**ATLANTIC INTERNATIONAL UNIVERSITY (A.I.U)**

**HIGH-PERFORMANCE BUILDING DESIGN AND DICISION-MAKING SUPPORT FOR ARCHITECTS IN THE EARLY DESIGN PHASES**

**(THESIS)**

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**Abstract**

Based on the design decision making process from an architect’s point of view, a related literature review, theoretical analyses, and inductive inferences, this thesis proposes a new interpretation of high-performance building (HPB), translates/maps criteria issues related to building environmental assessment (BEA) tools for key design decision making elements, and identifies sources of inspiration for HPB designs. This thesis intends to propose an integrated conceptual model for the design of HPBs to provide direct knowledge-based decision making support to architects in the early design phase. Studies on key design decision making elements, sources of inspiration and building information modeling are integrated into this genesis of conceptual design.

The concept of the HPB proposed in this thesis emphasizes comprehensive sustainable building performance in environmental, economic, and socio-cultural aspects. The concept takes the view that HPBs should be aesthetically attractive, socio-culturally adapted, safe, health, and comfortable, and should operate at a high level of environmental, resource, and economic efficiency throughout their life cycle. This thesis discusses the topics of the necessity, benefits, and design principles of HPBs.

An analysis of the characteristics of BEA tools and HPB design decision making revealed their relationship: the consequence of goals and the mismatch of practices. BEA tools provide the basic information (such as framework, content, evaluation method, and processes) related to decision making to promote a holistic HPB design at a practical level. However, given the mismatch of practices between BEA tools and HPB design decision making, must such tools are still used for testing and verifying the design results and do not consider the design decision making process. Existing BEA tools primarily guide or indirectly affect the design work but, in practice, play a limited role in directly helping architects make early decisions regarding HPB design.

Firstly, for a detailed comparison, this thesis identified the common criteria issues for the three existing BEA tools: SBTool 2012 (maximum version), LEED NC-v3, and the Chinese Evaluation Standard for Green Building (ESGB). A total of 51 common/similar criteria issues were identified and such issues were found to be primarily allocated in the energy and resources, indoor environmental quality, environmental loads, and site areas. SBTool 2012 contains the widest range and most comprehensive criteria issues of building performance, whereas the LEED NC-v3 and ESGB frameworks poorly cover social- and economic-related issues, second, this thesis separated the criteria into whether they relate to decision making factors or building performance factors. Third, this thesis mapped HPB criteria issues into HPB design decision making elements.

This thesis establishes a framework for key design decision element for Chinese residential buildings by selecting a residential building type in china as a case study for the mapping approach application. The optimum criteria issues for Chinese residential buildings contain 10 primary criteria issues and 35 sub-criteria issues that cover aspects within the entire sustainable performance range and that correspond to key design decision making elements in this framework.

This thesis also proposes two fundamental support approach to creative design for HPBs: rational technical support and irrational divergent inspirational support. Based on practical design examples, three major types of irrational sources of inspiration in an architect’s design for HPBs have been identified: previous empirics, nature objects and phenomena, and advanced science and technologies.

Finally, a new integrated conceptual model to support an architect’s early design decision is established based on the BIM platform. The model contains two main aspects of the work: an initial building information model and an optimal building information model for HPBs during the early design stage. This conceptual model is presented as a generic approach that can be customized for different designers and project conditions. The model can also be used as a framework for providing knowledge-based creative support for decision making related to HPB design.

In summary, this thesis intends to provide both a theoretical base and feasible measures for better HPB design and references for developing design decision making support tools for architects to use during the early HPB design process.

**Keywords**

High-performance building (HPB); sustainable performance; design decision making; building environmental assessment (BEA) tools; architects; design decision elements; sources of inspiration.

**Preface**

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**List of Abbreviations**

AHP Analytic hierarchy process

ASHRAE American Society of Heating, Refrigerating and Air-conditioning Engineers

BEA Building environmental assessment

BEU Building energy utilization

BEE Building Environment Efficiency

BIM Building Information Model/Modeling/Modeling

BREEAM Building Research Establishment Environmental Assessment Method

CASBEE Comprehensive Assessment Systems for Building Environmental Efficiency

CFC Chlorofluorocarbon

CO2 Carbon dioxide

Computer-Aided-Design CAD

D Factors Decision making factors

DSS Design decision support

DGNB Deutsche Gesellschaft fur Nachhaltiges Bauen

ESGB Evaluation Standard for Green Building GB/T50378-2006

ETS Environmental Tobaco Smoke

GBASBO Green Building Assessment System for Beijing Olympics

GHG Greenhouse gas

HPB High-performance Building

HVAC Heating, Ventilation, and air condition

IAQ Indoor air quality

IEQ Indoor environmental quality

LEED Leadership in Energy & Environmental Design

MOHURD Ministry of Housing and Urban-Rural Development (China)

NABERS National Australia Built Environmental Rating System (U.S.)

NIBS U.S. National Institute of Building Services

P Factors Performance factors

TIM Transparent insulation materials

VOC Volatile organic compounds

3D Three-dimensional

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**Introduction**

* + 1. **Background**

In the early first century CE, the roman architect Vitruvius describe a good building as satisfying ‘durability, utility, and a beauty’ (Rowland d,.& Howe TN.,1999. Today environment concerns, such as global climate change, environment pollution, the depletion of resources, and deforestation are important inevitable challenges. therefore; sustainable has gained increasing attention in the global context. Brundtland commission report refers to sustainable development as ‘the development that meets the needs of the present generation without compromising the ability of future generations to meet their needs.’ ( Brundtland commission 1987)

Buildings are the main contributors to the degradation of the nature environment. Typically, buildings account for 20-40 percent of industrialized countries, total energy utilization ( Juan, YK., Peng G., & Wang, J., 2010) during the twenty-first century people have become increasing aware of sustainability. Sustainable building design is no longer just about pursuing energy saving and environmentally friendly targets from a technical perspective; it is also about improving buildings overall performance from functional, aesthetic, and many other perspectives, with an ultimate goal of achieving harmony among humans, building, and nature. In this case, paying attention to how building should be built imperative to reducing their tremendous costs, abating the effect on the environment and maintaining better social and cultural benefits.

