Developing a life cycle assessment model for measuring sustainable performance of buildings in China

Jiani Liu

A thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy

University of Technology Sydney, Australia

2014

Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

Date: 7 July 2014

Acknowledgement

The PhD journey is the reward and it would not have been possible without the support of many people, to whom I offer my sincere thanks.

First and foremost, I must wholeheartedly thank Dr Grace Ding, who offers me an opportunity to study in Sydney. During the past four years, Grace keeps inspiring me with her approach in research and with her passion for it. In paper, she is my principle supervisor, in reality she did much more than that. She acts as a mentor who gives me strength and support, without which I do not know where I would be now. I would like to express my deepest gratitude and sincere appreciation to Grace for her support, guidance and encouragement during my PhD journey.

I would also like to thank my co-supervisor, Professor Bijan Samali. He is nice and helpful and helped me settle down in my faculty when I first here. He is sources of wisdom and humor and always willing to share his advice during our discussion. I also appreciate his proofreading of my thesis.

Great thanks go to University of Technology, Sydney, China Scholarship Council, Center for Building Infrastructure Research, and Faculty of Engineering and Information Technology, which offer me scholarships, funding and support my study abroad. Thanks for the design institutes, companies as well as the experts in China who offer me great support during my research data collection process.

Finally, thanks to my father Shiyu Liu and my mother Dongming Zhu who continuously gave me backing, love, and courage. Thanks to my husband Xianfeng Liu, thanks for his thoughtfulness. Thanks to all my families for their love, understanding and encouragement which support me and make me here. Thanks for my friend Ning Yan, who help me a lot and we have developed a strong friendship.

I also have a special thanks to everybody who accompanies me during my PhD, especially in the place so far away from home.

Contents

List of Abbreviations and Acronyms

Acronym	Definition
AHP	Analytical Hierarchy Process
BEPAC	Building Environmental Performance Assessment Criteria
BREEAM	Building Research Establishment Environmental Assessment Method
BRI	Building Related Illness
BSS	Building Sustainable Score
CASSBE	Comprehensive Assessment System for Built Environment Efficiency
CBA	Cost-Benefit Analysis
CF	Carbon Footprint
CSR	Corporate Social Responsibility
DEP	Direct Energy Path
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
EF	Ecological Footprint
EIA	Environmental impact assessment
EIO-LCA	Economic Input-Output LCA
EMS	Environmental Management Systems
EoL	End-of-Life
ESGB	Evaluating Standard for Green Buildings
FCA	Full Cost Accounting
FCP	Full Cost Pricing
GB Tool	Green Building Tool
GFA	Gross Floor Area
GHG	Greenhouse Gas
GOBAS	Green Olympic Building Assessment System

HLF	Health Footprint
HVAC	Heating, Ventilation and Air Conditioning
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCA*	Life Cycle Accounting
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Assessment
LEED	Leadership in Energy and Environmental Design
MFA	Material Flow Accounting
MOC	Ministry of Construction (China)
SAT	Sustainable Assessment Tool
SBS	Sick Building Syndrome
SD	Sustainable Development
SDA	Sustainable Development Ability
SDV	Sustainable Development Value
SEA	Strategic Environmental Assessment
SF	Social Footprint
SIA	Social Impact Assessment
TBL	Triple Bottom Line
TCA	Total Cost Accounting
VS	Value Score
WF	Water Footprint
WHO	World Health Organization
WLC	Whole Life Costing

List of Figures

List of Tables

List of publications during candidature

Journal paper

Liu, J., Ding, G.K. & Samali, B. 2013，'Building Sustainable Score (BSS)—A Hybrid Process Approach for Sustainable Building Assessment in China', *Journal of Power and Energy Engineering,* Vol.1, Issue 5, pp. 58-62.

Conference paper

Liu, J., Ding, G.K. & Samali, B. 2011, 'Quantifying and assessing impacts of building processes in a triple bottom line approach', SB11 Helsinki, Helsinki, Finland, October 2011 in *World Sustainable Building Conference*, ed Huovila, Pekka, Finish Association of Civil Engineers RIL & VTT Technical Research Centre of Finland, Helsinki, Finland, pp. 554-563.

Abstract

The construction industry contributes significantly to environmental pollution. The environmental problems caused by construction range from energy and resource consumption to waste emission throughout the building life cycle. With increasing attention being paid to building sustainability performance, numerous environmental assessment tools occurred. They have been developed and used to assist planning and design of sustainable buildings, and help improve overall environmental awareness and achieve the goal of sustainability in the construction industry.

However, with critical reviews on the current tools, they are criticized as being ineffective and inefficient in addressing the building performance issues, as most of them only focus on assessing building performance on environmental criteria and the assessment does not take into consideration economic and social analysis. Sustainability is like a three-legged stool, with each leg representing areas of environment, economy and society. Any leg missing from the 'sustainability stool' will cause instability because the three components are intricately linked together. In addition, most current tools have not considered all the building phases in their assessment. As economic, social and environmental impacts associated with project development will vary at different stages throughout its life cycle, sustainable performance should be assessed and incorporated into the building process.

Since the last century, China started to realize the importance of green buildings (CSUS 2012). A national SAT called Evaluation Standards for Green Buildings (ESGB) was launched in 2006 (Ye et al. 2013), and several international tools are adopted in China for assessing building performance. However, sustainable building assessment has significant regional differences and the application of international tools in China still have shortcomings. Moreover, the ESGB is also criticized for not

sufficiently taking into consideration of economic and social issues in building life cycle assessment.

In this research, different phases of a building life cycle are identified, as well as major activities for each phase in order to investigate how they influence the environmental, economic and social impacts. Both qualitative and quantitative methods are adopted in this research. Questionnaire survey and semi-structure interviews were used for data collection. The assessment indicators are generated by the data collection.

An assessment model is established based on the results of data analysis and the literature review. It combines environmental, economic and social assessment to aid decision making. The assessment is integrated into the building life cycle, and the building performance on each stage is also indicated. The assessment details of each indicator are also discussed.

The model is tested and verified by case study. Three projects are used as case studies. The sustainable performance of the three cases in every stage of the building life cycle as well as the overall performance will be analyzed. Quantitative methods and qualitative methods are used for assessing the indicators. The results using the developed model, the Building Sustainable Score (BSS), are also compared with the LEED and ESGB for deeper discussion. The value and innovation of this model are also discussed in this research.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Sustainable development has become a concern for people all over the world. The concept of sustainable development is broad and the concerns and judgments help ensure long-term growth and prosperity. According to World Commission on Environment and Development, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1986). From a project development point-of-view, it is thus concerned with the efficient utilization of resources and minimizing adverse effects on the natural environment, in order to meet the requirements and needs of present and future generations. Sustainable buildings and sustainable building assessment have therefore gained significant attention in recent times. With the fast growth of sustainable assessment models and tools around the world, some criticisms have arisen as most of these models and tools only consider the environmental aspects and few of them incorporate the assessment to life cycle stages and their impacts. To make the assessment more adequate for the themes of 'sustainability', this research aims to develop an assessment model based on the building life cycle and take three pillars into consideration.

1.2 Background to the research

Construction, including the building sector, first began to recognize the impact of its activities on sustainable development in the 1990s (Haapio & Viitaniemi 2008). The building sector has a strong influence on economics and the society itself and thus enhancing the standard of living and well-being of humankind. On the other side, construction development, often associated with the impairment of the environment, may result in the loss of valuable agricultural land, forests and wilderness, contributing to the pollution of both land and water, generating noise, consuming non-renewable natural resources and minerals and consuming large amounts of energy. The direct impacts on the environment from buildings always last through their whole life span, ranging from the use of raw materials for construction and renovation, to the emission of harmful substances (Balaras et al. 2005). According to UNEP (2003), the building and construction sector in the Organization for Economic Co-operation and Development countries consumes 25-40% of all energy used, and accounts for 40% of the world's greenhouse gas emission. In order to deal with the situation, construction sector must become more sympathetic to sustainability ideals and actions are needed to make these construction practices more sustainable. That's why sustainable buildings are gaining more and more attention in all disciplines. It has been treated as an indispensable way for a country to achieve the goal of sustainable development.

Environmental building assessment tools have emerged in such scenes and circumstances. They have been developed and used to assist planning and design of sustainable buildings. They aim to help improve overall environmental awareness amongst construction professionals towards sustainable practices and to achieve the goal of sustainability in the construction industry (Forsberg & von Malmborg 2004). The development of environmental assessment tools for buildings as a benchmark for best practices in sustainable design and construction of buildings is an important achievement in sustainable construction (Bossink 2002). It is also a way to define the construction industry's responsibility towards protecting the environment (Spencer & Mulligan 1995).

Nowadays, almost every country or region has at least one form of environmental assessment tool to improve sustainable performance for buildings. The tools developed currently vary a great deal, ranging from tools for individual building components to a whole building assessment. They consider environmental issues at local, regional and, in some cases, even global perspective. Since the release of Building Research Establishment Environmental Assessment Method (BREEAM) in 1990 the environmental building assessment tools have been multiplying throughout the world.

Moreover, environmental building assessment tools have moved beyond the voluntary market place mechanism as they are now increasingly being specified as performance requirements, and are being considered as potential incentives for development approval (Cole 2005). Some countries or regions have even made environmental assessments of building projects mandatory at some stages of a development, such as BASIX in Australia and EcoHomes in the UK for residential developments, and Green Mark for all types of constructions in Singapore (Blazey & Gillies 2008; Essa & Fortune 2008).

However, most of them just consider the environmental impact. Take the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan, for example, it covers energy efficiency, resource efficiency, local environment and indoor environment. According to De Plessis (2007), the goal of sustainable construction is to balance environmental protection with economic growth and social well-being. Therefore, the assessment tools should cover not only the environmental impact, but also the economic and social perspective. The definition of "building performance" is complex since different stakeholders in the building sector have different interests and requirements (Cole 1998). Economic performance, health and comfort related issues, social stability, biodiversity conservation, and so forth are all significant when environmental building performance is considered. Some suggest that the environmental assessment tools need to establish an overarching sustainability framework of environmental, social and economic criteria (Cole 2005; Lutzkendoef &

Lorenz 2006). In other words, it is more like ‘sustainable assessment tool’, rather than ‘environmental assessment tool’ (Ness et al. 2007; Castanheira & Braganca 2014).

Though some of the previous research has already covered the economic and social criteria in the assessment process, few of them have put it in each phase of building project during the whole life cycle. As suggested in the literature, economic, social and environmental impacts associated with project development will vary at different stages throughout its life cycle (Shen & Wang 2002; Lennie 2005; Ding & Shen 2010). Consequently, assessing and incorporating sustainability performance into building life cycle process from initial stage to end-of life is essential. A model is needed to provide an alternative approach for assessing the feasibility of a built project during its life cycle in attaining sustainable development. It reveals the sustainability performance at various stages of the development so that resources can be dedicated to the stages that have the most significant impacts.

1.3 Problem definition

Environmental building assessment tools which have been developed and used to assist planning and design of sustainable buildings, are criticized as being ineffective and inefficient in addressing the sustainability issues with regards to the increasing attention paid to building performance (Ding 2008). Indeed, most of the tools available only focus on assessing a building’s performance on a set of pre-determined criteria and the assessment does not sufficiently take into consideration economic and social issues. Sustainability is like a three-legged stool, with each leg representing areas of environment, economy and society. Any leg missing from the ‘sustainability stool’ will cause instability because the three components are intricately linked together (Robèrt et al. 2002).

Indeed, increasing sustainability assessment is required for "understanding the social, economic and environmental impacts associated with the way that buildings and their support systems are designed, built, operated, maintained, and ultimately disposed" (Thomson et al. 2011, pp 143). However, the lack of integrated assessment tools and the absence of common framework have resulted in the lack of a proper assessment approach for building life cycle. Assessing sustainable building performance in different stages in building life cycle has drawn gradual attention. Sev (2011) conducted a research about a comparative analysis of building environmental assessment tools. She indicates that "in the life-cycle approach, building is a process, rather than a product. Therefore, the life cycle of a building can be divided into phases (Sev 2011, pp 235). This viewpoint supports the suggestion on assessing building performance in different stages. Kaatz et al. (2006) also stated that a better understanding of assessment is required for delivering sustainability across different life cycle stages of the project.

In review of current building assessment situation, a fair amount of research has focused on several or one of the building phases with little research considering all stages from a life cycle perspective (Guggemos & Horvath 2003; Scheuer et al. 2003). They have not considered the impacts associated with the process of manufacturing products and transporting them to the site, ongoing operations and maintenance, and the disposal of waste at the end-of-life (Bilec et al. 2010). According to Sev (2011) creating a sustainable building requires looking at all stages of the building's life cycle. She further stated that the sustainable assessment tools should evaluate the social, economic, and environmental impacts from a life-cycle approach, by covering performance issues referring to each stage. Wu et al. (2012) support this viewpoint by stating the impacts during the life cycle of a project are highly inter-dependent, as one phase can influence one or more of the other phases. Each phase in a building life cycle plays an important role in achieving sustainability for a project. Therefore, when the sustainability performance of a construction project is examined, all the phases during the building life cycle should be taken into consideration.

In addition, the building performance criteria, including environmental, economic and social criteria, will have different impacts at various stages of a development (WCED 1998). The performance of both economic and environmental aspects of a development can be maximized through the sustainable principles being integrated into the building process (Van Paumgartten 2003). Kaatz et al. (2006) suggested that the use of environmental assessments will enhance the ability to impact the design and construction practice, challenging the existing norms and values of those responsible for the delivery of buildings. As a result it will be essential to assess a development for the entire building process (Shen & Wang 2002; Kaatz et al. 2006). This is beyond the current narrow technical focus and provides opportunities for a more conscious use of such methods to influence the quality of a building project through the building process.

With the widespread use of the environmental assessment tools all over the world, the problems of application occur, especially during regional adaptation in developing countries (Sev 2011). The majority of the environmental assessment tools have been developed nationally and consider the issues as they emerge. In that case, when they are adapted for use or even used directly in other countries, the problems emerge. One problem for regional adaptation is that assessment indicators vary from place to place. According to Sev (2011), the assessment indicators should reflect national, regional and cultural varieties if they are to be feasible and applicable. Applying the sustainable assessment tool (SAT) directly in other countries can cause biases and hence incorporate (Kai & Wang 2011).

Since the last century, China started to realize the importance of green buildings (CSUS 2012). A national SAT called Evaluation Standards for Green Buildings (ESGB) was launched in 2006 (Ye et al. 2013). Based on the ESGB, the assessment was divided into six groups and the evaluation results were presented at three levels of star rating ranging from one-star to three star. Similar with other SAT, ESGB only considers the environmental aspects of building performance. It also ignores the building life cycle in the assessment process.

To sum up, the major research problems are:

- The current environmental assessment tools are criticized as being ineffective and inefficient in addressing the sustainability issues with regards to the increasing attention paid to building performance
- Sustainable building assessment have strong regional differences, and the application of the international tools in China will still have some shortcomings
- China's own tool – Evaluating Standard for Green Buildings (ESGB) is criticized for not sufficiently taking into consideration economic and social issues in building life cycle
- Life cycle has not received sufficient attention in building assessment process

The major research questions that this thesis will attempt to address are:

- Can building performance be assessed in each stage of building from life cycle perspective?
- How to assess building performance from environmental, economic and social aspects in each stage?
- How to combine the quantitative data with the qualitative data in a meaningful fashion?
- To make a regional tool, how to arrive at a suitable weighting system?

1.4 Research aims and objectives

Given the previous discussion on the importance of incorporating economic, social and environmental assessments into the building life cycle, this research aims at developing a decision model to facilitate whole of life assessment that aids decision making.

In this research, not only the performance of the whole building, but also the performance of every single stage will be analysed. One reason is that different stakeholders in building industries have different emphasis. The residents value a comfortable living space; the construction companies hope that building's cost is low; while the designers put their emphasis on aesthetics. These indicators will impact differently in different phases of a building's life cycle. Two buildings might have the same performance score for the whole building process, but one might perform better at construction stage while the other is better at operation stage. No precise comparison can be made until the performance of each stage is analysed. Once the building performance in every single stage is assessed, the stakeholders can choose one which meets their requirements most.

In addition, some indicators can have opposite impacts on sustainable performance in different phases. The one improving the environmental impact in operation may have shortcomings in economic impact for construction. For example, the solar panel is one of the factors that have influence on energy consumption of a building. The cost of solar panel surely adds to the building cost which will in turn reduce points in economic impact at construction stage while it saves energy in operation which may bring huge environmental and economic benefits. According to Cole (1998), the definition of building performance varies according to the different interest groups involved in building development. Using an overall rating score to assess a building's performance is hard to satisfy all stake holders. In such a case, the performance scores for various stages become necessary.

