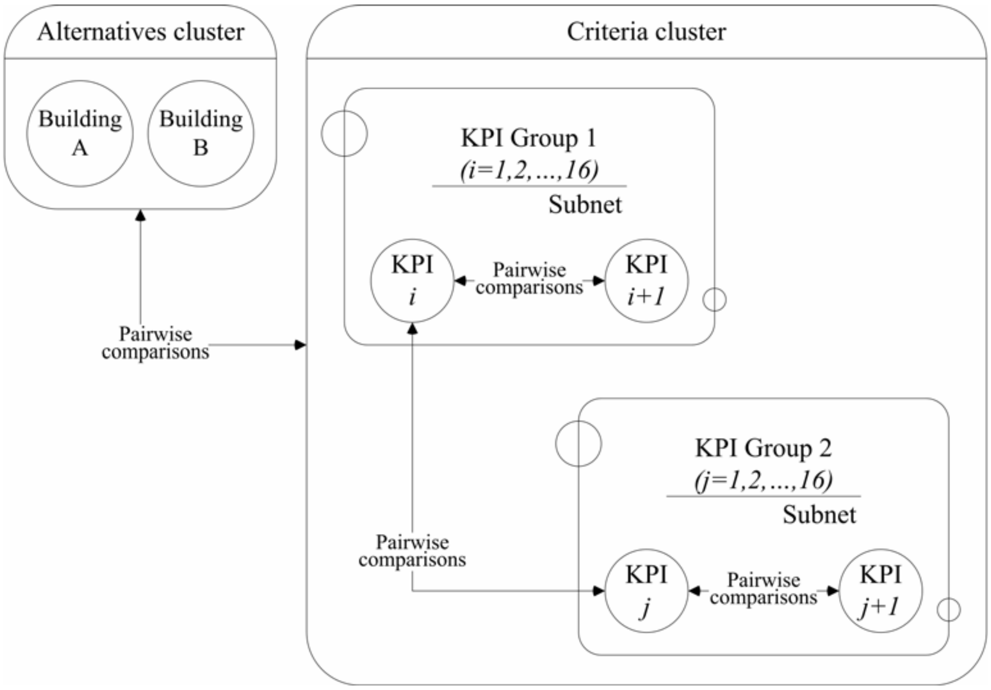


Figure 3.3 The IBAssessor ANP model

3.5.2 Step B: Paired Comparisons

The objective of step B is to carry out pairwise comparisons among clusters and sub-clusters, as well as pairwise comparisons between each two nodes, because they are interdependent on each other during the lifespan of intelligent buildings. The pairwise comparison is a quantitative description approach to interrelation connections illustrated in the IBAssessor ANP model (refer to Figure 3.3). In order to complete pairwise comparisons, the relative importance weight, denoted as a_{ij}, of interdependence is determined by using a scale of pairwise judgments, where the relative importance weight is valued from 1 to 9 (Saaty, 1996). Table 3.8 reproduce the fundamental scale of pairwise judgments generally applied in pairwise comparisons.

Table 3.8 Scale of pairwise judgment (Saaty, 1996)

Pairwise judgment	Equal	Equally to moderately	Moderately dominant	Moderately to strongly	Strongly dominant	Strongly to very	Very strongly	Very strongly to	Extremely dominant
Scale	1	2	3	4	5	6	7	8	9

Decision makers with professional experience and knowledge can use these scales for pairwise comparisons to determine the weight of interdependence. In this study, this is determined by me because the objective of this study is mainly to demonstrate the process and usefulness of the ANP model for intelligent buildings assessment; in practice, the building design team will make these comparisons. Table 3.9 gives some details for the case study.

Table 3.9 A case details about KPI & their values for the IBAssessor model

Classification	**Ref. No.**	**Indicators**	**Score of Design Alternatives** (AIIB, 2005)	
			Design A	**Design B**
KPI Group 1	KPIG101	Electricity & Electrical services	90	90
	KPIG102	Heating services	90	90
	KPIG103	Ventilation & air-conditioning	80	90
	KPIG104	Building services automation system	90	100
	KPIG105	Construction materials	100	70
	KPIG106	IT&C facilities and services	90	90
	KPIG107	Thermal comfort & indoor air quality	80	100
	KPIG108	Lifts/escalators and controls	90	80
	KPIG109	Security and safety control	90	90
	KPIG110	Flushing water system & drainage	80	90
	KPIG111	External & internal decoration	80	80
	KPIG112	Building architectural design	90	80
	KPIG113	Lavatory accommodation	60	90
	KPIG114	Refuse collection	70	80
	KPIG115	Circulation for the disabled	90	90
	KPIG116	CAD/CAM/CAC	90	70

KPI Group 2	KPIG201	Flexibility for renovation	50	70
	KPIG202	Structural monitoring and control	50	70
	KPIG203	Potable water system	70	90
	KPIG204	Fire detection and resistance	80	80
	KPIG205	Cleanliness	70	80
	KPIG206	Property management	80	80
	KPIG207	Carpark/transportation facilities	70	80
	KPIG208	Entertainment facilities	70	80
	KPIG209	External landscape	90	70
	KPIG210	Extensive use of artificial intelligence	50	70
	KPIG211	Environmental friendliness	90	90
	KPIG212	Conference and meeting facilities	70	90
	KPIG213	Access sign and directory	80	90
	KPIG214	Maintainability	70	90
	KPIG215	Usable areas	90	70
	KPIG216	Means of escape	80	100

Table 3.10 gives a general form for pairwise judgment between each two nodes inside the IBAssessor ANP model. There are two types of pairwise judgments, one is the pairwise comparison between a KPI and a building alternative, and another is the pairwise comparison between two KPIs. As an example, for the node KPIG103, i.e. Ventilation & Air-conditioning (refer to Table 3.9), the pairwise judgments are given in Table 3.10, in which the scale for Building B is 8, whilst it is 4 for Building A, because the use of natural ventilation in Building A is less than in Building B (refer to Table 3.10). In this regard, quantitative pairwise judgments can thus be conducted in order to define priorities of each indicator for each IB Candidate, and the judgments are based on the quantitative attribute of each indicator from each IB Candidate (refer to Table 3.9). Besides the pairwise judgment between an indicator and an IB Candidate, the IBAssessor model also contains all other pairwise judgments between each indicator. For example, Indicator I_i (KPIG103 as a representative) is *Very strongly dominant* to Indicator I_j (KPIG211 as a representative); therefore the judgment value equals seven (as shown in Table 3.10). In summary, the essential initialization for ANP modeling is set up based on the quantitative

attribute (as described in Table 3.9) of indicators for each IB Candidate and inherent characteristics of each indicators.

Table 3.10 Pairwise judgment of indicator Ii (KPIG203) and Ij (KPIG111)

Pairwise judgments		1	2	3	4	5	6	7	8	9
Indicator I_i	Building A	×	×	×	✓	×	×	×	×	×
	Building B	×	×	×	×	×	×	×	✓	×
Indicator I_i	Indicator I_j	×	×	×	×	×	×	✓	×	×

Note:

1. The fundamental scale of pairwise judgment is given in Table 3.7.
2. The symbol × denotes item under selection for pairwise judgment, and the symbol ✓ denotes selected pairwise judgment.

3.5.3 Step C: Supermatrix Calculation

This step aims to form a synthesized supermatrix to allow for a resolution based on the effects of the interdependences that exist between the elements (including nodes, sub-clusters and clusters) of the IBAssessor ANP model. The supermatrix is a two-dimensional partitioned matrix consisted of one nine sub-matrices (refer to Table 3.11).

Table 3.11 Formulation of supermatrix and its sub-matrix for IBAssessor ANP model

General format of supermatrix A

$$W = \begin{bmatrix} W_{1,1} & W_{1,2} & W_{1,3} \\ W_{2,1} & W_{2,2} & W_{2,3} \\ W_{3,1} & W_{3,2} & W_{3,3} \end{bmatrix}$$

$$C_i = \left(C_{sel.} \quad C_{KPIG2} \quad C_{KPIG1}\right)$$

$$N_i = \left(N_{sel.}^{2} \quad N_{KPIG2}^{16} \quad N_{KPIG1}^{16}\right)$$

General format of sub-matrix

$$W_{IJ} = \begin{bmatrix} w_1\big|_{I,J} & \cdots & w_1\big|_{I,J} \\ w_2\big|_{I,J} & \cdots & w_2\big|_{I,J} \\ \cdots & \cdots\cdots & \\ w_i\big|_{I,J} & \cdots & w_i\big|_{I,J} \\ \cdots & \cdots\cdots & \\ w_{N_{I1}}\big|_{I,J} & \cdots & w_{N_{In}}\big|_{I,J} \end{bmatrix}$$

Note: I is the index number of rows; and J is the index number of columns; both I and J correspond to the number of cluster and their nodes (I, $J \in$ (1, 2, …, 34)), N_I is the total number of nodes in cluster I, n is the total number of columns in cluster I. Thus a 34×34 supermatrix is formed.

Weights defined from pairwise judgments for all interdependences for each individual IB Candidate are then aggregated into a series of sub-matrices. For example, if the *Alternative* cluster and its nodes are connected to nodes in the sub-cluster KPI Group 1 (denoted as C_{KPIG1}), pairwise judgments of the cluster thus result in relative weights of importance between each IB Candidate and each indicator inside the KPI Group 1 sub-cluster. The aggregation of the determined weights thus forms a 2×16 sub-matrix located at "W_{13}" and "W_{31}" in Table 3.11. It is necessary to note that pairwise comparisons are necessary to all connections among each node, sub-cluster and cluster in the IBAssessor ANP model to identify the level of interdependences, which are fundamental in the ANP procedure. Upon the completion of pairwise judgments, the nine sub-matrices are then aggregated into a supermatrix, which is denoted to supermatrix *A* in this study (refer to Table 3.11). And it is then used to derive the initial supermatrix in the later calculation in Step C, and the calculation of the IBAssessor ANP model can thus be conducted following Step *C* to *D*.

In order to obtain useful information for intelligent buildings assessment, the calculation of supermatrix is to be conducted following three sub-steps, which transform an initial supermatrix to a weighted supermatrix, and then to a synthesized supermatrix.

At first, an initial supermatrix of the IBAssessor model is created. The initial supermatrix consists of local priority vectors obtained from the pairwise comparisons among clusters and nodes. A local priority vector is an array of weight priorities containing a single column (denoted as $w^T = (w_1, ..., w_i, ..., w_n)$), whose components (denoted as w_i) are derived from a judgment comparison matrix *A* and deduced by Equation 3.7 (Saaty, 1996-2001).

$$w_i\Big|_{I,J} = \sum_{i=1}^{I}\left(a_{ij} \Big/ \sum_{j=1}^{J} a_{ij} \right) \Big/ J \qquad (3.7)$$

Where $w_i\Big|_{I,J}$ is the weighted/derived priority of node i at row I and column J; a_{ij} is a matrix value assigned to the interdependence relationship of node i to node j. The initial supermatrix is constructed by substituting the sub-matrices into the supermatrix as indicated in Table 3.11. A detailed initial supermatrix is not given in this chapter.

After formatting the initial supermatrix, a weighted supermatrix is then transformed. This process is to multiply all nodes in a cluster of the initial supermatrix by the weight of the cluster, which has been established by pairwise comparison among clusters. In the weighted supermatrix, each column is stochastic, i.e. sum of the column amounts to 1 (Saaty, 1996-2001).

The last sub-step of supermatrix calculation is to compose a limiting supermatrix, which is to raise the weighted supermatrix to powers until it converges/stabilizes when all the columns in the supermatrix have the same values. Saaty (1996) indicated that as long as the weighted supermatrix is stochastic, a meaningful limiting result could be obtained for prediction. The approach to arrive at a limiting supermatrix is by taking repeatedly the power of the matrix, i.e. the original weighted supermatrix, its square, and its cube etc., until the limit is attained (converges), in which case the numbers in each row will all become identical. A calculus type algorithm is employed in the software environment of Super Decisions by Bill Adams and the Creative Decision Foundation to facilitate the formation of the limiting supermatrix and the calculation result is omitted in this chapter. As the limiting supermatrix is set up, the following step is to select a proper building design alternative using results from the limiting supermatrix.

3.5.4 Step D: Selection

This step aims to select the most appropriate IB Candidate based on the computation results from the limiting supermatrix of the IBAssessor model. Main results of the ANP model computations are the overall priorities of IB Candidates obtained by synthesizing the priorities of individual IB Candidate against different KPIs. The selection of the most appropriate IB Candidate that has the highest priority of lifespan energy efficiency is conducted by a limiting priority weight, which is defined in Equation 3.8.

$$W_i = \frac{w_{C_{IB},i}}{w_{C_{IB}}} = \frac{w_{C_{IB},i}}{\sum_i w_{C_{IB},i}} \tag{3.8}$$

Where W_i is the synthesized priority weight of IB Candidate i (i=1,…, n) (n is the total number of IB Candidates, n=2 in this study), and $w_{C_{IB},i}$ is the limited weight of IB Candidate i in the limiting supermatrix. Because the $w_{C_{IB},i}$ is transformed from pairwise judgments conducted in Step B, it is reasonable to be treated as the priority of IB Candidate i and thus to be used in Equation 3.8. According to the computation results in the limiting supermatrix, $w_{C_{IB},i}$ = (0.433, 0.561), so the Wi= (0.44, 0.56), as a result, the most appropriate IB is Candidate B (refer to Table 3.12).

Table 3.12 Selection of the most appropriate IB

Model	**No. of nodes**	**Synthesized priority weight W_i**		**Selection**
		Building A	Building B	
IBAssessor	34	0.44	0.56	Building B

According to the attributes of each IB Candidate listed in Table 3.9, the comparison results using W_i also implies that the most preferable building is the candidate that regulates the building performance of lifespan energy efficiency with best solutions for building services systems, least energy consumption, lowest ratio of wastage, and lower adverse environmental impacts. This indicates that the IBAssessor ANP model provides a quite logical comparison result for the aim of a sense of emotional and physical well-being of people and lifespan energy efficiency of intelligent buildings and thus can be applied in practice.

3.6 Stochastic ANP

In currently used ANP models, not limited in this research, there are no considerations or scenarios about conditional probabilities actually existed in either the network model or pairwised comparisions. As mentioned by Leskelä (2005), stochastic networks aim to use mathematical models to describe flows or connections in networks with uncertainty; further research initiatives will focus on theoretical innovation on conditional probability supported ANP modeling, and conditional probability supported pairwise comparisions.

3.7 Conclusions and Recommendations

This chapter presents an ANP model, named as IBAssessor, for intelligent buildings assessments emphasizing the lifespan energy efficiency of buildings. The IBAssessor ANP model is developed based on the ANP containing feedback and self-loops among clusters and sub-clusters (refer to Figure 3.3), but without the control model to simplify the ANP model. KPIs for the IBAssessor model are selected by a quantitative approach called *Energy-Time consumption Index* (*ETI*) based on a *Strategic Intelligent Buildings Evaluation and Renovation* (*SIBER)* model (refer to Figure 3.1) and a *Tactical Intelligent*

Buildings Evaluation and Renovation (*TIBER)* model (refer to Figure 3.2). However, there are implicit control criteria with respect to which all pairwise judgments are made in this model, i.e. lifespan energy efficiency of buildings focusing on products and processes with respect to the well-being of people. The supermatrix computations are conducted for the overall priorities of IB Candidates, and the priorities are obtained by synthesizing the priorities of the Candidates from all the sub-networks of the IBAssessor ANP model. Finally, the synthesized priority weight W_i is used to distinguish the degree of lifespan energy efficiency due to the deployment of design and construction plans from each IB Candidate. It is believed that the IBAssessor approach has advantages over the current building rating methods such as the Asian IB index because it can tackle both values and interrelationships among KPIs, which the current building rating systems do not achieve.

In summary, in order to apply the IBAssessor ANP model into practice, this chapter recommends the following steps:

1. assess IB Candidates on all KPIs using Table 8 and the scoring criteria of IB Index by the AIIB (2005);
2. make pairwise comparisons among all indicators using Table 3.8 and Table 3.10;
3. calculate supermatrix calculation to transform an initial supermatrix to a limiting supermatrix;
4. calculate each limiting priority weight of IB Candidates using limiting supermatrix;
5. select IB Candidate using Table 3.12.
6. If none of the candidates meets lifespan energy efficiency and well-being requirements, adjust the plans and re-evaluate by repeating the above procedure.

Although the IBAssessor ANP model has been built based on a group of KPIs extracted from IB Index, the author admit that the KPIs adopted in current IBAssessor model are not perfect to provide a complete coverage to lifespan energy efficiency of products and processes as well as well-being of people. Further research needs to go through all current building rating systems and conduct more surveys with practitioners to collect a conclusive group of KPIs to develop a revised IBAssessor model.

Equations

The following equations are used in this chapter:

$$IBI = \prod_{i=1}^{9} M_i^{\frac{w_i}{\sum_{i=1}^{9} w_i}} \tag{3.1}$$

$$M_i = \prod_{j=1}^{m} x_j^{\frac{w_{x_j}}{\sum_{j=1}^{m} w_{x_j}}} \tag{3.2}$$

$$IBI = x^{\frac{w_x}{w_x + w_y}} y^{\frac{w_y}{w_x + w_y}} \tag{3.3}$$

$$F_{ETI} = f(e,t) \tag{3.4}$$

$$ETI_i = \frac{\partial F_{ETI_i}}{\partial t} \tag{3.5}$$

$$ETI_i = \sum_{j=1}^{2} SEC_{i,j} \Big/ \sum_{j=1}^{2} STC_{i,j} \tag{3.6}$$

$$w_i\Big|_{I,J} = \sum_{i=1}^{I}\left(a_{ij}\Big/\sum_{j=1}^{J}a_{ij}\right)\Big/J \tag{3.7}$$

$$W_i = \frac{w_{C_{IB},i}}{w_{C_{IB}}} = \frac{w_{C_{IB},i}}{\sum_i w_{C_{IB},i}} \tag{3.8}$$

Notation

The following symbols are used in this chapter:

IBI =the IB index.

M_i =the score of the i^{th} modules.

w_i =the weight to the i^{th} module relevant to other modules ($w_i \in [1, 9]$).

x_j =the score of the j^{th} element of the i^{th} module ($x_j \in [1, 100]$).

w_{x_j} =the weight to the j^{th} element relevant to other elements of the i^{th} module ($w_{x_j} \in [1, 9]$).

m =the number of elements in the i^{th} module.

x, *y* =different modules.

w_x , w_y =the weight of module *x* and module *y*.

w_t =the synthesized priority weight of tender alternative *t*.

I, *J*=*I* is the index number of rows; and *J* is the index number of columns; both I and J correspond to the number of cluster and their nodes ($I, J \in (1, 2, \ldots, 318)$).

n=the total number of columns in Cluster *I*.

n_I =the total number of nodes in Cluster *I*.

n_T =the total number of tender alternatives (n_T =2 in this study).

$N_I^{(n_I)}$ =the node belongs to Cluster *I* and the total number of nodes in Cluster *I* is n_I .

W_{IJ} =a sub-matrix of the Supermatrix.

$w_i\big|_{I,J}$ =the weighted/derived priority of Node *i* at row *I* and column *J*, $i \in (1, 2, \ldots, n_I)$.

α_{ij} =a matrix value assigned to the interdependence relationship of Node *i* to Node *j* to reflect the relative importance weight of interdependence.

Chapter 4

AN INTELLIGENT DECISION SUPPORT SYSTEM

4.1 Introduction

Buildings are vital to national economy because they support most economic activities. However, due to the long-term extensive use, buildings are simultaneously aging. Therefore, the emphasis has shifted toward their preservation and modernization through repair, rehabilitating and replacement activities. This requires a rapid collection and processing of a large amount of data to select and prioritize the preservation strategies. Meanwhile, a huge amount of investments is flowing to new buildings every year. This definitely requires a rapid prototyping approach to select the most appropriate design among alternatives. Therefore nondestructive testing methods and knowledge-based assessment methods are necessary to the information collection and the performance assessment of buildings. The assessed condition of buildings can provide the base from which technological, social, environmental, political, and economical issues would be used to manage our buildings towards a sustainable future.

One research focus on intelligent buildings assessment is to develop innovative approaches to effectively and efficiently evaluating multilateral building performance, so that users can get reliable assessment results. As summaried in Chapter 1 and chapter 3, there are dozens of building assessment tools all over the world, including

- Building IQ (by University of Central England, UK) (Boyd and Jankoyic, 1992),
- BQA (Building Quality Assessment, by Building Economics Bureau, UK),

- BREEAM (Building Research Establishment Environmental Assessment Method, by Building Research Establishment Ltd. (BRE), UK) (Anderson, Shiers, and Sinclair, 2002),
- BSAT (Building Sustainability Assessment Tool, by the Department of Trade and Industry, UK) (Sayce, Walker, and McIntosh, 2004),
- Building IQ Rating Criteria (Task Force 1 - Intelligent Building Ranking System, Continental Automated Building Association (CABA), Canada) (CABA, 2004),
- CASBEE (Comprehensive Assessment System for Building Environmental Efficiency, by Japan Sustainable Building Consortium, Japan) (JSBC, 2004),
- DQI (Design Quality Indicator, by Construction Industry Council, UK),
- Eco-Quantum (Environmental Performance Express of Buildings, by IVAM, Netherlands),
- GBTool (Assessment Framework & Green Building Tool, by the International Initiative for a Sustainable Built Environment, Canada) (Cole, 2002),
- GMB (Green Mark for Buildings, by Building and Construction Authority, Singapore) (GMB, 2005),
- GOBAS (Green Olympic Building Assessment System, Ministry of Science and Technology, China)
- GreenStar (Green Star Environmental Rating System for Buildings, Green Building Council of Australia, Auatralia),
- HK-BEAM (Hong Kong Building Environmental Assessment Method, by HK-BEAM Society, Hong Kong) (HK-BEAM Society, 2004),
- IB Index (Asian Institute of Intelligent Buildings (AIIB), Hong Kong) (AIIB, 2005),
- ASCIB (Assessment Standards for Certifying Intelligent Buildings, by Intelligent Building Society of Korea (IBSK), Korea) (IBSK, 2002),

- LEED (Leadership in Energy and Environmental Design/Green Building Rating System, by U.S. Green Building Council, USA) (USGBC, 2005),
- LEGEP (Life-cycle-referred planning and ecological-economic evaluation of buildings, Quasar GmbH, Germany),
- Matool (Building Research Establishment Ltd. (BRE), UK) (Bassi, 2005),
- NABERS (National Australian Built Environment Rating System, by Department of the Environment and Heritage, Australia) (DEH, 2004),
- Office Scorer (Sustainable Refurbishment/Redevelopment Decision Support Tool for office buildings, Building Research Establishment Ltd., UK) (Anderson and Mills, 2002),
- SBAT (Sustainable Building Assessment Tool, Council for Scientific and Industrial Research, South Africa)
- Shanghai IB Rating (Shanghai Construction Council (SCC), Shanghai, China) (SCC, 2002),
- SPeAR (Sustainable Project Appraisal Routine, by Arup, UK) (Arup, 2002), and
- Sustainability Checklist (South East England Development Agency (SEEDA), UK) (Amato, 1996), etc.

Among these building assessment systems, there are six rating systems specially designed for intelligent buildings assessment, including

- AIIB method (AIIB, 2005) developed by the Asian Institute of Intelligent Buildings (AIIB), Hong Kong, China,
- BRE method (Rassi, 2005) developed by the Building Research Establishment Ltd., UK,

- CABA method (CABA, 2004) developed by the Continental Automated Building Association (CABA), Canada & USA,
- IBSK method (IBSK, 2002) developed by the Intelligent Building Society of Korea (IBSK), Korea,
- SCC method (SCC, 2002) developed by the Shanghai Construction Council (SCC), China, and
- TIBA method (Wen, 2003) developed by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan, China.

It has been noticed that building rating method is commomly adopted in above mentioned systems. The advantage of rating method is that it can evaluate buildings by their scores according to rules of a rating system; however, the rating method is not able to reflect interrelations between a pair of KPIs that objectively lead to their vital weakness such as the lack of reasonableness in buildings assessment. As analysed in Chapter 3, the above six current used rating systems for intelligent buildings assessment have common limitions. For example, none of them has mechanism to allow assessors to measure interrelation between any pair indicators, sometime and somewhere this interralation do exist and can definitely impact the reliability of assessment results. From this point of view, the Analytic Network Process (ANP) approach introduced in Chapter 3 has capacity to overcome this weakness.

The construction of an ANP model is actually a process of knowledge reuse, because all possibly existing interrelations are measured by using expertises. In order to make a reliable ANP model for intelligent buildings assessment, people have to spend a lot of time on the pairwise comparisons among KPIs, as there might be hundreds of or thousands of such comparisons. For example, in Chapter 3, there are 32 KPIs selected for the IBAssessor ANP model with two alternatives; in order to set up the model, it took an expert more than one week to complete more than 7,000 pairwise comparisons. In this regard, the ANP approach has advantages in knowledge reuse but it is not an efficient tool for practionners who have little knowledge in using ANP; however, the ANP approach is the only way to reuse large-scale expertises in intelligent buildings assessment. Based on this consideration, this chapter presents a novel knowledge-driven multicriteria decision-making prototype for intelligent buildings assessment.