Therefore, improving building performance has become a critical mission for the sustainability of the entire building industry. This trend call for architects to accept and accurately understand high- performance building (HPBS), Follow the guiding principle of sustainability, and maintain a comprehensive inventory of the various building factors to achieve the overall of high- performance \ sustainable building design.

* + 1. **Aims and Methods**

This thesis proposes a new understanding of high- performance building (HPB) translates\ maps criteria issues of building environmental assessment (BEA) tools into key design decision elements, and identifies the sources of inspiration for HPB design based on the design decision making process from the architect’s point of view and the related literature review, theoretical analyses and inductive inference. This thesis intends to propose an integrated conceptual model to provide direct knowledge-base support to an architect’s decision making during the early design of HPBs. The key design decision elements, sources of inspiration, and building information modeling will be integrated into this conceptual design genesis.

* + 1. **Outcomes and Contributions**

The outcomes of this research and its contributions to knowledge are that it:

* Identifies the relationship between BEA tools and HPB design decision making
* Proposes a new concept about high-performance building
* Summarizes similar criteria issues among SBTool 2012, LEED, NC-V3 and ESGB
* Establishes a conceptual frame work of key design decision elements for the design of high performance
* Recognizes the sources of inspiration for HPB design
  + 1. **Limitations**

This study has certain limitations. In addition to the time limit and financial constrains that most studies must address, further limitations existed for this study, first, this thesis is based on architects; perspectives and focuses on the design stages thus issues related to other stages in a building’s life cycle ( in other words, planning, construction, operations, management, and demolishment) are not addressed. Second, the comparative analysis of criteria issues in selective BEA tools does not involve benchmark, weighting and application aspect. Third, the conceptual mode for supporting HPB design decision making proposed in the thesis only addresses the early design stage and not the entire process of a building design project. Finally, inventible limitations also exist with BEA tools and the cases selected for the specific purpose of this research.

**CHAPTER 2**

**A new concept of high-performance building**

**2.1** **Definitions of a High-Performance Building**

The recent decades have witnessed growth in professional concern and interest in building performance. Many successful new building project are taking shape today, calling into question the performance of more typical construction endeavors (department of design and construction of New York, 199), a high-performance building’ (HPB) is also refered to as an ‘ energy saving’ or green’ building. Many different concepts of an HPB exist because of the broad range of building performance issues and the novely of sustainable principles, its the exception of state and local descriptions.

This definition presupposes that an HPB is a substantially better sustainable building than standard practices in terms of environmental, economic, and socio-cultural performance. An HPB must be design and built in the context of larger environmental, economic, and human concerns, and all aspects of the building must be addressed through a cohesive approach during its entire life cycle. In this thesis, the concept of HPB emphasizes total sustainable building performance based on a triple bottom-line; society, economy, and environment (figure 2-1). Because an HPB is a facility with energy, environmental and economic features and a performance that far exceed standard practices, social and cultural performance is also important to this type of building with excellent environmental performance but without high socio-cultural performance is not an HPB.

**2.2** **Benefits of High-Performance Building**

HPBs also demonstrate a commitment to initiatives that simultaneously benefit the environment, community and bottom line. The following benefits are briefly discussed to describe the advantages of HPB for the building industry.

1. **Environmental Benefits**

HPB practices can considerably reduce negative environmental effects and regress prodigality/ insalubrities during the entire life of a building. HPBs with improved envelopes and efficient lighting, equipment, and HAVC system use less energy than conventional buildings. For example, from an energy perspective alone. HPB technologies reduce building energy utilization by an average of 30-50 percent (Conway, B., 2010)

1. **Economic Benefits**

Economic benefits are primarily the result of competitive initial cost efficient operating and maintenance costs. Improved employee performance and optimal economic performance throughout a building’s life cycle.

HPBs cost the same or less than conventional buildings because resource –efficient strategies and an integrated design often allow downsizing of more costly mechanical, electrical and structural systems.

1. **Socio-Cultural Benefits**

Socio-benefit often reflects the intangible value to the wider community from occupant comfort. Safety and security, accessibility, and functionality are all beneficial to the performance of an HPB and provide physically and mentally healthy work places for employees. In addition, cultural values embedded in HPBs also contribute positively to the image of the enterprise and a city’s fabric.

**2.3** **Design Principles of High-Performance Buildings**

An HPB design emphasizes an all-inclusive principle that expresses good performance for the entire building, including efficient utilization of land, energy, water, materials, and other resources. Which decreases the environmental load and provides a health and comfortable working environment. In addition to the conventional building design requirements (function, aesthetic, technology, economy), HPB should also be in accordance with the following basic principles.

1. **Efficiency**

Efficiency is the essential guideline to realizing high-level performance. Energy efficiency is an important factor for the efficient development of an HPB. Reducing energy use and having a preference for renewable energy and passive solar techniques for an integrated building design are strategies that improve the energy efficiency of an HPB, for socio-cultural and economic efficiency performance. HPB demands the coordination and prediction of interactive relationships between building and economic/social developments, and the correct handing of the relationship between short and long-term benefits based on specific conditions.

1. **Occupant Satisfaction**

Occupants are a building’s core service objects. Thesis degree of satisfaction with the working environment directly influences the performance of the building. HPBs with high flexibility and adaptability according to occupants and the natural environment and provide a comfortable and healthy workplace for employees, thus improving occupants satisfaction. To achieve this, good ventilation, indoor air quality, thermal comfort, acoustics, lighting, and a number of other parameters characterizing a good indoor environment have to be provided.