As the goal of sustainable construction is to balance environmental protection with economic growth and social well-being, further improvement to the current environmental building assessment tools are needed in order to deal with more sophisticated circumstances in the decision-making process. The improvements include taking the assessment from a triple bottom line approach and consider it according to the building life cycle at various stages. The challenge of sustainability in construction, nowadays, is to integrate and manage these aspects in each stage of the building life-cycle that leads to sustainable results in a more detailed and more comprehensive way. In that case, the assessing model can be expected to contribute to reducing environmental impacts, increasing economic viability and satisfying client's development objectives.

This model is planned to be used for new buildings, it will be applied at inception stage for the users to evaluate the performance of the building and achieve highly rated new buildings. Based on the modelling principles, judgements can be made as to whether or not the development of a built project is in line with sustainable development principles and where improvements can be made accordingly. It reveals the sustainability performance at various stages of the development so that resources can be diverted to the stages that have the most significant impacts. In this model, the whole building performance will be assessed at each stage.

This research aims at developing a decision model incorporating economic, social and environmental assessments into the building process. In order to achieve the research aims, some clear and specific objectives are necessary for this research. The specific objectives for the research include:

1. Examining current environmental building assessment tools
2. Identifying building processes and phases of a building
3. Investigating the environmental, economic and social impacts related to building processes
4. Collecting primary data in China
5. Developing a model for assessing building performance from a triple bottom line approach
6. Testing and verifying the model by case studies

1.5 Research scope

Traditionally, the domain of building performance evaluation have been the building itself. However, this domain must change if buildings are to be made more accountable for their impacts. Buildings must be considered in terms of their environmental context at local, regional and global levels if impacts are to be measured, managed and reduced. In this research, the domain of building performance evaluation is national. The environmental, economic and social impact will be evaluated with national scope in mind. As China is a vast country, the climate and economic conditions vary from region to region. This research can, therefore, be used as a general base. When the model is applied to another region, modification is needed to satisfy the local conditions.

As the residential and commercial buildings are quite different from many perspectives, this research will only focus on commercial buildings. One of the reasons for this is that commercial buildings are found to have more impact on the environment as compared to the residential buildings (Sharma et al. 2011).

In the last few decades, the advent of large commercial buildings is unprecedented in China. These modern buildings are always associated with extensive curtain walls, artificial lighting, which all result in high energy consumption. Several studies have indicated that the energy consumption and carbon emission of commercial buildings are significantly higher than those of residential buildings (Jiang & Tovey 2009; Sharma et al. 2011; Zuo et al. 2012). Jiang and Tovey (2009) suggested that the commercial buildings should be given priority when considering the overall energy conservation and carbon reduction within the building sector, thus, achieving sustainability. Therefore, this research is focused on the sustainable performance of commercial buildings.

1.6 Research methodology

According to Neuman (2011), there are three types of research approaches, quantitative, qualitative and mixed methods. Quantitative approach is always used to deal with the numerical data; qualitative approach is for the textual data, while the mixed method is for both numerical and textual data. Quantitative research starts with a problem statement, followed by data collection such as survey or experiment (Creswell 2009). Three trends are normally mentioned in quantitative research, including research design, test and measurement procedures, and statistical analysis (Neuman 2011). Qualitative method is always used to develop a better understanding of complex situations, which is always hard to be present in numerical data. It is always based on documenting information from the literature and reviews.

In this research, the mix method is used. This research commences with literature review on current sustainable building and building assessment. The gaps in sustainable building assessment are identified, followed by the development of research aims and objectives. A comprehensive literature review is conducted to discuss the sustainable development and the triple bottom line approach. The building processes and building life cycle performance are also reviewed in this research. To get the primary data for the green building assessment in China and the data for model development, an industry survey, including a questionnaire survey and a semi-structured interview is conducted for data collection.

The questionnaires are used to collect information from a target population. All the information collected from the questionnaire, like current situation and status of construction practices, the key indicators for the model will be used as the foundation in the data analysis. In order to have in-depth discussion and more open ideas in relation to some issues generated in the questionnaire survey, interviews were conducted following the questionnaire. The model development is based on the questionaries and semi-structured interviews as well as the literature review. After establishing the model, case study is used to verify the model.

1.7 Significance of the research

As discussed above, the challenges of existing environmental building assessment tools will force further improvements in order to deal with the increasing readiness of its target market for a more sophisticated discourse with respect to the understanding of sustainability issues and in facilitating the integration of sustainability consideration on construction decision-making (Kaatz et al. 2006; Zimmerman & Kilbert 2007). Further improvement in building sustainability assessment may be promoted as collaborative activities among building stakeholders as well as the general public in order that the vision of sustainable construction can be valued and realized (Ofori & Ho 2004; Kaatz et al. 2006; Zimmerman & Kilbert 2007).

This research will consider all the phases in building life cycle, so that sustainability can be integrated into the project life cycle and communicated in a structured way for a more inclusive stakeholder representation during the building process. The model developed in this research can be used as a supplement to the current assessment tools to make the assessment of building performance more comprehensive.

1.8 Structure of thesis

Chapter 1 Introduction

This chapter introduces the reasons for undertaking this research and the process of the research. It presents the background of the research and discusses current gaps in this area. The research aims and objectives are also articulated. The research significance and the research structure are also included.

Chapter 2 Sustainability and triple bottom line

This chapter commences with the theoretical development of sustainability concept, followed by the triple bottom line of sustainability. The approaches in three pillars in sustainability, including environmental, economic and social are all analysed in this chapter.

Chapter 3 Sustainable building and sustainable assessment

Sustainable building is an indispensable way for a country to achieve the goal of sustainability. This chapter discusses the impact of buildings on the environment, economy and society. The methods for assessing the building performance are reviewed, including assessment models and tools. The sustainable building development and assessment in China are also discussed. Some criticisms about current models and tools arise based on the discussion.

Chapter 4 Building process and building life cycle performance

According to the research aims, the research is focused on sustainable building assessment in different stages in building life cycle. This chapter will analyze the building phases and building performance in these phases, which make this research necessary and also feasible. Environmental, economic and social impacts in different stages will also be analysed.

Chapter 5 Research methodology

In this chapter, the research design and methodology are discussed to explain how this research is conducted. Both qualitative and quantitative methods are adopted in this research. Questionnaire survey and semi-structured interviews are used for data collection, and case study is used for model verification.

Chapter 6 Data analyses and discussion

This chapter will present the process of data collection and the results of data analysis. The results have been analyzed in correlation with the literature review in previous chapters. The aim of this chapter is to report on the results of data analysis and draw conclusions from the results which have been used to develop the decision model for environmental building assessment at a later stage.

Chapter 7 Model development

Based on the literature review and industry survey, a model for assessing building sustainability performance has been proposed in this chapter. The model is titled Building Sustainable Score (BSS). The process of indicators generation is discussed followed by detailed assessment of these indicators. Both the quantitative and qualitative methods will be used for the indicators evaluation. After that, the weighting of each indicator is identified. The analytic hierarchy process (AHP) method is adopted for identifying the importance of the indicators against each other.

Chapter 8 Case studies and Model verification

After the model establishment, three cases are chosen for model verification in this chapter. The three cases are analysed based on BSS model. Their sustainable performance in every stage of building life cycle, as well as the overall performance will be analysed. The results of BSS are also compared with the LEED and ESGB for deeper discussion.

Chapter 9 Conclusion and further research

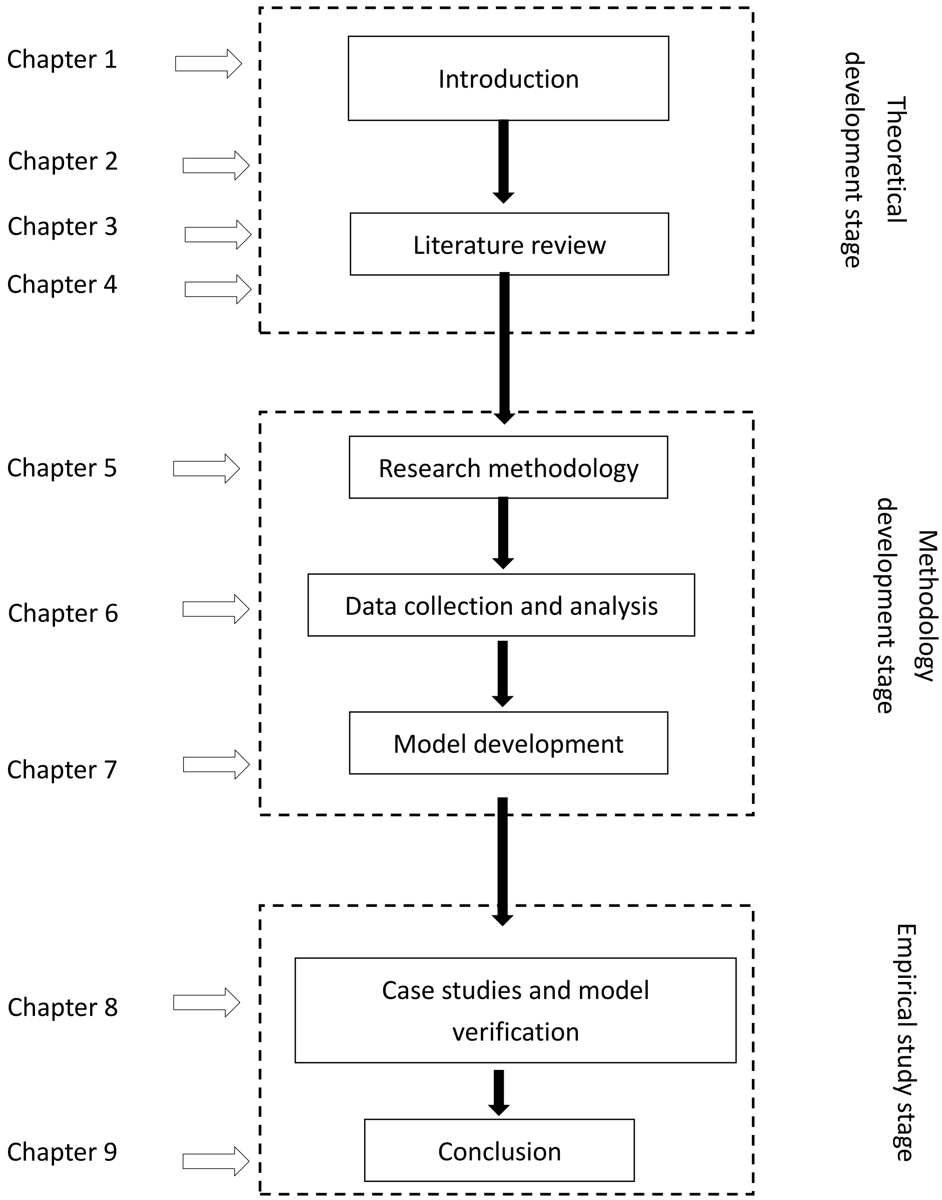
This chapter is to summarize the findings of the research and any conclusions within the research scope and to evaluate its aims and objectives that have been set for the research. After the model verification, the final results will be presented in this chapter. It will lay out the outcomes and contributions of this research. It also offers suggestions for further studies.

Figure 1.1 shows the structure of the research. It commences with literature review on the sustainability theory and triple bottom line approach. The sustainable impacts of buildings and assessment methods are also discussed, followed by the building process and the building sustainable impact associated with each phase. Based on the literature review, the research plan is designed. The research methodology is adopted after the comparison of different research approaches. Industry surveys are conducted for data collection. The data collected from the industry surveys are analysed and used for model development. Case studies are conducted for model verification.

1.9 Summary

This chapter introduced the concepts behind this research. It starts with the background of the research. The research problems and questions are figured out, followed by defining the research objectives and scope. It also discussed the significance of this research and the necessity and feasibility of conducting this research. Nine chapters are included in this thesis to present the whole aspects of this research. The structure of the thesis is also presented here. The following chapter will discuss a comprehensive literature review for this research.

Figure 1.1 The structure of research



CHAPTER 2

SUSTAINABLILITY AND TRIPLE BOTTOM LINE

2.1 Introduction

Sustainable development (SD) has drawn the attention of public and researchers since last century. Sustainability represents the interaction of environmental, economic and social aspects. With this concept, the triple bottom line (TBL) emerges from the assessment of environmental, economic and social values. This concept has been widely applied to the building industry. In this chapter, the assessment approaches to environmental, economic and social aspects are discussed. In environmental assessment, the life cycle assessment (LCA) and consumer-based approaches are discussed. In economic assessment, the life cycle costing (LCC) and other forms of cost estimating approaches are discussed. For social assessment, social impact assessment (SIA), social footprint, social benchmarking and other approaches are discussed.

2.2 The sustainability concept

SD is generally associated with the definition as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" given by Brundtland Commission's report 'Our common future' (WECD 1987). It has also been stated as "a strategy of development that results in the enhancement of human quality of life and the simultaneous minimization of negative environmental impacts (Jabareen 2008, pp 184)". SD strategies, therefore, seek to make some improvement in the quality of human life as well as take the needs of future generations into consideration (Müller et al. 2011).

The term sustainability originally refers to the field of ecology; including an ecosystem's potential for subsisting over time. When adding the concept of development, the term no longer focuses just on the environment, but also that of society and the capital economy (Reboratti 1999). The Brundtland Report discusses the relationship among environmental, economic and social aspects and it states that "development involves a progressive transformation of economy and society. A development path that is sustainable in a physical sense could theoretically be pursued even in a rigid social and political setting. But physical sustainability cannot be secured unless development policies pay attention to such considerations as changes in access to resources and the distribution of costs and benefits" (WCED 1987, pp 187). Thus, to achieve the goal of sustainability, the environmental, economic and social issues should be balanced effectively (Berke & Conroy 2000).

The attraction of SD is that it brings out a rapprochement between economic interest of ecological protective (Sachs 1993). Baeten (2000) supports this view point by stating that capitalism and ecology are no longer contradictory under the banner of SD, as its scope is to cope with the ecological crisis without affecting the existing economic relationships.

The environmental aspects of SD include conservation of natural capital stock and the protection of ecological form of human habitat (Jabareen 2008). Pearce et al. (1990, pp 1) define natural capital stock as "the stock of all environmental and natural resources assets, from oil in the ground to the quality of soil and groundwater, from the stock of fish in the ocean to capacity of the globe to recycle and absorb carbon." With the development of the concept of SD, constant natural capital is usually treated as a criterion for sustainability (Jabareen 2008). According to Pearce and Turner (1990), SD means the stock of capital should not decrease to endanger the opportunities of future generations to generate wealth and well-being.

The natural capital has great impact on the ecological economics. Collados and Duane (1999, pp 442) state that "ecological economics has highlighted the importance of the non-substitutability of natural capital and its complementary role in further development, while seeking to keep the scale of human society within sustainable bounds. Its contributions have been significant in clarifying concepts and linking the economic system with the environment."

Ecological form of human habitat represents the ecological design and urban forms that enable built environment and buildings for function in a more sustainable way (Jabareen 2008). Several theoretical works related to ecological design has emerged since the rise of SD (Hawken 1993; Thayer 1994; Edwards & Turrent 2000). They use many of the technologies and ideas related to ecology and sustainability; including alternative building materials, recycling materials, and renewable energy. Among them, some scholars state that, energy efficiency is a key factor in achieving ecological form through design of the building, community, city and regional level (Van der Ryn & Cowan 1995; Edward 1999). Another viewpoint about eco-form is that, the sustainability could be achieved where planning takes place at the local and regional levels (Haughton 1999). Thus, a series of sustainable habitats take place as the environmental problems also result from a city's design.

According to the content of the report, Our Common Future, environmental health is a precondition of social economic success. It is different from the previous viewpoint that the economic objectives, such as poverty alleviation and economic growth, should take precedence over environmental concerns (WCED 1987).

Social aspect, which is also referred to as equity, is another important pillar in SD. Haughton (1999, pp 64) state that "the social dimension is critical since the unjust society is unlikely to be sustainable in environment or economic terms in the long run."

Bullard and Evans (2002, pp 77) state that "wherever in the world environmental despoliation and degradation are happening, they are almost always linked to questions of social justice, equity, rights and people's quality of life in the widest sense". In their opinion, a truly sustainable society needs full integration of social needs, welfare, and economic opportunity into environmental limits imposed by ecosystems.