According to the conception of DAKIB system, there are four practical tools integrated for intelligent buildings assessment (see Figure 2.1). This chapter aims to provide an integrative prototype to facilitate the application of ANP approach as described in Chapter 3. The proposed prototype integrates an Artificial Neural Network (ANN) model with an ANP model with supports from a database of intelligent buildings. Regarding the weakness of current building assessment systems, the ANP model is design to quantitatively measure the interrelation between each two building performance indicators. As an innovative decision-making theory, the ANP has been applied to solve problems for complex social and natural systems in the past near ten years; however, the complex system analysis and control require the DAKIB system should be easy to use by practionners, and should provide more efficient tools to accelerate decision-making process. In this regards, the ANP has limitations to popularize its decision-making models into practice, especially when there are too many indicators involved in a model for a complex system. The aim of this integration is to facilitate the application of ANP with artificial intelligence support for solving real-world decision-making problems relevant to the intelligent buildings assessment. It is expected that the artificial intelligence supported ANP method can effectively speed the process of intelligent buildings assessment so as to lead to high-quality results.

4.2 Methodology

The methods adopted in the research of this Chapter include a quantitative approach to rating intelligent buildings, and integrative application of two generic quantitative approaches for decision making including the analytic network process, and the artificial neural network. Figure 4.1 illustrates a proposed knowledge-driven multicriteria decision-making model for intelligent buildings assessment, called IBAssessor prototype. It is an integration of three DAKIB tools, including the ANP approach, the ANN approach, and the rating approach (see Figure 2.1). In this Chapter, except the ANP approach is adopted directly from Chapter 3, the rating approach will be developed using the same group of KPIs adopted in the IBAssessor ANP model and some other relevant information described in Chapter 3, while the ANN model will be described based on the ANP model and the rating approach (see Figure 4.1).

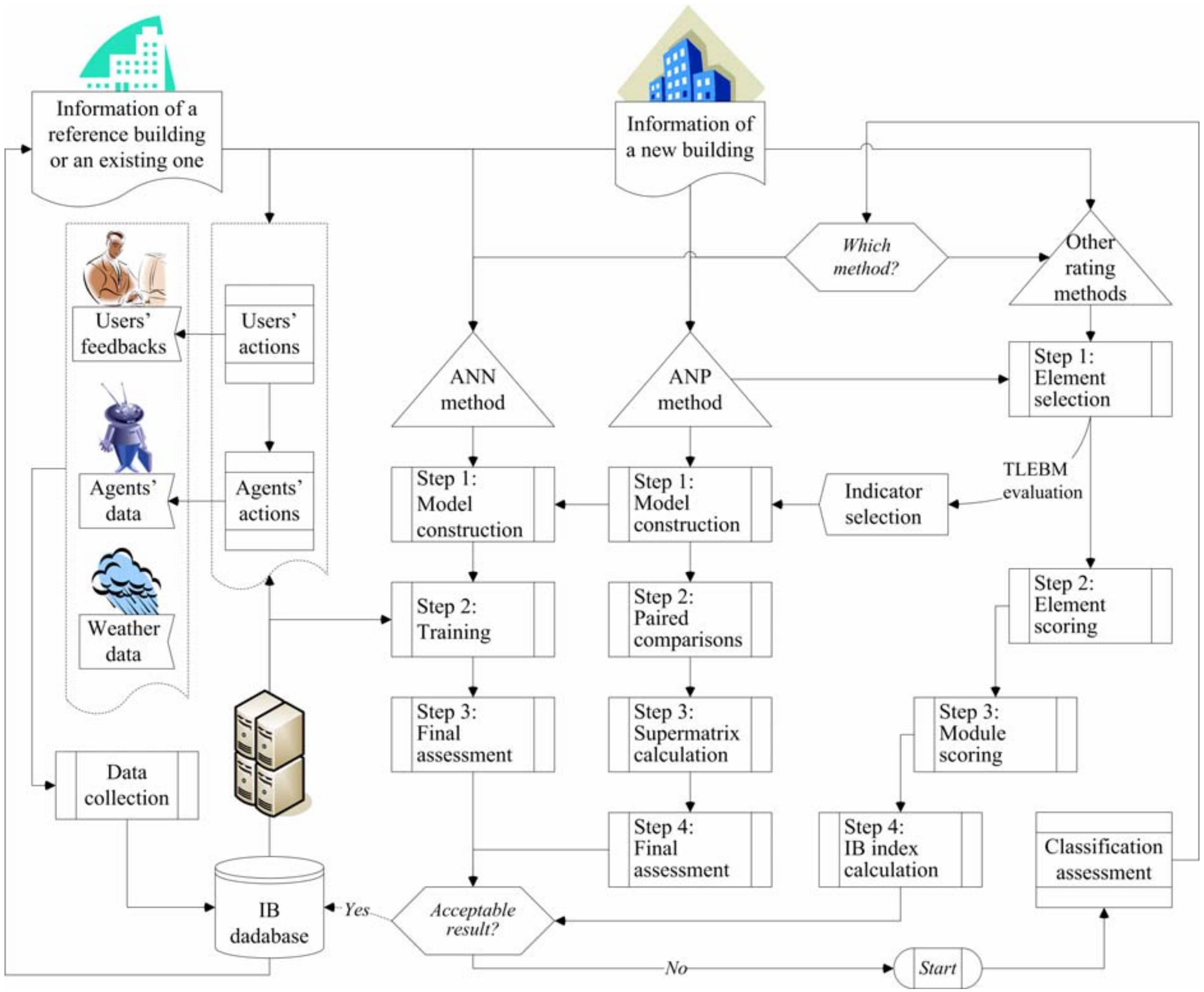


Figure 4.1 IBAssessor prototype

There are three main arrow-line flows in Figure 4.1, including

- The first flow: ANP modeling, which has been described in detailes in Chapter 3;
- The second flow: building rating, which covers all building assessment systems using rating method (refer to the Section 5.1 of this chapter). In order to effectively use existing building assessment systems, a quantitative indication selection approach, i.e. the ETI has been specifically developed for indicator evaluation in Chapter 3. An ETI based process can support the collection of KPIs for ANP modeling, structuring rating model, and ANN modeling; and
- The third flow: ANN modeling, which uses indicators relevant to ANP model and rating model for its input layer, while uses results from ANP process and rating process for its output nodes.

As the ANP requires many pairwise comparisons regarding the interrelation among KPIs, and this normally need a number of days or weeks to formalize an ANP model to be ready to use; while the rating process is too subjective to provide a reliable assessment, the implementation of the integrative IBAssessor prototype is expected to be able to accelerate the process of intelligent buildings assessment using ANP model. Practitioners as end-users can use the DAKIB rating model to subjectively assess buildings at first step, and then adopt the ANN model to finalize intelligent buildings assessment. The ANN model will be trained using the results from ANP-based intelligent buildings assessment and relevant rating scores according to DAKIB rating approach (see Section 4.3). From this point of view, the IBAssessor prototype and its appications can get benefits from the ANP model in which all interrelation between each two indicators are quantitatively measured, and therefore they have advantages than other currently used building rating systems (see Section 4.1).

4.3 A New Rating Approach

As mentioned in Section 4.1, there are dozens of building assessment systems currently used for building assessment, which are generally based on similar rating approach. The advantage of using rating approach is that it can provide an easily understandable score for any building under assessment, like the score of a student in an examination. During research period, feedbacks from building professionals indicate that they feel it's difficult to use ANP in buildings assessment, and they prefer using rating approach or using the ANN toolkit which is trained by using results from both ANP approach and rating approach. To further make the DAKIB a comprehensive system for intelligent buildings assessment, it is necessary to develop a rating model. Therefore, a new rating approach is under discussion.

4.3.1 The Selection of Indicators

In order to set up an assessment model for the DAKIB rating approach, a group of indicators are planned to be collected from currently used building assessment systems. The reasons why it is necessary to collect indicators from existing systems are

- currently used building assessment systems have a sound group of indicators that can be adopted in the ANP model, the rating model and the ANN model for intelligent buildings assessment, while a selection process is necessary; and
- this can reduce time in finding effective indicators.

In Chapter 3, the energy-time consumption index (ETI) has been put forward to evaluate KPIs, and 32 KPIs (see Table 3.5) have been finally collected for ANP modeling. As those 32 KPIs are selected from a comprehensive group of indicators developed by AIIB (2005), it is therefore regarded as a group of reliable KPIs for intelligent buildings assessment (see Chapter 3). In order to have consistency among the four DAKIB tools, including the ANP approach, the rating approach, the ANN approach, and the KIV approach, all these 32 KPIs for ANP modeling are directly adopted for the new DAKIB rating approach.

4.3.2 Scoring

According to ETI evaluation as described in Chapter 3, the values of ETI for each KPI are summarized in Table 4.1. The weight of each KPI is defined by Equation 4.1.

$$w_i = \frac{ETI_i}{\sum_{i=1}^{32} ETI_i} \tag{4.1}$$

Where the w_i is the weight of indicator *i*, i.e. KPI_i, ETI_i is the energy-time consumption index of KPI_i, *i* is the number of indicators, it ranges from 1 to 32 in accordance with the 32 KPIs. By using Equation 4.1, the weights of each indicator are defined (see Table 4.1).

Comparing the weighting method proposed in Equation 4.1 with AIIB's definition of weight (AIIB, 2005), it is clear that the proposed weight calculation method is much objective than those subjective definitions of weights to different kinds of buildings given by AIIB (2005). And it is one important objective for this study to achieve, which aims to make a more objective method for intelligent buildings assessment.

Besides its comprehensive list of indicators, the IB Index (AIIB, 2005) also has a very detailed description or guideline regarding how to give score to each indicator. As all KPIs for the DAKIB are collected from the IB Index (AIIB, 2005), it is therefore easy for auditors to give scores to all these 32 KPIs according to the guideline by AIIB (2005). In this dissertation, there will not be a refurbished version of scoring guideline, however, further research need to have a go. As a result, the scale of score is directly given in Table

4.1 as from 0 to 100. Table 4.2 gives some details about the combination of indicators during finalizing KPIs for the DAKIB system and its tools.

Table 4.1 KPIs and their weights for the DAKIB rating approach

Indicator	ETI_i	w_i	The scale of score*	S_i	IB_{Score}
Electricity & Electrical services	200	5.78	(0, 100)		
Heating services	200	5.78	(0, 100)		
Ventilation & air-conditioning	188	5.43	(0, 100)		
Building services automation system	178	5.14	(0, 100)		
Construction materials	178	5.14	(0, 100)		
IT&C facilities and services	175	5.06	(0, 100)		
Thermal comfort & indoor air quality	163	4.71	(0, 100)		
Lifts/escalators and controls	163	4.71	(0, 100)		
Security and safety control	138	3.99	(0, 100)		
Flushing water system	125	3.61	(0, 100)		
External & internal decoration	122	3.53	(0, 100)		
Building architectural design	120	3.47	(0, 100)		
Lavatory accommodation	113	3.27	(0, 100)		
Refuse collection	113	3.27	(0, 100)		
Circulation for the disabled	111	3.21	(0, 100)		
CAD/CAM/CAC	111	3.21	(0, 100)		
Flexibility for renovation	100	2.89	(0, 100)		
Structural monitoring & control	100	2.89	(0, 100)		
Potable water system	100	2.89	(0, 100)		
Fire detection and resistance	88	2.54	(0, 100)		
Cleanliness	88	2.54	(0, 100)		
Property management	86	2.49	(0, 100)		
Car-park/transportation facilities	71	2.05	(0, 100)		
Entertainment facilities	71	2.05	(0, 100)		
External landscape	71	2.05	(0, 100)		
Extensive use of AI	67	1.94	(0, 100)		
Environmental friendliness	50	1.45	(0, 100)		
Conference and meeting facilities	50	1.45	(0, 100)		
Access sign and directory	33	0.95	(0, 100)		
Maintainability	33	0.95	(0, 100)		
Usable areas	29	0.84	(0, 100)		
Means of escape	25	0.72	(0, 100)		

Note:
ETI_i means the energy-time consumption index of indicator *i*, w_i means the weight of indicator *i*, S_i means the score of indicator *i*, IB_{Score} means the total score of the intelligent building under assessment.

* AIIB, 2005

Table 4.2 The combination of indicators for KPIs based on the IB Index

Indicator	Codes of the IB Index	Modules of the IB Index									
		Green	Space	Comfort	Working Efficiency	Culture	High-tech Image	Safety & Structure	Management Practice & Security	Cost Effectiveness	Health & Sanitation
Group 1											
Electricity & Electrical services	multiple	✓	✓	✓	✓		✓	✓	✓		
Heating services	multiple	✓									
Ventilation & air-conditioning	multiple	✓	✓	✓	✓						✓
Building services automation system	multiple				✓		✓		✓		
Construction materials	multiple	✓					✓				
IT&C facilities and services	multiple				✓		✓				
Thermal comfort & indoor air quality	multiple	✓		✓	✓			✓	✓		✓
Lifts/escalators and controls	multiple	✓		✓	✓		✓		✓		✳
Security and safety control	multiple		✓		✓		✓	✓	✓		
Flushing water system & drainage	multiple	✓		✓					✓		✓
External & internal decoration	multiple		✓		✓						✓
Building architectural design	multiple	✓			✓	✓	✓				
Lavatory accommodation	multiple	✓		✓	✓						
Refuse collection & disposal	multiple	✓							✓		✓
Circulation for the disabled	multiple		✓						✓		
CAD/CAM/CAC*	multiple	✓					✓				
Group 2											
Flexibility for renovation	multiple		✓								
Structural monitoring & control	multiple							✓	✓		
Potable water system	multiple								✓		✓
Fire detection and resistance	multiple				✓			✓			
Cleanliness	multiple	✓		✓	✓						✓
Property management	multiple	✓	✓		✓		✓	✓	✓	✓	✓
Carpark/transportation facilities	multiple		✓		✓		✓		✓		✓
Entertainment facilities	multiple			✓	✓	✓					
External landscape	multiple	✓				✓					
Extensive use of artificial intelligence	multiple				✓		✓				
Environmental friendliness**	multiple	✓							✓		
Conference and meeting facilities	multiple				✓		✓				
Access sign and directory	multiple				✓		✓	✓			
Maintainability	multiple				✓				✓		
Usable areas	multiple		✓	✓	✓						
Means of escape	multiple							✓	✓		

Note:
✓ denotes the indicator is recognized by the IB Index in such module/cluster; ✳ denotes recommended feature.
* CAD/CAM/CAC: Computer Aided Design, Manufacturing, Construction/installation.
** Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

After subjectively giving scores to all KPIs, the total score of the intelligent building under assessment is calculated by using Equation 4.2.

$$IB_{Score} = \sum_{i=1}^{32} w_i \times S_i \qquad (4.2)$$

Where the IB_{Score} represents the total score of the intelligent building under assessment, S_i represents the score of indicator *i*, *i* is the number of indicators, it ranges from 1 to 32 in accordance with the 32 KPIs.

For further application, Table 4.1, as a form of the proposed DAKIB rating approach, can be used in intelligent buildings assessment. During the research, questionnaires about using the DAKIB rating approach to assess intelligent buildings have been distributed to practionners in China. Appendix 1 provides datailes about this questionnaire survey. Upon collecting all feedbacks, further efforts will be put into data analysis from this questionnaire survey for real case studies and improving the new rating approach. As a matter of fact, none rating system is objective enough, including the proposed DAKIB rating approach; therefore further research will also put efforts to find more reliable rating method. Currently, an alternative case study has been conducted to the City of Manchester Stadium in UK, which is given in Chapter 6 to demonstrate the effectiveness of the new rating approach for intelligent buildings assessment.

4.4 IBAssessor Prototype

4.4.1 An Integrated System

The ANN and ANP have been separately applied in building assessment and other building related areas for a long time. However, according to an extensive literature review, there are few publications about the integrative use of ANN and ANP not only in the building professions but also in other disciplines; and it has been noticed that current integrative application of ANN into multicriteria decision-making area focusing on how to use ANN to define priorities for decision-making models. For example, Bagchi (1997) introduced a modeling framework, based on analytical hierarchical processes (AHP), ANN and fuzzy logic using a value-based approach, for information technology (IT) adoption studies; Magoulas and Ghinea (2001) applied ANN to support AHP-based weighted priorities for interactive multicriteria decision making in a quality of perception-oriented management scheme. As ANP is new to most AHP users, there are also few publications about either applying ANP or an integrative ANP and ANN for multicriteria decision-making purposes.

Moreover, it has also been noticed that, among current publications, the purpose of using ANN and AHP was to treat an ANN model as a data supplier for an AHP model. As illustrated in Figure 4.1, in this study, the purpose of the integration of ANP, ANN and rating approach is to train an ANN model by using results generated from ANP model. It is clear that they are opposite processes in multicriteria decision-making. As a unique decision-making model, this innovation will make it easy for practionners to conduct intelligent buildings assessment by using valuable expertises accumulated in the IBAssessor ANP model. For other building rating systems such as the IB Index (AIIB, 2005), it is difficult or even impossible for auditors to reuse experts' knowledge. Therefore, the proposed IBAssessor prototype (see Figure 4.1) provies a completely new method for intelligent buildings assessment.

4.4.2 Layers for ANN Model

The proposed ANP model has three layers, including an input layer, a hidden layer and an output layer. In order to achieve a synergetic effect, the group of KPIs for both ANP model and rating model is used for the input layer; as the group of KPIs, with 32 indicators, doesn't involve the score of an intelligent building, i.e. IB_{Score} (see Equation 4.2), it is further put to the input layer as the 33rd input. For the output layer, there is noly one output, i.e. the relative weight of an intelligent building under assessment, which can be obtained from ANP model. All elements for these two layers are listed in Table 4.3.

In order to facilitate the application of ANN, commercial software, i.e. NeuroSolutions was selected, because NeuroSolutions for Microsoft Excel is an add-in that enables users to develop custom neural network models without ever having to leave the Excel environment (NeuroSolutions, 2005); And everything users need is all contained within the NeuroSolutions sub-menu of Excel. Therefore it could be much adaptable for users who are familiar with Microsoft Office to use this software for intelligent buildings assessment (see Figure 4.2).

A questionnaire survey has been conducted to building professionals in China to collect necessary data for training the ANN model. Detailes about the questionnaire survey are given in Appendix 1. It is regretted that there have not been any feedbacks received at this stage, so that I have to look forward to conducting data analysis and reuse for both rating approach and ANN approach in a near future.

Table 4.3 The inputs and outputs of the ANN model

The No. of Indicator	Inputs and Outputs
	Input layer
1.1	The score of Electricity & Electrical services
1.2	The score of Heating services
1.3	The score of Ventilation & air-conditioning
1.4	The score of Building services automation system
1.5	The score of Construction materials
1.6	The score of IT&C facilities and services
1.7	The score of Thermal comfort & indoor air quality
1.8	The score of Lifts/escalators and controls
1.9	The score of Security and safety control
1.10	The score of Flushing water system & drainage
1.11	The score of External & internal decoration
1.12	The score of Building architectural design
1.13	The score of Lavatory accommodation
1.14	The score of Refuse collection & disposal
1.15	The score of Circulation for the disabled
1.16	The score of CAD/CAM/CAC
2.1	The score of Flexibility for renovation
2.2	The score of Structural monitoring & control
2.3	The score of Potable water system
2.4	The score of Fire detection and resistance
2.5	The score of Cleanliness
2.6	The score of Property management
2.7	The score of Carpark/transportation facilities
2.8	The score of Entertainment facilities
2.9	The score of External landscape
2.10	The score of Extensive use of artificial intelligence
2.11	The score of Environmental friendliness
2.12	The score of Conference and meeting facilities
2.13	The score of Access sign and directory
2.14	The score of Maintainability
2.15	The score of Usable areas
2.16	The score of Means of escape
	The score of intelligent building from rating approach
	Output layer
	The score of intelligent building from ANP

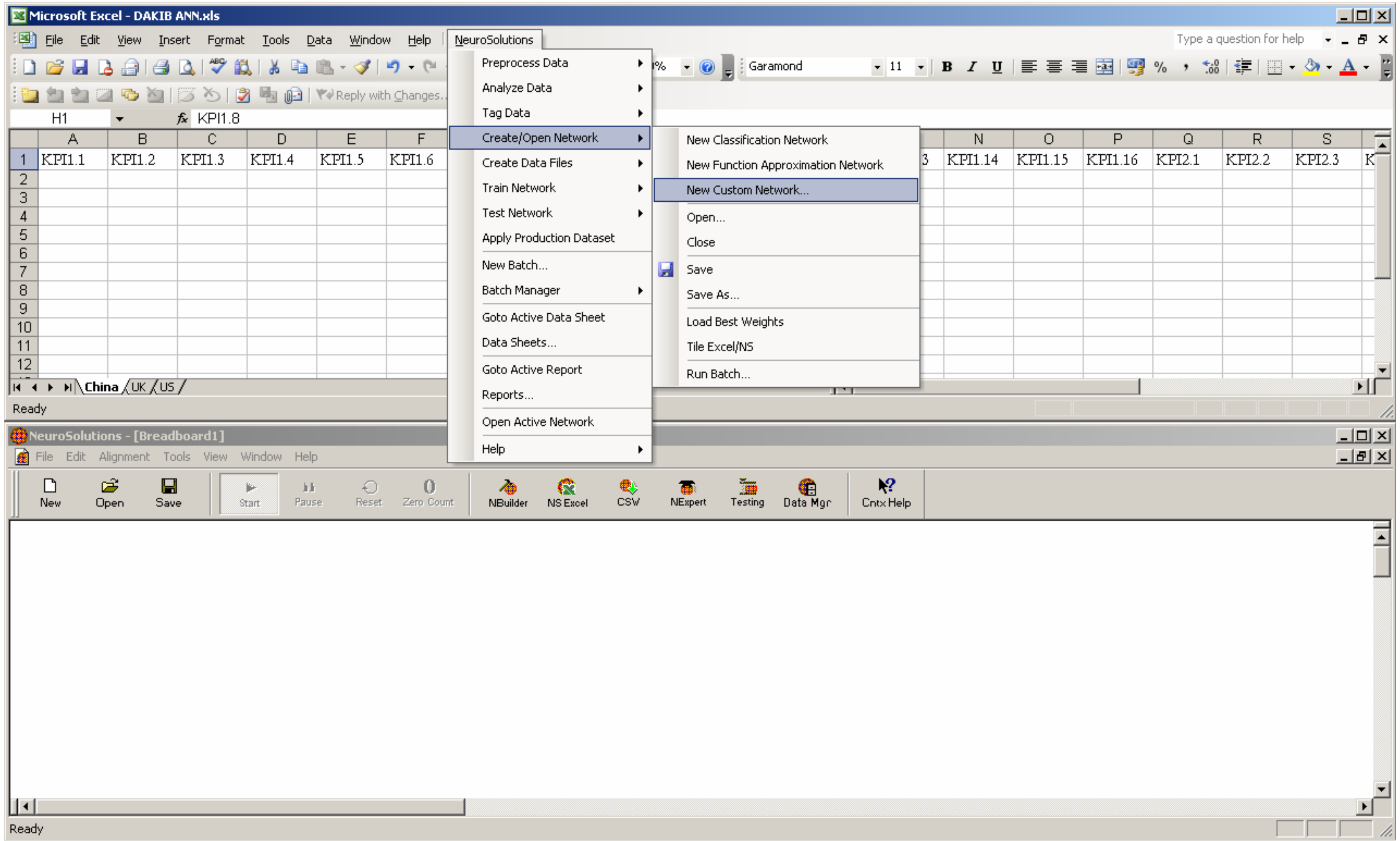


Figure 4.2 A screenshot of ANN application using NeuroSolutions

4.5 Conclusions

There are two contributions of this Chapter. The first one is the knowledge-driven multicriteria decision-making prototype for intelligent buildings assessment. The ANP and ANN are integrated to facilitate the process of building assessment, and another one is that an energy-time consumption index has been developed to quantitatively evaluate indicators based on energy and time consumptions in processes and products of buildings. The IBAssessor has advantages in intelligent buildings assessment because its indicators are collected from currently used building rating systems, and there is a quantitative measurement for all interrelations among indicators. Experimental case studies indicated that the ANP model is practical in intelligent buildings assessment. In order to facilitate the building assessment process, the ANN has been integrated into the IBAssessor. Regarding the effectiveness and efficiency of ANN supported ANP assessment; more case studies will be conducted in further research. Meanwhile, the second contribution of this Chapter is that a new rating approach is developed for intelligent buildings assessment. By being integrated into the IBAssessor prototype, the three DAKIB tools, including the ANP approach, the rating approavh, anf the ANN approach, can effectively work together so as to provide more objective results for intelligent buildings assessment.

Chapter 5

AN INFORMATION VISUALIZATION APPROACH

5.1 Introduction

The chapter presents a Knowledge-oriented Information Visualization (KIV) approach to facilitating the implementation of building rating systems such as the IB Index (AIIB, 2005) for the post-assessment of intelligent buildings. The KIV approach is introduced by using a prototype of KIV for intelligent buildings assessment. The KIV model consists of several toolkits, including an IB Casebase for the Applications of Sustainable Technology (called IB-CAST), a web-oriented information visualization toolkit for intelligent buildings assessment using Microsoft Office (called IB-Radar and IB-Compass), and a Geographical Information System (GIS) toolkit for bridging knowledge (called IB-GIS) in intelligent buildings assessment etc. A case study is used to demonstrate how the KIV approach can be applied to support intelligent buildings assessment.

5.1.1 Background

For building assessment, the currently most popular way is to use rating method. For example, the U.S. Green Building Council (USGBC, 2005) has developed the LEED Green Building Rating System for developing high-performance, sustainable buildings. Regarding the assessment of intelligent buildings, the author have reviewed six specially developed intelligent buildings assessment systems adopted or to be adopted all over the world, these include AIIB method developed by the Asian Institute of Intelligent Buildings (AIIB, 2005), BRE method developed by the Building Research Establishment Ltd. in UK (Bassi, 2005), CABA method developed by the Continental Automated Building Association in North America (CABA, 2004), TIBA method developed by the

Architecture and Building Research Institute in Taiwan, China (Wen, 2003), IBSK method developed by the Intelligent Building Society of Korea in Korea (IBSK, 2002), and SCC method developed by the Shanghai Construction Council in China (SCC, 2002). Among these intelligent buildings assessment systems, the AIIB method is identified as the most comprehensive one with more potential utilizations in intelligent buildings assessment.