1. **Respect for Local Conditions**

Because each HPB and its surrounding circumstances compose a unique organic system, creating designs base on local practical conditions is key for an HPB. An HPB design should respect the local natural, economic, societal, and cultural situation, such as protecting local characteristics including natural scenery and historical relics and taking advantage of the local climate, terrain, materials, and technologies.

**CHAPTER 3**

**Relationship Between Building Environmental**

**Assessment Tools and Sustainable**

**High-Performance Building Design Decision Making**

* 1. **Introduction**

When aiming to reduce building’s environment impact and increase their sustainable performance, an objective and quantifying assessment for decision making is needed (Sev, A, 2011). This chapter first provide an overview of building environmental assessment (BEA) tools, and then explains and briefly compare a selection of these tools used worldwide. Finally, after the analysis of BEA tools and HPB design decision making characteristics, this chapter describe their relationship.

* 1. **Overview of Worldwide Building Environment Assessment Tools**

Various building environmental assessment tools have been develop to gauge the ‘sustainable’ performance of a building (Papamichael,k,2000). ‘ sustainable’ performance is determined through an assessment of various environmental performance criteria that usually consist of site management, energy efficiency, air and atmosphere, materials, water efficiency, indoor environmental quality, transport, global warning, waste and pollution, and ecology. These BEA tools help owners and occupants realize the environmental friendliness of the building facility in which they reside and assist design teams in identify areas for improvement to keep environmental effects to a minimum ( RGO, S.Y., Brownhill A.D., & Howard, N., 2000). BEA tools for building are designed to provide an objective evaluation of resource use, ecological loadings, and indoor quality (Prior, J.J., Raw. G.J.& Charles orth. J.j., 2001). These tools can be used produce guidelines, benchmarks, ratings, and incentive to construct buildings with low environmental impact and to work as environmental management tools ( Wallhagen, M., 2010). However, these parameters, indicators and criteria have been determined in different ways and the result is a large number of different methods for the environmental assessment of buildings.

The history of BEA tools can be traced to the period during which a comprehensive discussion of ‘ sustainable buildings’ occurred and of the energy crisis during the 1970s, fundamental changes in building design concept were initiated (LIU, Y., 2005). Since the significant effort have been made to realize building operating energy factors and to develop energy efficient strategies and technologies.

Therefore, significant research has focused on assessing building performance, a variety of performance assessment tools have emerged, and performance assessment has become a fast-growing area of sustainable buildings research and practice. Many such tools were developed as rating systems that evaluate building performance across a board range of environmental considerations, and the evaluations are usually done against predefine criteria and benchmarks in hierarchy indicator structure. Examples of such tools include the Building Research Establishment Environmental Assessment Method (BREEAM) (U.K.), Leadership in Energy & Environmental Design (LEED) (U.S), Comprehensive Assessment Systems for Building Environmental Efficiency (CASBEE) (Japan), Miljobyggnad (Sweeden), Evaluation Standard for Green Building (ESGB) (China), National Austraila Built Environmental Rating System (NABERS) (Austrailia), Deutsche Gesellshaft Fur Nachhaltiges Bauen (DGNB) (Germany), and SBTool ( Formely known as GBTool) (Global versions);

In summary, BEA tools have performed important functions to encourage and improve HPB development by predicting and assessing building performance. Early studies in this area started from performance predictions tools, which are usually established in the form of computer-based simulation software that addresses single of a few building operation issues; recent studies placed more emphasis on performance assessment tools that are usually established in the form of a rating system that covers a boarder range of sustainable issue area. As Cole (Cole, R.J., 1999) stated, the increase in the development and application of performance assessment tools has provide considerable theoretical and practical experience on their potential contribution in furthering environmentally responsible building practices.

Their most significant contribution to date his clearly been to acknowledge and institutionalize the importance of assessing buildings across a broad range of considerations beyond established single performance criteria such as energy (cole, R.J., 1999).

* + 1. **Selective Building Environmental Assessment Tools**

Reijinders and Van Roekel (1999) roughly divided BEA tools into two groups: 1. Quantitative tools based on scores and a criteria system and

2. Tools base on a life-cycle assessment methodology using quantitative input and providing output data on material and energy flows. Given the limited time and scope of this research, this thesis only focuses on the widely used beam tools in the first group. the tools selected for a detailed study in this chapter are BREEAM, LEED, CASBEE, SBTool, and ESGB, which are considered the typical and representative tools that fit the needs of this study.

* BREEAM (Building Research Establishment Environmental Assessment Method)

BREEAM was launched in 1990 as the first BEA tool in the world (prior, J.J., Raw, G.J., & Charlesworth, J.L., 2001). BREEAM has been the most widely used tool for assessing the environmental performance of buildings in the UK and is increasingly accepted in the sector as offering practice in environmental design, and management (Gu, Z., Wennersten, R., & Assefa, G., 2006) (BREEM, 2011).BREEM has established a foundation for best practice in sustainable design, allowing it to become the most effective scheme around the world for the measurement and description of a building’s environmental performance (BREEAM, 2011). The tool was launched as a credit award system for new office buildings, and today it offers various tools to assess different types of buildings.

The goals of BREEAM are to reduce environmental impact, ensure the best environmental practice in design, operation, and management, and increase awareness of the effects of building on the environment various of the tools are continuously being developed.

* LEED ( Leadership in Energy and Environmental Design)

LEED was established in 1998 by the united state green building council (USGBC) through a consensus process involving many stakeholders to transform the market for green building (Zimmerman, A., & Kibert, C., 2007). Design team members can track their progress toward earring a LEED rating throughout the course of the project without the need for the speciality skills of consultants. LEED, which is well-grounded in science and relates to the market in hitch it operates, currently makes assessment of nine different types of buildings.