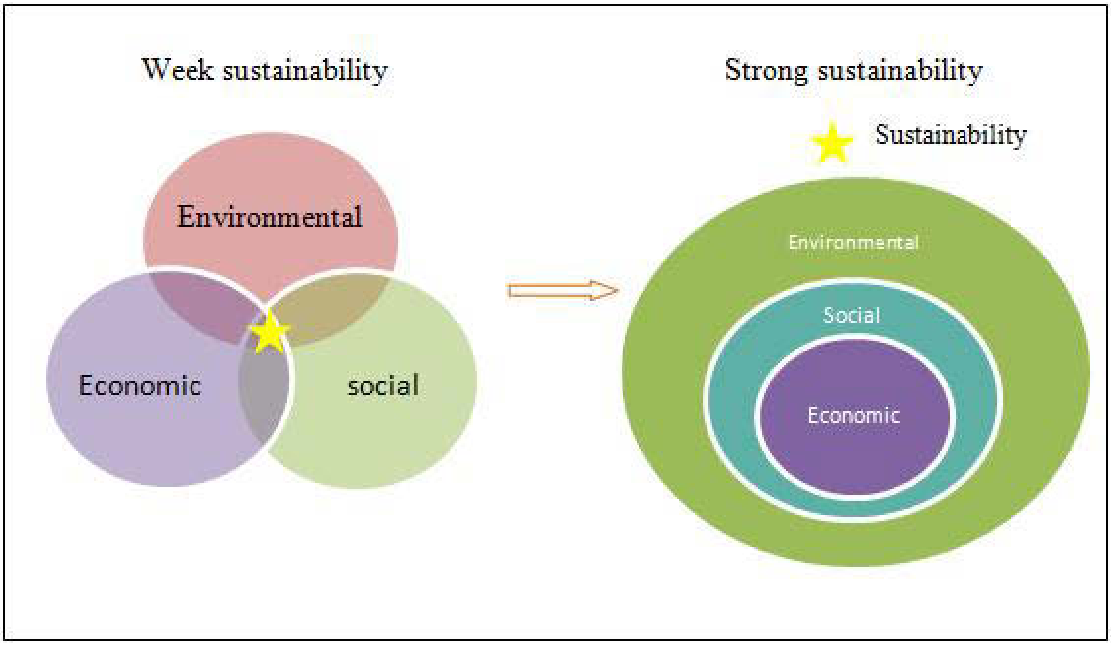
According to Bullard and Evans (2002), sustainability means that social needs, equity, welfare and economic opportunity are integrally related to environmental limits imposed by supporting ecosystems. In recent years, integrating environmental, economic and social concerns in planning and management in SD is drawing more and more attention (UNCED 1992; Robinson & Tinker 1998; CSD 2001). Agenda 21 (UNCED 1992) states that it is necessary to put the environment and development at the centre of economic and political decision-making.

In Chapter 8 of Agenda 21, the previous systems for decision-making are criticized as obstacles to actions of all groups in society and the development of SD as they tend to separate the environmental, economic and social factors at the policy, planning and management level (UNCED 1992). Therefore, Jabareen (2008) states that the integrated systems are needed to ensure the environmental, economic and social factors are considered together.

Hart (2000) presents the relationship between the three pillars like three concentric circles and states it as strong sustainability. It is based on the framework where the economy and society are recognized as fundamentally dependent upon the environment. The economy itself is wholly embedded in society and the interactions between people and society cannot exist in the society or the environment. The relationship of environmental, economic and social aspects in SD is presented in

Figure 2.1. It shows the development from interconnected benefits to interdependent benefits of the three pillars in SD.

Figure 2.1 The relationship of three pillars in SD



Source: Hart 2000

Sustainability increasingly draws attention in the construction industry as the environmental concerns related to buildings draw public as well as private attention (Anastaselors et al. 2009). From theoretical point of view, the scope of environmental evaluation is widening from a single criterion, such as energy or resource consumption, to a full range of issues during the building life cycle. These aspects include but not limited to the issues related to the inhabitants' physical health, productivity and emotional wellbeing, like life quality in operation stage. "Sustainability" is a broad and multi-criteria subject related to three basic interlinked parameters (Anastaselors et al.2009):

- Environmental issues - including those caused by land use, construction processes, demolition, etc.

- Economic issues - as a building stands for the entire economic and productive branch
- Social issues - based on human's need for comfort and "good living"

2.3 The triple bottom line of sustainability

2.3.1 The concept of triple bottom line

The term 'triple bottom line' (TBL) was made known after the publication of the book '*Cannibals with forks: Triple Bottom Line of 21st Century Business' by* John Elkington in 1997. Elkington (1997, pp 70) describes TBL as follows:

> "The triple bottom line focuses corporations not just on the economic value they add, but also on the environmental and social value they add - and destroy. At its narrowest, the term 'triple bottom line' is used as a framework for measuring and reporting corporate performance against economic, social and environmental parameters.
>
> At its broadest, the term is used to capture the whole set of values, issues and processes that companies must address in order to minimize any harm resulting from their activities and to create economic, social and environmental value. This involves being clear about the company's purpose and taking into consideration the needs of all the company's stakeholders – shareholders, customers, employees, business partners, governments, local communities and the public."

Thus, the concept of TBL includes the assessment of economic, environmental and social values of corporate performance. However, according to Vanclay (2004) the concept of TBL appears much earlier than that. Vanclay (2004) states that this concept has connection with ecologically sustainable development (ESD) thinking which was adopted in the Brundtland Report (WCED 1987) and the Rio Declaration and the Agenda 21 (UNCED 1992). The essence of ESD thinking was the metaphor of a ‘three-legged stool’, which means with three legs, each was equally important and all are needed for support. Sustainability, therefore, represents the interaction of all three aspects (Boyd & Kimmet 2005).

The World Business Council for Sustainable Development also supports Vanclay’s viewpoint (Holliday et al. 2002). This environmental, economic and social performance concept receives increasing support from corporate, government agencies and Non- Governmental Organizations gradually. However Vanclay (2004) continues to state that too many agencies and companies have not appreciated the philosophy behind TBL, and are responding only to the reporting requirements. Vandenberg (2002) conducts a study of 32 organizations in Australia and found that there was considerable confusion about the definition and philosophy behind TBL.

TBL which is initially intended as a philosophy or way of thinking about sustainability has now become a framework for accounting and reporting. While economic and environmental indicators are relatively easy to identify, select and measure, the social indicators are not. There has been a flurry of panic about what the social TBL indicators might be (Vanclay 2004; Boyd & Kimmet 2005).

2.3.2 Comparing triple bottom line approach with impact assessment

Vanclay (2004) argues that TBL might be a new buzzword and a current fad but it is not a new concept. It is substantially similar to the field of impact assessment. He goes on to state that TBL is introduced and promoted by people who ignore the field of impact assessment and it offers nothing in addition to existing approaches as it includes a series of impact assessment approaches that are already available. The impact assessment has been defined by Vanclay and Bronstein (1995) as the prediction or estimation of the consequences of a current or proposed action (project, policy and technology). Similarly, the International Association for Impact Assessment (IAIA) defines impact assessment as the process of identifying the future consequences of a current or proposed action (IAIA 2003).

Environmental impact assessment (EIA), as one of the impact assessment, is a process of identifying and predicting the potential environmental impacts of proposed action, policies, programs and projects. It is a method of communicating information to decision makers before they make their decisions on the proposed actions (Harvey 1998). The boundary of environment in EIA is defined by Harvey (1998) as 'bio-geophysical, socio-economic and cultural'.

Some criticisms about EIA state that though this approach is meant to be applicable at the policy and project level, but it is trapped in the project level in practice and experience (Vanclay 2004).

A new approach named strategic environmental assessment (SEA) is developed in this situation. Partidario (2000) defines it as a form of impact assessment that can assist managers and leaders in policy, planning and programmatic decisions. Though SEA makes improvement from the EIA, there is still some confusion about it, such as the extent to which it involves social as well as biophysical impacts (Partidario 2000). Boothroyd (1995) criticizes that SEA was limited itself by positivism, binding but empowering formality and narrow scope. In his opinion these limitations result from SEA being an extension of reductionist, linear and environmental.

A major progress in this field was the development of the environmental management systems (EMS) and it has become a mainstream impact assessment approach in the built environment. The widespread recognition of the EMS in the built environment was due to its endorsement by the International Organization for Standardization ISO 14001. EMS plans typically focus on environmental impacts and legal responsibilities.

In that case, some researchers state that the social indicators could be added into the EMS frameworks (Vanclay 2004). Van der Vorst et al. (1999) state that the best practice EMS needs intestate public participation and strategic environmental thinking into the corporate culture. In this regard, corporate social responsibility (CSR) is introduced in the EMS framework by some researchers (Zhao et al. 2012).

The different aspects of impact assessment as discussed above have both advantages and limitations. Vanclay (2004) compares these three assessment approaches with TBL and the results have been summarized in Table 2.1. TBL is the only approach which covers the social, environmental and economic factors as its scope. It covers the social aspects as part of its theory while EIA and SEA only consider environmental aspects and EMS considers environmental and potentially social aspects. Although TBL was criticized by some researchers as a similar concept to the other three impact assessment approaches (EIA, SIA and EMS), it has the advantages to assess building performance in three pillars (Granly & Welo 2014; Hollands & Palframan 2014).

Table 2.1 Comparison of various approaches in building assessment

	TBL	**EIA**	**SEA**	**EMS**
Year of development	2000	1970	1995	1990
Scope	Social, environmental & economic	Environmental	Environmental	Environmental & potentially social
Coverage of "social" in theory	As one of three dimensions	Varies in intention	Varies in intention	Social can be included as this is established as a goal by the organization
Data expectations	Predefined, discrete, quantitative indicators	Primarily quantitative indicators relevant to the activity as determined by a scoping process	Qualitative & quantitative indicators relevant to the activity, usually determined by experts	Qualitative & quantitative indicators relevant to the activity, usually determined by the organization
Technocratic or participatory	Technocratic	Should be participatory but tends to be technocratic	Should be participatory but tends to be technocratic	Usually participatory

Sources: Adapted from Vanclay 2004

Thus, the TBL is like a theme stating that environmental, economic and social aspects should all be supported. However, there are shortages of TBL in identifying, defining and measuring the indicators, especially the social indicators. It only shows the meaning to consider all three to aid decision making but do not offer accounting and reporting methods for doing it. Since the proponents of TBL fail to consider the way of identifying and measuring the indicators, different assessment methods need to be discussed for the three aspects to assist the framework in this research.

2.4 An overview of triple bottom line approach for building performance assessment

As discussed in Section 2.3, TBL has become a framework for accounting and reporting corporate performance and it has also been gradually used for building performance assessment. The building performance assessment approach using the three pillars in TBL include environmental assessment approaches, economic assessment approaches and social assessment approaches and the details are discussed in this section.

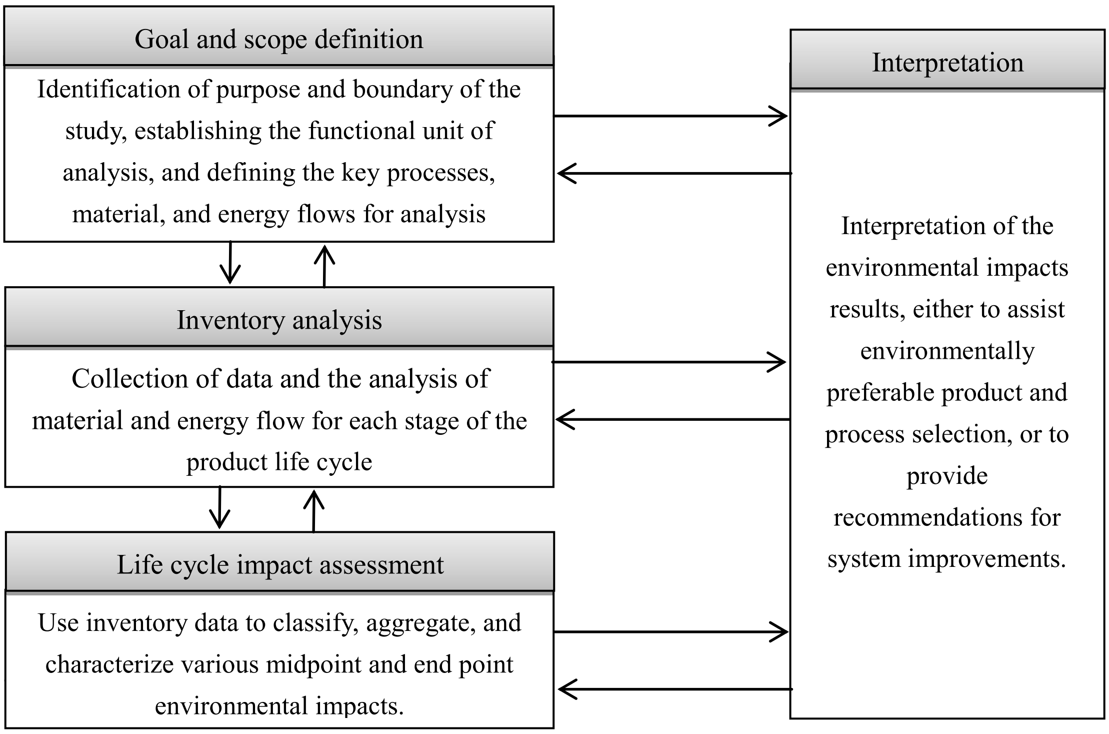
2.4.1 Environmental assessment approaches

With the increasing awareness of the environmental aspects of building performance, many approaches are developed to assess environmental impact from different viewpoints and different users (Joshi 2000; Singh et al. 2011; Wade et al. 2012; Alvarenga et al. 2013). Among them, life cycle assessment (LCA) and consumer-based approaches are widely used in the construction industry nowadays (Ortiz et al. 2009).

i) Life cycle assessment and its application in building performance assessment

Life cycle assessment (LCA), which is always considered as a 'cradle to grave' approach, is a tool for environmental performance evaluation (Singh et al. 2011). It is commonly used to analyze and assess environmental performance of products, materials or processes over their life cycle in a comprehensive and systematic way. It considers impacts from the acquisition of raw materials to final disposal of a project. In the 1990s, an environmental management standard was adopted by the International Organization for Standardization (ISO) as part of its 14000 standards series. In this series, 14040 Standards focus on establishing principles and framework for LCA study (ISO 2006a & b). According to the ISO 14040 Standard and the ISO 14044 which provides requirements and guidelines for LCA, the framework of LCA includes four steps: goal and scope definition, inventory analysis, life-cycle impact assessment, and interpretation (ISO 2006a & b). The relationship between these four steps is presented in Figure 2.2.

Figure 2.2 The LCA framework



Source: ISO 14040

There are three types of LCA approaches and they are process-based LCA, economic input-output LCA (EIO-LCA) and hybrid LCA. The LCA framework presented in Figure 2.2, which is referred as a process-based LCA, is criticized by Singh et al. (2011) as high cost, uncertain quality, with significant time investment. The ISO 14040:2006 has the following limitations within process-based LCA (Junnila & Horvarth 2003; Junnila et al. 2006):

- Subjective choices exist such as the data sources and the system's boundaries
- Typical assessment models are limited to linear rather than nonlinear models
- Local conditions are not adequately described by regional or global values
- Accuracy of results is limited to the accuracy of the data and its availability
- Uncertainty is introduced throughout the assessment

Joshi (2000) also states that the number of inputs which is used for modeling can be very large. Singh et al. (2011) state that some researchers try to limit the boundary of analysis to avoid this situation, which often turns out as compromising research objectivity and the reliability of results.

To improve this situation, an economic input-output LCA (EIO-LCA) has been developed by Joshi (2000). A geographical region, such as a national economy, is used as a boundary of analysis and incorporates economy-wide interdependencies. However, there are still some criticisms about this method due to high level of aggregation of disparate products in industry and commodity sectors in the national input-output tables, which make them unsuitable for LCAs as typical outputs of industry sectors (Singh et al. 2011). Wade et al. (2012) state the EIO-LCA has the benefit of being the national standard, thus being representative of average national cases, but it is a 'black box' analysis as the internal path is hard to trace. Another criticism is that embodied energy cannot be readily identified through analysis or calculations (Treloar 1997).

Hybrid method has been developed to combine the advantages of EIO-LCA and process-based LCA for LCA studies (Hoshi 2000; Suh et al. 2004; Suh & Huppes 2005; Bilec et al. 2006). In the hybrid methods, EIO-LCA models supply information for typical products or processes that are well represented by input-output categories, while the detailed product-specific information is derived from process analysis, thus preserving process specificity. The most popular hybrid method is Direct Energy Path Assessment Method (DEP), which is developed by Treloar (1998). It examines the decomposition of the energy Input Output model into mutually exclusive components.