However, it is also noticed that nearly all rating systems currently used in building assessment end at achieving a score of buildings. As to the rest, the current practice of building assessment doesn't cover issues about how to improve buildings. For example, designers or decision makers have to go through all indicators or aspects in accordance with the building assessment to find exact gaps between current status and further improvement in building design or building utilization. They have to study building appraisal report for detailed information regarding which part of the building need to be altered so as to get a higher score. Actually, this is time-consuming and confusing for either designers or decision makers to work accurately, effectively and efficiently. As mentioned by Rafiq, Packham, and Beck (2005) there is an urgent need for systems that allow proper visualisation of the information in an understandable manner particularly at the building design stage. Regarding how to effectively improve building designs based on assessment results, there is still lack of adequate skills and information available at the utilization level. In this regard, toolkits to support decision-making at the post-assessment stage of intelligent buildings are in demand.

In the building professions, the drawing of buildings is engineers' language, information visualization is therefore an inherent means in their daily work no matter whether computer is used or not; and it is always used by designers in various formats such as drawings, diagrams, maps or photos etc. However, research for the innovative use of modern information visualization technology other than the traditional way of information expression in the building professions has been rapidly evolving over the past decade (Malkawi, 2004). For example, Bouchlaghem, Sher, and Beacham (2000) introduced an application of digital imagery and visualization materials to aid building technology related modules in higher education; the Arup (2002) adopted an “umbrella” to show building sustainability; the Japan Sustainable Building Consortium (JSBC, 2004) used radar chart to illustrate the results of building assessment. Intelligent buildings are different from each other in characteristic, and different buildings have different features in both design and utilization. It is reasonable to believe that the experience and expertise of building designers and end-users are developed over time through their continuous interaction with particular building spaces for either imaging or using, and their expertise can be accessed by means of visualization technologies (Carvajal, 2005). The evolving research of applied information visualization technology in the building professions reveals a developing trend from which information visualization and decision support integrated applications are required.

There are two tasks for decision making at the post-assessment stage of intelligent buildings including active gap identification and reliable decision making. As mentioned above, building rating systems can give scores to each building under assessment, but they can’t give definite explanations regarding where their specific weaknesses are and what necessary variations are. In this regard, this paper takes an initiative to integrate information visualization with decision support so as to facilitate making accurate variations for buildings at post-assessment stage. To undertake these tasks, this paper will introduce a knowledge-oriented information visualization (KIV) approach. It comprises several toolkits including a casebase for the knowledge management of intelligent buildings; a radar chart made in Microsoft Excel to illustrate current and gap scores of intelligent buildings based on their rating; an internet-enabled portal for intelligent buildings information navigation based on the radar chart; and a geographical information system for spatial information management of intelligent buildings. On the other hand, the information available in multiple languages is significantly increasing (Yang, Wei, and Chen, 2005), and knowledge reuse for decision making on buildings variations at their post-assessment stage have to rely on information from multilingual information resources in a global perspective. From this point of view, it is also my initiatives to further engage in the language alternation of these KIV toolkits as mentioned above in order that multilingual information can be delivered to users speaking multiple languages. A case study will be finally conducted to demonstrate how to use the KIV approach at the post-assessment stage of intelligent buildings.

5.1.2 E-learning

E-learning has rapidly advanced to a mission-critical component of an institution’s both on-campus and distance educational environment, and has become a fixture in tertiary education; as the world's leading e-learning system tool for educational institutions, WebCT is widely adopted by thousands of institutions in more than eighty countries worldwide to expand the boundaries of teaching and learning (WebCT, 2004). Since the latest edition of WebCT and Blackboard are adopted to construct e-learning system, universities makes online units available in a number of forms for both on-campus and distance students, and the system is being used to leverage e-learning courses with its updated interface and features. However, there are still large spaces of innovation accompanying the fast development of information and communication technologies (Steeples, Jones, and Goodyear, 2002; Dunn, Morgan, O’Reilly, and Parry, 2003). To uniquely meet the rapidly evolving needs of educators around the world, two leading providers of enterprise software and services to the education community, Blackboard Inc. and WebCT, Inc., finally announced a definitive agreement to merge (Stanton, Chotiner, Farrar, and Pennington, 2005).

It has also been noticed that the tight structure and fully embedded support toolkits of current WebCT system make it more appropriate for guided learning than independent learning (Marshall et al., 2003), while the latter one is generally recognized and emphasized in most courses in tertiary education. For example, although there are some wizards in the development environment of WebCT to facilitate online course construction such as *URL* and *Image Database*, it is not easy for designers to provide internal relation among hyperlinks, images and other course materials for use by students. In other words, the lack of unity among courses materials in current WebCT system leads to an inactive learning environment, where students only receive unsystematic or unstandardized knowledge. On the other hand, current WebCT system can only passively accept course materials from individual faculty member on duty; in case some faculty members left, the WebCT cannot keep and recall any knowledge materials they didn't upload to the system but those materials are normally valuable not only to students when they study these courses but also to Institutes/Departments at universities when they look forward to a developing but persistent reputed education characteristic or sustainability. As a result, the currently used WebCT system actually are not effective enough for faculty to manage e-learning course materials in the education of independent learning ability to students, and it restricts the development of sustainable e-learning materials as well.

5.1.3 The Case Method with Potentials

The case method was pioneered by Harvard Business School (HBS) faculty in the 1920s as a way of importing slices of business reality into the classroom in order to breathe life and instill greater meaning into the lessons of management education (HBS, 2004), and it has become a major teaching method adopted at leading Business Schools (B-schools). For example, as one of the leading providers of case materials in entrepreneurship education to other B-schools around the world, the London Business School (LBS) provides a catalogue of over 70 cases for use in electives (LBS, 2003). Although B-schools also make use of lectures, simulations, fieldwork, and other forms of teaching as appropriate, more than 80% of their classes are built on the case method (HBS, 2004), and it is also believed that the case method can help students make the most of experience, providing a solid foundation that serves them for a lifetime, no matter what path they choose to follow.

As there is no substitute of experience, the education that students may receive at either B-schools or Building Engineering Schools (BE-schools) for future practice in the field of intelligent buildings would be actually not good enough if case materials hadn't been prepared well to assist them to go through the situation personally in case a student were not a veteran of many wars. Although it is acceptable that students are required to make a defensible decision without all data they would desire due to the shortage of necessary data (Davis, 1972), the case method can either potentially accelerate experience or knowledge transformation from on-site accumulation to practice-driven efficient IB education or effectively replenish and develop IB courses with a rounded knowledge coverage of various cases instead of limited fieldwork. Otherwise, graduates can hardly be knowledge-qualified to undertake real projects. Accordingly, there is a high potential requirement on instruments in preparing cases to facilitate the supplement of educational knowledge in the specific area of intelligent buildings.

Another potential of the case method is that it provides an occasion or possibility to integrate scattered knowledge in a special case study. As students might not have rounded knowledge or a developed knowledge system of intelligent buildings, it is thus important to provide an appropriate knowledge network (Novak & Gowin, 1984) of intelligent buildings for each teaching case.

5.1.4 Aims and Objectives

In order to effectively educate on-campus and distance students at either undergraduates or postgraduates level in IB related programmes to gain mature, active and independent learning competence, and to systematically set up a knowledgebase system including its structure and contents for sustainable development of e-learning curricula of IB programmes at universities, this research proposes a novel knowledge-based system to initially cover undetermined issues such as case-based teaching and learning in IB programmes. The proposed system is entitled the Casebase of Intelligent Buildings for the Applications of Sustainable Technology (shortly IB-CAST). The proof of concept deployment of IB-CAST can then be fully evaluated for extension and deployment throughout the University to support all on-campus and distance students not only in IB programmes but also in other built environment related programmes where case method can be adopted. Further to its potential applications at universities, the IB-CAST can also be evaluated for its huge potentials in training courses of intelligent buildings to professionals.

5.2 Methodology

The methodology adopted in this research comprises several methods focusing on detailed objectives mentioned above. First of all, an extensive literature review is required to explore achievements in the areas of information visualization, knowledge management, decision support, and building assessment etc. After that, system analysis will be used to develop a prototype for applying the KIV approach to intelligent buildings assessment. For each toolkit of the KIV approach, system analysis and development techniques will be adopted to realize their various functions. In addition, software tools such Microsoft Office will be used to make toolkits easy to be used in the building professions.

The methodology comprises several research methods focusing on objectives including an educational knowledge classification for the IB-CAST based on several essential specifications and standard industrial classifications (i.e. the *MasterFormat*, the *North American Industry Classification System*, the *United Kingdom Standard Industrial Classification*, the *Australian and New Zealand standard industrial Classification*, the *New York City Building Classification Codes*, and the *Japan Industrial Standards*, etc.), the prototype of IB-CAST system, the knowledgebase shell for the IB-CAST, the retrieval, evaluation, collection and access of IB-CAST knowledge materials such as IB cases from global scope using the IB-CAST knowledge classification and IB-CAST knowledgebase shell, and some theoretical work such as a multi-criteria assessment tool for IB-CAST knowledge materials selection based on the IB-CAST classification. Questionnaire surveys and statistical analysis for the construction of the IB-CAST knowledge evaluation criteria will also be adopted. All research methods will be adopted in sequence to achieve the aim of this project that is to build a practical IB-CAST system for on-campus and distance IB courses conducted either in classrooms or via WebCT or Blackboard. Research methods to achieve individual objectives are described below:

5.2.1 Extensive Literature Review

The literature review aims to obtain comprehensive information that are essentially relevant to educational Knowledge Management (KM) (including process such as classification, capture, storage and access) and student assessment in IB related courses from worldwide tertiary education, and it is conducted to continuously pursue professional and academic publications, reports and guidelines from selected resources via Internet and interviews. A perfect literature review frame will be introduced to normalize review processes. Survey and comparative study will also be conducted inside the literature review.

5.2.2 Knowledge Classification & Case Assessment

The knowledge classification is to make a building classification for knowledge organization inside the IB-CAST, while the knowledge assessment is to adopt a homologous multi-criteria lifecycle assessment approach to selecting knowledge materials for the IB-CAST by using a knowledge mapping network (Novak & Gowin, 1984). Theoretical work and experimental research are adopted to develop the IB-CAST knowledge classification and assessment approach, including a knowledge-driven multi-criteria decision-making model development and case study.

5.2.3 Knowledge Assembly

The knowledge assembly is to capture, collect and evaluate educational knowledge materials for the IB-CAST using KM tools including a proposed knowledgebase shell and the assessment model. System analysis, modelling and development are adopted to develop a knowledge shell for IB-CAST. Knowledge retrieval, experimental research and case study are used to consummate the knowledgebase of IB-CAST and provide an evaluation report regarding system performance. In addition, process loops among different research tasks at different stages are accepted to smooth problems or difficulties occasionally occurred. Sufficient data will be obtained from literature review, experimental research and case studies to support further research as well.

5.3 The KIV Model

The KIV model is a prototype to describe the theory of the KIV approach for intelligent buildings assessment. Figure 5.1 illustrates a conceptual KIV model.

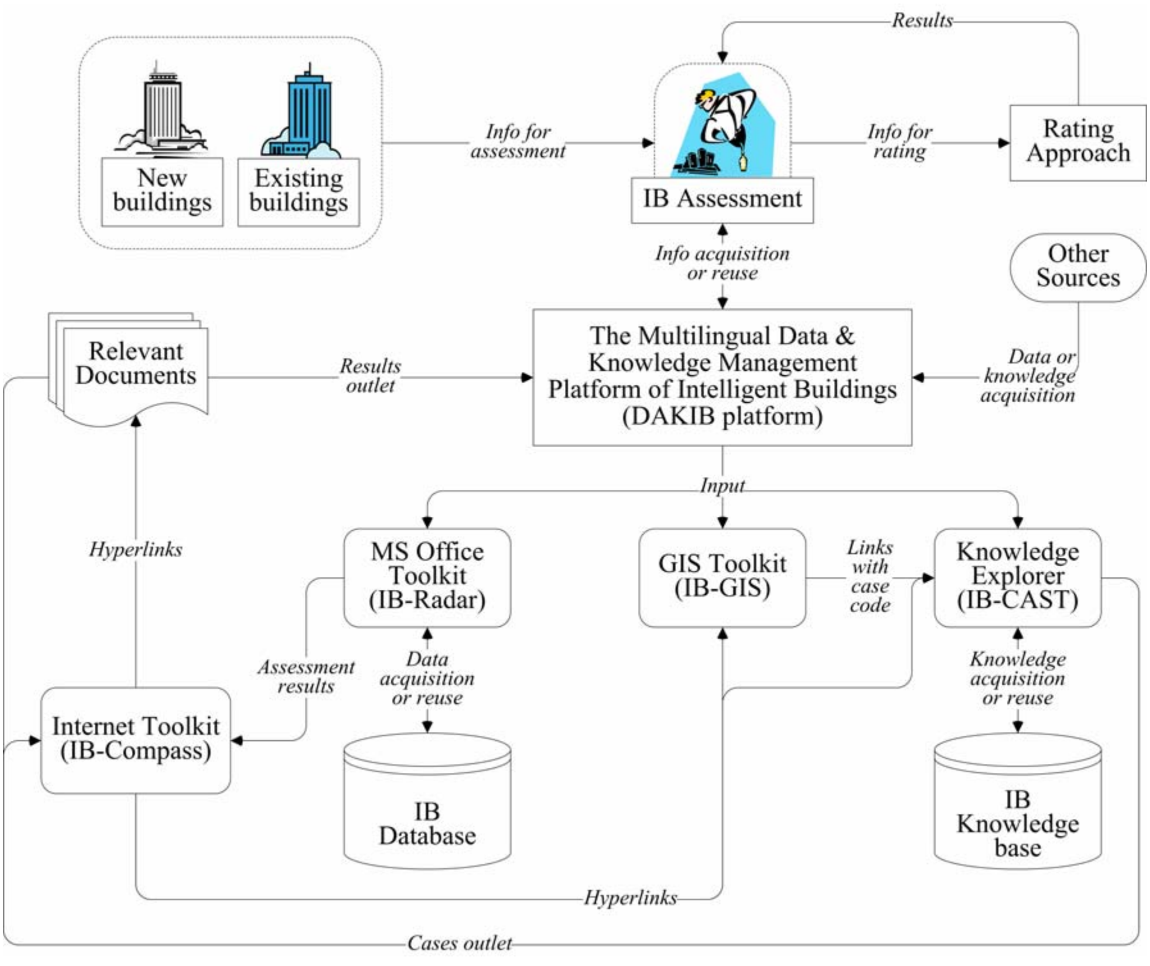


Figure 5.1 The prototype of KIV for intelligent buildings assessment

In order to realize the function of intelligent buildings assessment for the KIV approach, several toolkits are integrated to the *Data & Knowledge Management Platform of Intelligent Buildings* (DAKIB platform) (refer to Figure 2.1), which is an open information platform by system users including Building Designers, Construction Contractors, Property Managers, Recyclers or Manufacturers, and Educators, etc. to share their data or knowledge with the community or their peers (Hong, et al., 2006). There are three main toolkits, including an Intelligent Buildings Casebase for the Applications of Sustainable Technology (called IB-CAST), a web-oriented information visualization toolkit for intelligent buildings assessment using Microsoft Office (called IB-Radar and IB-Compass), and a Geographical Information System (GIS) toolkit for reusing intelligent buildings knowledge between IB-Compass and IB-CAST in intelligent buildings assessment (called IB-GIS). For each toolkit, its functions and relations to other components of the KIV model are explained below:

5.3.1 The IB-CAST Toolkit

The IB-CAST is a casebase for the knowledge management of intelligent buildings. It is a result of a series of research focusing on system prototype, knowledge classification, case assessment, and knowledgebase. The system prototype is a product model for IB-CAST system development. The knowledge classification is a category of buildings for sorting IB-CAST case materials. The case assessment is a case selection process for evaluating case materials for the IB-CAST based on a knowledge-driven multi-criteria decision-making model. The knowledgebase is a consummative knowledge system with various e-book formats. To facilitate the utilization of IB-CAST, both online and offline versions are developed. For example, the IB-CAST portal is to be used for online education, training and consultancies in the area of intelligent buildings, and the IB-CAST DVD is an e-book detached from IB-CAST portal and to be used for offline education, training and consultancies in the area of intelligent buildings. In order to facilitate knowledge management, IB-CAST shell as a knowledge management tool is adopted to accumulate knowledge materials for the IB-CAST portal. Figure 5.2 illustrates one of the main interfaces of the IB-CAST (Baltsoft, 2004), in which a case study on the Hong Kong International Finance Centre (IFC) complex is shown.

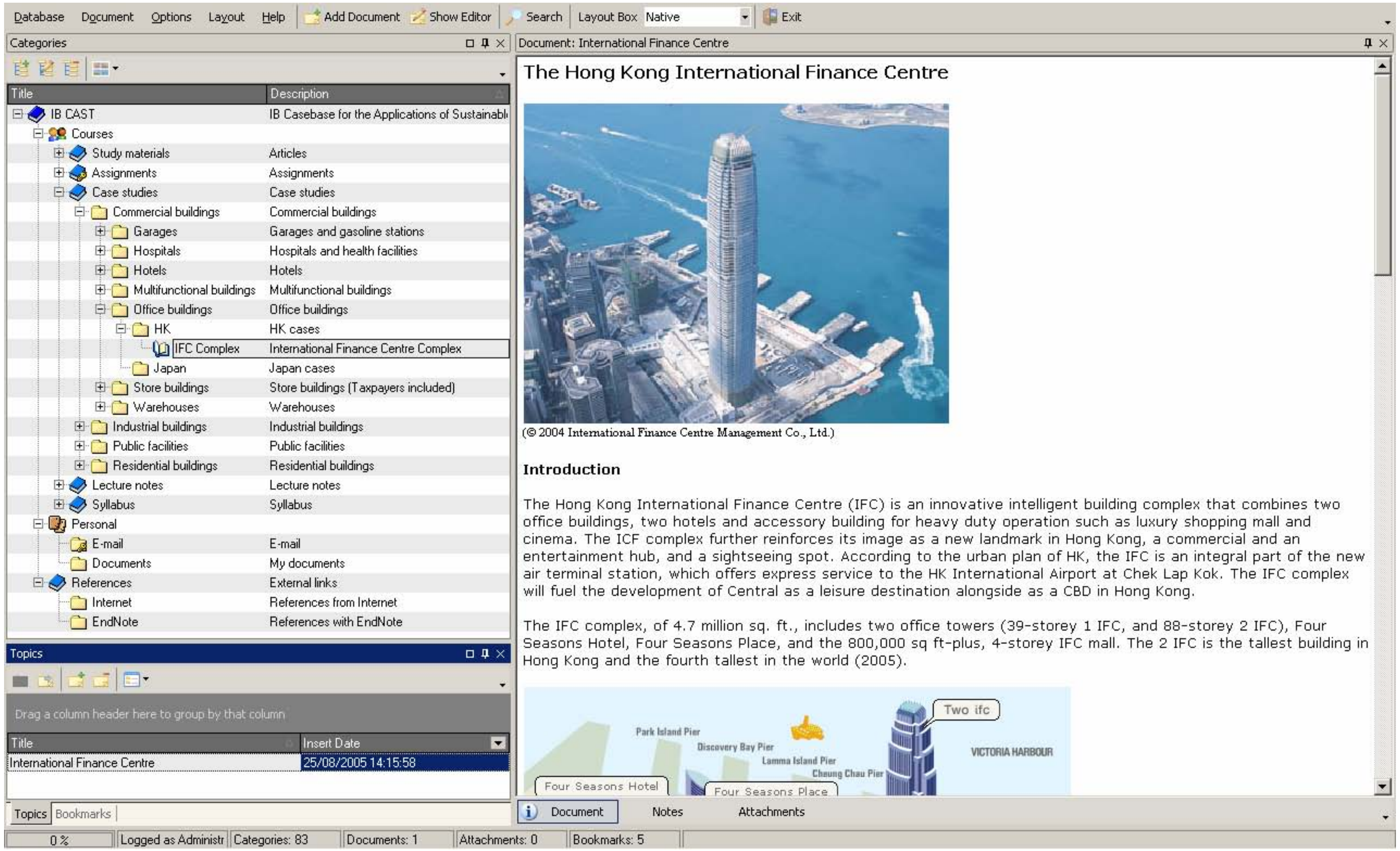
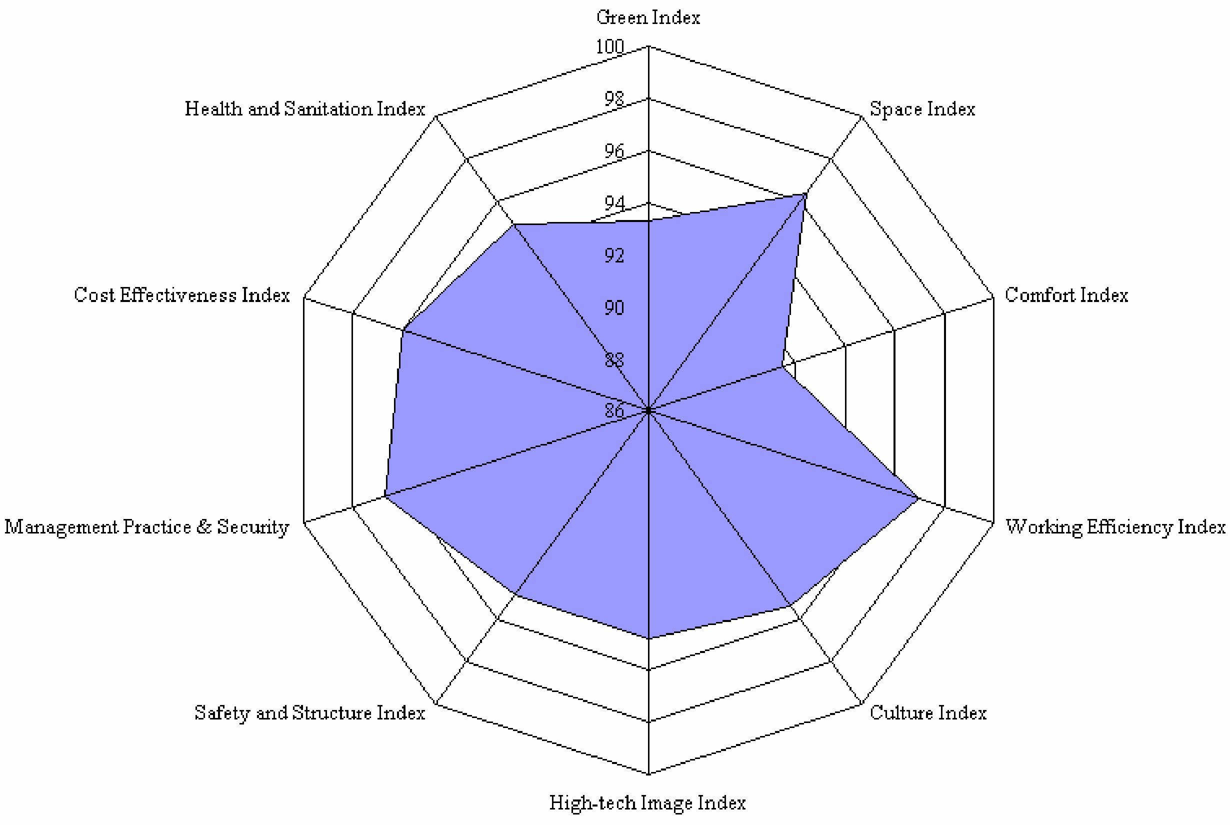


Figure 5.2 A screenshot of the IB-CAST

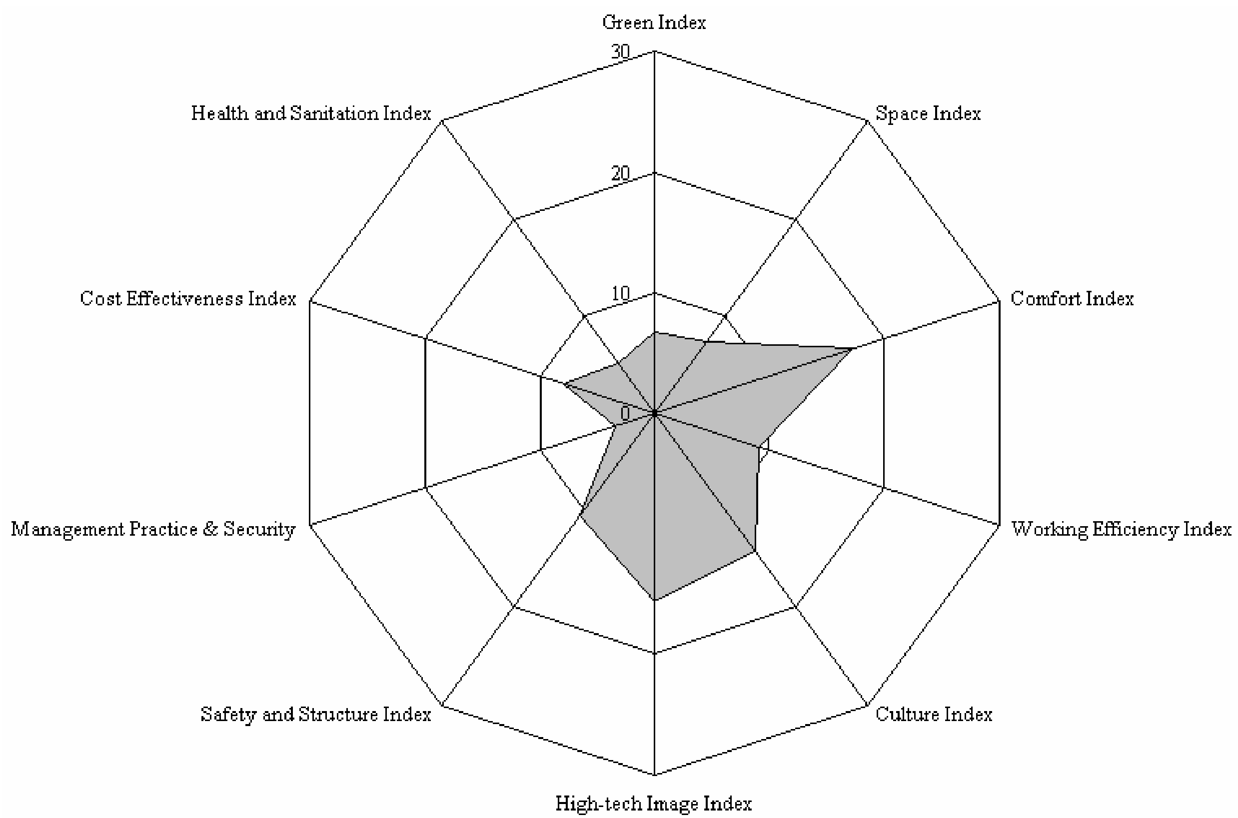
5.3.2 The IB-Radar Toolkit

The IB-Radar is a radar chart made in Microsoft Excel to illustrate current and gap scores of intelligent buildings based on their rating. It uses an n-dimension diagram to illustrate the status of an intelligent building in accordance with its scores corresponding to each dimension. The number of dimensions of the IB-Radar equal to the number of clusters, which are used to classify indicators for intelligent buildings rating. For example, the IB Index (AIIB, 2005) adopts a multi-dimension intelligent buildings rating system covered ten models including Green Index module, Space Index module, Comfort Index module, Working Efficiency Index module, Culture Index module, High-tech Image Index module, Safety and Structure Index module, Management Practice and Security Index module, Cost Effectiveness Index module, and Health & Sanitation Index module. The IB-Radar is useful in describing the status of an intelligent building regarding its score, and indicating the gap between current status and further efforts. It is a visual measurement for intelligent buildings assessment, and can facilitate decision-making in the design or management of intelligent buildings. Figure 3 gives an example to show how IB-Radar can be applied in intelligent buildings assessment. The example has been conducted by using an existing intelligent building case, previously conducted by Chow and Choi (2005) using the IB Index (AIIB, 2005). There are two main radar charts adopted by the IB-Radar to illustrate current status of the building under rating from the IB Index (AIIB, 2005), and further effort required for a better design or utilization with respect to expected targets for the building. Based on visual information provided by the IB-Radar (see Figure 5.3 and 5.4), building auditors can use the IB-Radar as an effective visualization approach to showing the results of assessment and measuring the gap from current status to ideal status of the building under assessment. It is called decision support at the post-assessment of intelligent buildings. Therefore, the IB-Radar is a necessary complement of building rating method such as the IB Index (AIIB, 2005) at the post-assessment stage of intelligent buildings.