* New construction
* Existing building
* Core and shell
* Commercial interiors
* Retail
* Homes
* Neighbourhoods
* Schools
* Healthcare

A new version for new construction was launched in April 2009, entitled LEED-version 3 (USGBC 2010) LEED is a voluntary certification program developed through a consensus process involving key stakeholders to provide an inclusive simple framework for assessing building performance and meeting sustainability goals (Zimmerman, A., & Kibert, c., 2007). To calculate the achieved credits, LEED uses a simple additive approach (10f 1) with all certain being weighted equally rather than using a weighting system.

All LEED standards have three main types of requirement.

* Prerequisites: criteria that must be included before a project can be assessed.
* Core credits: given for meeting or exceeding the requirement in the five categories
* Innovation credits: given for exemplary performance beyond the core credits.

**CASBEE (Comprehensive Assessment System for Built Environment Efficiency)**

CASBEE, developed by the Japan sustainable building consortium involving committees in the academic, industrial, and government sectors, comprises a variety of tools for different phases of building under assessment planning, design, completion, operation, and renovation (GU, Z., Wennersten, R., & Assefa, G., 2006; Say, C., & Wood, A., 2008; IBEC, 2010). The assessment process acquires a different characteristic from many other criteria-based tools by employing an additive/weighting approach, which differs from the simple addition of points achieved in all performance areas. On the other hand, this tools covers almost every aspect of construction; on the other hand, the tools is extremely difficult to implement (Sev, A., 2011).

* 1. **Comparisons and Discussions**
     1. **Building Types for Assessment in BEA Tools**

BEA tool can be used to access different building types. (See table 3-2). Different BEA tools have developed their own versions that are typically related to different types of buildings,

A comparative analysis how that BREEAM , LEED, CASEBEE provide more versions than the others for specific building types. Because SBTool is a genetic framework and a toolkit that allows local organizations to develop their own tools, the types of building for assessment vary by regions; Miljobyggnad assesses both new builds and existing premises without specifying building types. ESGB assesses two types of buildings-residential buildings and public, buildings, where public buildings refers to all building types its public access, such as government offices, restaurants, school, hotels, libraries, transport stations, and entertainment facilities. ESGB appears too general and ignores the specific characteristics of different building types. For examples, school buildings are considered public buildings in ESGB, but the requirements for such buildings should be different from those of other public buildings. Compared with other existing BEA tools, Miljobyggnad and ESGB need to develop more specific versions for different building types in the future.

**Table 3-2 Building Types for Assessment in Selective BEA Tools.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | BREEAM | LEED | CASBEE | SBTool | Miljobyggnad | ESGB |
| New Construction |  |  |  |  |  |  |
| Existing Building |  |  |  |  |  |  |
| Renovation |  |  |  |  |  |  |
| Office |  |  |  |  |  |  |
| Residential (Multiunit) |  |  |  |  |  |  |
| Residential (Single) |  |  |  |  |  |  |
| Schools |  |  |  |  |  |  |

* + 1. **Evaluation Methods in BEA Tools**

Although BEA tools each have their own and different hierarchical structures and ESGB adopt quantitative stacking-based methods. This method awards credits to each indicator (option) according to its performance or numbers and adds them together to determine a single overall score. Specific details about how to access and stack credits are different for each BEA tool. Mandatory issues or baseline requirements in BEA tools ensure that the minimum building performance can be qualified, such as the LEED prerequisites and the ESGB control items. The parameters involved in this method are mostly limited to quantized data and minimally consider economic, service, or socio-cultural performance. This method also limits the adaption of the weighting system for different regions users or phases.

* + 1. **Uses of BEA Tools**

Different users may use BEA tools for various purpose for example, designers use these tools to aiding design because they are able identify systematized and sustainable performance targets and criteria during the design process. BEA tools also help investor and occupants make purchase decisions based on the ecological characteristics of alternatives. The structure of the selected tools leads to broader users groups including the design team ( comprised of, for example architects, engineers, landscape architects), investors and owners, occupants and clients, facility managers, and consultants. Local or regional authorities are expected to contribute to promoting BEA tools more suitable for the local or regional conditions. SBTool set a good example that allows authorized users, including local organizations or national teams, to establish their own scope system based on the generic version to reflect the relative importance of performance issues and benchmarks for a specific region.

Although BEA tools are applicable for different users for different reasons, the primary and basic purpose of this tool s is to evaluate building performance. In this case, the next sections identify the relationship between BEA tools and designers decision making process during design.

* + 1. **Relationship Process and Decision Making**

Different design have different vision on whether sign should focus on its process or on its product (Atkin, B., 1993) the notion that design is decision making process is consistent with the definition of a decision as a choice from among a set of options and an irrevocable allocation of resources. Decision making and design are so intertwined that the entire decision making process could be viewed as design ( Simon, H,A,. 1996). The evolution and selection of design concept undertaking when exploring the solution space making the conceptual design stage a decision-intensive process ( Mistree, F., smith, W., & Bras, B. 1993; Stavrvey, C.V. 1992; Josh, S.P., Umaretiya, J.R., & Joshi, S.B. 1991). Decisions are made on various aspects of the building design and typically involve the selection of design goals, principles, and corresponding design strategies making rational decision from a performance point of view originates from ideas presented by Heher A. Simon in the science of the artificial (Simon, H.A., 1969). Many engineering design process models were created and cross (Cross, N., & Cross, N., 1994) and Biminghamet al. (Bimingham, R., Cleland, G., Driver, R., & Maffin, D., 1997) provided good reviews of some of these models. Various studies on the decision process distinguished the three successive phases in this generic process that are not limited to the engineering design area, and are distinguished as follows.

Operations and maintenance phases

(4) Documentation and communication of the final design

**3.5.2** **Relationship Between BEA Tools and HPB Design Decision Making**

BEA tools have played the role as a bridge between building environmental assessment and design decision making goals for various stakeholders. With three main parts: ‘physical framework’, ‘and BEA tools’. The physical framework contains evaluative building performance, building technical systems. The stake holder framework contains various potential users and different types of design and decisions processes that stakeholders intend to execute ( Baldwin, R., Russel, P., Nibel, S., Boonstra, C., & Lutzkendorf, T., 2000).