Nowadays, interest is increasing to incorporate the LCA method into environmental building assessment. A series of studies have attempted to assess a complete building, building systems, and construction process using LCA approaches (Keoleian et al. 2000; Junnila & Horvath 2003; Citherlet & Defaux 2007). Table 2.2 summarizes the LCA approaches for the building performance assessment.

Table 2.2 Summary of LCA approach for the assessment of building performance

Methods	Research studies	Major findings	References
Process-based LCA approach	Evaluate life-cycle energy use, green-house gas emissions, and costs of a standard residential home in Michigan, covering pre-use, use and demolition phases.	The use phase accounts for 91% of total life-cycle energy consumption over 50-year home life.	Keoleian et al. 2000
Process-based LCA approach	Evaluate environmental impacts of a concrete-framed office building in Finland	The electricity and heating use during building operation and building material production caused the most significant environmental impact, consistent with other previous studies	Junnila & Horvath 2003
Process-based LCA approach	Evaluate two new office buildings in Europe and the US from material production through construction, use, maintenance and end-of-life stage	The use phase accounts for 70% of energy consumption and all of the emissions except PM_{10}. Materials production and maintenance are significant in emissions, especially in the US. The maintenance phase has a	Junnila et al. 2006

		larger environmental burden than the construction phase and end-of-life stage only relevant for overall NO_x and PM_{10} emission.	
Process-based LCA approach	Evaluate the design of three homes in Switzerland	Direct environmental impacts (all use-related energy consumption) can be significantly reduced by better insulation and by the use of renewable energy sources.	Citherlet & Defaux 2007
Process-based LCA approach	Analyze environmental impacts of a single-story residential building using different exterior wall systems	The use phase accounts for around 94% of total energy consumption	Kahhat et al. 2009
EIO-LCA	Evaluate three residential buildings in Pennsylvania, Texas, and Michigan, USA	The use phase accounts for over 90% of energy use, electricity use, fossil fuel depletion, and human-health impact categories, and for over 50% of global warming effects and air pollution	Ochao-Franco 2004
EIO-LCA	Compare economic and environmental impacts of a green roof with a built-up roof	In material acquisition stage, a green roof emits three times more environmental pollutants than built-up roof. But in the use and maintenance life stages, a built-up roof emitted three times more pollutants than a green roof. Overall, from the building life cycle, the built-up roof contributes 46% more environmental emissions than a green roof over a 45 year life span.	Muga et al. 2008
Hybrid LCA	Evaluate environmental effects of steel-and concrete-framed buildings	The building use phase contributes the most energy-use impacts, but this can best be controlled through energy-efficient design. The construction phase impacts contribute to a small part (0.4-11%) of energy consumption and emission in the building life cycle. The maintenance and end-of-life also account for a small part.	Guggemos & Horvath 2005

Hybrid LCA	Analyze environmental effects for the construction phase of commercial buildings in California	Equipment use accounts for about 50% of environmental effects, while temporary construction materials have the second largest impact on the environment.	Guggemos & Horvath 2006
Hybrid LCA	Analyze environmental impacts on construction phase of a precast parking garage in Pittsburgh, USA	Transportation has the largest impact in most categories.	Bilec et al. 2006
Hybrid LCA	Examine environmental impacts to the construction phase of commercial buildings	Construction stage, while not as significant as the use phase, is as important as the other life-cycle stages and PM2.5 emissions are significant in construction stage.	Bilec et al. 2010

Table 2.2 shows some research studies in the applications of LCA for environmental building assessment. Some target one or several stages of the building life cycle, for example, Keoleian et al. (2000) cover the pre-use, use and demolition stages when they evaluate the life-cycle energy use and GHG emission. Guggemos and Horvath (2006) evaluated the environmental effects in the construction stage of a commercial building. Bilec et al. (2010) also conducted a research about the environmental impacts in the construction stage of a commercial building and stated that the construction stage is as important as the other stages in sustainability assessment.

Besides, some other research works targeted all the stages in a building life cycle. For example, Junnila et al. (2006) evaluated the energy consumption and GHG emission for two new office buildings from material production to construction, use, maintenance and end-of-life (EoL) stage. Guggemos and Horvath (2005) conducted a research to evaluate the environmental aspects of steel-and concrete-framed buildings. They stated that the ‘building use’ stage contributed the most energy use, followed by the ‘construction’ phase. The ‘maintenance’ and the ‘EoL’ stage account for a small part.

Among these three types of LCA, hybrid LCA modelling requires both breadth and depth and the work done by Bilec et al. (2010) in examining environmental impacts at the construction stage of a commercial building reveals the nature of the hybrid LCA approach. The hybrid LCA effectively combines process-based and EIO-LCA. The hybrid LCA construction model is created in the software Analytica. It not only includes construction processes from site preparation to painting but also includes detailed modelling of construction equipment combustion. As the main goals of hybrid LCA models are improving, the time and cost associated with process-based LCAs and the development of an inclusive boundary has contributed to its widely used in the construction industry (Guggemos & Horvath 2005; Guggemos & Horvath 2006; Bilec et al. 2006).

Comparing the process-based LCA with the EIO-LCA, the advantages of process-based LCA include detailed analysis of specific processes, identifying process improvements, and product comparisons. But the process-based LCA is criticized as uncertain, time and cost intensive, lacking comprehensive data in many cases, and subjective boundary selection (Bilec et al. 2006). While the advantages of EIO-LCA include publicly available data, reproducible economy-wide results, system LCA and boundary is defined as the entire economy. The disadvantages of EIO-LCA include aggregated level of data, difficult to identify process improvements, uncertainty, product use and end-of-life not include non-US data.

ii) Consumer-based approaches

LCA, as an environmental assessment tool, is gradually developed and has received lots of attention. It is an objective and feasible tool to analyse energy, emission and resources in a building life cycle. In environmental assessment of buildings, there are another group of approaches which have attracted much attention and are usually termed the ‘footprint family’ (Galli et al. 2012). Galli et al. (2012) called the ecological, carbon and water footprints as consumer-based approaches. These three approaches are able to complement traditional analyses of human demand by coupling producer and consumer perspectives (Beynon & Munday 2008; Galli et al. 2012). These approaches present a quantifiable and rational basis on which to begin discussions and develop answers regarding the efficiency of production processes, the limits of resource consumption, the international distribution of the world's natural resources, and how to address the sustainability in the use of ecological assets across the globe. They provide an important framework to evaluate the actual material flow in the construction industry and are useful to the assessment of environmental performance of buildings.

a) Ecological footprint approach

The ecological footprint (EF) was initially developed by Wackernagel and Rees in 1996. The approach works to account for the consumption of the planet's resources. Essentially, the footprint provides a proportional estimate of the demands on global bio-capacity and the supply of that bio-capacity. Alvarenga et al. (2013) described EF as a methodology that transforms the inputs and outputs from an economic system or human population into an area of productive land or water. Thus, this approach reflects the area required to ensure the survival of a population or system (Wackernagel & Rees 1996; Van Bellen 2004). The EF approach has been used to reveal the bio-productive land area needed to provide the resources for a given population and to assimilate their wastes. Usually, the reference population is a nation, but the EF approach has been usefully applied to individual industry, organization and a specific type of consumption (Ferng 2001; Wiedmann et al. 2006).

There are several methods to estimate the footprint (Wackernagel et al. 1999). One of the most popular methods in EF is input–output framework (Bicknell et al. 1998; Ferng

2001; Lenzen & Murray 2001; Turner et al. 2007; Wiedmann et al. 2006). A group of researchers have focused on this method in the past decades. The first study about the input–output framework was conducted by Bicknell et al. (1998). They used it to estimate the land resources that underpin domestic final consumption. Since then, a group of researchers have extended this method and the details are summarized in Table 2.3.

Table 2.3 Research studies on input-output framework used in EF

Research studies	Major findings	References
Estimate the land resources that underpin domestic final consumption in New Zealand	The input-output framework provides "a consistent mean", and with the method potentially allowing some element of comparability and standardization between studies	Bicknell et al.1998
Proposed an improvement to the construction method suggested by Bicknell et al. (1998)	• the end result would include not only the production land of manufacturing, but also the production land of sectors, such as agriculture that supply to manufacturing • it is necessary to use the composition of land multipliers, rather than land multipliers themselves to calculate the production land footprint, meaning that calculated areas are expressed by land category • produced different intermediate results in regards to the energy component of the EF	Ferng 2001
Estimate a footprint for Australia based on actual, instead of hypothetical, land use and land distribution	• reveal high levels of uncertainty on energy and emissions land figures used in conjunction with the input-output framework to derive Footprint estimates. • show that input-output based estimates are associated with several types of error, not least in terms of aggregation of data and the assumption of homogeneity of industry output	Lenzen & Murray 2001
Uses input-output tables to allocate footprints to final consumption categories	• footprint is becoming more widely used as a performance indicator • prior estimates of the ecological footprint were difficult to compare, since there was no commonly accepted methodological procedure for construction • describe a method through which National Footprint Accounts can be consistently disaggregated to	Wiedmann et al. 2006

	provide information by industry sector, final consumption categories, sub-national area and by socio-economic group • footprint results can then be used to provide better quality information for policy scenario	
Raised the issue of footprint estimation techniques that focus on a single region input-output case	• the inclusion of land use and emissions connected to imports exceeds the effective 'boundary' of the input-output table • the solution is a multi-regional input-output framework that potentially provides better quality information on the land use connected to imported goods and services to a reference economy	Turner et al. 2007

As summarised in Table 2.3 Ferng (2001) proposes an improvement to the construction method suggested by Bicknell et al. (1998) to estimate the land resources. He states that the production land of sectors should also be included as well as the production land of manufacturing. Lenzen and Murray (2011) also use the input-output framework to estimate the land use and land distribution. They replaced money row in the input-output framework with values in physical units, and found that there is high level of uncertainty on energy and emission figures used in conjunction with the input-output framework. They also pointed out that the input-output framework based estimates are associated with several types of error including aggregation of data and the assumption of homogeneity of industry output. These two research works used EF to estimate the land use and land resources, whilst Widemann et al. (2006) uses it as a performance indicator for final consumption categories.

Widemann et al. (2006) use input-output tables to allocate footprints to final consumption categories. They develop a method through which National Footprint Accounts can be consistently disaggregated to provide information by industry sector, final consumption categories, sub-national area and by socio-economic group. They state that the footprint results can be used to provide better quality information for policy scenario. Turner et al. (2007) improved the single region input-output case into a multi-regional input-output framework. They stated that the multi-regional input-output framework that potentially provides better quality information on the land use connected to imported goods and services to a reference economy (Table 2.3). According to Beynon and Munday (2008), the input-output frameworks for ecological footprint analysis offers the potential for greater transparency and consistency in estimating footprints. However, there appears to be some ways to go before methods are fully standardized. The varying levels of sectoral aggregation used in the input-output framework remains limited by a series of constraining assumptions (Miller & Blair 1985), which influence the data availability and reconciliation (Turner et al., 2007). It is also criticized by Beynon and Munday (2008) as being poor in accuracy in the underlying data and different levels of aggregation.

Compared with LCA, The Global Footprint Network (2009) indicates that the newest standard of ecological footprint analysis determines criteria for nations, organizations and products, and for the latter, it recommends using the life cycle perspective. Huijbregts et al. (2008) conduct a research on ecological footprint accounting on the life cycle assessment of products. They state that when applied to products, the EF method can be considered as an LCA method. Alvarenga et al. (2012) support this viewpoint by stating that the EF of a product is actually an LCA method, when the life cycle perspective is taken into account. However, in another instance, EF and LCA are different from each other. Finnveden and Moberg (2005) conduct a research as an overview of the environmental systems analysis tools including EF, LCA, Material Flow Accounting (MFA), Environmental Management System (EMS), Life-Cycle Costing (LCC), Cost-Benefit Analysis (CBA), etc. They stated that when applied to building performance assessment, these two methods cannot be confused easily in replacing each other.

b) Carbon footprint approach

Carbon footprint (CF) measures the total amount of greenhouse gas (GHG) emissions that are directly (on-site, internal) and indirectly (off-site, external, embodied, upstream and downstream) caused by an activity or are accumulated over the life cycle of a product (Cheng et al. 2011). This includes activities of individuals, populations, governments, companies, organizations, processes, industry sectors, etc. As a consumption-based approach, CF complements the production-based approach taken by national GHG inventories (Galli et al. 2012). By making consumers aware of the GHG emissions from their life-style and raise awareness of indirect emissions in governments and businesses, the CF could encourage and facilitate international cooperation between developing and developed countries (Weidema et al. 2008).

In the quantification of CF, standardization is necessary to provide guidance for users. With the aim of defining a common standard for the assessment of GHG emissions associated with products (goods and services), in 2007 the Carbon Trust and the Department for Environment, Food and Rural Affairs (DEFRA) initiated a procedure that developed the Publicly Available Specification 2050:2008 (BSI, 2008), together with other complementary documents such as the Guide to PAS2050 (BSI, 2008).

PAS2050 specifies requirements for the assessment of the life cycle GHG emissions of goods and services based on key life cycle techniques and principles. PAS2050 is built upon the existing ISO 14040/44 standards for LCA which it further clarifies and specifies for the calculation of CF of goods and services (BSI 2008). This methodology accounts for emissions of all GHG including CO_2, N_2O, CH_4 and families of gases such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), and each gas is converted into a CO_2 equivalent value.

Thus, PAS2050 builds on the LCA guidance and requirements articulated in ISO 14040:2006 and ISO 14044:2006, adopting a life cycle approach to emissions assessment and the functional unit as the basis of any reporting (Sinden 2009). Furthermore, this specification also deals with other relevant methods and approaches in the field of GHG assessment such as ISO 14064.

The CF is not expressed in terms of area though it has 'footprint' in its name. The total amount of GHG is simply measured in mass units (e.g. kg, tonne, etc.) and no conversion to an area unit (e.g. ha, m^2, km^2, etc.) takes place (Galli et al. 2012). Any conversion into a land area would have to be based on a variety of assumptions that would increase the uncertainties and errors associated with a particular CF estimate.

When CO_2 is calculated, the unit kg CO_2 is used for CO_2 only. If other GHGs are calculated the unit is kg CO_2-e, expressing the mass of CO_2-equivalents (see Table 2.4). Those are calculated by multiplying the actual mass of a gas with the global warming potential factor for this particular gas, making the global warming effects of different GHGs comparable and additive. Six common GHGs are CO_2, CH_4, N_2O, HFC, PFC, and SF_6 (Galli et al. 2012).

Table 2.4 Calculation units for GHG in CF

GHG		Unit
CO_2		kgCO_2
Other emissions	CO_2, CH_4, N_2O, HFC, PFC, and SF_6	kgCO_2-e

Source: Galli et al. 2012

When applied to a nation, the CF relates to consumption of goods and services by households, governments, capital investment, etc. Galli et al. (2012) indicate that the CF of a nation is the sum of all emissions related to the nation's consumption, including imports and excluding exports. When applied to a project, the CF can help to weigh the CO_2 equivalent emissions and the primary energy use of buildings.

Airaksinen and Matilainen (2011) conduct a research about CF of an office building. They studied different design options to influence building energy consumption and CO_2 equivalent emissions. The embodied energy comes from building materials and CO_2 equivalent emissions come from energy use. They state that the reduction of energy use reduces both the primary energy use and the CO_2 emission. The CO_2 equivalent emissions from embodied energy have an important share, which indicate the building materials have a high importance. This viewpoint is often ignored when only the energy efficiency of running a building is considered.

Li et al. (2011) conduct a research to evaluate the CF over the full life cycle of a large public building in China. They estimated the GHG emissions of the public building in terms of CO_2 equivalent emissions. They stated that the analysis of CF is an important part of saving energy and reducing CO_2 emission in the building. Bendewald and Zhai (2013) mention using carrying capacity as a baseline for building sustainability assessment with CF model. They stated that a building is considered sustainable if by the end of its expected lifetime the total amount of carbon emissions are completely offset. They established a method that equitably distributes carbon based on the native-site carbon storage and provides an absolute assessment of sustainability with regard to carbon emission. The carbon emission from site development, building construction, and operation are all estimated in their model. Proietti et al. (2013) also use a CF model to assess environmental and energy compatibility of different solutions of thermal insulation in building envelope. They assessed the GHG emissions in CO_2 equivalent terms from the extraction of raw material to the disposal. They state that the CF can be seen as a LCA model with climate change as the single impact category.