Current status

Figure 5.3 A screenshot of the IB-Radar using MS Excel



Further efforts

Figure 5.4 A screenshot of the IB-Radar using MS Excel

5.3.3 The IB-Compass Toolkit

The IB-Compass is an internet-enabled portal for intelligent buildings information navigation based on IB-Radar chart. Generally speaking, the DAKIB platform (refer to Figure 2.1 and 5.1) can lead all potential participants from each life-cycle stage of intelligent buildings to release or to acquire relevant data and knowledge via Internet. As a matter of fact, all participants including building designers, construction contractors, property managers, and academic educators, etc. can obtain benefit from the IB-CAST and the IB-Radar regarding the decision support at the post-assessment stage of intelligent buildings, and obtain benefit from the content management of intelligent building projects. However, they are actually demanding a more efficient delivery approach to facilitating decision making at the post-assessment or the others relevant to content management of intelligent buildings. As mentioned by JC&A (2004), of all the applications of the Internet in the design professions, none has more wide-ranging significance than web-based project management. In this regard, the internet-enabled portal called IB-Compass is developed to further support the post-assessment of intelligent buildings. Figure 5.5 gives an example of the IB-Compass in Microsoft Internet Explore. As shown on the IB-Compass (see Figure 5.5), different Intelligent buildings are located at different places on relevant axes based on their scores to each dimension of assessment. The ten-dimension radar chart for the IB Index (AIIB, 2005) is adopted here. Although this example uses the chart of IB-Radar for the HK IFC complex (see Figure 5.3 and 5.4) as a compass, the compass can generally use an empty radar chart too. By using the IB-Compass, DAKIB system users can go through each intelligent building project for relevant data and knowledge previously collected into the IB-CAST or the IB-Radar by just clicking on embedded hyperlinks to each building. Hyperlinks embedded to intelligent buildings will lead to other webpage or knowledge management toolkits such as the IB-CAST or the IB-GIS (see Section 5.3.4 below).

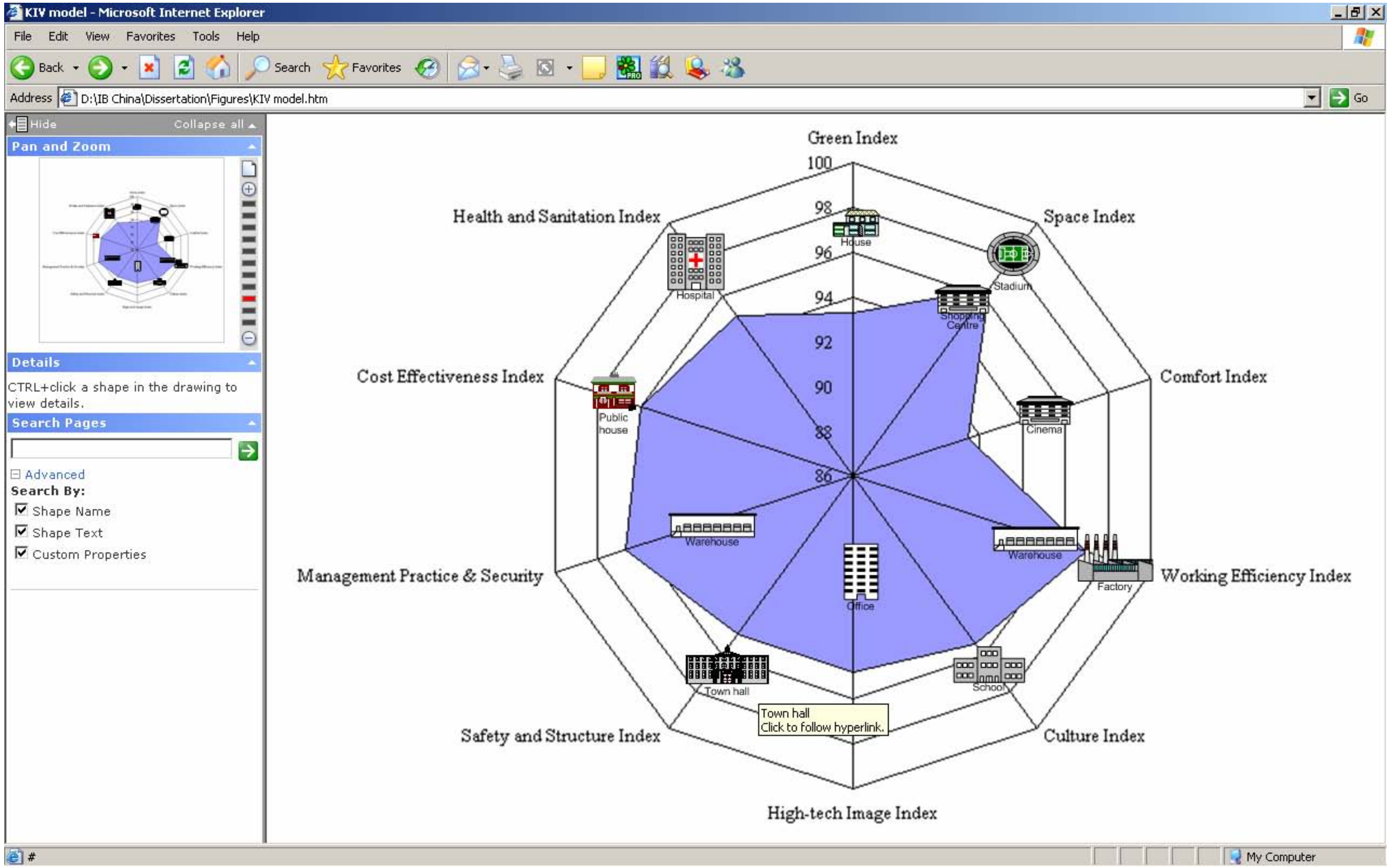


Figure 5.5 A screenshot of the IB-Compass in MS Internet Explore

5.3.4 The IB-GIS Toolkit

The IB-GIS is a geographical information system for spatial information management of intelligent buildings. The IB-GIS is another information visualization toolkit to support the post-assessment of intelligent buildings. The main reason why the GIS is adopted here is that a comprehensive assessment of intelligent buildings actually requires an extensive information support. In other words, although the IB-CAST and IB-Radar can provide some relevant information for use at the post-assessment stage of intelligent buildings, they are not able to support decision-making regarding suggestions to single building development or local area regeneration. In this regards, the GIS is introduced to the DAKIB system (see Figure 2.1 and 5.1) to integrate a decision-making function. As illustrated in Figure 5.1, the IB-GIS is linked from the IB-Compass, and linked to the IB-CAST. To further support decision-making within the IB-GIS, integration with the IB-CAST is required. Figure 5.6 gives an example to apply GIS for the information management of intelligent buildings. The HK IFC Complex is also used to demonstrate its usability. Google Earth is adopted as a novel GIS shell for the IB-GIS because it uses aerial color photography as mapping interface which involves much information than hand-drawn maps.

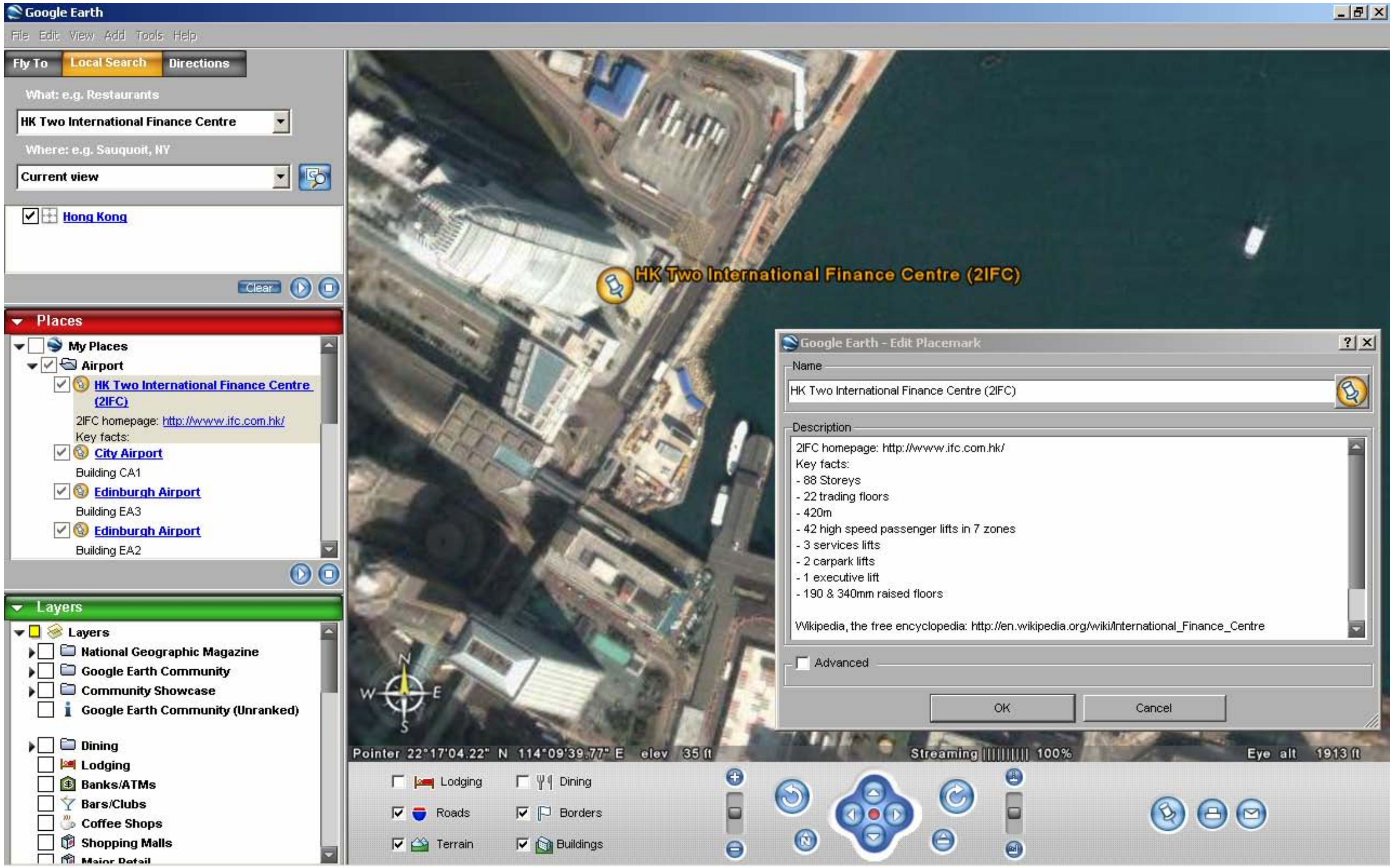


Figure 5.6 A screenshot of the IB-GIS using Google Earth

5.3.5 Multilingual Web-based Services

The multilingual Web-based services for intelligent buildings assessment and variations can be realized by using the toolkits developed based on the KIV model (see Figure 5.1). As to multilingual utilization, there are two adaptations. The first adaptation is to translate interfaces of these toolkits into required languages. For example, a Chinese building architect may like to use these toolkits with Chinese interfaces. In this regard, interface translations are required. The second adaptation is to translate appropriate multilingual contents for these toolkits into required languages. For example, the English version toolkits require contents from both English speaking areas and non-English speaking areas. Multilingual information retrieval and processing techniques are thus required. Regarding multilingual information management for the KIV approach, the author recommend using translations by native language speakers with or without computer assistance, because machine translation is currently not able to give satisfied results in the building professions. On the other hand, as the toolkits to facilitate the KIV approach described above are all assessable through Microsoft Office and Internet Explorer, users can also obtain benefit from Microsoft software which provides the function of multilingual Web-based services in some extent.

Previous research into the interaction of expertise and semantic grouping in hypertext search tasks has revealed that expert users outperformed novice users in information retrieval when the elements of a system interface are organized semantically, not randomly (Salmerón, Cañas and Fajardo, 2005). Although this dissertation doesn't take any semantic study into consideration, theories of human expertise actually support the design and development of the KIV approach without my active consciousness. Actually, the KIV model finally forms a semantic network for knowledge representation in intelligent buildings assessment and decision-making processes. From this point of view, the multilingual Web-based services for intelligent buildings assessment and variations proposed in this dissertation can further make the facilitative effect of expertise in hypertext information retrieval tasks for decision support at the post-assessment stage of intelligent buildings, because it is designed and developed with comprehensive considerations on the process and details of intelligent buildings assessment, as well as the interaction between user and system characteristics. It is therefore reasonable to believe that the KIV approach can play a key role to support decision making at the post-assessment stage of intelligent buildings.

5.4 The Knowledgebase

The expected research outcomes and the likely impact of the proposed research include a system prototype, a knowledge classification, a case assessment model, a knowledgebase with physical format. The system prototype is a product model and to be used in IB-CAST system development. The knowledge classification is a category of buildings and to be used to sort IB-CAST case materials. The case assessment is a decision-making model and to be used to evaluate case materials for the IB-CAST based on a knowledge-driven multi-criteria decision-making model. The knowledgebase with physical format is a consummative knowledge system with various e-book formats including a DVD and an online portal. The IB-CAST portal is to be used for online education, training and consultancies in the area of IB, and the IB-CAST DVD is an e-book detached from IB-CAST portal and to be used for offline education, training and consultancies in the area of intelligent buildings. To support KM for these two formatted knowledgebase, IB-CAST shell as a KM tool is to be used to accumulate knowledge materials for the IB-CAST portal. Figure 5.7 and 5.8 illustrate one of the main interfaces of the IB-CAST.

As a new knowledge product in the built environment area, the IB-CAST can result in economic and/or social benefits based on the following considerations:

- Commercial potentials: IB-CAST portal and DVD are new knowledge products. Because building related programmes and various courses are being provided at many universities from many countries, and currently there is not an alternative regarding the competitive features of IB-CAST, it is thus expected to have a huge benefit from potentially large requirements from universities. In addition to its adoption in education, it can also provide consultation and training services to the construction industry.
- Achieving excellence: IB-CAST facilitates KM in the construction industry. The IB-CAST products are able to be a new toolkit to facilitate practitioners to achieve excellence and best practice in new project development. For example, the IB-CAST classification & assessment can play an active part in knowledge-driven multi-criteria decision-making, the IB-CAST portal and DVD can provide up-to-date worldwide real-time professional support and consultancies for the construction sectors. And
- Creating opportunities: IB-CAST portal and DVD need daily maintenances. After the proof of concept deployment of IB-CAST, there will be a large number of building cases to be accumulated and most of them will be collected from advanced countries. However, the contents of IB-CAST need to be enriched and updated continually to keep its strength and to provide leadership of KM in the area of built environment. In this regard, the IB-CAST requires daily maintenance support from system administrators and knowledge crews.

All these benefits will be examined in further research.

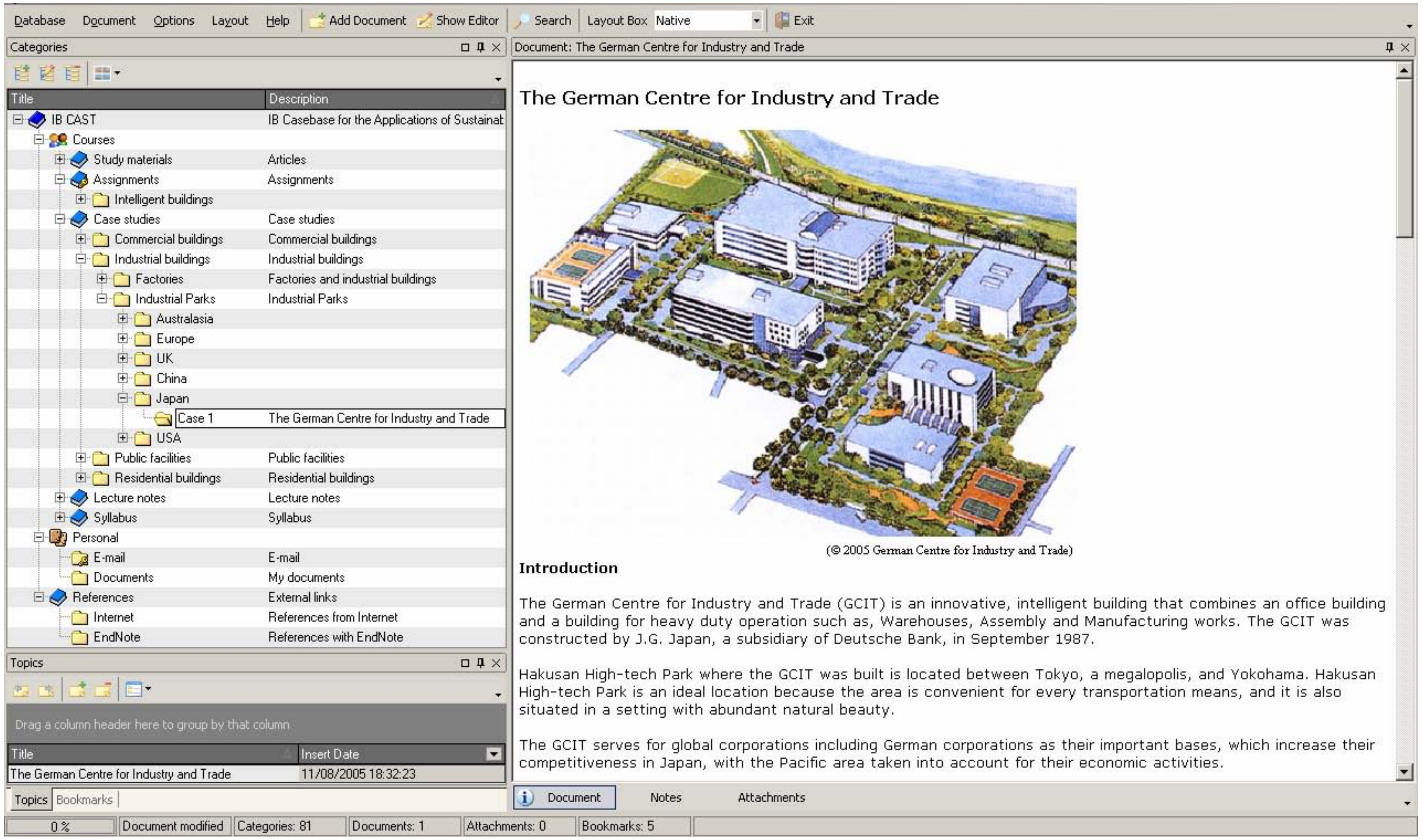


Figure 5.7 A screenshot of the IB-CAST (Industrial Buildings)

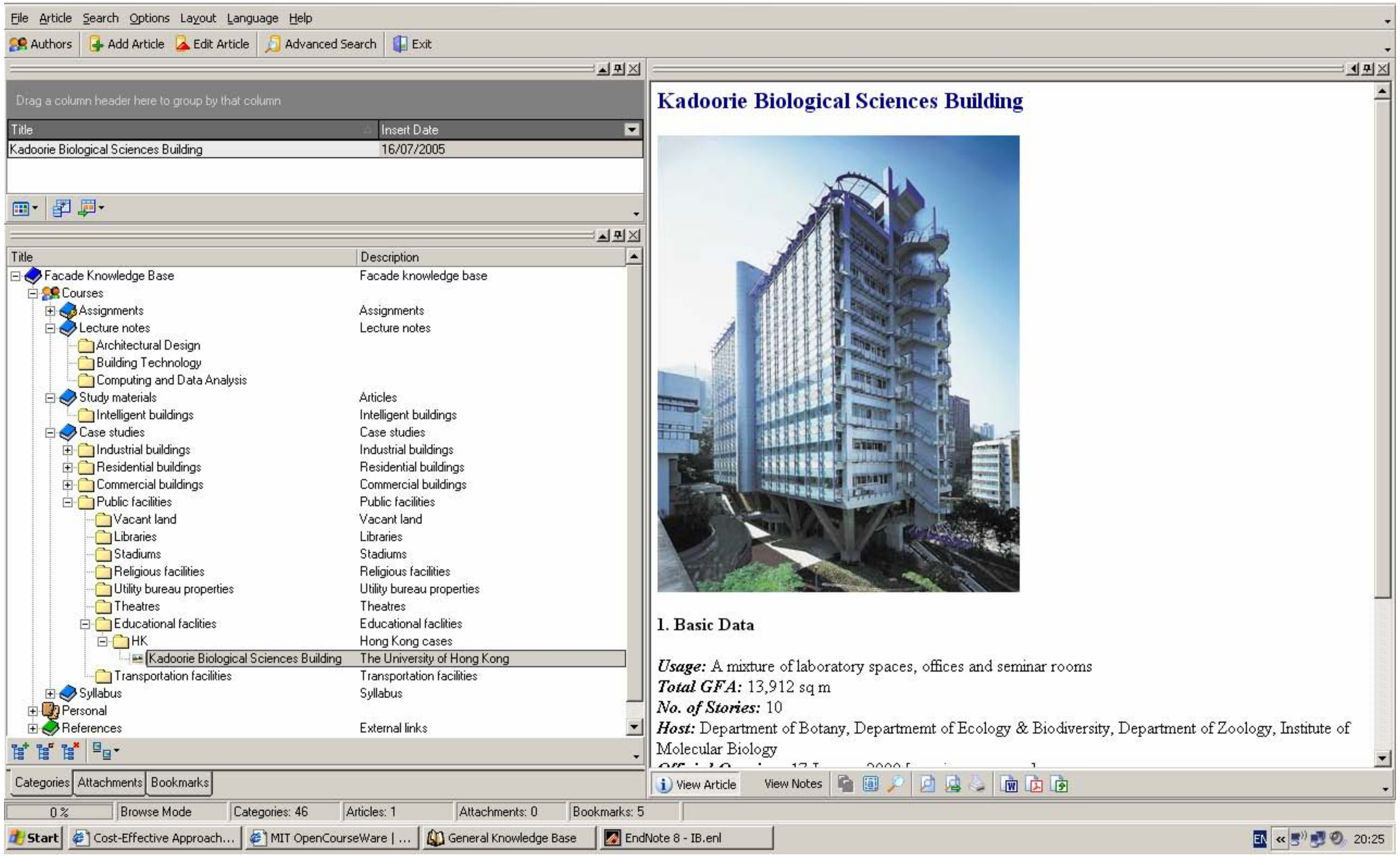


Figure 5.8 A screenshot of the IB-CAST (Office Buildings)

5.5 An Experimental Case Study

The Hong Kong International Finance Centre (IFC) is an innovative intelligent building complex that combines two office buildings (IFC I (39 storeys) and IFC II (90 storeys)), two hotels and accessory building for heavy duty operation such as luxury shopping mall and cinema. It is located adjacent to the narrowest crossing of Hong Kong (HK) Victoria Harbour, one of the most beautiful urban sites in the world, marking a new gateway to the HK Island. After the completion of the IFC II in 2003, it became the new headquarters for the Hong Kong Monetary Authority, and the ICF complex further reinforces its image as a new landmark in Hong Kong, a commercial and an entertainment hub, and a sightseeing spot. The project reflects the importance of HK as a world financial centre. According to the urban plan of HK, the IFC is an integral part of the new air terminal station, which offers express service to the HK International Airport at Chek Lap Kok. The IFC complex is playing an important role to accelerate the development of Central as a leisure destination alongside as a CBD in Hong Kong.