**CHAPTER 4**

**Identification of Design Decision Elements from Building Environmental Assessment Tools for High-Performance Buildings**

**4.1 Introduction**

BEA tools contain quantitative and qualities criteria to integrate environmental, social, economic, and cultural issues into decision making at all levels ( Hakkinen, T. 2001 & Ding, G.K.C 2008). These criteria are primarily used to quantify building performance, simplify the evaluation process, and contribute to communications. The criteria are also essential for target setting and monitoring. Furthermore, criteria indicate future development trends in initial HPB development phases ( Bell, S., Morse, S., 2003 ).

Because BEA tools are some of the most important sustainable building instruments with a solid scientific basis, the relationship between these tools and design decision making is important for this chapter of first identity. Grounded theory is a research method based on collected data to provide an explanation for the major concern of the analyzed population of the selected phenomenal research situation and how that concern is undertaken or treated (Glaser, B., 1992 & Strauss, A., 1987 ). This chapter adopts the concept of grounded theory and selects the criteria issues for the design phase of different BEA tools to compare to determine the common trend \ target and the essential considerable aspects for HBP design decisions. Finally, base on the comparisons, the separation of different criteria issues BEA tools expected to establish the mapping approach from these issues to the design decision elements.

**4.2** **Comparative Analysis of Criteria Issues Among SBTool 2012, LEED Nc-v3, and ESGB**

**4.2.1** **Similar Criteria Issues Among SBTool 2012, LEED Nc-v3, and ESGB**

This research extracted and compared the similar criteria issues for the design phase among SBTool 2012 ( maximum version ). LEED NC-v3, and ESGB

These three assessment systems were selected for comparison primarily because of the following three reasons.

First, the SBTools system is ‘ a rating framework or tool box designed to allow countries to design their own locally relevant rating systems’ SBTool considers the religional situations and values in local languages within is generic evaluation framework and methodology, and the tool can provide both relative and absolute results. SBTools is also a valuable intercontinental to benchmaking tool that offers information about sustainable building performance to me local industry in regional situation and provide absolute information for international comparisons ( IISBE, SBTool, 2007).

SBTools cover almost all issues related to sustainable building performance, and the scope system can be modified to be as narrow or as board as desire. SBTools also places high consideration on socio-cultural and economic performance issues than other assessment. The SBTools 2012 provides ”a clear distraction between guidelines for design features and operating strategy”, for example, SBTools 2012 provide selective criteria solely for the design phase of residential building. “ designer can additionally specify performance targets and score self-assessed performance” (iiSBE,2012) because this research is concerned with design decision for HPB in born generic and local conditions, SBTools 2012 (maximum version) is selected as a comparative study prototype because it contains all fully developed criteria. The basement structure of the comparative result is based primarily on the SBTools 2012 categories for classifying similar criteria issues.

Second, since its inception in 1998, the U.S. green building councils LEED has established strong credibility among expert and has increased its number of affiliates, (Ding, G., Langston , C., 2012). Although the frame work and criteria are less comprehensive and adaptable man SBTools, LEEDS projects have been successfully established in 135 countries and its international projects outside the United States comprise more than 50 percent of total LEED registered square footage (USGBC, 2009). LEED is one of the most important and widely used BEA tools in the world, and is used as a reference frame work for green building assessment in countries that have no current method of building environmental assessment (Hockwood, C., 2006). LEED v3, launched in 2009, represents the first major change since its inception and provides a new structure that places greater emphasis on incorporating new technology and addressing the most urgent priories such as energy use and CO2  emissions (LEED, 2009) this research selected LEED NC-v3 for comparative analysis.

Third, ESGB was enacted in 2006 and is the first Chinese national standard for evaluating green residential and public building in china. ESGB draws on the advance experience of other assessment from countries worldwide. It has multi-targets, multi-level content to comparatively assess building performance. ESGB plays a very important role in the building/managing/assessing/developing sustainable building assessment in China; ESGB has undergone no upgrades or modifications until now. Corresponding design strategies demonstrated in the assessment tools have also been summarised. The comparative method first compares two selective assessment tools and the compares another assessment tool. The results of these comparisons show that many similar criteria issues are common to all the three assessment tools, whereas some similar issues are common to just two tools. This research extracted 51 similar criteria issues for the design phase, 32 common similar criteria issues among SBTools 2012, LEED-NC 2009, and ESGB, and 19 common similar criteria issues between two BEA tools [10 common similar issues for SBTool 2012 and LEED –NV- V3 and nine common similar issues for SBTool2012 and ESGB].

**4.2.2**  **In-Depth Analysis of Comparative Topics**

Before classifying the comparative works among SBTool 2012 ,LEED-NV-V3 ,and ESGB, classifying that each assessment system has different identified criteria and a classification framework is very important [table 4.3].

**Table 4.3 comparison of criteria classification framework among SBTool 2012 LEED NC-V3 and ESGB**

|  |  |  |
| --- | --- | --- |
| SBTool 2012  Site Local, Available services, and site characteristics | LEED NC-v3  Sustainable sites | ESGB  Land saving and outdoor environment |
| Energy and Resource consumption | Water efficiency | Energy saving and energy utilization |
| Environmental Loads | Energy and Atmosphere | Water saving and water resource utilization |
| Indoor environmental quality | Materials and resources | Material saving and material resources utilization |
| Service quality | Indoor environmental quality | Indoor environmental quality |
| Social cultural, and perceptual aspects | Innovation in design | Operations management |
| Cost and economic aspects | Regional priority |  |

SBTool identifies qualities and load criteria issues, whereas, LEED and ESGB consider them in related categories for example, SBTool consider building energy performing aspect to be in two primary categories [Energy and Resource consumption and Environment heads]where as LEED and ESGB consider them in just one category

In addition, LEED and ESGB consider aspect related to materials and water in independent categories, whereas SBTool consider them to be in several categories.