According to Weidema et al. (2008), CF is not a new topic since it is related to the quantification of life cycle impact indicators for the global warming midpoint category. In fact, CF's opponents think this tool is just as a sub-set of the data covered by a more complete LCA. SETAC (2008) indicates that the use of carbon footprints questions the aptitude of the existing ISO standards to address the environmental impacts, because GHG emissions from products are in a consistent and comprehensive way. Even with these criticisms, there are undeniable links between LCA and CF in assessing global warming impact category (Weidema et al. 2008; Galli et al 2012).

c) Water footprint approach

The water footprint (WF) concept was introduced in response to the need for a consumer-based indicator of freshwater use (Hoekstra 2003; Jeswani & Azapagic 2011). It is closely linked to the embodied water concept as it accounts for the appropriation of natural capital in terms of the water volumes required for human consumption (Allan 1998; Hoekstra 2009). The WF concept aims primarily at illustrating the links between water use and human consumption, and between water global trade and water resources management. This concept has been brought into water management science in order to show the importance of human consumption and global dimensions in good water governance (Aviso et al. 2011; Hoekstra 2009).

The WF looks at both direct and indirect water use of a consumer or producer on a life cycle basis. Three key water components are tracked in its calculation. Firstly, the blue WF refers to the consumption of surface and ground water. Secondly, the green WF refers to the consumption of rainwater stored in the soil as soil moisture, and finally, the grey WF refers to pollution which is defined as the volume of freshwater required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra 2009; Jeswani & Azapagic 2011).

WF can be calculated for a particular product, for any well-defined group of consumers (e.g. an individual, city, province, state, or nation) or producers (e.g. a public organization, private enterprise, or economic sector). It is defined as the total volume of freshwater that is used to produce goods and services consumed by the individual or community or produced by the business (Hoekstra & Chapagain 2008). Water use is measured through the WF method in terms of water volumes consumed (evaporated or incorporated into the product) and polluted per unit of time. Depending on the level of detail that one aims to provide, it can be expressed per day, month, or year (Hoekstra 2009).

When compared with LCA, WF refers to the approach that emerged in the water resource management community, while LCA (water) refers to the approach that emerged from the LCA community and focuses only on the assessment impacts related to water. Boulay et al. (2013) conduct a research on comparison of water-focus LCA and WF. They state that though the WF and LCA have some similarity as they both consider the water use in life cycle perspective, there are still some differences between them. These two methods both have indirect goals to help with water conservation, but in different ways. The LCA quantifies the potential environmental impacts in a wide range of environmental issues, while the WF is primarily designed to quantify and measure the water resource with three types of water use: the blue, the grey and the green water footprint. Boulay et al. (2013) also state that though LCA and WF use quantitative indicators, but WF relies on water use indicators in the inventory phase and LCA focuses on the impacts phases.

d) Comparative study of the three consumer-based approaches

As the members of the consumer-based approaches family, ecological footprint, carbon footprint, and water footprint based on different research have different advantages in relation to each other. Galli et al. (2012) undertake a comparative study on the three approaches and they are summarized in Table 2.5.

Table 2.5 A comparative study of the three consumer-based approaches

	Ecological footprint (EF)	Carbon footprint (CF)	Water footprint (WF)
Content	The amount of the biosphere's regenerative capacity that is directly and indirectly used by humans compared with how much is available at both local and global scales	The total amount of GHG emission (CO_2,CH_4,N_2O, HFC, PFC, and SF_6) that are directly and indirectly caused by human activities or accumulated over the life stages of products	The human appropriation of the volume of freshwater required to support human consumption
Purpose	Track human pressures on the planet in terms of the aggregate demand that resource consumption and CO_2 emissions places on the ecological assets	Uses a consumer-based approach to track human pressures on the planet in terms of total GHG emissions and human contribution to climate change	Use a consumer-based approach to track human pressure on the planet in terms of the water volumes required for human consumptions
Data and resources	• Data on local production import and export for agricultural, forestry and fisheries products • Land use data • Local and trade embedded CO_2 emission • Land yield and potential crop productivity	• National economic accounts • International trade statistics • Environmental accounts data on GHG emissions	• Data on population • Data on available lands and total renewable water resources and water withdraws • Data on international trade in agricultural and industrial produces • Local data on various parameters such as climates, cropping , etc.
Unit	• Global hectares (gha) of bioproductive land • Actual physical hectares	• kgCO_2 for CO_2 only • kgCO_2-e when other GHG included	• Water volume per unit of time (m^3/yr) • m^3/tonne or litre/kg for the water footprint of produces
Strength	• Allows benchmarking human demand for renewable resources and carbon uptake capacity with	• Allows for a comprehensive assessment of human contribution to GHG	• Represents the spatial distribution of a nation's water 'demand'

	nature supply and determine clear targets • Provides an aggregated assessment of multiple anthropogenic pressure • Easy to communicate and understand with a strong conservation message	emission • Consistent with standards of economic and environmental accounting • Consistent emissions data available for the majority of counties	• Expands traditional measures of water withdrawals • Visualizes the link between consumption and appropriates of freshwater
Weakness	• Cannot cover all aspects of sustainability, neither all environmental concerns, especially those for which no regenerative capacity exists • Shows pressures that could lead to degradation of natural capacity, but does not predict this degradation • Not geographically explicit • Some underlying assumptions are controversial, though documented	• Cannot track the full palette of human demands on the environment • Additional impact assessment models are needed to analyse the impact of climate change at both national and sub-national levels	• Only tracks human demand on freshwater • It relies on local data frequently unavailable/ or lard to collect. It suffers from possible transactional errors • No uncertainty studies are available, though uncertainty can be significant • Grey water calculation heavily relies on assumptions and estimates

Source: Galli et al. 2012

From Table 2.5, CF and WF focus on GHG emissions and water resource separately, while EF focuses on resource consumption including land use, GHG and others. They are all consumer-based approaches to track human pressure on the planet, but in different terms. Compared with CF and WF, which focus on a single subject, EF provides an aggregated assessment of multiple anthropogenic pressures. There are some advantages in these three approaches, like EF is easy to communicate and allows benchmarking human demand for renewable resources and carbon uptake capacity. CF offers a comprehensive assessment of GHG emissions. WF expands traditional measures of water withdrawals. However, none of these three approaches can cover all aspects of sustainability, and some parts of the calculation heavily relies on assumptions and estimates (Gallie et al. 2012).

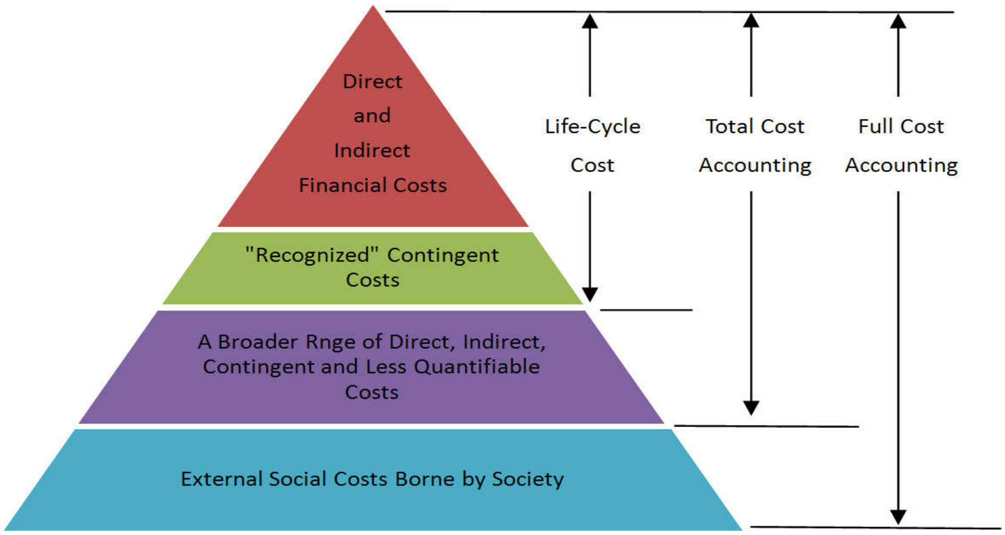
2.4.2 Economic assessment approaches

The building industry around the world is now facing many substantial challenges, which include meeting society's requirements for sustainable buildings as well as reducing the cost of buildings for both construction and operation stages. The initial cost of buildings can be reduced by adopting more appropriate construction methods, simplifying the structure, etc. However, reducing the initial cost of building is far from enough. According to Flanegan and Norman (1989), operation and maintenance costs consist of approximately 55% of the total cost in a 40 year life span. Bull (1993) states that in some developed countries, about 60% of the total project budget has been spent on repair and maintenance. This phenomenon reveals that there is a critical need to not only design durability and construct economically, but also planned finance, maintenance and repair scheduling.

Sterner (2000, pp 388) states that "one way to create a more comprehensive view of costs in the different phases of a building project is to perform life cycle cost analysis." Life cycle costing (LCC) is a technique which enables comparative cost assessments to be made over a specified period of time. It takes into account all relevant economic factors, both in terms of initial and future operation costs as detailed in ISO 15686 (Pelzeter 2007). Ferry and Flanagan (1991, pp 9) further state that "it puts the estimated capital, maintenance, operating and replacement costs into a comparable form and brings them into a single figure which allows for the fact that these items for expenditure will take place at different stages within the time-scale." In that case, comparison can be made among different design options and investment can get the optimum value by choosing the most suitable one.

Except for LCC, there are some other methodologies that can be used to account and provide for a more comprehensive view of costs, such as total cost accounting (TCA) and full cost accounting (FCA) (BC MELP 1997). Figure 2.3 shows the differences among these three methods. Total cost accounting considers a broader range of direct, indirect and contingent costs of buildings. Full cost accounting takes an even broader range that accounts for environmental and social costs associated with buildings into consideration (Spitzer et al. 1993).

Figure 2.3 Cost accounting methods



Source: BC MELP 1997

In the past decades, many researchers have dedicated relevant research in this field. In addition to the LCC, TCA and FCA, as discussed above, the full cost pricing (FCP), life cycle accounting (LCA*), life cycle cost assessment (LCCA) and whole life costing (WLC) are proposed by researchers and organizations (Spitzer et al. 1993; EPA 1993; Bennett& James 1997; Clift & Bourke, 1999). Table 2.6 summarizes these different forms of economic approaches since the last century. Though they have different names and descriptions, they all have similar objectives and involve estimating all cost elements of a project from life cycle perspective.

Table 2.6 Summary of different forms of economic approaches

Types	Description	References
Life cycle costing (LCC)	A technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial costs and future operation costs	ISO 15686
Total cost assessment (TCA)	Long-term, comprehensive financial analysis of the full range of internal costs and saving s of an investment	White & Becker 1992 Spitzer et al. 1993
Full cost accounting (FCA)	Identifies and quantifies the full range of costs throughout the life cycle of the product, product line, process, service or activity	Spitzer et al. 1993
Full cost pricing (FCP)	Term used as a synonym for FCA or LCC	Spitzer et al. 1993
Life cycle accounting (LCA)	The assignment or analysis of product-specific costs within a life cycle framework	EPA 1993
Life cycle cost assessment (LCCA)	Systematic process for evaluating the life cycle cost of a product or service by identifying environmental consequences and assigning measures of monetary value to those consequences	Bennett& James 1997
Whole life costing (WLC)	Synonym for TCA or LCC. More specifically defined as the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset	Clift & Bourke, 1999

Source: adapted from Gluch & Baumann, 2004

In this research the TBL approach that includes environmental, economic and social aspects will be used to assess performance of a building from a life cycle perspective. The methods such as TCA and FCA cover the environmental and external social cost will cause double counting. Thus, LCC will be used to assess the economic aspect of building performance.

Olubodum et al. (2010) state that the validity and usefulness of LCC make it suitable for practical applications and implementation within the construction industry. Nowadays, LCC has been widely used in assessing economic performance of buildings. Table 2.7 summarizes some of these research undertakings.

Table 2.7 Life cycle cost analysis of buildings

Research studies	Major findings	References
Analyze energy-saving renovation measures for urban existing residential buildings in China	A significant potential of energy savings can be made from high-performance building envelops of the existing residential buildings in Hangzhou city, China	Ouyang et al. 2009
Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings	The investor's time horizon determines the cost-effective building design for many building type-location combinations	Kneifel 2010
Analyze a multi-storey residential Net Zero Energy Building in Denmark	The investment in energy efficiency is more cost-effective than investment in renewable technologies.	Marszal & Heiselberg 2011
Analyze energy saving in residential buildings for different types of construction masonry blocks	LCC was performed in order to estimate the optimum thickness, saving and pay-back period which minimizes the total cost including the masonry material and energy consumption costs. Results find that the highest energy saving was obtained by the use of hollow blocks with 4 rows; the most suitable fuels for all climate zones appear to be electricity and fuel-oil.	Uygunoğlu & Keçebaş 2011
Analyze construction cost of upgrading ageing residential buildings in China	Among all the investments, only one third of the original investment costs was spent on energy savings	Ouyang et al. 2011

As the LCC analysis estimates all the cost elements of the subject and translates them into cost at present, there are three key areas that must be considered to facilitate the purpose of LCC (Olubodum et al. 2010):

- Firstly, LCC must obtain the capital cost and it includes the cost of maintaining and operating, and subsequent cost of replacement or disposal.
- Secondly, the life span should be considered when making assumptions or predictions. This will determine the operational period and the frequency of the maintenance or replacement of the elements.
- Thirdly, it needs to involve forecasting future market conditions such as interest rates, inflation and risk.

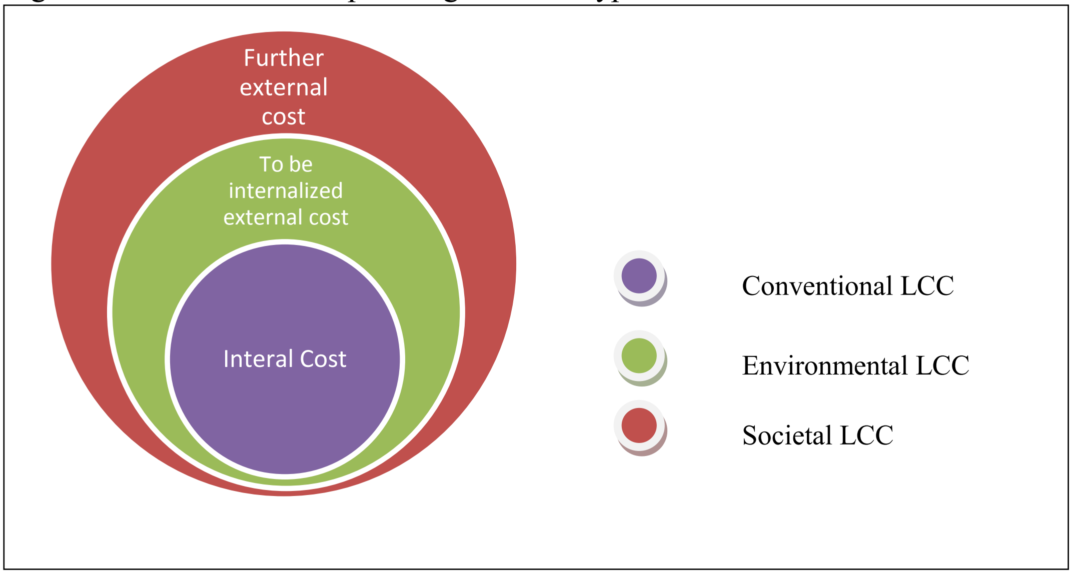
Aouad et al. (2001) state that these factors determine the discount rate which will be used to calculate future costs. The lowest discounted rate to be applied would be the market interest rate corrected for inflation, or the cost of equity, with the upper range being the internal rate used by organizations for their intended return on investment (Hunkeler et al. 2008). Discount rate affects the result of an LCC calculation significantly. Sterner (2000, pp 388) states that "choosing a discount rate which is too high will bias decisions in favour of short-term low capital cost options, while a discount rate which is too low will give an undue bias to future cost savings".
As the deficiency of sufficient cost data and other uncertainties are concerned, some questions have arisen about whether LCC calculations are in fact beneficial on the decision making process of construction projects (Olubodum et al. 2010; Sterner 2010). One is that, in many areas, the common practice is to choose the design option with the lowest capital cost and do not consider the operation and maintenance cost (Bull 1993). Another obstacle is from the complications and difficulties in life cycle cost estimation. According to the discussions above, an accurate calculation of LCC needs sufficient cost data as well as accepted industry standards for describing the life cycle behaviour of facilities and internal process systems (Abraham & Dickinson 1998). However, the cost data is sometimes difficult to get due to the limited ability to foresee future consequences and the limitations of reliable historical information on costs (Sterner 2000). That is the reason to estimate many of the parameters. For the parameters which are uncertain in the calculation, estimation is needed and this is criticized as a cause for inaccuracy (Hunkeler et al. 2008). Gluch and Baumann (2004) state that another limitation of the tools based on LCC as "using discount rates that rely on principles based on today's knowledge may result in future costs from decisions being given relative small weight in the LCC calculation."