According to the characteristics of IFC II, an IB Index (AIIB, 2005) based assessment was conducted to the tallest building in Hong Kong by the AIIB in 2004 (Chow and Choi, 2005), and it has been identified that the IFC II is the most intelligent building in Hong Kong compared with all other buildings their had audited. Table 5.1 gives some of their assessment results for the IFC II in accordance to the ten modules adopted by the IB Index (AIIB, 2005).

For the post-assessment of IFC II using IB-KIV approach, the following steps are adopted:

- Step 1: make a case study using IB-CAST (see Figure 5.2);

- Step 2: make radar charts using IB-Radar (see Figure 5.3 and 5.4);
- Step 3: make compass pages using Microsoft Office (see Figure 5.5);
- Step 4: make place-mark with description using Google Earth (or other GIS shell) (see Figure 5.6);
- Step 5: study the gap information indicated in IB-Radar;
- Step 6: click on relevant hyperlinks on IB-Compass for improvement;
- Step 7: review relevant information from IB-CAST and IB-GIS;
- Step 8: make decisions to fill in the gaps.

Table 5.1 The assessment results of the IFC II

Modules		Scores		
		Current	**Target**	**Gap**
1	Green Index	93	100	7
2	Space Index	96	100	4
3	Comfort Index	91	100	9
4	Working Efficiency Index	97	100	3
5	Culture Index	95	100	5
6	High-tech Image Index	95	100	5
7	Safety and Structure Index	95	100	5
8	Management Practice and Security Index	97	100	3
9	Cost Effectiveness Index	96	100	4
10	Health & Sanitation Index	95	100	5

Reference: Chow & Choi, 2005.

In this case study, target scores to each module are set to 100 (see Table 5.1), accordingly gap scores to each module are calculated using Table 5.1 in Microsoft Excel. Based on this result, it is identified that Comfort and Green issues are the most important ones for improvement in IFC II. In order to find appropriate solutions to improve the levels of

Comfort and Green, suggestions are searchable from other existing buildings marked on the IB-Compass (see Figure 5.5) (The compass background can be replaced by a radar chart of Gaps), which links to IB-CAST and IB-GIS to provide detailed suggestions. Regarding how to improve the status of Comfort Index and Green Index of IIFC II, this paper doesn't provide more details.

5.6 Conclusions

Although building rating method such as the IB Index (AIIB, 2005) is currently adopted in intelligent buildings assessment, it is noticed that toolkits to support post-assessment of intelligent buildings are in demand. In this regards, a knowledge-oriented information visualization (KIV) approach is introduced in this paper. The KIV approach comprises a group toolkits including IB-CAST (a casebase for the knowledge management of Intelligent buildings), IB-Radar (a radar chart made in Microsoft Excel to illustrate current and gap scores of Intelligent buildings based on their rating), IB-Compass (an internet-enabled portal for IB info navigation based on IB-Radar chart), and IB-GIS (a geographical information system for spatial information management of Intelligent buildings). Regarding multilingual utilizations, it is recommended to use human translation for multilingual information retrieval and reuse; on the other hand, the Microsoft Office and Internet Explorer are adopted as a platform to support implementing the KIV approach. As Microsoft products have embedded functions for multilingual utilizations, it is therefore concluded that toolkits introduced in this paper can be used by multilingual users in case multilingual information has been translated into their native language and stored in the system for use. A case study on the IFC II is conducted to demonstrate how to use KIV approach to decision-making on innovative variations at post-assessment stage of intelligent buildings.

In addition, as case method is currently adopted by construction MBA programmes at some universities in Europe (Reading, 2004; Oxford, 2004), it is noticed that the number of IB case is much small, and there is a huge potential for both B-schools and BE-schools to acquire high quality hand-on cases in their building related courses. From this point of view, all expected outputs from this research project will effectively, efficiently and economically facilitate the general deployment of case method into teaching and learning in IB programmes. Based on current literature review, the proposed research is anticipated to have five major contributions:

- Knowledge classification and case assessment model provide an innovative methodology to conduct KM in the area of built environment.
- IB-CAST portal and DVD are innovations for high-quality education and training in building related programmes with a worldwide perspective.
- IB-CAST is able to overcome shortcomings inside currently used e-learning systems by dedicating to cultivate an active independent learning habit for students, which will bring lifelong benefits to them as well.

IB-CAST can dramatically establish worldwide corporations to benefit not only the education of IB programmes but also the research and practice in IB related area.

Chapter 6

A CASE STUDY

6.1 Introduction

This Chapter aims to provide a case study to demonstrate the effectiveness of DAKIB tools such as the rating approach and the ANP approach. The City of Manchester Stadium, an intelligent stadium, is selected for this case study.

6.2 Background

The City of Manchester Stadium locates at Maine Road, which is actually situated at the very middle-point of Manchester City centre. It is also the headquarters of the Manchester City Football Club (MCFC) <www.mcfc.co.uk>, and the MCFC is actually the proprietor of the Stadium.

This massive Stadium (see Figure 6.1 and Figure 6.2) included many innovative engineering and management techniques. As the principle designer of the Stadium, Arup made a set of fundamental principles in designing the City of Manchester Stadium, including

- At the layer of audiences, it will promote the connotation of the stadium across-the-board so as to create joviality when they arrive, it will provide straightway passages, it will divide uproarious sections from quite places, and it will achieve a comfort but stirring extensity, etc.;

- At the layer of architectural design, it will make the level feeling and dynamic feeling of visualization in order to clearly reflect and emphasize its architectural functions of sports buildings;
- At the layer of urban planning, it will be able to attract public, it will be a good destination that can content their requirements, and it will become a landmark of urban regeneration; and
- At the layer of urban landscape, it will be an attempt to adopt ultra geometry carving model for roof and stand.

Some of the key features include housing central plant in the architectural and structural ramp towers; a buried raceway around the Stadium which distributes electricity, water, gas, heating and communications. Integrated plant rooms and the services raceway proved themselves during several value engineering exercises to be very cost effective. Moreover, the Stadium adopted a set of wireless local area network (WLAN) based information management system, including the smart card system, Fortress intelligent stadium management system, Radio Frequency Identification (RFID) equipments such as HP iPAQ 5550, and Cisco Aironet 1200 Series Access Point, etc. All these innovations in the design of this Stadium finally made the first intelligent stadium in the world, which can provide unprecedented high-effective and high-efficient personalized building services for people; and this Stadium has therefore got more than 12 main rewards in the building professions since 2002 (see Table 6.1).

Figure 6.1 Architectural perspective of the City of Manchester Stadium (PanStadia, 2001)

Figure 6.2 The City of Manchester Stadium interior (Photographer: Dennis Gilbert, architecture.com)

Table 6.1 The full building credits of the City of Manchester Stadium

Project:	The City of Manchester Stadium
Location:	Rowsley Street, Manchester M11 3FF, UK
Architect:	Arup Associates
Principal designer:	Arup Associates with Arup Sport
Client:	Manchester City Council
Structural Engineer:	Arup Associates and Arup
Services Engineer:	Arup
QS:	Davis Langdon Ltd.
Main contractor:	Laing O'Rourke Ltd.
Steelwork Contractor:	Watson Steel Structures Ltd.
Contract value:	GBP110m
Gross internal area:	50,000 sq m
Date of start/Date of completion:	2 December 1997/31 August 2003
Main rewards:	• British Construction Industry (BCI) Major Project Award 2002: High Commendation • Manchester Civic Society Renaissance Award 2002: Joint Winner • Institute of Civil Engineers (ICE) 2003: North West Merit Award • City Life Awards 2002: Building of the Year • Institute of Civil Engineers (ICE) 2003: Brunel Medal • Institution of Structural Engineers Structural Awards 2003: Structural Special Award • The Structural Special Awards 2003, the Institution of Structural Engineers (IStructE), UK • Building Services Award 2003: Major Project of the Year, CIBSE, UK • Structural Steel Design Awards 2003, the British Constructional Steelwork Association, UK • The Royal Institute of British Architects (RIBA) Inclusive Design Award 2004 • The Northwest Development Agency (NWDA) Manchester Tourism Awards 2004 • IOC/IAKS International Award 2005: Gold medal for sports facilities. The International Olympic Committee (IOC), the International Association for Sports and Leisure Facilities (IAKS).

6.3 ANP analysis

During the design of several core sections, including stand, roof, access, electricity and illumination, ventilation and safety, etc., professionals from Arup have presented and discussed many possible alternative plans. For example, according to Austin et al (2003), in this Stadium the fire and safety aspects were developed in fire engineering terms in contrast to prescriptive codes. The fire engineering aims for high safety standards, and simultaneously to facilitate design innovation and limit costs. For fire safety design, the standard solution is to suppress fire with sprinklers, and either extract smoke directly or allow it to enter the concourse area and extract from there at high level. In order to face with protecting the escape routes whilst keeping the architectural design intent, designers looked for an alternative solution, i.e. an innovative 'sweeper system'. With the aid of computer modelling, the fire engineered approach demonstrated to the statutory authorities that the Stadium is safe. At the same time, costs (both capital and lifetime) were reduced and design aspirations realized. This example shows that the complexity in building design actually makes it difficult for designers to say definitely that which solution is the most appropriate one than others.

In order to further demonstrate how ANP can work effectively in buildings assessment, this Section gives a case study on selecting one design alternative for the Stadium based on several scenarios (Austin et al., 2003), including the alternative design of fire safety system. Table 6.2 and Table 6.3 are used to separately give scores to all 32 KPIs cooresponding to the 10 criteria for scoring, which are in accordance with the 10 modules of IB Index (AIIB, 2005). Regarding how to give a score to each KPI, Chapter 4 and Appendix 1 have more detailed prescriptions. This case study only provides results in Stadium assessment.

Table 6.2 Score matrix for Design A

Indicator		Codes related to the IB Index (AIIB, 2005)	Criteria for Scoring: Modules of the IB Index (AIIB, 2005)										
			Green	Space	Comfort	Working Efficiency	Culture	High-tech Image	Safety & Structure	Management Practice & Security	Cost Effectiveness	Health & Sanitation	*Average*
Group 1													
1.1	Electricity & Electrical services	multiple	8	9	9	10		10	10	10			9.4
1.2	Heating services	multiple	7										7.0
1.3	Ventilation & air-conditioning	multiple	6	8	7	8						9	7.6
1.4	Building services automation system	multiple				9		10		9			9.3
1.5	Construction materials	multiple	7					8					7.5
1.6	IT&C facilities and services	multiple				10		10					10.0
1.7	Thermal comfort & indoor air quality	multiple	8		9	8			10	9		9	8.8
1.8	Lifts/escalators and controls	multiple	7		9	9		8		9			8.4
1.9	Security and safety control	multiple		10		9		9	10	10			9.6
1.10	Flushing water system & drainage	multiple	9		10					8		10	9.3
1.11	External & internal decoration	multiple		9		8						8	8.3
1.12	Building architectural design	multiple	10			8	9	9					9.0
1.13	Lavatory accommodation	multiple	8		9	8							8.3
1.14	Refuse collection & disposal	multiple	7							6		9	7.3
1.15	Circulation for the disabled	multiple		9						9			9.0
1.16	CAD/CAM/CAC	multiple	8					9					8.5
Group 2													
2.1	Flexibility for renovation	multiple		8									8.0
2.2	Structural monitoring & control	multiple							10	9			9.5
2.3	Potable water system	multiple								10		10	10.0
2.4	Fire detection and resistance	multiple				10			10				10.0
2.5	Cleanliness	multiple	9		10	8						10	9.3
2.6	Property management	multiple	8	9		10		8	10	9	8	9	8.9
2.7	Carpark/transportation facilities	multiple		8		7		9		10		7	8.2
2.8	Entertainment facilities	multiple			9	7	9						8.3
2.9	External landscape	multiple	7				10						8.5
2.10	Extensive use of artificial intelligence	multiple				6		7					6.5
2.11	Environmental friendliness	multiple	8							8			8.0
2.12	Conference and meeting facilities	multiple				10		10					10.0
2.13	Access sign and directory	multiple				10		9	10				9.7
2.14	Maintainability	multiple				8				7			7.5
2.15	Usable areas	multiple		10	10	9							9.7
2.16	Means of escape	multiple							9	9			9.0
Total													

Note:

1. CAD/CAM/CAC: Computer Aided Design, Manufacturing, Construction/installation.
2. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

Table 6.3 Score matrix for Design B

Indicator		Codes related to the IB Index (AIIB, 2005)	Modules of the IB Index										
			Green	Space	Comfort	Working Efficiency	Culture	High-tech Image	Safety & Structure	Management Practice & Security	Cost Effectiveness	Health & Sanitation	*Average*
Group 1													
1.1	Electricity & Electrical services	multiple	9	9	10	9		9	9	9			52.8
1.2	Heating services	multiple	7										40.5
1.3	Ventilation & air-conditioning	multiple	8	8	7	8						9	43.5
1.4	Building services automation system	multiple				8		9		9			44.6
1.5	Construction materials	multiple	7					8					38.6
1.6	IT&C facilities and services	multiple				8		9					43.0
1.7	Thermal comfort & indoor air quality	multiple	9		9	8			10	9		8	41.6
1.8	Lifts/escalators and controls	multiple	8		9	9		8		9			40.5
1.9	Security and safety control	multiple		9		8		9	9	10			35.9
1.10	Flushing water system & drainage	multiple	9		10					8		10	33.4
1.11	External & internal decoration	multiple		9		9						8	30.6
1.12	Building architectural design	multiple	10			8	9	9					31.2
1.13	Lavatory accommodation	multiple	9		9	7							27.2
1.14	Refuse collection & disposal	multiple	8							6		9	25.0
1.15	Circulation for the disabled	multiple		9						8			27.3
1.16	CAD/CAM/CAC	multiple	7					8					24.1
Group 2													
2.1	Flexibility for renovation	multiple		8									23.1
2.2	Structural monitoring & control	multiple							10	9			27.5
2.3	Potable water system	multiple								8		10	26.0
2.4	Fire detection and resistance	multiple				10			10				25.4
2.5	Cleanliness	multiple	10		9	7						10	22.9
2.6	Property management	multiple	8	9		8		8	10	9	8	8	21.1
2.7	Carpark/transportation facilities	multiple		8		6		9		8		7	15.6
2.8	Entertainment facilities	multiple			9	7	9						17.1
2.9	External landscape	multiple	8				10						18.5
2.10	Extensive use of artificial intelligence	multiple				5		5					9.7
2.11	Environmental friendliness	multiple	9							7			11.6
2.12	Conference and meeting facilities	multiple				7		8					10.8
2.13	Access sign and directory	multiple				8		9	9				8.3
2.14	Maintainability	multiple				8				7			7.2
2.15	Usable areas	multiple		9	10	9							7.8
2.16	Means of escape	multiple							9	9			6.5
Total													

Note:

1. CAD/CAM/CAC: Computer Aided Design, Manufacturing, Construction/installation.
2. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

Table 6.4 A summary to two design alternatives for the IBAssessor model

Group	Ref. No.	Indicators	w_i	Score of Design Alternatives (S_i)	
				Design A	Design B
KPI Group 1	KPIG101	Electricity & Electrical services	5.78	54.5	52.8
	KPIG102	Heating services	5.78	40.5	40.5
	KPIG103	Ventilation & air-conditioning	5.43	41.3	43.5
	KPIG104	Building services automation system	5.14	48.0	44.6
	KPIG105	Construction materials	5.14	38.6	38.6
	KPIG106	IT&C facilities and services	5.06	50.6	43.0
	KPIG107	Thermal comfort & indoor air quality	4.71	41.6	41.6
	KPIG108	Lifts/escalators and controls	4.71	39.6	40.5
	KPIG109	Security and safety control	3.99	38.3	35.9
	KPIG110	Flushing water system & drainage	3.61	33.4	33.4
	KPIG111	External & internal decoration	3.53	29.4	30.6
	KPIG112	Building architectural design	3.47	31.2	31.2
	KPIG113	Lavatory accommodation	3.27	27.2	27.2
	KPIG114	Refuse collection	3.27	23.9	25.0
	KPIG115	Circulation for the disabled	3.21	28.9	27.3
	KPIG116	CAD/CAM/CAC	3.21	27.3	24.1
KPI Group 2	KPIG201	Flexibility for renovation	2.89	23.1	23.1
	KPIG202	Structural monitoring and control	2.89	27.5	27.5
	KPIG203	Potable water system	2.89	28.9	26.0
	KPIG204	Fire detection and resistance	2.54	25.4	25.4
	KPIG205	Cleanliness	2.54	23.5	22.9
	KPIG206	Property management	2.49	22.1	21.1
	KPIG207	Carpark/transportation facilities	2.05	16.8	15.6
	KPIG208	Entertainment facilities	2.05	17.1	17.1
	KPIG209	External landscape	2.05	17.4	18.5
	KPIG210	Extensive use of artificial intelligence	1.94	12.6	9.7
	KPIG211	Environmental friendliness	1.45	11.6	11.6
	KPIG212	Conference and meeting facilities	1.45	14.5	10.8
	KPIG213	Access sign and directory	0.95	9.2	8.3
	KPIG214	Maintainability	0.95	7.2	7.2
	KPIG215	Usable areas	0.84	8.1	7.8
	KPIG216	Means of escape	0.72	6.5	6.5
		IB_{Score}		865.7	838.8

Unweighted Super Matrix

1 2 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

16 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

1 0.00000 1.00000 0.72222 0.72222 0.70588 0.60000 0.50000 0.71429 0.61538 0.75000 0.50000 0.50000 0.50000 0.50000 0.50000

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0.15639 0.11073 0.08650 0.17014 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250

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13 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.00000 0.06667 0.06667 0.06667

14 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.00000 0.06667 0.06667

15 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.00000 0.06667

16 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06250 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.06667 0.00000

Weighted Super Matrix

1 2 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

16 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

1 0.00000 0.29696 0.18006 0.18006 0.17599 0.14959 0.12466 0.17808 0.15343 0.18699 0.12466 0.12466 0.12466 0.12466 0.12466

0.12466 0.12466 0.12466 0.23379 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849

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2 0.29696 0.00000 0.06925 0.06925 0.07333 0.09973 0.12466 0.07123 0.09589 0.06233 0.12466 0.12466 0.12466 0.12466 0.12466

0.12466 0.12466 0.12466 0.06319 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849 0.14849

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1 0.01189 0.07762 0.00000 0.03810 0.06317 0.10449 0.01726 0.09244 0.07569 0.11902 0.10723 0.03078 0.02971 0.03710 0.05770

0.09284 0.06573 0.05135 0.09180 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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2 0.03845 0.07191 0.06303 0.00000 0.02957 0.02211 0.01842 0.03905 0.03579 0.01050 0.01068 0.01315 0.01548 0.03710 0.03117

0.01291 0.01464 0.01169 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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3 0.00858 0.04571 0.10203 0.09972 0.00000 0.03585 0.05244 0.05101 0.05352 0.03263 0.01893 0.01589 0.04653 0.03710 0.05518

0.05290 0.02783 0.05456 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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4 0.01747 0.04534 0.07761 0.05567 0.05616 0.00000 0.02519 0.12781 0.03001 0.07129 0.06588 0.02923 0.02310 0.03710 0.01079

0.10444 0.07825 0.07595 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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5 0.12036 0.03531 0.01222 0.05078 0.02175 0.00516 0.00000 0.00507 0.09438 0.07589 0.06734 0.05097 0.12802 0.03710 0.04157
0.01161 0.02402 0.05299 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372
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6 0.05762 0.01649 0.06643 0.02015 0.02643 0.15968 0.01781 0.00000 0.02284 0.06314 0.07143 0.01764 0.01032 0.03710 0.00757
0.03022 0.02523 0.02781 0.01844 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372
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7 0.02661 0.01632 0.03049 0.15420 0.11567 0.06059 0.05228 0.02936 0.00000 0.03475 0.03146 0.01525 0.07814 0.03710 0.05917
0.01898 0.02193 0.00887 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372
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8 0.08072 0.01361 0.08533 0.00873 0.01933 0.04010 0.01818 0.06199 0.01351 0.00000 0.10111 0.01605 0.01014 0.03710 0.00841
0.13320 0.14039 0.03549 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372
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9 0.02224 0.02716 0.04033 0.00757 0.00560 0.03553 0.01198 0.05435 0.00997 0.06418 0.00000 0.01729 0.00989 0.03710 0.02097

0.03667 0.05274 0.02218 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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10 0.02224 0.02716 0.01368 0.00808 0.00981 0.01920 0.01737 0.01148 0.00596 0.00701 0.00917 0.00000 0.00743 0.03710 0.08434

0.01103 0.00949 0.02604 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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11 0.02224 0.02716 0.01802 0.05688 0.05255 0.00485 0.10832 0.00743 0.08474 0.03274 0.01919 0.07141 0.00000 0.03710 0.04577

0.01264 0.01215 0.05424 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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12 0.02224 0.02716 0.01468 0.05546 0.12963 0.05807 0.14805 0.03195 0.10741 0.04987 0.04993 0.12768 0.11166 0.03710 0.03831

0.03820 0.05225 0.11927 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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13 0.02224 0.02716 0.00802 0.01360 0.04336 0.01934 0.03615 0.00954 0.03874 0.00806 0.00855 0.12952 0.02460 0.03710 0.00000 0.01507 0.05585 0.02198 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

14 0.02224 0.02716 0.00682 0.01258 0.01099 0.01232 0.01413 0.00584 0.01016 0.00608 0.00769 0.02012 0.00862 0.03710 0.08764 0.00000 0.00806 0.00784 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

15 0.02224 0.02716 0.00571 0.00579 0.00526 0.01021 0.02860 0.00972 0.00620 0.01339 0.01975 0.01974 0.01868 0.03710 0.03815 0.01499 0.00000 0.02334 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

16 0.02224 0.02716 0.04922 0.00630 0.00435 0.00612 0.02745 0.05658 0.00468 0.00505 0.00527 0.01889 0.07129 0.03710 0.00688 0.00792 0.00506 0.00000 0.03067 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372 0.03372

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3 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.01090 0.01090 0.00000 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090

4 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.01090 0.01090 0.01090 0.00000 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090 0.01090

5 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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6 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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7 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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8 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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9 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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15 0.01021 0.01021 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982 0.00982
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Limit Matrix

1 2 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

16 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

1 **0.14609** 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609 0.14609

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2 0.12370 **0.12370** 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370 0.12370

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1 0.05091

2 0.03432

3 0.03955

4 0.04328

5 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044 0.05044
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9 0.02756

10 0.02188

11 0.03475

12 0.05320

13 0.02739

14 0.02100

15 0.02127

16 0.02458

1 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999 0.00999
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Table 6.2 and Table 6.3 give evaluation results for two alternatives, including Design A and Design B. The last column of each Table gives the score of each KPI, which is an average of all individual score to the KPI cooresponding to its scoring critetra. After scoring all KPIs, Table 6.4 gives the result of total score of each scenario, i.e. the score of buildings denoted as IB_{Score} (see Chapter 4). As a summary of KPIs evaluation or scoring, Table 6.4 is then used for pairwise comparisons among the two design scenarios and all 32 KPIs. After pairwise comparison, a standard ANP generate three supermatrices, including Unweighted Super Matrix, Weighted Super Matrix, and Limit Matrix (as given above). According to the computation results in the limiting supermatrix, $w_{C_{IB},i}$ = (0.14609, 0.12370), so the W_i = (0.5415, 0.4585), as a result, the most appropriate plan is Design A (refer to Table 6.5).

Table 6.5 Selection of the most appropriate design for the MCFC*

Model	No. of nodes	Synthesized priority weight W_i		Selection
		Design A	Design B	
IBAssessor	34	0.5415	0.4585	Design A

*MCFC: Manchester City Football Club.

6.4 Summary

This case study demonstrate the effectiveness of applying DAKIB rating approach and ANP approach in the assessment of intelligent buildings. It is concluded that both of these two proposed approaches are effective for intelligent buildings assessment; however, in order to give a more reliable assessment, results generated from these two approaches need to further be integrated with a result from DAKIB ANN approach. As the ANN model is still waiting for data to be trained at this stage, a more detailed discussion about their effectiveness in building assessment will be given later.

Chapter 7

CONCLUSIONS

7.1 Research Findings

This dissertation presents comprehensive details of research achievements in my PhD research project entitled A Study on Analytic Approaches to Intelligent Buildings Assessment. The research project has been encompassed an integrative methodology named DAKIB for comprehensive intelligent buildings assessment. The DAKIB prototype has been developed for generic conditions relating to intelligent buildings, and it can be generally applied in any assessment practice for intelligent buildings. In order to support the implementation of the DAKIB methodology, four analytic approaches for quantitative intelligent buildings assessment have also been developed and integrated into DAKIB platform; and the four analytic approaches as tools for the DAKIB system include

- The ANP approach for generic intelligent buildings assessment in Chapter 3, based on the simple TIBER model;
- The Rating approach and ANN approach for generic intelligent buildings assessment in Chapter 4, based on the improved TIBER model; and
- The KIV approach for decision-making in intelligent buildings assessment in Chapter 5.

In addition to the DAKIB model and its four useful tools, subsidiary experimental case studies and questionnaire surveys have been used in this dissertation to demonstrate their effectiveness in the assessment of intelligent buildings. Moreover, more than 20 publications have been produced for this research, including two book chapters, six refereed journal articles and fifteen refereed conference articles; all these publications are used to support the dissertation and further research and development of the DAKIB methodology and its tools.