Compared with other BEA tool, SBTool contain the widest range and most comprehensive criteria issues for building performance moreover, the SBTool is a’’ generic framework for building performance assessment that can be used developed for a variety of local condition and building types’’ (iiSBE, 2012).SBTool has unique advantage when use in academic comparative studies by different researchers with different background. For this reasons, this comparative work selected SBTool as a prototype to ensure that each similar criteria issue is compared according to its contents. Nevertheless, additional analysis and supplementary similar criteria on issue are stated that are not limited to the scope of SBTool.

1. **Site regeneration and development, urban design and infrastructure.**

Site selection and development HPBs should reduce the entail consist pollution from construction activities with ecological care ensured though protection and restoration of wetlands and the coastal environment, carbon sequestration, soil erosion, sedimentation , biodiversity, and contrimination area development . HPBs also aim to deliver good communication though easy access to public services and relevant facilities and adequate provision for cyclist, drivers, and pedestrians (iiSBE, SBTool page, 2012) (leed, 2009).

SBTool consider the HPBs site from the ‘’site regeneration & development and urban design & infrastructure’’ energy which equivalent to the “sustainable site” category in LEED and ‘’land saving and outdoor environment “category in ESGB.

This category has is selective similar criteria issues ; 10 similar criteria issues are common to SBTool , LEED, and ESGB, LEED does not consider one issue on building orientation, and ESGB lacks four issues on bicycles, consist treatment of liquid waste private vehicle packaging, and exterior lighting quality. Although many similar criteria issues are common to these three BEA tools, the place a different emphasis on the same category SBTool considers building land utilization to be very important for example, SBTool considers building orientation with respect to three issues, SBTool provides detail quantitative strategies such as orienting the long axis of the building within 300 of east –west to0 obtain good passive solar exposure. Generally, sunshine, ventilation and other factors without providing detailed quantitative indicators or strategies. Although LEED pays more attention to brown field redevelopment and public transportation access, it lacks building orientation and morphology. ESGB pays more attention to residence –used land and the outdoor environment but does not consider the safety of cyclists and private vehicle packing limitation

1. **Energy and Resources Consumption**

Because a key function of BEA tools is to improve building performance and alleviate the environmental effect from buildings, most of these tools consider the utilization of “ energy” that leads to “carbon emission” as the most important criterion (Rodericy, Y., McEwan, D., Wheatley, C., & Alonso, C., 2009). Given energy’s significant effect on the environment, this aspect has the largest proportion of credits distributed among the environmental categories (LEED, 2009).

Therefore, BEA tools place vital importance on energy design, renewable energy strategies, energy conservation, and monitoring when targeting the efficient use of environmental resources or the care of the surrounding atmosphere, particularly with increasing concerns about many ecological threats such as global warming, the rise in the sea level, and acid rain (Lee, W.L., & Burnentt, J., 2006).

Importantly, the identification and classification of energy performance categories among SBTool, LEED, and ESGB differ. SBTool considers energy performance both from the total life cycle of non-renewable energy, including the embodied non-renewable energy in building materials and energy utilization for building operations. Different from SBTool, LEED and ESGB have criteria for building energy utilization but without clear direct criteria for embodied energy assessment in their categories. Some environmental loads aspects such as C02 emissions interact with ESGB, where as SBTool classifies them into another independent category that primarily focuses on environmental loadings.

Unlike SBTool, which places the criteria of green house gas (GHG) emission into another category of “Environmental Loads LEED and ESGB have different classifications: GHG emission is in the “Energy and Atmosphere” category in ESGB, Because the comparative work of this thesis is based on the SBTool framework, the criteria issues related to GHG emission are not included in this category and belong to the category “Eanvironmental Loads.”

1. **Environmental Loads**

SBTool evaluates the category “Energy Loads” from five sub-categories, whereas LEED and ESGB do not include this category in their frameworks. This thesis selected the corresponding similar criteria issues from different categories of LEED and ESGB to compare with the SBTool prototype related to environmental loadings.

Green house gas (GHG) emissions are significant impact factors on building environmental loadings. Compare with LEED and ESGB, SBTool lists GHG emissions as an independent aspect to evaluate from various perspectives (for example, embodied energy, primary energy utilization, Ozone depleting substances). LEED and ESGB involve criteria issues from different categories but related to GHG emissions. For example several indicators are directly/ indirectly relevant to CO2 emission both in the “Energy and Atmosphere” (EA) and “Materials and Resources” (MR) categories of LEED (Table 4.3).

LEED-NC=v3, release in April 2009, made the assessment of carbon emission and energy performance mandatory for buildings in the U.S. ( Stancich, R., 2009).

Regarding other atmospheric emission related to environmental loads, acidifying emissions and Photo-Oxidants aspects are less considered in LEED and ESGB. The regulation of Ozone-depleting substances, such as CFC-11, is included in both SBTool and LEED but not in ESGB. SBTool and ESGB, more strongly than LEED, consider the impact from adjacent property for daylight or solar energy through design strategies.

Note that the criterion “recharge of ground water” is considered in the environmental loads area, which will affect the project site in SBTool. However, because ground and underground water storage are still the main sources of waster in some parts of the world (Environment-agency, 2011), this criterion is also relevant- to some extent- for evaluation in water resource consumption.

**4.3.3** **Discussions**

1. **Comprehensive Comparison Discussion of SBTool, LEED, and ESGB**

SBTool, LEED, and ESGB cover the main aspects of sustainable high performance buildings: reduce resource consumption and environmental loads and period human comfort and healthy buildings with high environmental, socio-cultural, and economic performance. Although these three assessment system have different names, frameworks, and practice methods they all have the same characteristics and are based on sustainable principles; have their own clear hierarchical structure; and their common target is providing standards or guidance to improve the development of sustainable buildings.