In the process of the LCC development, another two types of LCC methods have been developed – environmental LCC and societal LCC (Rebitzer & Hunkeler 2003;

Hunkeler et al. 2008). Conventional LCC, as discussed above, is the assessment of all costs associated with the life cycle of a product that are directly covered by the main producer or user in the product life cycle. According to Hunkeler et al. (2008), conventional LCC is, to a large extent, based on a purely economic evaluation, considering various stages in the life cycle. Environmental LCC is the assessment covered by one or more of the factors in the product life cycle, with the inclusion of externalities that are anticipated to be internalized in the relevant future decision (Rebitzer & Hunkeler 2003).

Societal LCC is the assessment covered by anyone in the society, whether today or in the long-term future (Hunkeler et al. 2008). All of environmental LCC plus additional assessment of further external costs will be included in societal LCC (Figure 2.4). Table 2.8 summarizes the differences among these three types of LCC methods. The most improvement of environmental LCC and society LCC is that they take external cost into consideration, which includes the environmental and social impacts not directly borne by any of those taking part in the product life cycle.

Figure 2.4 The relationship among the three types of LCC



Source: Rebitzer & Hunkeler 2003; Hunkeler et al. 2008

Table 2.8 Comparison of the three types of LCC

Aspects	Conventional LCC	Environmental LCC	Society LCC
Value added compared to conventional LCC	-	Consists environmental assessment (LCA) at the same time	Opportunity costs or credits considered
Product system	Life cycle, without EoL* phase	Complete life cycle	Complete life cycle
System boundaries	Only internal costs	Internal costs, plus external costs expected to be internalized	Internal plus all externalities
Cost model	Generally quasi dynamic model	Steady-state model	Generally quasi dynamic model
Discounting of result of LCC	Recommended	Inconsistent and not recommended	Recommended
Note: EoL* - end of life phase			

Source: Hunkeler et al. 2008

Substantially, the definition of the three types of LCC methods is similar to the definition of three economic approaches - LCC, TCA and FCA (see Figure 2.4). The further developments of the LCC method, which make it cover broader concepts that include internal and external cost, coincide with the definition of TCA and FCA. The difference between conventional LCC and the other two is the number and type of costs incorporated in the analysis treated as ‘contingency’ cost as well as the broader environmental and social costs.

However, some criticisms still exist about traditional LCC. Cole and Sterner (2000) state that the lack of access to reliable performance data, the lack of universal methods, standard formats, etc. all become the limitations when applying LCC method in the construction industry. However, they further indicate that although there are some limitations of the LCC method, it is still a “valuable approach for comparing alternative building designs” (Cole & Sterner 2000, pp 374). Kirkhan et al. (2002)

supported it by describing LCC as a valuable tool in assessing economic efficiency of construction facilities. Schade (2007) states that LCC is an important tool which can make the construction client to be involved in early stage of decision making.

In applying traditional LCC methods into building assessment, the life expectancy of materials and products needs to be discussed first. This study focuses on the building assessment in China, where many of the LCC studies are based on the international literature (Ouyang et al. 2009; Zhang & Xiao 2009; Ying & Neng 2010; Ouyang et al. 2011). In addition, data for life span of building materials and components is limited in China and according to Ying and Neng (2010) the life span of construction materials/components in China is quite similar with data in the west. The Australian Cost Management is one of the currently used standards in this field and, therefore, it was used as a base for studying LCC for this research. Table 2.9 presents the economic life span of some common building materials/components.

Table 2.9 Economic life of building components

Elements	Components	Economic life (years)
Roofs	Pitched clay tiles	40-75
	Pitched concrete tiles	30-50
	Asphalt	20-25
External walls	Brickwork	40-75
	Curtain wall systems	35-40
	Precast concrete	10-70
External door	Timber	10-15
	Aluminum	15-25
	Glass	15-25
	Steel-roller	20-40
Windows	Aluminum	15-25
	Timber	10-15
	Steel - Plain - PVC coated	 10-15 10-25
Internal doors	General	25-30

Wall finishes	Plasterboard	10-15
	Render	20-30
	Ceramic tiles	15-20
	Terrazzo	35-45
	Timber paneling	30-75
	Faced brickwork	40-75
	Painting / decoration - Wallpaper - Painted render - Painted woodwork - Stained / clear finishes - Painted metalwork	 5-10 5-10 5-10 7-12 5-10
Floor finishes	Carpet	5-15
	Quarry tiles	25-30
	Ceramic tiles	35-40
	Hardwood T&G strip	20-50
	Softwood T&G strip	15-20
Ceiling finishes	Timber strip	30-50
	Suspended - Plaster tile - Metal panel - Mental strip - Acoustic plaster tile	 20-30 25-40 15-20 25-40
Sanitary fixtures	Generally	15-20
Sanitary plumbing	Generally	20-25
Water supply	Generally	20-25
External site surfaces	Bitumen - Entrance roads - Paving	 8-10 15-20
	Concrete paving	20-25
	Brick paving	30-40

Source: Australian Cost Management Manual, Volume 3, pp 52

In addition to the life span of materials/components, the study period of whole project and the discount rate are also important when LCC is used. Ding and Shen (2010) use the discount rate of 5% when they developed the SDV model for sustainable performance of built projects. They use 40 year economic life span for bringing future costs and benefits into an equivalent monetary value to present day.

Zhang et al. (2006) define a life span of 50 years when they develop a life cycle building environmental performance assessment model-BEPAS. During the 50 years, the projects contain material exploitation, material production, construction and installation, operation and maintenance, and demolition. Varun et al. (2012) also use 50 year life span for their research on life cycle environmental assessment of an educational building in Northern India.

Blengini and Di Carlo (2010) conduct a detailed life cycle assessment on a low energy family house in Northern Italy. They use a 70 year building life span which covered pre-use and maintenance, use, and end-of-life phase. Peuportier et al. (2013) conduct a research of life cycle assessment with a sensitivity study on 50 year and 100 year life spans. These results show the possibility to reduce most environmental impacts and rely on the efforts made by professionals in the design and construction stage. The inhabitants to adopt a more sustainable behaviour can also help.

Based on the discussion above, the life span of between 40 to 70 years is believed to be reasonable for building assessment. Therefore a 50 year life span is mostly used in LCC research studies in China (Zhang et al. 2006; Gu et al. 2009; You et al. 2011). According to this situation, as well as in accordance with the prevailing design specifications in China, 50 year life span is chosen for this research.

In the LCC analysis, sensitivity analysis is used to test the accuracy and robustness of the results. Neale and Wagstaff (1985) conduct sensitivity analysis in their research about discounted cash flow and life cycle costing for construction projects. Ding (2005) conducts a research about developing a multi-criteria approach for the measurement of sustainable performance. A 5, 10 and 15% discount rate was used to calculate the net present value of the three design options of a project. The results show that all three options are acceptable with regard to the 5% discounted rate, whilst all three options are unacceptable with regards to the 15% discounted rate. At a 10% discounted rate, only one option is acceptable.

2.4.3 Social assessment approaches

Social performance assessment is another essential component in the triple bottom line approach. However, in the past, social impacts are ignored due to people's misunderstanding and misconception that social impacts seldom occur or cannot be measured, slow down or stop projects' development as it always deals with costs, not benefits (Burdge 1987). Labuschagne and Brent (2006, pp 3) state that "the social dimension is commonly recognized as the 'weakest' pillar of sustainable development due to a lack of analytical and theoretical underpinnings." Lehtonen (2004) believes that the development of measurement techniques for social pillars fall behind approximately 20 years of the development of environmental performance assessment. The framework for social assessment such as social impact assessment (SIA) has been developed since early 1970s. Since then several other approaches have been developed for assessing social impact (Vanclay 2003; McElroy et al. 2007).

i) Social impact assessment (SIA)

Social impact assessment (SIA) was developed in early 1970s and it offers an effective means of anticipating and planning for social impacts prior to project development (Burdge 1987). It has emerged along with EIA and as part of the United States National Environment Policy Act of 1969 (NEPA) (Ortolano & Shepherd, 1995). The US Inter-organizational Committee (1993, pp 1) defines SIA as:

> "Social impact assessment in terms of efforts to assess or estimate, in advance, the social consequences that are likely to follow from specific policy actions

> (including programs, and the adoption of new policies), and specific government actions."

This definition has been updated in 2003 by broadening the scope to include private projects and regulations (USIC 2003, pp 231-232):

> "In the 2003 version, we continue to define social impact assessment in terms of efforts to assess, appraise or estimate, in advance, the social consequences that are likely to follow from proposed actions. These include: specific government or private projects, such as construction of buildings, sitting power generation facilities, large transportation projects, managing natural resources, fish and wildlife."

With the development of SIA, the measurement of social impacts becomes relatively reliable because data can be collected and evaluated in project or at community level (Burdge 1987). Some SIA models are established to assess the magnitude, duration and sequence of social affects. Burdge (1987) conducts a research on developing a social impact assessment model to be incorporated in the planning process. It allows the social concern to be considered during the initial phase of planning instead of after the decision has been made. According to Burdge (1987, pp 143), "social impact assessment generally increases the price of the project. In the long run, it always saves money."

The International Handbook of Social Impact Assessment defines the SIA into three types of micro, meso and macro (Becker & Vanclay 2003). Micro-social impact assessments focus on individuals and their behaviour; meso-social impact assessments focus on organizations or social networks (including communities); and macro-social impact assessments focus is national or international wide.

At project level, the social effects will be different for each stage as not all impacts will occur at each stage (Burdge 1987). Data expectation in SIA contains both qualitative and quantitative indicators relevant to the activity. Both direct and indirect effects of social impacts are observed, measured and interpreted in the SIA process (Burdge 1987). It can provide information about the likely benefits and costs of social impacts to the community leaders, planners and project proponents (Finsterbusch 1980). However, it is difficult, to some extent, to measure the procedures for each project. Burdge (1987) in a research outlining the consideration of social impacts in the planning process explains the SIA model as well as the way for measurement. He suggests that the major difficulty in the application of SIA process has been in identifying and measuring the social impacts that occur with each project.

To some extent, SIA has been criticized as a component of EIA, since the environment is defined broadly as some social issues are treated as part of the environment in former research studies (Partidario2000). But Vanclay (2002) comments that SIA is more than a component of EIA, it is a philosophy about development and democracy. Vanclay (2002) in a research on conceptualizing social impacts states that SIA should consider:

- Pathologies of development (i.e. harmful impacts)
- Goals of development (clarifying what is appropriate development, improving quality of life)
- Processes of development (e.g. participation, building social capital)

Becker (2001) comments on the usefulness of SIA as it fails to consider the positive outcomes of development and treat impact on individual instead of whole society. Vanclay (2004) further states that similar to EIA, SIA is meant to be applicable at the policy and project level, but it is trapped at the project level in practice and experience.

The criticisms seem to point to the fact that SIA can be better used when it is combined with other approaches to incorporate economic and environmental aspects into the assessment. At the early stage of SIA development Wolf (1975) indicated that in order to make SIA a useful tool, it should only be in conjunction with those of economic and environmental impact assessments.

ii) Other social assessment approaches

Except the SIA, there are some other approaches developed for assessing social impact and they are social benchmarking, social footprint, etc. They are developed in the past decade to supplement social impact assessment (Porte et al. 2001; Cary & Pisarski 2011; Fitzsimons et al. 2012).

Porte et al. (2001 pp 292) define social benchmarking as a tool "by which an organization assesses how well it is meeting its objectives and how they could be more effective." Cary and Pisarski (2011 pp 1148) use social benchmarking in their research on improving river ecosystems. They state that "a benchmark is simply a standard by which something can be measured or judged and change over time". Boyd and Kimmet (2005) in their research on applying triple bottom line approach to assess property performance suggest that social benchmarking can be used to complete the triple bottom line performance assessment approach to the evaluation of operational built assets.

The social benchmarks used will vary depending on a number of variables, such as asset type, utility and locality, and will change over time according to market demands, social attitudes and political and economic conditions (Boyd & Kimmet 2005). Sayce and Ellison (2003) state that social benchmarks should be in accessible format that allow meaningful comparison of one building with another. At the same time, it should be used as a standard appraisal tool, without specialist environmental or engineering training.

Boyd and Kimmet (2005) conduct a research study on the development of triple bottom line performance benchmarks for operational built assets. In their research, a series of indicators and measures are identified. For example: health and safety is measured by compliance with H & S regulations and appropriate signage; adequate public liability and service provider insurance, etc. Other indicators also assessed in social benchmarking in their research included stakeholder relations, community engagement, accessibility, occupier satisfaction and productivity, cultural issues, and local impacts (Boyd & Kimmet 2005).

Social footprint (SF) method is a social sustainability measurement model, which was developed by McElroy et al. (2008) in their research on sustainability quotients and the social footprint. It is a measurement for quantifying the social sustainability performance of an organization. The SF addresses the impacts on anthrocapital (human, social, and construction) (Center for Sustainable Organizations 2009). It is a context-based measurement model for determining the social sustainability of a human collective, analogous to the manner in which the EF functions for ecological concerns.

Except for those approaches mentioned above, there are other ways for social impacts assessment and they are summarized in Table 2.10.

Table 2.10 Methods to calculate social impacts

Methods	Content	References
The health footprint (HLF)	HLF is the measurement of an individual's health, and the effect that an individual's health may have on those around them. The healthier the decisions made, the higher the HLF becomes	Anthem Insurance Companies Inc., 2011
Expert panel interview	a. Way of life -how they live, work, play b. Culturally -shared beliefs, customs, values c. Community-stability, cohesion, services, and facility	Vanclay 2003
Contingent Valuation Technique	This technique is used to survey a representative sample of the local population on how much they value a particular non-market preference. It can be applied to environmental protection or society improvements. The method tries to identify people's preferences by asking direct questions about how much they are willing to pay (willingness-to-pay, WTP) to obtain, maintain, or increase some environmental benefits. Another form of the contingent valuation technique is the willingness-to-accept (WTA) as compensation to tolerate an environmental loss. An example would be how much they are ready to pay for the preservation of a particular recreational area (WTP), or what compensation they would be willing to settle for if there was damage to that area	Gilchrist & Allouche 2004
Aesthetic impact assessment	a. Impact due to visibility b. Impact due to colour c. Impact due to efficiency	Torres-Sibille et al. 2009

The approaches mentioned above are used for social assessment in research studies. All of them have their own advantages and limitations. Social benchmarking needs regulation and policy support; social footprint focuses on a broader range of impacts; aesthetic impact assessment focuses on a particular aspect of the society. Compared with them, SIA, for one thing, is suitable for project level, for another it is good to incorporate the methods in environmental and economic aspects in this research.

2.5 Summary

In this chapter, the sustainability concept and the triple bottom line of sustainability were discussed. After that, an overview of triple bottom line for building assessment was conducted. The environmental assessment approaches, economic assessment approaches and social assessment approaches for assessing building performance are analysed. In environmental assessment, different approaches are discussed including LCA and consumer-based approaches, followed by their application in the construction industry. In economic assessment, different cost accounting methods including LCC, TCA and FCA were discussed. Furthermore, different forms of LCC and the application of LCC in the construction industry were also discussed. In social assessment, SIA and other approaches were reviewed in this chapter including social footprint, social benchmarking, etc, as the aim of this research is to establish a sustainable building assessment model based in building process in China. The current environmental building performance assessment methods will be analysed in the next chapter. The sustainable building development and assessment in China will also be discussed.

CHAPTER 3

SUSTAINABLE BUILDING AND SUSTAINBLE ASSESSMENT

3.1 Introduction

Construction industry is one of the major sources of environmental pollution. The environmental problems caused by construction range from energy and resource consumption to waste production throughout the building life cycle. Sustainable performance of construction projects is an indispensable aspect for a country to attain the goal of sustainable development. With increasing attention being paid to building sustainability performance, numerous environmental assessment tools have emerged worldwide. They have been developed and used to assist planning and designing of sustainable buildings, and help raising overall environmental awareness and achieving the goal of sustainability in the construction industry. In this chapter, the sustainable building and different building assessment tools are discussed, as well as the specific situation of environmental sustainable development in China.