The key finding of this research is an innovative theory of intelligent buildings assessment, including one integrative analytical model, i.e. DAKIB, and its four subsidiary approaches, including the ANP approach, the rating approach, the ANN approach and the KIV approach. The DAKIB model has been designed to provide a knowledge-driven methodology, which integrates various functional-different quantitative approaches, to getting more effective and objective assessment of intelligent buildings. In addition, all these tools have been designed to have feasibility for further integration into a co-ordinate software environment, i.e. the proposed DAKIB system for intelligent buildings assessment. In addition to the DAKIB methodology, this research also developed four functional-different quantitative approaches to intelligent buildings assessment, not only to demonstrate the effectiveness of each individual approach but also to unveil their synergistic effect in a DAKIB system. Although the software environment of DAKIB system has not been achieved in this research, case studies from Chapter 5 and Chapter 6 have demonstrated that the proposed system can effectively and efficiently provide a more objective assessment for intelligent buildings. More over, it also unveiled that the DAKIB methodology is flexible for more relevant tools to be integrated.

7.2 Contributions to Existing Theories or Practice

According to the purpose and detailed objectives of DAKIB methodology for intelligent buildings assessment, this research mainly contributes to existing theory of buildings assessment in the area of quantitative analytic approaches and their integrative implementation. According to extensive literature reviews and questionnaire surveys conducted for this research, the lack of objective quantitative analytical approach is one of obstacles to implementing intelligent buildings assessment. Therefore, there are six points of contribution of this research to the existing theory or practice for intelligent buildings assessment:

- This research has developed an integrative methodology, i.e. DAKIB prototype, for more objective intelligent buildings assessment. A Strategic Intelligent Building Evaluation and Renovation (SIBER) model and a Tactical Intelligent Buildings Evaluation and Renovation (TIBER) model have been developed to regulate intelligent buildings assessment through the life cycle of buildings. All analytic approaches, including the ANP approach, the rating approach, the ANN approach and the KIV approach, are all designed to effectively conduct reliable intelligent buildings assessment across a building life cycle. The DAKIB is originally created in both the theory and practice for intelligent buildings assessment, and it is open to further integration of various functional approaches for intelligent buildings assessment besides the four approaches developed in this research. Because of the DAKIB is designed to support knowledge-based lifecycle intelligent buildings assessment, it can thus help various building sectors including Building Designers, Construction Contractors, Property Managers, Recyclers or Manufacturers, and Academic Educators, etc. to implement building study from a messy situation to a normalised system, and to effectively share relevant knowledge and information internally and externally.
- The ANP approach is a multicriteria decision-making method based on 32 KPIs which have been extracted from 378 indicators currently adopted in the IB Index (3rd version) developed by the Asian Institute of Intelligent

Buildings in 2005. There are two main reasons why these 32 KPIs are used for ANP modelling, including

- The IB Index has a comprehensive list of indicators for intelligent buildings assessment, although 378 indicators are too many to be evaluated in practice; and
- An originally developed Energy-Time consumption Index (ETI) has been developed in Chapter 3 to effectively evaluate indicators which could be used for intelligent buildings assessment.

Therefore, the ANP model is built upon a group of reliable KPIs. Moreover, the significant advantage of ANP approach is that it adopts pairwise comparisons among all KPIs, on which all currently used buildings assessment method fall far behind. Actually, the proposed ANP approach has created a new atmosphere in the area of buildings assessment, and it is that the buildings assessment needs to concern the interrelations among different indicators.

- The DAKIB rating approach developed in Chapter 4 is a new rating approach to intelligent buildings assessment. The DAKIB rating approach adopts the 32 KPIs used for the ANP model, and define the weight of each KPI based on its ETI score. Comparing with other building rating methods, the DAKIB rating approach has more reliable indicators and more objective weights of indicators. Therefore, the result from DAKIB rating is expected more reliable and objective.
- The ANN approach developed in Chapter 4 is a novel application, which integrates ANP and rating approach for efficient intelligent buildings assessment. The ANN model is to be trained by using assessment results

from ANP approach and rating approach. Although there aren't enough data to train the proposed ANN model, it has been demonstrated that the innovative integration of ANN approach with ANP model and rating model can efficiently facilitate the practice of intelligent buildings assessment, where the results from the novel ANP approach and rating approach, and expertises integrated inside ANP model can be effectively used.

- The KIV approach originally developed from this research is a knowledge management toolkit, including IB-CAST, IB-Radar, IB-Compass, and IB-GIS, to support decision-making in intelligent buildings assessment through knowledge reuse based on knowledge engineering and information visualization technologies. The case study of the Hong Kong International Finance Centre in Chapter 5 demonstrated how KIV approach can be used to support decision-making for intelligent buildings assessment.
- The additional contribution of this research is two series of questionnaire surveys. The first series of questionnaire survey, including intelligent buildings assessment using rating approach and intelligent buildings assessment using ANP model, is used to collect the information of intelligent buildings and ask for comments to KPIs from building professionals in China at first stage, and to collect expertises to finalize the ANP model at the second stage. The second series of questionnaire surveys, including a questionnaire survey for real estate developers, a questionnaire survey for system suppliers, and a questionnaire survey for property managers, is used to collect background information about the status of intelligent buildings in China. Although these questionnaire surveys have been only distributed to building professionals in China, it is believed that they can further be conducted to building professionals in other countries.

7.3 The Implications/Impact on the Sponsors

This research is supported by a by the China Electronic Standardization Institute, and further sustained by the Research Centre of Construction Innovation at the Department of Building & Real Estate in the Hong Kong Polytechnic University. The title of the research project is An Assessment System for Intelligent Buildings in China; research partners include Beijing Institute of Civil Engineering and Architecture; the Hong Kong Polytechnic University; China Electronic Standardization Institute; and the Research Centre 4 of the Ministry of Information Technology of China. Although the research has not provided a commercial software package to implement the DAKIB system for intelligent buildings assessment, which has been developed in this research, the DAKIB prototype and its subsidiary functional toolkits have explored new research and development areas of building assessment, where the knowledge-driven analytic approaches and their integrative implementation for more reliable intelligent buildings assessment are adopted. Research deliverables, including the DAKIB prototype and its four practical tools with case studies, have also demonstrated potential commercial usefulness of the DAKIB system. It can be expected the further research and development of the DAKIB system and its toolkits will definitely contribute to intelligent buildings assessment, and a commercial DAKIB system will benefit the building professions for more reliable intelligent buildings assessment.

7.4 The Implications/Impacts on the Wider Community

The DAKIB methodology and its subsidiary functional approaches have received a world-wide recognition on relevant publications in internationally refereed journals and internationally refereed conference proceedings throughout the research. Although there is still a distance from the commercial DAKIB system, the four functional approaches for the DAKIB system, including the ANP approach, the rating approach, the ANN approach, and the KIV approach, are ready to use. Besides these publications, informal interviews about the DAKIB system and its subsidiaries with both academics and professionals also received a positive awareness, and useful experiences have also been achieved from case studies by using these developed DAKIB approaches. It can also be expected the adoption and further research and development of the DAKIB system will definitely contribute to more reliable intelligent buildings assessment.

7.5 Limitations

Although this research project has been accomplished with satisfied results, there are some limitations not only within the research but also in the implementation of the DAKIB tools developed in the research. The limitations of the research exist in the following areas:

- This research has not been finished the development of a DAKIB software to further demonstrate its usefulness and efficiency for intelligent buildings assessment through more real case studies;
- The ANN model has not been trained for utilization due to the lack of data;
- The ANP approach has also not been developed into a fully user-oriented tool to facilitate intelligent buildings assessment, although it is proposed to use ANN approach to provide assessment services.

7.6 Recommendations

Recommendations for the building professions come from the usefulness and efficiency of the four DAKIB functional approaches, which have been demonstrated in the Chapter

3 to 6. However, due to the limitations of current research, it is thus recommended to implement further researches on both the development of the DAKIB software and more DAKIB approaches for more reliable intelligent buildings assessment. For example, the DAKIB prototype can be further developed to a web-based data and knowledge management system of intelligent buildings for practitioners to implement more reliable intelligent buildings assessment. As a conclusion, it is recommended that the further research and development need to focus on the realisation of a web-based DAKIB system, the integration of current functional approaches for intelligent buildings assessment, and the development of new functional approaches for the system.

APPENDICES

Appendix 1: Questionnaire Survey One

The aim of Questionnaire One is to collect expertise from building professionals so as to modify the IBAssessor ANP model described in Chapter 3 and conduct case studies. Two stages are designed to achieve these two objectives. The first stage is to use questionnaire (see Section A1.1 (an English questionnaire) or Section A1.2 (a Chinese questionnaire)) to further examine the degree of recognition to KPIs and to collect necessary data for case studies by using DAKIB rating approach (see Chapter 4); in addition, data collected will be further treated as inputs of the ANN model (see Chapter 4). The second stage is to use a group of revised KPIs, which will be modified based on the results from first stage, as finalized nodes for the ANP model and to further ask experts to make all necessary pairwise comparisons so as to finalize the model. At this moment, the questionnaire survey for the first stage is ongoing, and the questionnaire survey for the second stage will follow up after data analysis for the fisrt stage is completed and a revised group of KPIs is defined. Although the total 32 KPIs (see Chapter 3 and Chapter 6) have been successfully used for an ANP model in an experimental case study, i.e. the City of Manchester Stadium, it is really necessary to further finalize a new group of KPIs, which means by reducing the total number of KPIs, we can save a lot of time in pairwise comparisons for ANP modeling. Anyway, to finalize KPIs need to wait for respondents' opinions from the first-stage questionnaire survey.

The first-stage questionnaire survey is being conducted by using questionnaire described in Section A1.1, in which the 32 KPIs, which have been verified for the IBAssessor ANP model, are used to indicate scores cooresponding to the ten modules of IB Index (AIIB, 2005). Below is the list of current KPIs:

KPI 1.1: Electricity & Electrical services

KPI 1.2: Heating services

KPI 1.3: Ventilation & air-conditioning

KPI 1.4: Building services automation system

KPI 1.5: Construction materials

KPI 1.6: IT&C facilities and services

KPI 1.7: Thermal comfort & indoor air quality

KPI 1.8: Lifts/escalators and controls

KPI 1.9: Security and safety control

KPI 1.10: Flushing water system & drainage

KPI 1.11: External & internal decoration

KPI 1.12: Building architectural design

KPI 1.13: Lavatory accommodation

KPI 1.14: Refuse collection & disposal

KPI 1.15: Circulation for the disabled

KPI 1.16: CAD/CAM/CAC

KPI 2.1: Flexibility for renovation

KPI 2.2: Structural monitoring & control

KPI 2.3: Potable water system

KPI 2.4: Fire detection and resistance

KPI 2.5: Cleanliness

KPI 2.6: Property management

KPI 2.7: Carpark/transportation facilities

KPI 2.8: Entertainment facilities

KPI 2.9: External landscape

KPI 2.10: Extensive use of AI

KPI 2.11: Environmental friendliness

KPI 2.12: Conference and meeting facilities

KPI 2.13: Access sign and directory

KPI 2.14: Maintainability

KPI 2.15: Usable areas

KPI 2.16: Means of escape

Although these KPIs have been extracted from the IB Index (AIIB, 2005) (see Chapter 3), the specification of KPIs for the DAKIB system is still required in order to facilitate the scoring process for each intelligent building, however, before finalizing the group of KPIs, it is believed that the IB Index can be alternatively used to specify these KPIs according to their relations to the IB Index (see Table 4.2). At the beginning of first-stage survey, Questionnaire A1.1 or Questionnaire A1.2, and KPI specifications are distributed to experts. Feedback from experts will then be accumulated and analyzed. Results from this survey will be used in case studies and training the ANN model as described in Chapter 4.

Questionnaires used for the first-stage survey are given in Section A1.1 and Section A1.2.

A1.1 The Evaluation of KPIs for Intelligent Buildings Assessment

A Questionnaire Survey on Intelligent Buildings Assessment

Ju Hong

PhD Candidate, Department of Building and Real Estate, The Hong Kong Polytechnic University

<02901958r@ >

This questionnaire survey is for my PhD study, entitled A Study on Analytic Approaches to Intelligent Buildings Assessment, at the Hong Kong Polytechnic University. It is also for a funded research project, entitled An Assessment System for Intelligent Buildings in China, by the China Electronic Standardization Institute. Research partners of this research project include Beijing Institute of Civil Engineering and Architecture; The Hong Kong Polytechnic University; China Electronic Standardization Institute; and the Research Centre 4 of the Ministry of Information Technology of China. As one part of the research project, this questionnaire survey aims to collect necessary data of existing buildings in the form of subjective judgment to the 32 Key Performance Indicators (KPIs) and 10 relevant criteria clusters for KPI scoring (see the questionnaire below). Please refer to the IB Index developed by the Asian Institute of Intelligent Buildings for regulations regarding how to make subjective judgment for each KPI. Your participation is very important for the research team to complete this research project. Thank you!

The Questionnaire

Requirements:

1. Please ask your colleagues to make more respondence seprately, so that the research team can have more than one set of data for one building; and this can bring advantages for the research team to further make a specification for subjective judgment.
2. Respondences from from email, mail, or fax are all welcome.
3. Respondences about more buildings are extremely welcome.
4. Please provide the following information for recording. The research team will keep all information you provide confidential and will use it only to conduct the requested research in this project.
5. Please refer to a sample questionnaire sheet attached for reference.

Information of the Respondent

Name:

Organization:

Position:

Address:

Telephone:

E-mail:

Date:

Information of the Building

Name of the Building:

Location:

Owner:

Architect:

Main Contractor:

Sub-Contractors:

Engineering Supervisor:

Construction Duration:

Construction Cost:

Opening Date:

Property Manager:

Customers:

Design Specification: (Please provide relevant information regarding the 32 KPIs and the 10 criteria clusters. This will help the research team to understand the score your give to each KPI. Please provide e-file if it's convenient for you.)

The Evaluation of KPIs for Intelligent Buildings Assessment

Key Performance Indicators (KPIs)	**Scores to relevant criteria** $(S_i \in [0,10])$*									
	1 Green	**2 Space**	**3 Comfort**	**4 Working Efficiency**	**5 Culture**	**6 High-tech Image**	**7 Safety & Structure**	**8 Management Practice & Security**	**9 Cost Effectiveness**	**10 Health & Sanitation**
Group 1										
1.1 Electricity & Electrical services										
1.2 Heating services										
1.3 Ventilation & air-conditioning										
1.4 Building services automation system										
1.5 Construction materials										
1.6 IT&C facilities and services										
1.7 Thermal comfort & indoor air quality										
1.8 Lifts/escalators and controls										
1.9 Security and safety control										
1.10 Flushing water system & drainage										
1.11 External & internal decoration										
1.12 Building architectural design										
1.13 Lavatory accommodation										
1.14 Refuse collection & disposal										
1.15 Circulation for the disabled										
1.16 CAD/CAM/CAC										
Group 2										
2.1 Flexibility for renovation										
2.2 Structural monitoring & control										
2.3 Potable water system										
2.4 Fire detection and resistance										
2.5 Cleanliness										
2.6 Property management										
2.7 Carpark/transportation facilities										
2.8 Entertainment facilities										
2.9 External landscape										
2.10 Extensive use of artifical intelligence										
2.11 Environmental friendliness										
2.12 Conference and meeting facilities										
2.13 Access sign and directory										
2.14 Maintainability										
2.15 Usable areas										
2.16 Means of escape										

Note:

1. This form is for evaluating one single building. For each blank cell, respondents need to give a score corresponding to the specific criteria of each KPI. There is no need to give score for shadow cell. For example, as there are 7 corresponding criteria for KPI 1.1, including criteria 1, 2, 3, 4, 6, 7 and 8, 7 scores are required individually for each of the 7 blank cells; and the characteristics of KPI 1.1 in accordance with each of these 7 criteria are bases in subjective judgments.
2. *The scope of score is from 0 to 10. You need to transform a 100-scale score based on the specifications of IB Index (AIIB, 2005) to a 10-scale score, as current specification for scoring is the IB Index (see Chapter 4).
3. Please refer to sample form for reference.
4. CAD/CAM/CAC: Computer Aided Design, Manufacturing, Construction/installation.
5. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

The Evaluation of KPIs for Intelligent Buildings Assessment (Sample)

Key Performance Indicators (KPIs)	Scores to relevant criteria ($S_i \in [0,10]$)*									
	1 Green	2 Space	3 Comfort	4 Working Efficiency	5 Culture	6 High-tech Image	7 Safety & Structure	8 Management Practice & Security	9 Cost Effectiveness	10 Health & Sanitation
Group 1										
1.1 Electricity & Electrical services	10	10	10	10		10	10	10		
1.2 Heating services	10									
1.3 Ventilation & air-conditioning	10	10	10	10						10
1.4 Building services automation system				10		10		10		
1.5 Construction materials	10					10				
1.6 IT&C facilities and services				10		10				
1.7 Thermal comfort & indoor air quality	10		10	10			10	10		10
1.8 Lifts/escalators and controls	10		10	10		10		10		
1.9 Security and safety control		10		10		10	10	10		
1.10 Flushing water system & drainage	10		10					10		10
1.11 External & internal decoration		10		10						10
1.12 Building architectural design	10			10	10	10				
1.13 Lavatory accommodation	10		10	10						
1.14 Refuse collection & disposal	10							10		10
1.15 Circulation for the disabled		10						10		
1.16 CAD/CAM/CAC	10					10				
Group 2										
2.1 Flexibility for renovation		10								
2.2 Structural monitoring & control							10	10		
2.3 Potable water system								10		10
2.4 Fire detection and resistance				10			10			
2.5 Cleanliness	10		10	10						10
2.6 Property management	10	10		10		10	10	10	10	10
2.7 Carpark/transportation facilities		10		10		10		10		10
2.8 Entertainment facilities			10	10	10					
2.9 External landscape	10				10					
2.10 Extensive use of artifical intelligence				10		10				
2.11 Environmental friendliness	10							10		
2.12 Conference and meeting facilities				10		10				
2.13 Access sign and directory				10		10	10			
2.14 Maintainability				10				10		
2.15 Usable areas		10	10	10						
2.16 Means of escape							10	10		

Note:

1. This form is for evaluating one single building. For each blank cell, respondents need to give a score corresponding to the specific criteria of each KPI. There is no need to give score for shadow cell. For example, as there are 7 corresponding criteria for KPI 1.1, including criteria 1, 2, 3, 4, 6, 7 and 8, 7 scores are required individually for each of the 7 blank cells; and the characteristics of KPI 1.1 in accordance with each of these 7 criteria are bases in subjective judgments.
2. *The scope of score is from 0 to 10. You need to transform a 100-scale score based on the specifications of IB Index (AIIB, 2005) to a 10-scale score, as current specification for scoring is the IB Index (see Chapter 4).
3. CAD/CAM/CAC: Computer Aided Design, Manufacturing, Construction/installation.
4. Environmental friendliness: Green features in design, manufacturing, construction, and utilization, etc.

A1.2 The Chinese Version of the Questionnaire Survey for evaluating KPIs

智能建筑评估指标及评价的问卷调查

北京建筑工程学院 洪桔

(香港理工大学建筑及房地产学系博士候选人)

<hongjucn@ >

本研究得到中国电子技术标准化研究所中国智能建筑评估系统研究项目的资助。作为该研究项目的一部分，本问卷调查的目的是在前期研究的基础上，针对全国范围内若干具有代表性的智能建筑，收集业内人士运用本研究中采用的两组总共 32 个指标及其对应的 10 个评分准则（参见调查问卷）的主观评价。您的参与将有效地促进中国电子技术标准化研究所在该研究项目上的研究工作。谢谢！

调查问卷

问卷需求：

1. 为了得到对同一个建筑的不同意见，以获得可比性数据，敬请若干技术专业人员对同一个建筑分别进行打分。
2. 为了满足各种填表习惯，问卷的填写可以采用电子文档形式或书面形式。
3. 欢迎您提供多个建筑物的评分表；并请提供下列若干相关信息供问卷分析使用。

填表人基本信息

单位：

职称及职务：

通信地址：

电话：

电邮：

填表日期：

建筑物基本信息

名称：

地点：

业主：

建筑设计承包单位：

智能集成设计承包单位：

施工承包单位：

监理承包单位：

施工起止日期：

启用日期：

建筑总造价：

物业管理承包单位：

主要购买或承租单位：

建筑物详细信息

建筑设计说明书：

（说明：要求针对调查表中的两组总共 32 个指标及其它们 10 个评分准则，提供相关信息帮助问卷分析人了解填表人打分的依据。最好提供电子文档。）

智能建筑评估模型的关键性能指标及评价表

智能建筑评价指标	智能建筑指标的评分准则 （由极差 0 分到极优 10 分）									
	1 环境保护	2 空间的利用	3 提供的舒适度	4 工作效率	5 文化氛围	6 高新技术的使用	7 安全与建筑结构	8 管理现状与保安	9 成本效率	10 健康与卫生
第一组指标										
1.1 电力与电器设备及服务										
1.2 供热设备及服务										
1.3 通风及空调设备及服务										
1.4 建筑设备及服务自动化系统										
1.5 建筑材料										
1.6 信息与通讯设备及服务										
1.7 室内环境的热舒适度和空气质量										
1.8 电梯与电动扶梯及控制										
1.9 保安与安全设备控制										
1.10 污水排放系统										
1.11 建筑物内外装饰										
1.12 建筑设计综合水平										
1.13 浴室及卫生间档次										
1.14 废物收集与处理										
1.15 无障碍通道										
1.16 计算机辅助设计/制造/施工的使用										
第二组指标										
2.1 各种翻新的灵活性										
2.2 结构监控与控制										
2.3 饮用水系统										
2.4 火灾探测及防御										
2.5 清洁										
2.6 物业管理										
2.7 停车场及运输设施										
2.8 娱乐设施										
2.9 建筑园林										
2.10 人工智能的系统化应用										
2.11 环境保护										
2.12 会议设施										
2.13 通行指引										
2.14 可维护性										
2.15 使用空间										
2.16 各种意外情况下的逃生方法										

填表说明：

1. 问卷调查表中空白处需要针对同一个**具体建筑**，根据各个指标所对应的评分准则，给出每个指标的相应得分。
2. 每个空格处的打分范围：0-10 （依据打分者的主观判断由极差 0 分到最优 10 分）。例如：指标 1.1 （电力与电器设备及服务）对应 7 项准则，即准则 1，2，3，4，6，7，8，需要有 7 项打分 （阴影方格对应的准则不需要打分）。需要针对具体建筑就该项指标与这 7 项准则相对应的内容分别进行打分。其它指标以此类推。
3. 每张表格用于一次打分，可根据需要重复索取该表格（同一个建筑物，不同打分者；同一个打分者， 不同的建筑物 ）。
4. 填表格式请参考表格样本。

智能建筑评估模型的关键性能指标及评价表
（样本）

智能建筑评价指标	**智能建筑指标的评分准则** （由极差（0 分）到极优（10 分））									
	1 环境保护	2 空间的利用	3 提供的舒适度	4 工作效率	5 文化氛围	6 高新技术的使用	7 安全与建筑结构	8 管理现状与保安	9 成本效率	10 健康与卫生
第一组指标										
1.1 电力与电器设备及服务	10	10	10	10		10	10	10		
1.2 供热设备及服务	10									
1.3 通风及空调设备及服务	10	10	10	10						10
1.4 建筑设备及服务自动化系统				10		10		10		
1.5 建筑材料	10					10				
1.6 信息与通讯设备及服务				10		10				
1.7 室内环境的热舒适度和空气质量	10		10	10			10	10		10
1.8 电梯与电动扶梯及控制	10		10	10		10		10		
1.9 保安与安全设备控制		10		10		10	10	10		
1.10 污水排放系统	10		10					10		10
1.11 建筑物内外装饰		10		10						10
1.12 建筑设计综合水平	10			10	10	10				
1.13 浴室及卫生间档次	10		10	10						
1.14 废物收集与处理	10							10		10
1.15 无障碍通道		10						10		
1.16 计算机辅助设计/制造/施工的使用	10					10				
第二组指标										
2.1 各种翻新的灵活性		10								
2.2 结构监控与控制							10	10		
2.3 饮用水系统								10		10
2.4 火灾探测及防御				10			10			
2.5 清洁	10		10	10						10
2.6 物业管理	10	10		10		10	10	10	10	10
2.7 停车场及运输设施		10		10		10		10		10
2.8 娱乐设施			10	10	10					
2.9 建筑园林	10				10					
2.10 人工智能的系统化应用				10		10				
2.11 环境保护	10							10		
2.12 会议设施				10		10				
2.13 通行指引				10		10	10			
2.14 可维护性				10				10		
2.15 使用空间		10	10	10						
2.16 各种意外情况下的逃生方法							10	10		

填表说明：

1. 问卷调查表中空白处需要针对同一个**具体建筑**，根据各个指标所对应的评分准则，给出每个指标的相应得分。
2. 每个空格处的打分范围：0-10（依据打分者的主观判断由极差 0 分到极优 10 分）。例如：指标 1.1（电力与电器设备及服务）对应 7 项准则，即准则 1，2，3，4，6，7，8，需要有 7 项打分（阴影方格对应的准则不需要打分）。需要针对具体建筑就该项指标与这 7 项准则相对应的内容分别进行打分。其它指标以此类推。

Appendix 2: Quesstionnaire Survey Two

A2.1 Questionnaire to Real Estate Developers (English version)

(Please check all that applies)

1.1 In the past five year, the total number of construction projects that your company has completed is _________, including _____ intelligent building projects, and ______ have finished.

1.2 The most representative intelligent building completed by your company is ________. Location: _____________________________. Plot area (m2): ________; Floor area (m2): _______; Number of Units: ________; Price (CNY/m2):_______.