The results of the comparative analysis found 51 similar criteria issues for the design phase, 32 common similar criteria issues among SBTool 2012, LEED-NC 2009, and ESGB, and 19 common similar criteria issues between two assessment tools (10 common similar issues for SBTool 2012 and LEED NC-v3 and nine common similar issues for SBTool 2012 and ESGB). The similar criteria issues primarily focus on energy and resources, indoor environmental quality, environmental loads, and site areas. SBTool 2012 contains the widest range and most comprehensive criteria issues for building performance, whereas the LEED NC-v3 and ESGB assessment frameworks poorly cover social and economic issues.

**4.3 Mapping Criteria Issues to Design Decision Elements**

**4.3.1 Basic Hierarchical Structure of Criteria Issues**

According to research by Liu ( Liu, Y., 2005 ), the common elements and general framework of EPA tools can be described as a basic hierarchical structure of sustainable building issues and supporting elements. Other tools are more or less established around environmental issues organized in a hierarchical structure from higher to lower levels contain issues from broader to narrower scopes. Individual indicators are established at the bottom of the structure. Criteria are based on each indicator; weights may be determined for issues at each level; and benchmarks may be determined for each indicator. In this general framework, indicators and criteria are the essential elements and weights and benchmarks are optional.

**4.3.2 Separating Performance Factors and Decision Factors**

According to Liu et al. (2006), criteria issues in BEA tools can be classified into two types: one type is decision making (D) factors related to stakeholders and their activities and the other type is performance (P) factors related to building performance.

* “P factors describe the targets/results of building activities (include plan, design, construction, operation, maintenance, refurbishment, demolition) and derive from building environmental science research and are typically more general and stable. They can normally be assessed quantitatively and the results may be comparable in.

**CHAPTER 5**

**Framework of key design decision elements of high-performance building**

**-case study of Chinese residential building=**

**5.1 Development of High-Performance Building in China**

**5.1.1 The Necessity to Implement HPBs in China**

Statistics show that the residential building area in china is approximately 40 billion m. Total building energy utilization is 16 billion tons of standard coal, which accounts for 20.7 percent of the total energy utilization in china (Xiao Y. J., & Qiao Z. C., 2009). Because the building area of northern china accounts for 70 percent of the building area of the entire nation and it requires heating in the winter, the energy utilized for heat in northern china constitutes 45 percent of the total urban building energy utilization throughout the country. Poor thermal insulation of the building envelop and the low efficiency of heating systems results in energy used for heating at approximately 25 kg/m2, or two to four times as high as that of northern Europe, which has a similar climate (Cai, W. G., Wu, Y., & Ren, H., 2009). Meanwhile, the hot summer area in southern china also accounts for a high percent of energy utilization for air conditioners.

**5.1.2** **Implementation of HPBs in China**

According to Xiao Yuejun et al. (2009), development of the sustainability concept in the building industry has gone through three developmental stages: the energy-saving and environmental protection stage, the ecological afforestation stages, and the comfortable and healthy stage. The energy-saving environmental protection stage started to recognize the inseparable relationship among humans, buildings, and the surrounding environment. Then, a large number of strategies for ecological afforestation protection were popularized. In the third stage, the comfort and health of humans in buildings were also considered.

During the 1970s and 1980s, thermal insulation performance and renewable resource utilization earned widespread respect and development. In the meantime, environmental issues and protection of the ecological system were gradually being recognized in china. The concept of the green/sustainable building was introduced into china in the 1990s and related studies were in the initial stage and lacked practical experience during this period. However, the Chinese government made significant effort to spread and research green/sustainable buildings on a large scale. In 2006, green buildings were included in china’s 11th five-year plan and highlighted as a core content of urban development. The 2006 Chinese national standard, the Evaluation Standard for Green Building (ESGB), provided a clear authoritative definition of green building in china: “a building which during its life cycle, to a maximum degree, can save resources such as energy, land, water and material, help protect the environment, help diminish pollution, provide healthy, suitable and high-performance spaces for the people to use, and coexist harmoniously with nature.”

**5.1.3** **Development of Building Environmental Assessment Tools in China**

Several energy-efficient standards for buildings have been established in china, such as the Residential Building Energy Conservation Design Standard (issued in 1996), the Residential Building Energy Conservation Design Standard of Hot Summer and Cold Winter Region (issued in 2001, updated in 2003), the Public Building Energy Conservation Design Standard (issued 2005), and the specification for Energy Efficient Constructional Quality Acceptance (issued in 2007). Today, in most regions of china, the lowest building energy efficiency is 50 percent, and some large cities such as Beijing and Shanghai set higher standards for building energy efficiency, at a minimum 65 percent (Cai, W. G., Wu, Y., & Ren, H., 2009).

In 1996, research on the Chinese Green Building System was listed as a key funding area for the Ninth Five-Year plan by the Natural Science Foundation of china (NSFC). Since then, a series of green building documents and regulations, such as the Residential Green Building Elements and Technical Guidelines, China’s Eco-house Technical Evaluation Handbook, the Assessment System for Green Buildings of Beijing Olympic Games, Green Building Technical Guidelines, Evaluation Standard for Green Buildings, Rules for the implementation of Green Building Evaluation Logo, and others, were released.

1. **First stage: china’s Eco-house Technical Evaluation Handbook**

To improve the overall eco-efficiency of Chinese building, china began to design a green building evaluation system in the early 2000s. In 2001, china’s Eco-house Technical Evaluation Handbook was prepared (Li, C., 2010). Later, three upgraded editions were released, in 2002, 2003, and 2007, to incorporate the most recent progress. All four editions were edited based on a combination of both the LEED standard from the United States and realities in china.

1. **Second stage: Released Green Building Assessment System for the Bejing Olympics (GBASBO)**

To host a “green Olympics” in Beijing, a special research project on developing GBASBO was initiated in November 2002 (Zhu, Y.X., 2005). GBASBO was developed primarily by referencing the Japanese CASBEE standard. To meet the special requests of a “green Olympic Games,” Chinese were considered particularly the local conditions in Beijing.