3.2 Impacts of building on the environment

Buildings have great impacts on the environment. It is one of the main energy users and GHG emitters (Wu et al. 2012). In Canada, residential and commercial/institutional buildings consume about 30% of the total energy use and are responsible for approximately 29% of CO_2 equivalent GHG emissions during their operating phase (Finnveden & Moberg 2005). In the US, buildings account for 39% of the total energy consumption and within which 70% was electricity consumption (Koroneos & Kottas 2007). About 38% of CO_2, 52% of SO_2, and 20% of NO_x are produced in the US because of building-related energy consumption. In the UK, the building sector is responsible for about 40-50% of energy consumption (Finnveden & Moberg 2005). In Brazil, buildings account for more than half of the national energy use during their operating (Melchert 2007).

In China, the building sector also accounts for an important part of environmental problems (Qiu 2007). In 1992, energy consumption in building operating stage amounted to 15% and this figure has increased since then (Jiang 2005; Qiu 2007). According to Jiang and Tovey (2009), buildings accounted for more than one quarter of the total energy consumption in China in 2009. In 2013, building-related energy consumption has increased to 34% and it is likely to increase continually (Li 2008; Wu & Xu 2013).

With respect to the energy consumption by buildings in China, it includes the energy used in maintaining thermal comfort and operations, as well as the energy embedded in the material manufacturing, construction process, and transportation. Among these energy consumptions, heating and cooling amounted to 60-70% (Wu & Xu 2013).

High energy consumption is accompanied by a large amount of GHG emission. According to Cai et al. (2010), 5 billion tonnes of CO_2 equivalent emission was generated by the energy use in 2010. With rapid urbanization in China, this figure would grow by 11% annually (Qiu et al. 2007). Li (2008) forecasted that the GHG emissions produced by the building sector will rise to 25% by 2030.

Another source for the higher GHG emissions and resulting air pollution is the process of converting raw materials into energy (Cai et al. 2010). According to the China

Statistical Yearbook (2011), 70% of the total primary energy source in China was generated from the burning of coal. Jiang et al. (2013) stated that 0.8kg of CO_2 is produced withthe generation of 3.6 MJ of electricity in China compared with 0.69 kg of CO_2 in the UK. This figure is likely to increase with an increase in the demands for comfort living environments due to the revenue growth and rapid urbanization process for the next 20-30 years (Cai et al. 2010).

In addition to contribution to energy consumption and GHG emission, construction waste is another major environmental problem. Construction waste is a major source of municipal solid waste around the world (Li & Zhang 2013). In Brazil, site activities generate up to 40% of the total waste generated from construction (Melchert 2007). In the UK, over 100Mt waste are produced by the construction industry per year, about a third of all UK waste arising (Hobbs et al. 2011). In some mega cities around the world, construction waste is also a major source of municipal solid waste. Frequently, the construction waste consists of 10 to 30% of the total waste. In Hong Kong, construction waste account for 30 to 40% of the total waste (Wong et al. 2006). The Hong Kong Development Protection Department (2010) predicted that with an estimated 24% annual increase in construction waste disposal, the land fill facilities in Hong Kong would be full by 2017. In Chicago, 4,656,037 tons of construction waste was generated in 2007, accounting for 61% of the total waste (7,669,097 tons) generated that year (CDM 2010). In addition the construction industry also account for approximately 17% of the fresh water consumption, 25% of the wood harvest, and 40% of resource use globally (Sev 2011).

With these environmental issues caused by the building sectors, social and economic problems have followed. McGraw-Hill Construction (2008) stated that construction industry has an annual output of US $4.6 trillion worldwide. It contributes approximately 8-10% of the global gross domestic product (GDP) along with a workforce of 120 million people. In the US, construction industry contributes to 13.4% of the US GDP, where the commercial and residential building construction comprises 6.1% (Chan et al. 2009). In the European Union, construction industry is the largest industry employer with 11.8 million operatives directly employed. This figure accounts for 7% of total employment and 28% of industry employment in the EU-15 (European Commission 2006). The European Commission (2006) further stated that about 910 billion Euros was invested in construction in 2003, comprising 10% of the GDP and 51.2% of the Gross Fixed Capital Formation of the EU-15. Furthermore, the importance of construction sector related to social problems also causes attention (Ofori 2003). As stated in the Agenda 21 for Sustainable Construction in Developing Countries in 2002, regions marked by economic problems and extreme poverty within developing countries have much more accentuated social problems, particularly in urban areas, such as slums and illegal settlements, where the lack of proper infrastructure, sanitation and housing leads to the contamination of soils and water bodies.

With the increasing awareness of the environmental aspects of building sustainability, plenty of approaches are developed to assess environmental impact from different viewpoint and for a variety of users (Joshi 2000; Singh et al. 2011; Wade et al. 2012; Alvarenga et al. 2013). Among them, life cycle assessment (LCA) and consumer-based approaches are widely used in construction industry nowadays as discussed in Chapter 2 (Ortiz et al. 2009).

3.3 An overview of environmental building performance assessment methods

As the building sector has great impact on environment, as well as the economic and social, more attention has been paid to the green buildings (Chiang et al. 2001). Chan et al. (2009) stated that the green buildings can save their occupants 8-9% in operation costs once completed, though it costs a bit more to be constructed. This would add up to significant saving over time. Kats et al. (2003) stated that the green design in LEED certified building can bring financial benefits from $50 to $70 per square foot, which is more than ten times the additional cost caused by construction green. McGraw-Hill Construction (2008) supported this viewpoint by stating that the reduction in operating costs of green building has increased from 8.9 to 13.6%. They further stated that building values also increase from 7.5-10.9% as it become ‘green’. The increasing demand for green building calls for the sustainable assessment methods to evaluate the building performance and regulate the construction market (Chan et al. 2009). In this section, building performance modelling and environmental building assessment tools are analysed.

3.3.1 Building performance modelling

In the past decades, many assessment models are established for assessing building performance. Gangolells et al. (2009) presented a model for predicting and assessing the environmental impact of building in the construction process. In their research, the environmental aspects related to the construction process were identified. After that, they developed the indicators of environmental aspects related to the construction process as well as the formulation of the significance limits. In the end, the overall environmental impacts of a construction project were determined. This model was based on the construction process and activities, and the impact is assessed by the duration, scale and probability of occurrence.

Bilec et al. (2010) presented a life-cycle assessment model of construction processes for commercial buildings. It also examined the environmental impacts due to the construction stage of a building. Their research conducted using the hybrid LCA to model the construction phase, which combined the advantages of process LCA and EIO-LCA. The process LCA assessed the environmental inputs and outputs by using a process flow diagram, while the EIO-LCA quantified proportional interrelationships among sectors in economy (see Chapter 3.3). Bilec et al. (2010) chose the hybrid LCA due to the reason that it could improve the time and cost associated with the process LCA and developing an inclusive boundary. They further indicated the reason as the hybrid LCA decrease reliance on the limited amount public data, and utilize available data within the context of excising structure of the construction industry. Finally, a hybrid LCA model was created in the software program Analytic, and it included construction processes from site preparation to painting and also included detailed modelling of construction equipment combustion.

Ali and Al Nsairat (2009) developed a green building assessment model for Jordan and name it as the SABA green building rating system. In their model, three aspects include environmental, economic and social impacts have been taken into consideration. Seven categories have been chosen depend on the situation of Jordan include site, energy efficiency, water efficiency, material, indoor environment quality, waste and pollution and cost and economic. Analytical Hierarchy Process (AHP) method was adopted for dealing with the multi-dimensional criteria for decision making. Though this model mentioned about address all stages of building life cycle with regards to sustainable issues, it has not integrated the assessment criteria into the building process. Besides, there was no quantification for each category in this model, and the score were based on the interview ranking.

Ding and Shen (2010) presented a model to integrate the sustainability assessment into the building process and name it as the sustainable development value (SDV). It measured the building sustainability in different stage of a building life cycle; include inception, construction, commissioning, operating and demolition. The SDV in each stage would be amalgamated into the model of sustainable development ability (SDA). It was the first assessment model that integrates the sustainability assessment in building process. However, the three pillars in their research to demonstrate the sustainable performance are economic, energy and environmental. These three criteria would be insufficient to reflect the building performance as energy can be considered as part of environmental aspects and other social aspects are also not included in this model.

Akadiri et al. (2013) conducted a research about multi-criteria evaluation model for the selection of sustainable materials for building projects. They stated that the sustainable assessment criteria should be chosen based on the TBL and the need of stakeholders. They mentioned about four guidelines for selecting sustainable assessment criteria; these include comprehensiveness, applicability, transparency and practicability. Comprehensiveness means the criteria chosen should cover all the aspects in sustainability, include environmental, economic and social aspects. They stated that the criteria chosen need to "have the ability to demonstrate movement towards or away from sustainability" (Akadiri et al. 2013, pp 116). Applicability means the criteria chosen should be applicable across the range of options. Transparency means the criteria should be chosen in a transparent way, which helps the stakeholder to identify which criteria need to be considered due to their purpose. Practicability means the criteria need to be practicable to be used and the time and resources need for the assessment are reasonable.

These researches on building assessment modelling give examples about how to establish a model about sustainable building performance, how to choose the assessment criteria and how to deal with the multi-dimensional criteria. The questionnaire and interview are commonly used in these researches for data collection (Ali & Al Nsairat 2009; Bilec et al. 2010; Akadiri et al. 2013). In the models on the performance of building life cycle, they mention the three pillars in building process. However, few of them truly achieve this objective.

3.3.2 Sustainable building assessment tools

With increasing attention being paid to building sustainability performance, numerous sustainable assessment tools (SATs) have emerged to evaluate environmental performance of buildings. Some of these tools include BREEAM (UK), Green Star (Australia), CASBEE (Japan), LEED (USA) and BEPAC (Canada). The Building Research Establishment Environmental Assessment Method (BREEAM) developed by the Building Research Establishment (BRE) in UK was the first sustainable building assessment tool, and came into prominence in 1990 (Prior 1993). The first version of BREEAM for offices was first revised in 1993, and further revised in September 1998. The current BREEAM version for non-domestic premises is BREEAM 2004, which covers a range of building types, including offices; industrial premises; retail outlets; schools, etc. It is the best-known scheme and has embraced 15-20% of the new office building in the UK (Haroglu 2013).

Building Environmental Performance Assessment Criteria (BEPAC) in Canada was launched in 1993. It is a voluntary tool that comprises a comprehensive set of environmental criteria and these criteria have been structured in five major topics (ozone layer protection, environmental impacts of energy use, indoor environmental quality, resource conservation and site, and transportation (Cole 1994). In 1995, the Green Building Tool (GB Tool) was launched as the first internationally developed tool. It is a rating system that handles both new building and renovation projects for multi-unit residential, office and school developments. Potential energy and environmental performance of buildings are assessed in this system using four levels of parameters (Fowler & Rauch 2006).

Leadership in Energy and Environmental Design (LEED) is developed by the US Green Building Council (USGBC). The pilot version (LEED 1.0) for new construction was first launched at the USGBC Membership Summit in August 1998. Since then, LEED continues to evolve to respond to the needs of the market and has expanded to other building types. The current version of LEED contains 9 branches. The LEED in the US consists of four levels of certification and five overarching categories corresponding to the specialties that are available under the LEED Accredited Professional program.

Green star has been used in Australia since 2003. It is a voluntary rating system used for many different types of buildings incorporating seven assessment criteria. It is Australia's first comprehensive method for evaluating environmental building performance (Ding 2008).

Comprehensive Assessment System for Built Environment Efficiency (CASBEE), which originated in Japan 2004, considers regional characters and assessing impacts for four phases of buildings. It is applicable in accordance with the stages of a development in pre-design, new construction, existing building and renovation. The environmental capacities are determined by the concept of closed ecosystems in CASBEE (Ding 2008).

Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is developed by the German Sustainable Building Council and the German Government (http://www.dgnb-china.com/). It includes ecological quality, economic quality, sociocultural and functional quality. In the meantime, the technical quality, process quality and site quality are also taken into consideration.

Several comparative analyses have been conducted by the researchers in recent years, including Ding (2008), Haapio and Viitaniemi (2008), Nguyen and Altan (2011), Ng et al. (2013), etc. Table 3.1 summarizes the key features of four selected SATs due to their relative maturity of development and their widespread use in practice (Nguyen & Altan 2011; Ng et al. 2013). The popularity and influence of these SATs are also discussed in the Table 3.1.

Table 3.1 The key features of selected four SATs

Criteria		BREEAM	LEED	CASBEE	Green Star
First launch		UK (1990)	USA (1998)	Japan (2001)	AU (2002)
No. of countries used*		21+	100+	1	1
No. of buildings involved	Registered	500,000+	27,000	-	404
	Certified	110,000+	4,400	80	237
Versatility**		12	10	1	0
Methodology Summary		Score-based system. Building's performance is rated based on overall score.	Score-based system. Building's performance is rated based on overall score.	Building is rated based on the "BEE Factor'	Score-based system. Building's performance is rated based on overall score.
Weightings		Applied to each issue category	All credits equally weighted	Highly complex system applied at every level	Applied to each issue category
Environmental criteria covered		Land use and ecology; pollution; waste; water; materials; energy; health and wellbeing; management; and innovation	Sustainable site; water efficiency; energy and atmosphere; materials and resources; IEQ; innovation in design; and regional priority	Global warming; air pollution; heat island effect; load on local infrastructure; noise, vibration and odour; wind damage and sunlight obstruction; and light pollution	Management; IEQ; energy; transport; water; materials; land use and ecology; emissions; and innovation
Rating levels		5 levels	4 levels	5 levels	6 levels
Standardization		Yes	Yes	Yes	Yes
Energy/ CO_2 simulation methodology		National Calculation Method (NCM)	Performance rating method - computerized	$LCCO_2$ standard calculation - no computerized	There is no baseline building required to be modelled

	- computerized modelling required	modelling required	modelling required

Note:

* Number of countries used means countries which have buildings assessed by the system

** Versatility means number of systems that use it as its basis for development or comparison

Source: Nguyen & Altan 2011; Ng et al. 2013

According to Cole (2005), a series of SATs include LEED and Green Star are developed based on the ground work of BREEM except CASBEE. The assessment results of buildings generated from BREEAM, LEED and Green Star are presented as total score by accumulating the points achieved under each of the identified environmental criterion (Ng et al. 2013). While CASBEE employs a ratio approach known as “building environmental efficiency” (BEE) determined by the quality (Q) and loading (L) (JaGBC & JSBC 2010).

These SATs are design to evaluate building performance against a series of environmental criteria include material and resource consumption, energy consumption, ecological loading, etc. (Cole 2005). Table 3.1 summarizes the environmental criteria covered by the four SATs, which include site management, energy efficiency, material and resources, water, IEQ, etc. BSRIA Ltd. (2009) stated that the indigenous climate and geography condition may vary on different locations and it is logical to incorporate certain environmental criteria which could reflect the local condition and requirement.

3.4 Sustainable building development and assessment in China

3.4.1 The development of sustainable building and legal systems

Since the last century, China started to realize the importance of green buildings. A series of rules and regulations have been devised to help promoting green buildings in China (Fan et al. 2013). The government support plays an essential role in sustainable building development in China. The legal systems for green building in China can be divided into three levels. On the top are laws which are launched by the Standing Committee of the National People's Congress. The second level is a series of administrative regulations issued by the State Council. It is followed by ministry rules such as the rules promulgated by the Ministry of Construction (MOC) (Ye et al. 2013). In addition, there are many Standards, Codes, and Technical Guidelines which must be met in the planning, design, construction or evaluation practice of green building.

i) Sustainable building laws and regulations

Table 3.2 summarizes the development of laws and regulations of green building in China. Full details such as regions and contents as well as the year and organization of issue of these laws, regulations and rules are included in Appendix A1 at the end of thesis.

Laws and policies on sustainable construction are the foundation of green building development in China (Ye et al. 2013). The Energy Conservation Law of China was the first green building related law promulgated in 1997 (see Table 3.2). Since the introduction of the law China has gradually paid attention to the building sustainability. This law is the top rule in the field of energy conservation. It requires construction projects to reduce energy consumption to meet certain requirement. This is the starting point of China to pay attention to building performance. It has been amended in 2007, and states that saving energy resource is one of China's basic national policies (Li et al. 2011). However, it has been criticized that the amendment did not provide detailed procedures for the implementation of projects (Hu 2012). Hu (2012) further stated that more detailed and regional policies and approaches are needed for the implementation.