Comparing with local average level, the price was

☐ much higher,

☐ higher,

☐ moderate,

☐ lower, or

☐ much lower.

1.3 Major reasons for your company to develop this project are:

☐ Governmental requirements

☐ Demands from the market

☐ The image of our company

☐ Decisions with partners

☐ Don't know or not clear.

☐ Others. (Please descript:____.)

1.4 Total investment to this project is CNY ______ million, including CNY

million to building intelligentization.

1.5 The detailed work relevant to the intelligentization of this project includes:

☐ Asymmetric Digital Subscriber Line (ADSL).

☐ Digital cable TV system.

☐ Computer systems for facilities management.

☐ Website.

☐ ID reorganizations.

☐ Vehicle reorganizations.

☐ Video monitoring system.

☐ Fence security system.

☐ Visual intercommunication telephone.

☐ Un-visual intercommunication telephone.

☐ Door security system.

☐ Electrical patrols.

☐ Family security and alarm management.

☐ Remote control to household appliances.

☐ Remote meter measure and calculation.

☐ Electronic mapping management for monitoring and controlling facilities.

☐ Electronic mapping management for monitoring and controlling residential community.

☐ Central control room.

☐ Smart card system.

☐ Background music.

☐ Synthetically wiring.

☐ Lightning protection and earthing system.

☐ Database for facilities management.

☐ Others. (Please describe:____.)

1.6 Which ones, as mentioned in 1.5, is/are the mostly concerned item by clients? ______.

1.7 Which ones, as mentioned in 1.5, can be mostly used to measure the level of intelligentization? ____.

1.8 For the representative project mentioned in 1.2,

☐ The contractor of system integration is ____________________________________.

☐ Main contractor is _______________________________________, contract covers _.

☐ DIY.

1.9 The investor for the telephone system of the project is:

☐ Telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

1.10 The investor for the Cable TV system of the project is:

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

1.11 The investor for the ADSL system of the project is:

☐ Telecommunication profession.

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

1.12 The ADSL/Cable TV/Telephone system(s) of the project is/are:

☐ A 3-in-1 system.

☐ Integrated ADSL & Telephone system.

☐ Independent systems.

1.13 The control network system of the project is:

☐ With the aid of local ADSL.

☐ With the aid of Cable TV network.

☐ An independent system.

1.14 The wiring structure of the control network system of the project is:

☐ A comprehensive wiring system.

☐ A tree structure wiring system.

☐ A star structure wiring system.

☐ Independent systems.

1.15 The intercom system adopted in the project is:

☐ Color visual intercom system.

☐ White-Black visual intercom system.

☐ Unvisual intercom system.

☐ None.

1.16 The home safety and security systems adopted in the project is/are:

☐ Independent product.

☐ Attached with intercom system.

☐ Attached with other product.

☐ None.

1.17 The long-distance/remote control function of domestic electric appliances applied in the project is:

☐ Independent products.

☐ Attached with other products.

☐ None.

1.18 The information issue system adopted in the project is:

☐ Electronic screen.

☐ Public information screen.

☐ Direct email/mail.

☐ None.

1.19 The terminal of smart card built in the project located at:

☐ Main entrance.

☐ Unit entrance.

☐ Home security gate.

☐ Car park.

☐ Electrical patrols.

☐ Shops.

☐ Others. (Please describe:____.)

1.20 Whether there is a website of the project and its services include:

☐ No website.

☐ Yes, its services include:

☐ Internal information services, main contents: ________________________________.)

☐ Internal e-commerce services, main contents: ________________________________.)

☐ Others. (Please describe:____.)

1.21 The equipment(s) of intelligent systems in the project is/are:

☐ Foreign products.

☐ Domestic products.

☐ Joint-venture products.

1.22 The decision making on selecting intelligent systems in the project relies on:

☐ Client.

☐ Sub-contractors.

☐ System providers.

1.23 The decision making on selecting these intelligentized equipment(s) in the project relies on:

☐ Client.

☐ Sub-contractors.

☐ System providers.

1.24 The current operation situation of the project is:

☐ In use.

Utilization rate: ☐ 100%. ☐ 80%. ☐ >50%. ☐ <50%.

☐ To be used.

☐ Disuse.

1.25 The problems, relevant to governmental management, existed in the construction of digital residential communities are:

☐ Lack of regulations.

☐ Lack of national standards.

☐ Lack of professional guidelines.

☐ Lack of a normalized market.

☐ The most important one is :____.

1.26 The problems, relevant to industry development, existed in the construction of digital residential communities are:

☐ Poor qualities of products.

☐ Poor qualifications of system providers.

☐ Low accomplishment of developers.

☐ Poor diathesis of clients.

1.27 The problems, relevant to products, existed in the construction of digital residential communities are:

☐ poor qualities.

☐ not practicable.

☐ high price.

☐ user unfriendly.

1.28 Can intelligentization be an important advantage of digital residential buildings in real estate market?

☐ Yes.

☐ No.

☐ Not sure.

☐ Yes, but 5~10 years later.

Contact Information

For further contact, please provide following information. Thank you!

Company Name			
Website			
Business Scope			
Grade			
Contact Person	Mr. / Ms.	Position	
Mail Address			
City and Province		Zip Code	
Telephone No.		E-mail	

The End of the Questionnaire.

APPENDIX 2: QUESTIONNAIRE TWO (*continued*)

A2.2 Questionnaire to System Providers (English version)

(Please check all that applies)

2.1 In the past five year, the total number of intelligentized systems integrated into construction projects that your company has completed is _______; among them, has/have been completed and in use, and ______ is/are under construction.

2.2 The most representative residential community with intelligentized system completed by your company is ____.
Location: _____________________________. Plot area (m2): ________; Floor area (m2): ________; Number of Units: ________; Price (CNY/m2):________.

Comparing with local average level, the price was

☐ much higher,

☐ higher,

☐ moderate,

☐ lower, or

☐ much lower.

The investment to this intelligentized system is CNY______ million.

2.3 The detailed work relevant to the intelligentization of this project include:

☐ Asymmetric Digital Subscriber Line (ADSL).

☐ Digital cable TV system.

☐ Computer systems for facilities management.

☐ Website.

☐ ID reorganizations.

☐ Vehicle reorganizations.

☐ Video monitoring system.

☐ Fence security system.

☐ Visual intercommunication telephone.

☐ Un-visual intercommunication telephone.

☐ Door security system.

☐ Electrical patrols.

☐ Family security and alarm management.

☐ Remote control to household appliances.

☐ Remote meter measure and calculation.

☐ Electronic mapping management for monitoring and controlling facilities.

☐ Electronic mapping management for monitoring and controlling residential community.

☐ Central control room.

☐ Smart card system.

☐ Background music.

☐ Synthetically wiring.

☐ Lightning protection and earthing system.

☐ Database for facilities management.

☐ Others. (Please describe:____.)

2.4 Which ones mentioned in 2.3 is/are the mostly concerned item for clients?

____.

2.5 Which ones mentioned in 2.3 can be mostly used to measure the level of intelligentization? ____.

2.6 The equipment(s)/facilities selected as intelligent systems in the project is/are:

☐ Foreign products.

☐ Domestic products.

☐ Joint-venture products.

2.7 The home safety and security system adopted in the project is:

☐ Independent product.

☐ Attached with intercom system.

☐ Attached with other product.

☐ None.

2.8 The technology adopted for home safety and security systems in the project is:

☐ TCP/IP protocol

☐ Industrial bus.

☐ 485 bus.

☐ Others.

2.9 The current operation situation of the project is:

☐ In use; and Utilization rate: ☐ 100%. ☐ 80%. ☐ >50%. ☐ <50%.

☐ To be used.

☐ Disuse.

2.10 The investor of the telephone system in the project is:

☐ Telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

2.11 The investor for the Cable TV system of the project is:

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

2.12 The investor for the ADSL system of the project is:

☐ Telecommunication profession.

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

2.13 The ADSL/Cable TV/Telephone system(s) of the project is/are:

☐ A 3-in-1 system.

☐ Integrated ADSL & Telephone system.

☐ Independent systems.

2.14 The control network system of the project is:

☐ With the aid of local ADSL.

☐ With the aid of Cable TV network.

☐ An independent system.

2.15 The wiring structure of the control network system of the project is:

☐ A comprehensive wiring system.

☐ A tree structure wiring system.

☐ A star structure wiring system.

☐ Independent systems.

2.16 The intercom system adopted in the project is:

☐ Color visual intercom system.

☐ White-Black visual intercom system.

☐ Unvisual intercom system.

☐ None.

2.17 The home safety and security systems adopted in the project is/are:

☐ Independent product.

☐ Attached with intercom system.

☐ Attached with other product.

☐ None.

2.18 The long-distance/remote control function of domestic electric appliances applied in the project is:

☐ Independent products.

☐ Attached with other products.

☐ None.

2.19 The information issue system adopted in the project is:

☐ Electronic screen.

☐ Public information screen.

☐ Direct email/mail.

☐ None.

2.20 The terminal of smart card built in the project located at:

☐ Main entrance.

☐ Unit entrance.

☐ Home security gate.

☐ Car park.

☐ Electrical patrols.

☐ Shops.

☐ Others. (Please describe:____.)

2.21 Whether there is a website of the project and its services include:

☐ No website.

☐ Yes, its services include:

☐ Internal information services, main contents: _____________________________.)

☐ Internal e-commerce services, main contents: ____________________________.)

☐ Others. (Please describe:____.)

2.22 The problems, relevant to governmental management, existed in the construction of digital residential communities are:

☐ Lack of regulations.

☐ Lack of national standards.

☐ Lack of professional guidelines.

☐ Lack of a normalized market.

☐ The most important one is :____.

2.23 The problems, relevant to industry development, existed in the construction of digital residential communities are:

☐ Poor qualities of products.

☐ Poor qualifications of system providers.

☐ Low accomplishment of developers.

☐ Poor diathesis of clients.

2.24 The problems, relevant to products, existed in the construction of digital residential communities are:

☐ poor qualities.

☐ not practicable.

☐ high price.

☐ user unfriendly.

2.25 Can intelligentization be an important advantage of digital residential buildings in real estate market?

☐ Yes.

☐ No.

☐ Not sure.

☐ Yes, but 5~10 years later.

Contact Information

For further contact, please provide following information. Thank you!

Company Name			
Website			
Business Scope			
Grade			
Contact Person	Mr. / Ms.	Position	
Mail Address			
City and Province		Zip Code	
Telephone No.		E-mail	

The End of the Questionnaire.

APPENDIX 2: QUESTIONNAIRE TWO *(Continued)*

A2.3 Questionnaire to Property Managers (English version)

(Please check all that applies)

3.1 In the past 5 year, the total number of projects that your company has engaged in is ____, including _____ intelligent building projects.

3.2 The most representative intelligent building managed by your company is ____.

Location: ____________________________. Plot area (m2): _________; Floor area (m2): ________; Number of Units: ________; Price (CNY/m2):________.

Comparing with local average level, the price was

☐ much higher,

☐ higher,

☐ moderate,

☐ lower, or

☐ much lower.

The developer of the project is:____.

The system provider(s) of the project is/are:_______________________________________.

3.3 The detailed work relevant to the intelligentization of this project include:

☐ Asymmetric Digital Subscriber Line (ADSL).

☐ Digital cable TV system.

☐ Computer systems for facilities management.

☐ Website.

☐ ID reorganizations.

☐ Vehicle reorganizations.

☐ Video monitoring system.

☐ Fence security system.

☐ Visual intercommunication telephone.

☐ Un-visual intercommunication telephone.

☐ Door security system.

☐ Electrical patrols.

☐ Family security and alarm management.

☐ Remote control to household appliances.

☐ Remote meter measure and calculation.

☐ Electronic mapping management for monitoring and controlling facilities.

☐ Electronic mapping management for monitoring and controlling residential community.

☐ Central control room.

☐ Smart card system.

☐ Background music.

☐ Synthetically wiring.

☐ Lightning protection and earthing system.

☐ Database for facilities management.

☐ Others. (Please describe:____.)

3.4 Which ones mentioned in 3.3 are mostly concerned item for clients?

____.

3.5 Which ones mentioned in 3.3 can be mostly used in property management?

____.

3.6 Among all intelligent systems, please give the most useful ones for property management:

☐ Equipment one

Name:

Model:

Amount:

Unit:

Manufacturer:

☐ Equipment two

Name:

Model:

Amount:

Unit:

Manufacturer:

☐ Equipment three

Name:

Model:

Amount:

Unit:

Manufacturer:

3.7 Among all these three intelligent systems, please give the most reliable ones for property management:

☐ Equipment one

☐ Equipment two

☐ Equipment three

3.8 The equipment(s) of intelligent systems in the project is/are:

☐ Foreign products: ______%

Reliability ☐ High ☐ Low;

Practicability ☐ High ☐ Low.

☐ Domestic products: _____%

Reliability ☐ High ☐ Low;

Practicability ☐ High ☐ Low.

☐ Joint-venture products: ______%

Reliability ☐ High ☐ Low;

Practicability ☐ High ☐ Low.

☐ Main problem:

3.9 The investor for the telephone system of the project is:

☐ Telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

3.10 The investor for the Cable TV system of the project is:

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

3.11 The investor for the ADSL system of the project is:

☐ Telecommunication profession.

☐ Broadcast telecommunication profession.

☐ Developer.

☐ System provider.

☐ Others.

3.12 The ADSL/Cable TV/Telephone system(s) of the project is/are:

☐ A 3-in-1 system.

☐ Integrated ADSL & Telephone system.

☐ Independent systems.

3.13 The control network system of the project is:

☐ With the aid of local ADSL.

☐ With the aid of Cable TV network.

☐ An independent system.

3.14 The wiring structure of the control network system of the project is:

☐ A comprehensive wiring system.

☐ A tree structure wiring system.

☐ A star structure wiring system.

☐ Independent systems.

3.15 The intercom system adopted in the project is:

☐ Color visual intercom system.

☐ White-Black visual intercom system.

☐ Unvisual intercom system.

☐ None.

3.16 The home safety system adopted in the project is:

☐ Independent product.

☐ Attached with intercom system.

☐ Attached with other product.

☐ None.

3.17 The long-distance/remote control function of domestic electric appliances applied in the project is:

☐ Independent products.

☐ Attached with other products.

☐ None.

3.18 The information issue system adopted in the project is:

☐ Electronic screen.

☐ Public information screen.

☐ Direct email/mail.

☐ None.

3.19 The terminal of smart card built in the project located at:

☐ Main entrance.

☐ Unit entrance.

☐ Home security gate.

☐ Car park.

☐ Electrical patrols.

☐ Shops.

☐ Others. (Please describe:____.)

3.20 Whether there is a website of the project and its services include:

☐ No website.

☐ Yes, its services include:

☐ Internal information services, main contents: ________________________________.)

☐ Internal e-commerce services, main contents: ________________________________.)

☐ Others. (Please describe:____.)

3.21 The status of e-map adopted in the project is/are:

☐ Using e-map for safety and security management.

☐ Using e-map for facilities management.

☐ None.

3.22 The current operation situation of intelligent systems in the project is:

☐ In use; and the utilization rate is: ☐ 100%. ☐ 80%. ☐ >50%. ☐ <50%.

☐ To be used.

☐ Disuse.

3.23 The problems, relevant to governmental management, existed in the construction of digital residential communities are:

☐ Lack of regulations.

☐ Lack of national standards.

☐ Lack of professional guidelines.

☐ Lack of a normalized market.

☐ The most important one is ____.

3.24 The problems, relevant to industry development, existed in the construction of digital residential communities are:

☐ Poor qualities of products.

☐ Poor qualifications of system providers.

☐ Low accomplishment of developers.

☐ Poor diathesis of clients.

3.25 The problems, relevant to products, existed in the construction of digital residential communities are:

☐ poor qualities.

☐ not practicable.

☐ high price.

☐ user unfriendly.

3.26 Can intelligentization be an important advantage of digital residential buildings in real estate market?

☐ Yes. ☐ No. ☐ Not sure. ☐ Yes, but 5~10 years later.

3.27 he qualifications of human resources in your company:

☐ How many people own their bachelor degrees:

☐ How many perple own professional certificates:

☐ How many people graduated from compute or electronics professions:

Contact Information

For further contact, please provide following information. Thank you!

Company Name			
Website			
Business Scope			
Grade			
Contact Person	Mr. / Ms.	Position	
Mail Address			
City and Province		Zip Code	
Telephone No.		E-mail	

The End of the Questionnaire.

APPENDIX 2: QUESTIONNAIRE TWO (*continued*)

A2.4 Questionnaire to Real Estate Developers (Chinese version)

数字社区建设调查问卷

（房地产商）

说明：

1. 本次调查遵循客观原则进行，请你单位实事求是填写表中数据，我们对你单位所填具体内容严格保密；
2. 请你单位主管领导填写本调查问卷；
3. 完成调查问卷时，请在所选答案前面的□上打上√，或在横线上填入内容。

问卷反馈者基本情况：

姓名：

职务：

单位名称：

资质等级：

主要业绩有：

地址：

邮编：

联系电话：

电子邮件地址：

问卷

1.贵公司近五年所进行的房地产（住宅）项目中有多少项目含有智能化工程？

近五年共进行项目___项，其中建设有智能化内容的___项，完成__项。

2.贵公司所进行含智能化工程建设内容的最具代表性的房地产项目是：

名称：

地点：

占地面积（M^2）：

建筑面积（M^2）：

住宅（户）：

房屋平米均售价（圆）：

在当地售价水平：

□高

□偏高

□中

□偏低

□低

3.贵公司决定该房地产项目建设智能化内容的主要原因是：

□政府规定 □市场原因 □为树立企业品牌 □合作方决定

□不清楚

□其它（请注明）：

4.该房地产项目的总投资额：____万元，其中：智能化工程投资：___万元。

5.该房地产项目含下述智能化建设子项内容：

□兆宽带入户　　　　　□双向有线电视

□小区物业计算机管理　　　□小区网站

□小区出入口人员身份识别管理　□小区出入口车辆识别管理

□小区摄像监控　　　　　□小区围栏防翻越报警

□非可视对讲系统　　　　□可视对讲系统

□小区单元门禁管理　　　□小区电子巡更

□家庭安防报警管理　　　□家用电器远程控制

□家庭能耗远传计量　　　□小区设备监控电子地图管理

□小区安防电子地图管理　　□小区中央控制室

□小区"一卡通"　　　　□背景音乐

□小区综合布线系统　　　□小区智能化系统防雷与接地

□建有小区智能化管理统一数据库

□其它（请注明）

6. 您认为上述智能子系统，最有市场卖点（最受业主关心）的功能（不唯一）是：

7. 您认为上述智能子系统，最能代表小区智能化水平的功能（不唯一）是：

8. 上述智能化系统工程建设采用：

□系统集成；系统集成商是：

□分项承包；

主要承包商是：____________，完成的项目是：_________.

□自己完成

9. 住户电话系统建设投资：

□电信行业 □开发商 □系统集成商 □其它

10. 住户有线电视系统建设投资：

□广电行业 □开发商 □系统集成商 □其它

11. 小区宽带网络系统建设投资：

□电信行业 □广电行业 □开发商 □系统集成商

□其它

12. 小区宽带网络/有线电视/电话系统

□三网合一 □小区宽带网络/电话系统两网合一 □各自独立分离

13. 小区控制管理网络系统

□借助电信/宽带网络 □借助有线电视网络 □独立

14. 小区控制管理网络布线系统

□综合布线系统 □采用树型 □星型结构 □各自独立布线

15. 访客对讲系统采用：

□彩色可视对讲 □黑白可视对讲 □对讲 □没有

16. 家居安防系统采用：

□独立家居安防产品 □由可视对讲附带 □由其它产品附带 □没有

17. 是否具有家用电器远程控制功能：

□采用独立产品 □由其它产品附带 □没有

18. 是否具有小区信息发布功能：

□采用电子屏幕 □采用公共信息屏 □直接发送到住户 □没有

19. 建设有“小区一卡通”地点：

□出入大门 □单元门 □家居安防 □停车场

□电子巡更 □消费

□其它（请描述）：

20. 是否建有小区网站，提供信息服务？

□没有

□有，请回答：

□提供小区电子信息服务，主要内容有：

□提供小区电子商务服务，主要内容有：

□其它小区网站服务，主要内容有：

21. 上述智能化系统的设备选择主要为：

□进口产品 □国产产品 □合资企业

22. 上述智能化系统的选择权：

□公司 □分项承包商推荐 □集成商推荐

23. 上述智能化设备的选择权：

□公司指定　　　□分项承包商推荐　　□集成商推荐

24. 目前该项目的投运情况：

□已经投运，投行率为：□100%　□80%　□50%以上　□不足 50%

□无法投运

□尚未投运

25. 您认为目前数字社区建设政府管理方面存在的问题是(不唯一)：

□缺乏政府规范　□缺乏国家标准　□缺乏行业指导　□市场不规范

其中最突出的是：

26. 您认为目前数字社区建设行业发展急需解决的问题是(不唯一)：

□产品质量差　□集成商素质差　□开发商素质差　□业主素质差

27. 您认为目前数字社区行业产品存在的问题是(不唯一)：

□质量差　□不实用　□价格高　□业主不会用

28. 您是否认为智能化可能成为未来房地产行业的重要卖点之一?

□是　□不是　□不清楚　□5-10 年以后

（问卷结束）

APPENDIX 2: QUESTIONNAIRE TWO (*continued*)

A2.5 Questionnaire to System Providers (Chinese version)

数字社区建设调查问卷

（系统集成商）

说明：

1. 本次调查遵循客观原则进行，请你单位实事求是填写表中数据，我们对你单位所填具体内容严格保密；
2. 请你单位主管领导填写本调查问卷；
3. 完成调查问卷时，请在所选答案前面的□上打上√，或在横线上填入内容。

问卷反馈者基本情况：

姓名：

职务：

单位名称：

资质等级：

主要业绩有：

地址：

邮编：

联系电话：

电子邮件地址：

问卷

贵公司近五年所进行的房地产（住宅）智能化系统集成项目情况：

近五年共进行___项，其中，已完成并投运___项，在建__项。

贵公司所进行的最具代表性的小区智能化系统集成工程是：

名称：

地点：

占地面积（M^2）：

建筑面积（M^2）：

住宅（户）：

房屋平米均售价（圆）：

在当地售价水平：

□高

□偏高

□中

□偏低

□低

智能化工程投资：___万元。

3. 该项目含下述智能化子项：

□___兆宽带入户 □双向有线电视

□小区物业计算机管理 □小区网站

□小区出入口人员身份识别管理 □小区出入口车辆识别管理

□小区摄像监控 □小区围栏防翻越报警

□非可视对讲系统　　　　□可视对讲系统

□小区单元门禁管理　　　　□小区电子巡更

□家庭安防报警管理　　　　□家用电器远程控制

□家庭能耗远传计量　　　　□小区设备监控电子地图管理

□小区安防电子地图管理　　　□小区中央控制室

□小区“一卡通”　　　　□背景音乐

□小区综合布线系统　　　　□小区智能化系统防雷与接地

□建有小区智能化管理统一数据库

□其它（请注明）：

4.您认为上述智能子系统，最有市场卖点（最受业主关心）的功能（不唯一）是：

请描述：

5．您认为上述智能子系统，最能代表小区智能化水平的功能（不唯一）是：

请描述：

6.上述工程设备选择主要为：

□进口产品　　　　□国产产品　　　　□合资企业

7. 家庭安全报警产品采用：

□独立的家庭安全报警产品 □保全型可视对讲　　□由其它产品附带

□其它（请描述）：

8. 家庭安全报警产品的技术路线采用：

□TCP/IP 协议　　　□工业总线　　　□485 总线　　　□其它

9. 目前该项目的投运情况：

投行率：□100% □80% □50%以上 □不足 50%

□尚未投运

10. 住户电话系统建设投资：

□电信行业 □开发商 □系统集成商 □其它

11. 住户有线电视系统建设投资：

□广电行业 □开发商 □系统集成商 □其它

12. 小区宽带网络系统建设投资：

□电信行业 □广电行业 □开发商 □系统集成商

□其它

13. 小区宽带网络/有线电视/电话系统

□三网合一 □小区宽带网络/电话系统两网合一 □各自独立分离

14. 小区控制管理网络系统

□借助电信/宽带网络 □借助有线电视网络 □独立

15. 小区控制管理网络布线系统

□综合布线系统 □采用树型 □星型结构 □各自独立布线

16. 访客对讲系统采用：

□彩色可视对讲 □黑白可视对讲 □对讲 □没有

17. 家居安防系统采用：

□独立家居安防产品 □由可视对讲附带 □由其它产品附带 □没有

18. 是否具有家用电器远程控制功能：

□采用独立产品 □由其它产品附带 □没有

19. 是否具有小区信息发布功能：

□采用电子屏幕 □采用公共信息屏 □直接发送到住户 □没有

20. 建设有“小区一卡通”地点：

□出入大门 □单元门 □家居安防 □停车场

□电子巡更 □消费

□其它（请描述）：

21. 是否建有小区网站，提供信息服务？

□没有

□有，请回答：

□提供小区电子信息服务，主要内容有：

□提供小区电子商务服务，主要内容有：

□其它小区网站服务，主要内容有：

22. 您认为目前数字社区建设政府管理方面存在的问题是(不唯一)：

□缺乏政府规范 □缺乏国家标准 □缺乏行业指导 □市场不规范

其中最突出的是：

23. 您认为目前数字社区建设行业发展急需解决的问题是(不唯一)：

□产品质量差 □集成商素质差 □开发商素质差 □业主素质差

24. 您认为目前数字社区行业产品存在的问题是(不唯一)：

□质量差 □不实用 □价格高 □业主不会用

25. 您是否认为智能化可能成为未来房地产行业的重要卖点之一?