One feature of this assessment system is that it was the first to officially raise the concept of a green building in china. The progress of the assessment contains four stages: the planning stage, the design stage, the construction and final inspection stage, and the operation and management stage (GOBAS-Group, 2003). Different from other green building standards, this assessment system requires each stage to be evaluated separately and for the entire process to be evaluated.

**5.2**  **Framework of Key Design Decision Elements for Chinese Residential High-performance Buildings**

5.2.1 **Optimization of Criteria Issues for Chinese High-performance Buildings- Residential Building Type**

This thesis adapted the research framework from the China National Natural Science Foundation support project, “Decision-making support research for green building design based on building environmental performance assessment systems” (No. 50778153) (Liu, Y., Guo, L., Yao, J., Ren, J., etc., 2008). First, based on the analysis of SBTool, LEED, ESGB, and the other Chinese building performance evaluation tools, this thesis proposes a generic HPB criteria framework for Chinese residential building as a case study.

According to distinguished studies on the D and P factors in the preceding section, the following optional exist for a generic HPB criteria framework;

* Decrease the criteria related to the D factors, such as site selection, construction indoor air quality management plan (in LEED) and use of vegetation to provide ambient outdoor cooling and shading of buildings by deciduous trees (in SBTool), among others.
* Change several criteria related to D factors into P factors, change land saving into floor space ratio, and change utilization renewable energy into renewable energy utilization efficiency.
* Specify the range and contents of some P factor-related criteria issues. For example, several criteria about the site aspects of BEA tools should be specified for each quantitative criterion within outdoor climate, lighting, wind and acoustic conditions, air quality areas.
* Include a building’s economic and socio-cultural criteria issues. Three main criteria issues contain 10 sub-criteria to cover socio-cultural aspects, and three criteria issues assess a building’s economic performance.

This framework takes the two perspectives of resource and energy to assess building materials. Consideration of embodied energy aspects has been show in this framework.

Note that the criterion “quality of services” actually belongs to a building’s socio-cultural performance and is also related to the environmental and economic performance. For example, automatic illumination control in a stairwell at night is one reflection of the construability of “quality of service”. Appropriate control and necessary illumination levels influence occupant safety, which is socio-cultural performance. Additionally, energy utilization for illumination and electricity bills depend on the automatic system.

**CHAPTER 6**

**Conclusions and Future Work**

This thesis, based on the design decision making process from an architect’s point of view and by using the related literature review, theoretical analyses, and inductive inferences, proposes a new understanding of a high-performance building (HPB), translates/maps criteria issues of building environmental assessment (BEA) tools into key design decision elements, and identifies sources of inspiration for HPB designs.

This thesis intends to propose an integrated conceptual model to provide direct knowledge-based support to an architect’s early design decision making for HPBs. The key design decision elements, sources of inspiration and building information modelling is integrated into this conceptual design genesis. This thesis intends to provide a theoretical base and feasible measures for better HPB design references for developing design decision support tools for architects during the HPB design process. The following paragraphs present conclusions from this research.

1. A high-performance building (HPB) is a sustainable building with better environmental, economic, and socio-cultural features and performance than standard practices. HPBs should be aesthetically attractive, socio-culturally adapted, safe, healthy, and comfortable, and should operate with a high level of life cycle environmental, resource, and economic efficiency. HPB emphasizes sustainable performance of the entire building within the triple bottom line (environment, society, and economy) and is a substantial better sustainable building than standard practice in terms of environmental, economic and socio-cultural performance. HPBs must be designed and built against a backdrop of stronger environmental, economic, and human concerns, and all parts of a building need to be addressed through a cohesive building approach during its entire life cycle.
2. The relationship between BEA tools and HPB design decision making is about the consequences of goals and the mismatch of practices. From the evaluation objective and range perspectives, BEA tools and HPB design have the same common generic sustainability goals, both contribute to HPBs achieve high sustainable performance. The analysis of the practical characteristics of BEA and design decision making from primal functions, procedures, controllability, and outcome-related aspects shows obvious differences/mismatches between them at a pratical level. Given the consequence of goals, BEA tools provide the basic information (such as framework, content, evaluation method, and process) that relate to decision making to promote a holistic HPB design at a practical level. BEA tools also refer to another type of design support tool. However, given the mismatch in practice between BEA tools and HPB design decision making, most BEA tools are still used to test and verify the design results and do not consider the design decision making process. Existing BEA tools mostly guide or indirectly affects design work but play a limited role in directly assisting an architect’s early design decision making for HPBs in practice.

**8.2 Future Work**

This thesis is the first step in knowledge-based support toward the development of an entire design decision making support system. Specific to the integrated conceptual design model of HPB for an architect’s early design, this thesis also provides preliminary open study results. In this case, the following several suggestions for future work are presented.

1. Further research on HPB design decision making support can adopt the filter system theory as a research method and refine the research for different regions and building types.
2. A qualitative and quantitative study of HPB design decision elements should be done, in which the Delphi technique, the analytical hierarchy process (AHP), and appointing a panel of experts are considered.
3. Research on design decision support (DDS) instruments should continue toward the establishment of one practical DDS tool for architects. A literature retrieval, a field survey, and an interview can be combined to investigate architects’ attitudes and applications of DSS tools during the HPB design process
4. Vernacular architecture is an important source of inspiration for HPB design. In future work, subjects related to vernacular architecture (for example, design strategies, construction techniques, and cultural inheritance) should attract more attention and concerns.
5. Moreover, future work should consider combining practical HPB projects to verify and revise the study results. Doing so would be conducive to improving the scientific reliability of research and would provide more efficient support and assistance for HPBs.

In summary, the architect as a main stakeholder plays an essential role in promoting and developing HPBs. The design decision support research that an architect faces has important practical significance.

Developments in sustainable building theories/technologies and the application of HPBs should further the design decision support for HPBs.

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