□是 □不是 □不清楚 □5-10 年以后

（问卷结束）

APPENDIX 2: QUESTIONNAIRE TWO (*continued*)

A2.6 Questionnaire to Property Managers (Chinese version)

数字社区建设调查问卷

（物业管理公司）

说明：

1. 本次调查遵循客观原则进行，请你单位实事求是填写表中数据，我们对你单位所填具体内容严格保密；
2. 请你单位主管领导填写本调查问卷；
3. 完成调查问卷时，请在所选答案前面的□上打上√，或在横线上填入内容。

问卷反馈者基本情况：

姓名：

职务：

单位名称：

资质等级：

主要业绩有：

地址：

邮编：

联系电话：

电子邮件地址：

问卷

1．贵公司近五年所管理的物业小区项目，有多少项目借助智能化设备进行管理？

近五年共进行物业管理小区___座，其中借助智能化设备管理的___座。

2．贵公司目前正进行的、借助智能化设备管理的小区是：

名称：

地点：

占地面积（M^2）：

建筑面积（M^2）：

住宅（户）：

房屋平米均售价（圆）：

在当地售价水平：

□高

□偏高

□中

□偏低

□低

该项目开发商：

该项目智能化系统承包商：

3. 该小区含下述智能化功能内容：

□ __兆宽带入户　　□双向有线电视

□小区物业计算机管理　　□小区网站

□小区出入口人员身份识别管理　□小区出入口车辆识别管理

□小区摄像监控　□小区围栏防翻越报警

□非可视对讲系统　□可视对讲系统

□小区单元门禁管理　□小区电子巡更

□家庭安防报警管理　□家用电器远程控制

□家庭能耗远传计量　□小区设备监控电子地图管理

□小区安防电子地图管理　□小区中央控制室

□小区“一卡通”　□背景音乐

□小区综合布线系统　□小区智能化系统防雷与接地

□建有小区智能化管理统一数据库

□其它（请注明）

4. 您认为上述智能化系统，最受业主关心的功能（不唯一）是：

5. 您认为上述智能化系统，对物业管理最为有用的功能（不唯一）是：

6. 请您对您认为对物业管理最为有用的系统所采用的主要设备做一描述：

设备①名称：_____型号：_____数量___台/套　生产厂家：

设备②名称：_____型号：_____数量___台/套　生产厂家：

设备③名称：_____型号：_____数量___台/套　生产厂家：

7. 您认为上述智能化系统，运行最为可靠的子系统（不唯一）是：______系统，

所采用的设备是：_____型号：____数量___台/套，

生产厂家：

8．请您对主要智能化子系统的主要设备做一描述：

进口产品占__%；　　　国产产品占__%；　　　合资产品占_ %

进口产品 可靠性：□高　□差　　实用行：□好　□差

国产产品：可靠性：□高　□差　　实用行：□好　□差

合资产品：可靠性：□高　□差　　实用行：□好　□差

请描述存在的主要问题：

9. 住户电话系统建设投资：

□电信行业　　　□开发商　　　□系统集成商　　□其它

10. 住户有线电视系统建设投资：

□广电行业　　　□开发商　　　□系统集成商　　□其它

11. 小区宽带网络系统建设投资：

□电信行业　　　□广电行业　　□开发商　　□系统集成商

□其它

12. 小区宽带网络/有线电视/电话系统

□三网合一　　□小区宽带网络/电话系统两网合一　　□各自独立分离

13. 小区控制管理网络系统

□借助电信/宽带网络 □借助有线电视网络 □独立

14. 小区控制管理网络布线系统

□综合布线系统　　□采用树型　　□星型结构　　□各自独立布线

15. 访客对讲系统采用：

□彩色可视对讲　□黑白可视对讲　□对讲　□没有

16. 家居安防系统采用：

□独立家居安防产品　□由可视对讲附带　□由其它产品附带　□没有

17. 是否具有家用电器远程控制功能：

□采用独立产品　□由其它产品附带　□没有

18. 是否具有小区信息发布功能：

□采用电子屏幕　□采用公共信息屏　□直接发送到住户　□没有

19. 建设有“小区一卡通”地点：

□出入大门　□单元门　□家居安防　□停车场

□电子巡更　□消费

□其它（请描述）：

20. 是否建有小区网站，提供信息服务？

□没有

□有，请回答：

□提供小区电子信息服务，主要内容有：

□提供小区电子商务服务，主要内容有：

□其它小区网站服务，主要内容有：

21. 请您对小区智能控制管理情况做一描述：

□有小区安防管理电子地图　　□有设备监控管理电子地图

22. 目前该小区的智能化系统投运率（与原设计比）：

□100%　□80%　□50%以上　□不足 50%　□无法投运

23. 您认为目前数字社区建设政府管理方面存在的问题是(不唯一)：

□缺乏政府规范　□缺乏国家标准　□缺乏行业指导　□市场不规范

其中最突出的是：

24. 您认为目前数字社区建设行业发展急需解决的问题是(不唯一)：

□产品质量差　□集成商素质差　□开发商素质差　□业主素质差

25. 您认为目前数字社区行业产品存在的问题是(不唯一)：

□质量差　□不实用　□价格高　□业主不会用

26. 您是否认为智能化可能成为未来房地产行业的重要卖点之一?

□是　□不是　□不清楚　□5-10 年以后

27. 目前贵公司运行和维护该物业智能化管理系统和设备人员的技术素质：

本科以上___人；大专生___人；中专以下___人；其中：计算机及电子专业___人。

（问卷结束）

Appendix 3: Indicators adopted by the IB Index (AIIB, 2005)

Module	Element/IB Indicators
Green Index (GRI)	
	GRI01: Existence of green features
	GRI02: Lift & escalators - Energy consumption
	GRI03: Lift & escalators - Handling capacity in percentage of total population
	GRI04: Lift & escalators - Maximum interval time
	GRI05: Lift & escalators - Journey time
	GRI06: Lift & escalators - Waiting time
	GRI07: Lift & escalators - Drive and controls systems
	GRI08: Lift & escalators - Noise- In-car noise
	GRI09: Lift & escalators - Noise- Lobby noise
	GRI10: Lift & escalators - Noise- Machine room noise
	GRI11: Lift & escalators - Vibration
	GRI12: Lift & escalators - Modernisation
	GRI13: Lift & escalators - Maximum allowance electrical power of traction lifts
	GRI14: Lift & escalators - Total harmonics distortion of motor drive systems for lifts & escalators
	GRI15: Lift & escalators - Total power factor of motor drive systems of lifts and escalators
	GRI16: Lift & escalators - Maximum allowance electrical power of escalators & passenger conveyors
	GRI17: Lift & escalators - Regeneration into the supply system
	GRI18: Lift & escalators - Compliance with the Code of Practice for Energy Efficiency by EMSD
	GRI19: Lavatory & provision of appliances - Flushing system - Toilet
	GRI20: Lavatory & provision of appliances - Flushing system - Urinal
	GRI21: Lavatory & provision of appliances - Fresh water supplies
	GRI22: Lavatory & provision of appliances - Provision of consumables
	GRI23: Lavatory & provision of appliances - Functionality of water systems
	GRI24: Thermal comfort - Temperature and relative humidity
	GRI25: Thermal comfort - Indoor air quality
	GRI26: Thermal comfort - Overall thermal transfer value (OTTV)
	GRI27: Electricity demand provision
	GRI28: Electrical - Compliance with the Code of Practice for Energy Efficiency by HK EMSD
	GRI29: Electric power quality

	GRI30: Heating services - Energy recycling
	GRI31: Heating services - Pollution related to fuel consumption
	GRI32: HVAC services - Condition of pipe insulation
	GRI33: HVAC services - Provision of heat pump and heat wheel
	GRI34: HVAC services - Provision of heat recovery (i.e. free cooling or free heating)
	GRI35: Ventilation & air-conditioning (V&A) - Amount of fresh air changes per second
	GRI36: V&A - Refrigerant
	GRI37: V&A - Coefficient of performance of air-conditioning installation
	GRI38: V&A - Method of cooling
	GRI39: V&A - Cool air distribution
	GRI40: V&A - Non-smoking building
	GRI41: V&A - Noise Level
	GRI42: V&A - Special ventilation for some areas, e.g. kitchen, restaurant & toilet
	GRI43: V&A - Contamination of chilled & condensing water, virus, bacteria or others
	GRI44: V&A - Total energy consumption
	GRI45: V&A - Access for erection and maintenance
	GRI46: V&A - Appearance
	GRI47: V&A - Condensate drain water leakage
	GRI48: V&A - Cleanliness
	GRI49: V&A - Use of water-cooled chillers with fresh water or sea water
	GRI50: V&A - Compliance with the Code of Practice for Energy Efficiency by HK EMSD
Module	**Element/IB Indicators**
Green Index (GRI) (*continued*)	
	GRI51: Lighting - Adequate day lighting measured in average daylight factor
	GRI52: Lighting - Permanent artificial lighting average power density
	GRI53: Lighting - Permanent artificial lighting average glare index
	GRI54: Lighting - Permanent artificial lighting average lux level
	GRI55: Lighting - Average efficacy of all lamps
	GRI56: Lighting - Average colour temperature
	GRI57: Lighting - Maintenance factor
	GRI58: Lighting - Ease of control
	GRI59: Lighting - Compliance with the Code of Practice for Energy Efficiency by HK EMSD
	GRI60: Environmental friendliness - Pollution produced
	GRI61: Environmental friendliness - Sunlight pollution by curtain wall
	GRI62: Environmental friendliness - Outdoor noise pollution

	GRI63: Environmental friendliness - Indoor noise pollution in terms of average noise level
	GRI64: Environmental friendliness - Management of recycle of wastes produced by the building
	GRI65: Environmental friendliness - Substantial use of non-exhaustible material for construction
	GRI66: Environmental friendliness - Plans to lower the life cycle usage of energy
	GRI67: Environmental friendliness - Use of natural ventilation
	GRI68: Environmental friendliness - Substantial use of renewable energy
	GRI69: Environmental friendliness - Plantation and landscape gardening
	GRI70: Environmental friendliness - Image of environmental friendliness
	GRI71: Waste Disposal
	GRI72: Drainage
	GRI73: Green building materials
	GRI74: Green design
	GRI75: Special feature(s) recommended by the auditor
Space Index (SPI)	
	SPI01: Areas per person
	SPI02: Average width of corridor
	SPI03: Accommodation - Average usable area in percentage of total GFA
	SPI04: Circulation for the disabled
	SPI05: Aid provided by the building management to the disabled
	SPI06: Carpark & transportation (C&T) - Number of carpark space
	SPI07: C&T - Location of carpark
	SPI08: C&T - Ventilation of carpark
	SPI09: C&T - Lighting of carpark
	SPI10: C&T - Security of carpark
	SPI11: C&T - Space of carpark
	SPI12: C&T - Ease of access to main public transport terminals
	SPI13: C&T - Number of loading and unloading areas for taxis, cargo vehicles and private cars
	SPI14: Flexibility for installing new false ceiling and floor utilities for a totally different use
	SPI15: Flexibility for re-partitioning
	SPI16: Flexibility of internal re-arrangement of personnel
	SPI17: Building provision for high tech equipment
	SPI18: Special feature(s) recommended by the auditor
Confort Index (CFI)	
	CFI01: Areas per person

Module	Element/IB Indicators
	CFI02: Average width of corridor
	CFI03: Average usable area in percentage of total GFA
	CFI04: Lift - Vibration
	CFI05: Lift - Acceleration and deceleration
	CFI06: Lift - Average illumination
	CFI07: Lift - Air change
	CFI08: Lift – In-car noise
	CFI09: Lift – Lobby noise
	CFI10: Lift – Machine room noise
Module	**Element/IB Indicators**
Confort Index (CFI) (*continued*)	
	CFI11: Lavatory and provision of appliances - Number
	CFI12: Lavatory and provision of appliances - Location
	CFI13: Lavatory and provision of appliances - Cleanliness
	CFI14: Lavatory and provision of appliances - Flushing system
	CFI15: Lavatory and provision of appliances - Fresh water supplies
	CFI16: Lavatory and provision of appliances - Provision of consumables
	CFI17: Lavatory and provision of appliances - Repair of water system
	CFI18: Thermal comfort - Temperature and relative humidity
	CFI19: Thermal comfort - Indoor air quality
	CFI20: Thermal comfort - Overall thermal transfer value (OTTV)
	CFI21: Ventilation & air-conditioning (V&A) - Amount of fresh air changes per second
	CFI22: V&A - Noise level
	CFI23: V&A - Frequency of breakdown
	CFI24: V&A - Special ventilation for some areas, e.g. kitchen, restaurant & toilet
	CFI25: V&A - Odour and freshness of indoor air
	CFI26: V&A - Contamination of chilled & condensing water by virus, bacteria or others
	CFI27: V&A - Access for erection and maintenance
	CFI28: V&A - Appearance
	CFI29: V&A - Condensate drain water leakage
	CFI30: V&A - Cleanliness
	CFI31: Lighting - Adequate daylighting measured in average daylight factors
	CFI32: Lighting - Permanent artificial lighting average power density
	CFI33: Lighting - Appearance of finishes of lighting
	CFI34: Lighting - Average colour temperature
	CFI35: Lighting - Colour rendering

Module	Element (IB Indicators)
	CFI36: Lighting - Cleanliness
	CFI37: Lighting - Noise from luminaries
	CFI38: Lighting - Maintenance factor
	CFI39: Lighting - Ease of control
	CFI40: Lighting - Glare
	CFI41: Lighting - Suitability for the task
	CFI42: Lighting - Window shape and position
	CFI43: Lighting - Colour matching of the finishes
	CFI44: Access - Entrance width
	CFI45: Access - Operating time of the building
	CFI46: Acoustics - Indoor ambient noise level
	CFI47: Colour
	CFI48: Entertainment facilities
	CFI49: Provision of lobby lounge on every floor
	CFI50: Special feature(s) recommended by the auditor
Working Efficiency Index (WEI)	
	WEI01: Areas per person
	WEI02: Average width of corridor
	WEI03: Average usable area in percentage of total GFA
	WEI04: Lift & escalators - Existence of AI based supervisory control
	WEI05: Lift & escalators - Provision of in-car information display system
	WEI06: Lift & escalators - Handling capacity in percentage of total population
	WEI07: Lift & escalators - Journey time
	WEI08: Lift & escalators - Waiting time
	WEI09: Lift & escalators - Location
	WEI10: Lift & escalators - Servicing and repair
	WEI11: Lift & escalators - Modernisation
	WEI12: Lavatory and provision of appliances - Number
	WEI13: Lavatory and provision of appliances - Cleanliness
	WEI14: Lavatory and provision of appliances - Operational

Module	**Element (IB Indicators)**
Working Efficiency Index (WEI) (*continued*)	
	WEI15: Lavatory and provision of appliances - Location
	WEI16: Thermal comfort - Temperature and relative humidity
	WEI17: Thermal comfort - Indoor air quality
	WEI18: Lighting - Adequate day lighting measured in average daylight factors

WEI19: Lighting - Permanent artificial lighting average power density
WEI20: Lighting - Appearance of finishes of lighting
WEI21: Lighting - Uniformity of Lux level
WEI22: Lighting - Cleanliness
WEI23: Lighting - Maintenance factor
WEI24: Lighting - Ease of control
WEI25: Lighting - Attractive design
WEI26: Lighting - Suitability for the task
WEI27: Lighting - Glare
WEI28: Lighting - Colour matching of the finishes
WEI29: High tech - Electric power outlets
WEI30: High tech - Electric power supply
WEI31: High tech - Broad band internet – Ethernet
WEI32: High tech - Broad band internet - Existence of fire wall
WEI33: High tech - Broad band internet - Workstation
WEI34: High tech - Broad band internet - Transmission rate inside building
WEI35: High tech - Broad band internet - Transmission rate outside building
WEI36: High tech - Broad band internet - IP address per staff
WEI37: High tech - Availability of multi-media facilities
WEI38: High tech - Public address system
WEI39: High tech - Voice mail and music for telephone system
WEI40: High tech - Intranet management system
WEI41: High tech - Satellite conferencing or high speed video conference by a superhighway
WEI42: High tech - Office automation
WEI43: High tech - Security control automation at main entrances
WEI44: High tech - Area monitored by closed circuit television (CCTV)
WEI45: High tech - Usage of electronic payment
WEI46: High tech - Usage of electronic directory
WEI47: High tech - Provision of updated information at public area
WEI48: High tech - Remote monitoring of lifts and escalators
WEI49: High tech - Provision of webpage for the building
WEI50: High tech - Provision of hotline
WEI51: High tech - Number of telephone lines
WEI52: High tech - Grade of service (GOS) and number of exchange lines
WEI53: High tech - Provision of fibre-optic network

Module	Element (IB Indicators)
	WEI54: High tech - Building services automation system
	WEI55: High tech - Grade of BAS (CIBSE Guide H on Building Control Systems)
	WEI56: High tech - Large size wall LCD or plasma display panel
	WEI57: High tech - Architectural design of the building (image)
	WEI58: High tech - Advanced carpark facilities
	WEI59: High tech - Area of mobile phone coverage
	WEI60: Sign and directory - Maps
	WEI61: Sign and directory - Interactive directory
	WEI62: Carpark and transportation (C&T) - Number of carpark space
	WEI63: C&T - Location of carpark
	WEI64: C&T - Ventilation of carpark
	WEI65: C&T - Lighting of carpark
	WEI66: C&T - Security of carpark
	WEI67: C&T - Ease of access to the main public transport terminals
	WEI68: C&T - Number of loading & unloading areas for taxis, cargo vehicles & private cars
	WEI69: Property management
Module	**Element (IB Indicators)**
Working Efficiency Index (WEI) (*continued*)	
	WEI70: Access - Entrance width
	WEI71: Access - Operating time of the building
	WEI72: Access - Helicopter apron
	WEI73: Provision of clean earth
	WEI74: Frequency of major breakdown
	WEI75: Existence of public conference and meeting facilities
	WEI76: Entertainment facilities within buildings
	WEI77: Building provision for high-tech equipment
	WEI78: Maintainability of installation
	WEI79: Bank or ATM service at podium
	WEI80: Special feature(s) recommended by the auditor
Culture Index (CLI)	
	CLI01: Entertainment facilities within building
	CLI02: Food and beverage supply
	CLI03: Choice of colour and indoor decoration
	CLI04: Office layout
	CLI05: Privacy

	CLI06: Feng Shui (geomantic omen)
	CLI07: External landscape
	CLI08: Indoor plants (including artificial ones)
	CLI09: External view (sea view, mountain view, garden view, sunrise view, sunset view etc.)
	CLI10: Religious facilitation
	CLI11: Culturally based interior design
	CLI12: Promotion activity and vibrancy regularly
	CLI13: Special feature(s) recommended by the auditor
High-tech Image Index (HTI)	
	HTI01: Electrical services - Electric power outlets
	HTI02: Electrical services - Electric power supply
	HTI03: Board band internet - Ethernet
	HTI04: Board band internet - Workstation
	HTI05: Board band internet - Transmission rate inside building
	HTI06: Board band internet - Transmission rate outside building
	HTI07: Board band internet - IP address per staff
	HTI08: Intranet management system
	HTI09: Satellite conferencing or high speed video conference by a superhighway
	HTI10: Office automation
	HTI11: Security control automation at main entrances
	HTI12 : Area monitored by closed circuit television (CCTV)
	HTI13: Usage of electronic payment
	HTI14: Usage of electronic directory
	HTI15: Provision of updated information at public area
	HTI16: Internet connection
	HTI17: AI based supervisory control for elevators
	HTI18: Choice of finishes
	HTI19: Remote monitoring of lifts and escalators
	HTI20: Provision of webpage for the building
	HTI21: Provision of hotline
	HTI22: Number of telephones
	HTI23: GOS and number of exchange lines
	HTI24: Provision of fibre-optic network
	HTI25: Building services automation system
	HTI26: Grade of BAS

Module	Element (IB Indicators)
	HTI27: Large size wall LCD or plasma display panel
	HTI28: Architectural design of the building
	HTI29: Advanced carpark facilities
Module	**Element (IB Indicators)**
High-tech Image Index (HTI) (*continued*)	
	HTI30: Area of mobile phone coverage
	HTI31: Extensive use of artificial intelligence
	HTI32: Extensive employment of energy sources without pollution
	HTI33: Extensive use of robots
	HTI34: Horizontal and vertical people movers
	HTI35: Construction materials
	HTI36: Building provision for high-tech equipment
	HTI37: Electrical services - Uninterruptible power outlets
	HTI38: Special feature(s) recommended by the auditor
Safety and Structure Index (SSI)	
	SSI01: Earthquake monitoring devices
	SSI02: Unauthorized building work within building
	SSI03: General building structural condition survey
	SSI04: Structural monitoring in large space frame, etc.
	SSI05: Tile debonding monitoring plan
	SSI06: Terrorist attack precaution plan
	SSI07: Indefensible space
	SSI08: Average width of corridor
	SSI09: Means of escape
	SSI10: Circulation for the disabled
	SSI11: Fire detection and fire fighting
	SSI12: Fire resistance
	SSI13: Means of access
	SSI14: Electrical wiring regulation
	SSI15: Reliability of elevator systems
	SSI16: Time to identify trapped passengers without a mobile phone
	SSI17: Time needed for public announcement of disasters
	SSI18: Time for total egress
	SSI19: Quality of systematic escape route plan
	SSI20: Essential electric power
	SSI21: Comprehensive scheme of preventive maintenance

Module	Element (IB Indicators)
	SSI22: Thermal comfort - Indoor air quality
	SSI23: Water leakage during raining seasons
	SSI24: Cracks on finishes or spalling
	SSI25: Safety management system
	SSI26: Settlement monitoring plan
	SSI27: Building risk management plan
	SSI28: Security & crowd control management plan
	SSI29: Overall building (including services) operation and maintenance plan
	SSI30: Water cooling tower for non-residential building
	SSI31: Special feature(s) recommended by the auditor
Management Practice & Security Index (MPS)	
	MPS01: Aid provided by the building management to the disabled
	MPS02: Lift and escalators - Servicing and repair
	MPS03: Lighting - Maintenance factor
	MPS04: High tech - Security control automation at main entrances
	MPS05: High tech - Area monitored by closed circuit television (CCTV)
	MPS06: Carpark and transportation - Security of carpark
	MPS07: High tech - Building services automation system
	MPS08: Safety management system
	MPS09: Property management
	MPS10: General building structural condition survey
	MPS11: Tile debonding monitoring plan
	MPS12: Terrorist attack precaution plan
	MPS13: Indefensible space
Module	**Element (IB Indicators)**
Management Practice & Security Index (MPS) (*continued*)	
	MPS14: Circulation for the disabled
	MPS15: Reliability of elevator systems
	MPS16: Time to identify trapped passengers without a mobile phone
	MPS17: Response to special event
	MPS18: Security control system
	MPS19: Number of unmonitored exits and entrances
	MPS20: Advanced AI based security system
	MPS21: Time needed to report a disastrous event to the building management
	MPS22: Time needed for public announcement for disasters
	MPS23: Time for total egress

	MPS24: Quality of systematic escape route plan
	MPS25: Comprehensive scheme of preventive maintenance
	MPS26: Maintainability of installation
	MPS27: Thermal comfort - Indoor air quality
	MPS28: Extensive use of AI
	MPS29: Building risk management plan
	MPS30: Security and crowd control management plan
	MPS31: Potable water quality certificate
	MPS32: Potable water tanks cleaning frequency
	MPS33: Flushing water tanks cleaning frequency
	MPS34: Potable and flushing water - management practice
	MPS35: Pest and mosquitoes control - management practice
	MPS36: Playground and gym - management practice
	MPS37: Water cooling tower for non-residential buildings
	MPS38: Promotion of activity and vibrancy regularly
	MPS39: Environmental friendliness - Management of recycle of wastes produced by the building
	MPS40: Special feature(s) recommended by the auditor
Life Cycle Costing (Cost Effectiveness Index) CEI	
	CEI01: Rent-to-cost ration
Health & Sanitation Index (HSI)	
	HSI01: Potable water quality certificate
	HSI02: Potable water tanks cleaning frequency
	HSI03: Potable water examination
	HSI04: Potable water - bonus points
	HSI05: Flushing water tanks cleaning frequency
	HSI06: Flushing water examination
	HSI07: Flushing water - bonus points
	HSI08: Potable & flushing water - management practice
	HSI09: Drainage - sufficient fall
	HSI10: Drainage - main stack condition
	HSI11: Drainage - pipe leakage observation
	HSI12: Drainage - last manhole cleaning
	HSI13: Drainage - grease trap and petrol interceptor cleaning
	HSI14: Drainage - bonus points
	HSI15: Drainage – u-trap provision with water seal

Module	Element (IB Indicators)
	HSI16: Toilet ventilation - sufficient air changes
	HSI17: Toilet ventilation - door louver provision
	HSI18: Toilet ventilation - exhaust condition
	HSI19: Toilet ventilation - internal toilet/bath room
	HSI20: Cleanliness - building in general
	HSI21: Refuse collection room - enclosed room
	HSI22: Refuse removal from building - frequency
	HSI23: Refuse room cleaning - frequency
	HSI24: Refuse collection - bonus point
	HSI25: Life - ventilation

Module	Element (IB Indicators)
Health & Sanitation Index (HSI) (*continued*)	
	HSI26: Pest and mosquitoes control - management practice
	HSI27: Swimming pool, Jacuzzi, sauna - filtration and water sampling in regular period
	HSI28: Car park - ventilation and odour
	HSI29: Playground and gym - management practice
	HSI30: Indoor air quality for non-residential building
	HSI31: Water cooling tower for non-residential building
	HSI32: Special feature(s) recommended by the auditor

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