Since the introduction of the Energy Conservation Law of China in 1997, a series of regulations and rules about energy conservation on residential building and public buildings have been issued (see Table 3.2). These regulations and rules focused mainly on energy saving. In 2004, a ministerial rule 'Process Management of National Green Building Innovation Award' was promulgated (Table 3.2). It considers the other environmental issues beside energy conservation, such as land saving, resource consumption, water consumption, outdoor environment, and indoor environmental quality.

In 2005, 'Provisions on the Administration of Energy Conservation for Civil Building' was launched. It is also a nationwide ministry rule, indicated heat preserving and thermal insulation technologies and materials, technologies for centralized heat supply and those for district heating supply and applied technologies and equipment utilizing solar energy, terrestrial heat and other renewable energies (Table 3.2). It regulates energy conservation, as well as optimizes the functions of the buildings based on the safety of structure.

Table 3.2 The development of legal system for sustainable buildings in China

Name	Year	Type	Content	References
Energy Conservation Law of China	1997	Laws	• Energy conservation administration • Rational utilization and energy conservation • Progress in energy conservation technologies • Incentive measures • Legal liability	http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/03/energy-conservation-law.pdf
Process Management of National Green Building Innovation Award	2004	Ministry Rules	• Land saving and outdoor environment • Energy saving and energy consumption • Water saving and water consumption • Material saving and material & resource consumption	China Architect &Building Press 2008, pp444

			• Indoor environmental quality and operation management	
Provisions on the Administration of Energy Conservation for Civil Building	2005	Ministry Rules	• Heat preserving and thermal insulation technologies and materials • Technologies for centralized heat supply and those for district heating supply • Applied technologies and equipment utilizing solar energy, terrestrial heat and other renewable energies, etc.	http://www.chinacourt.org/flwk/show1/php?file_id=106168
The Ordinance for Energy Conservation of Civil Buildings	2008	Administrative Regulations	• local energy conservation plan for civilian buildings • Specific funding for energy saving of civilian buildings • Energy conservation projects can enjoy tax exemption • Assessment criteria of building won't be endorse unless meet the energy conservation	http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176550.htm
The Ordinance for Energy Conservation of Public Buildings	2008	Administrative Regulations	• Examining the implementation of energy saving standards • Assessing the gross and per capita energy consumption • Examining the implementation of the proposals raised in the last auditing • Putting forward the new conservation proposals • Examining the implementation of annual energy conservation plan, and the actual consumption in contrast to the ration	http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176549.htm

In 2008, another two administrative regulations were issued, 'The Ordinance for Energy Conservation of Civil Buildings' and 'The Ordinance for Energy Conservation of Public Buildings'. The former one covers local energy conservation plan for civilian buildings and specific funding for energy saving of civilian buildings. The latter one encompasses examining the implementation of energy saving standards, assessing the gross and per capita energy consumption, examining the implementation of the proposals raised.

ii) Sustainable building standards and guidelines

Some standards also issued by MOC for some specific regions or building types, such as 'The National Standards for Energy Efficiency of Civil Buildings: for heating in residential buildings' and 'Design Standard for energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone' (see Table 3.3). Table 3.3 summarizes some of the standards as well as the guidelines for green buildings in China. The detail information include property, year of issue, organization of issue, region, applicable building type, criteria, and assessment method of all the standards and guidelines related to green building in China can be found in Appendix A2.

As the Chinese government issued the 12^{th} Five-Year Plan in March 2011, these laws and regulation are an important guarantee to achieve the goals include saving energy 16% than 2010, reducing GHG emission to 10% than 2010 national wide (Li & Wang 2012). It is the guideline for China's economic and social development for the next 5 years. The 12^{th} Five-year Plan proposed some green target for the coming years, include to reduce energy consumption of per unit GDP by 16%, and to reduce CO_2 emissions of per unit GDP by 17% (Hu 2012). Special plan for green building has also been issued during China's 12^{th} Five-Year Plan in January 2012. According to it, newly built green building will reach no less than 65% in towns and 95% of new buildings should meet the mandatory energy-saving requirements by the end of 2015 (Wu & Xu 2013).

Table 3.3 Standards and guidelines for green buildings in China

Name	Year	Building type	Important criteria	References
The National Standards for Energy Efficiency of Civil Buildings: for heating in residential buildings	1995	Civil buildings	• Index of building heat loss • Index of heating coal consumption	http://igshpa.org/edit/UploadFile/2007127102330678.pdf
Design Standard for energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone	2001	Residential buildings	• Index of heat loss • Index of cool loss • Annual cooling electricity consumption • Annual heating electricity consumption	http://www.ib-china.com/jzjn/law/xiare.pdf
Technical Guidelines for Green Building	2005	Residential buildings	• Criteria of green buildings • Technical outlines for planning and design • Technical outlines for construction	http://www.chinahouse.gov.cn/cyzc8/84173.doc
Technical Guidelines for Green Construction	2001	Construction operation	• Construction management • Environmental protection • Material saving & use of resource • Water saving and use of water	Technical Guidelines for Green Construction, Green Buildings 2008, p457
Outlines and Technical Principles for Green Building Quarter	2001	Residential community	• Residential power system • Water environmental systems • Air environmental systems • Sound environmental systems	http://jijian.sdkd.net.cn/ReadNews.asp?NewsID=33

These standards are the major energy conservation standards for residential buildings with consideration of the different climate zone. In addition, a number of technical guidelines also help to guide the green buildings for different types, for example, 'Technical Guidelines for Green Building' for residential buildings; 'Technical Guidelines for Green Construction' for construction process and 'Outlines and Technical Principles for Green Building Quarter' for residential community (see Table

3.3). Technical Guidelines for Green Building, which is issued by MOC and Ministry of Science and Technology (MST), was the first technical guideline for green building issued at ministry level. These guidelines have specific requirement for the energy saving and other green indicators for buildings. For example, according to the 'Technical Guidelines for Green Building', building's annual overall energy consumptions such as heating, ventilation, air conditioning and lighting required reducing to 50% by 2015 (Wu & Xu 2013).

This series of laws and regulations have improved the system of China's green building policy, and also promoted the green building concept in China. They also proposed economic incentive policies from various angles. It helps to improve the building performance by those energy conversation requirements and economic incentive policies to encourage the stakeholder to put more emphasis on the environmental aspects of the buildings. These laws, regulations and rules as well as a series of standards form the foundation for the development of China's green building (CSUS 2012). However, there are some criticisms about the legal system about green building in China. Kai and Wang (2012) in China Real Estate Research Community conducted a research about comparing the green building in China with the US, they state that some clause in the green building rules are conflict with the current regulations and standards in construction industry. They further stated that an SAT which considers the local condition and integrate current policy standard would help to improve the sustainable building in China.

3.4.2 The development of sustainable building assessment tools in China

Supported by the legal systems in China, the environmental building assessment developed gradually in these years. Firstly, China adopts the international sustainable assessment tools, such as LEED. When it come to realize some problems associated with adopting the international tools directly, such as regional difference, China begin to develop its own sustainable assessment tool.

i) The adoption of international sustainable assessment tools in China

In China, sustainable construction and green building are gradually becoming the focus of the government. During this period international green building assessment tools were adopted in China and these include LEED from the US, BREEAM from the UK, and DGNB from Germany. Among them, LEED is the most-adopted scheme in China as the building developers preferred to demonstrate the improved environmental performance of their building assets in attracting international investors (Chen & Lee 2013). LEED has strong bases and high market acceptance, followed by BREEAM and DGNB in China's construction market (CSUS 2012). LEED was the first international tool applied in China whilst DGNB-China was founded in June 2009.

Compared with the first generation green building tools like BREEAM and LEED, the advantage of DGNB is that it has rigorous and comprehensive evaluation methods and support by huge databases and computer software (Ni 2011). It provides a more comprehensive, complete, advanced assessment and quality certification standards. DGNB contains ecological, economic and sociocultural aspects, and it issues the calculation method of carbon emissions in construction, which is one of the latest achievements in the development of sustainable buildings (Lu 2010). The carbon emissions calculation method by DGNB has been recognized by international institutions, including United Nations Environment Programme (UNEP) (Mena Report 2013).

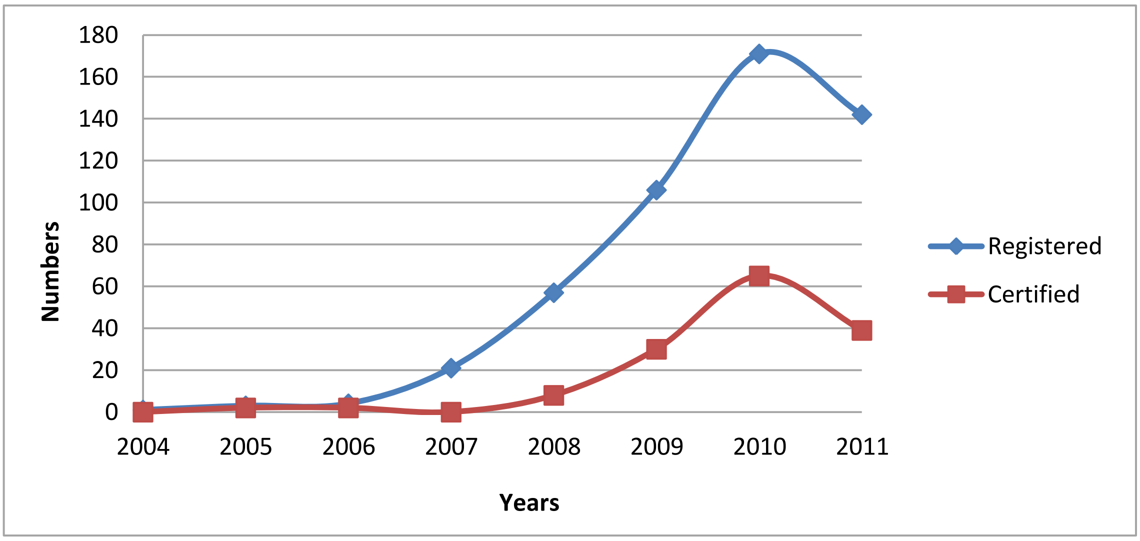
These advantages make DGNB to experience a rapid growth in the Chinese market nowadays (Lu 2010). For example, the ecological park of German business center in

Qingdao City in China received gold awarding of DGNB certificate. The passive building named 'Brook' in Changxing county in Zhejiang province was constructed with the DGNB standard by Landsea R&D. Besides, Green Mark from Singapore has also been applied in China. For example, Kaide project in Foshan received Green Mark Gold PLUS Award. In addition a number of buildings in Eco City in Tianjing have also received Green Mark award.

ii) The application of international sustainable assessment tools in China - The case of LEED

LEED is the most-adopted international scheme in China, it has been adopted since 2003 (Chen & Lee 2013). Projects began to register for LEED assessment in 2004 and two projects got certification in 2005. With the growing reputation of LEED in China, more and more projects are willing to apply for this certificate. According to Tian et.al (2012), there are 515 projects registered and 149 projects have received certification by August 2011 in China and the number is increasing in the coming years (see Figure 3.1).

Figure 3.1 LEED certified projects in China by August 2011

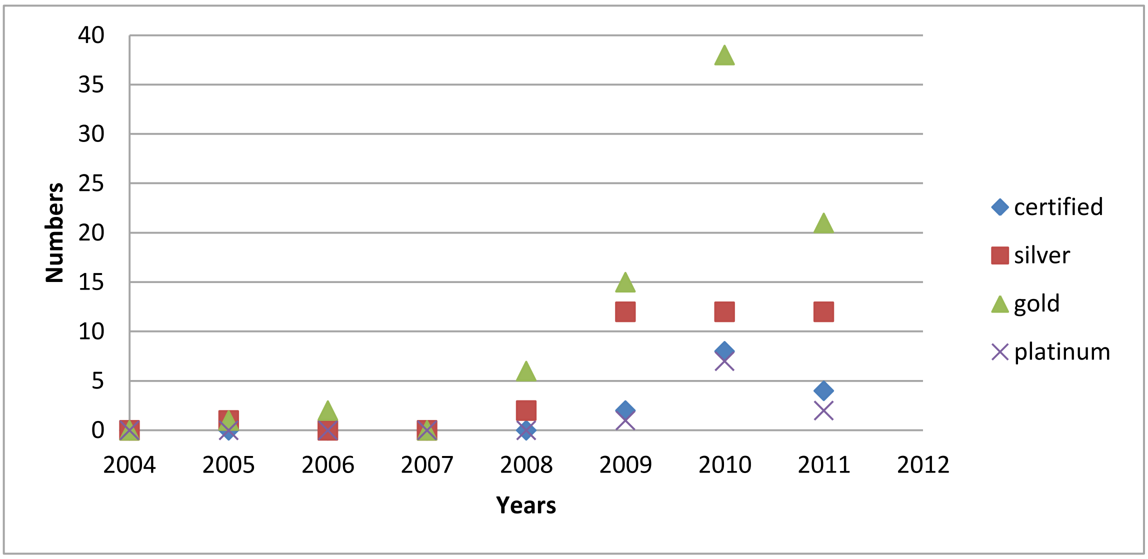


Note: the quantities for 2011 are for half year (by August)

Source: Tian et.al 2012

Figure 3.1 indicates that the use of LEED in assessing building performance has increased significantly since 2008. In 2006, there were only a few certified projects, while in 2008, there was a giant leap and peaked in 2010 towards both registered and certified projects. Among them, 38 of projects achieved LEED gold level. Figure 3.2 shows the distribution of the LEED certified projects in China from 2004 to 2011.

Figure 3.2 Distribution of the LEED certified projects in China (2004 - 2011)



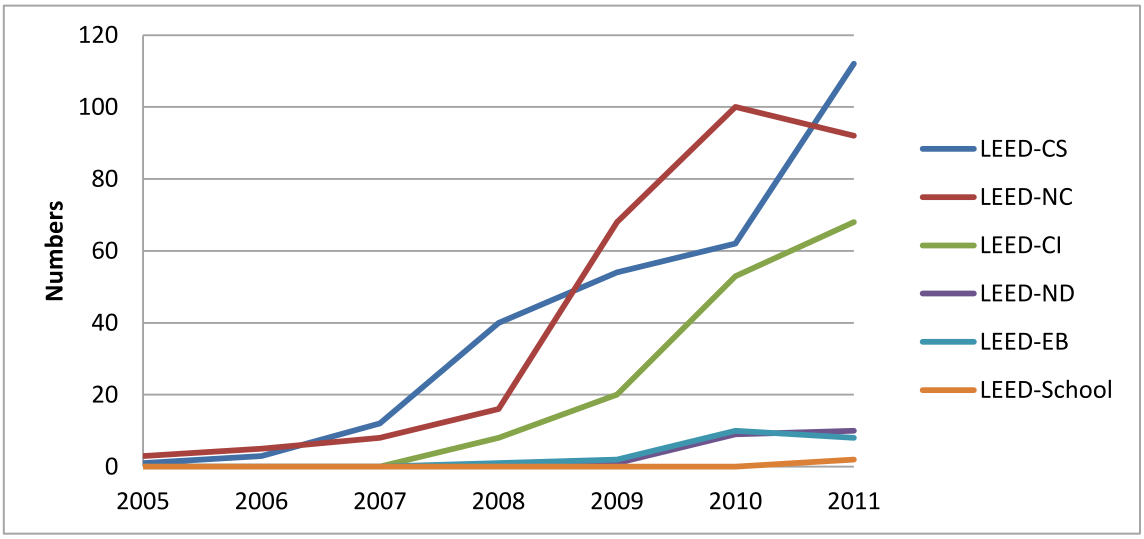
Source: Tian et al. 2012

The passion for LEED is more and more intense now. According to a report by the China Academy of Building Research Shanghai Branch (2013), there are 1,045 projects registered for LEED certification till October 2012, and 267 projects were certified. Among them, there are 18 LEED platinum projects, 158 gold, 20 silver and 71 certified.

As discussed before, LEED has a suite of tools and they include LEED-CS, LEED-NC and so on. Figure 3.3 summarizes the number of registered projects in different LEED tools from 2005 to 2011 in China. From Figure 3.3 the LEED-CS, LEED-NC and the LEED-CI were the fastest growing systems. All these three systems experienced significant growth from 2007 and LEED-CS had rapid growth from 2010 to 2011.

LEED-school started from 2011 and got 2 registered projects by 2011 (CSUS 2012).

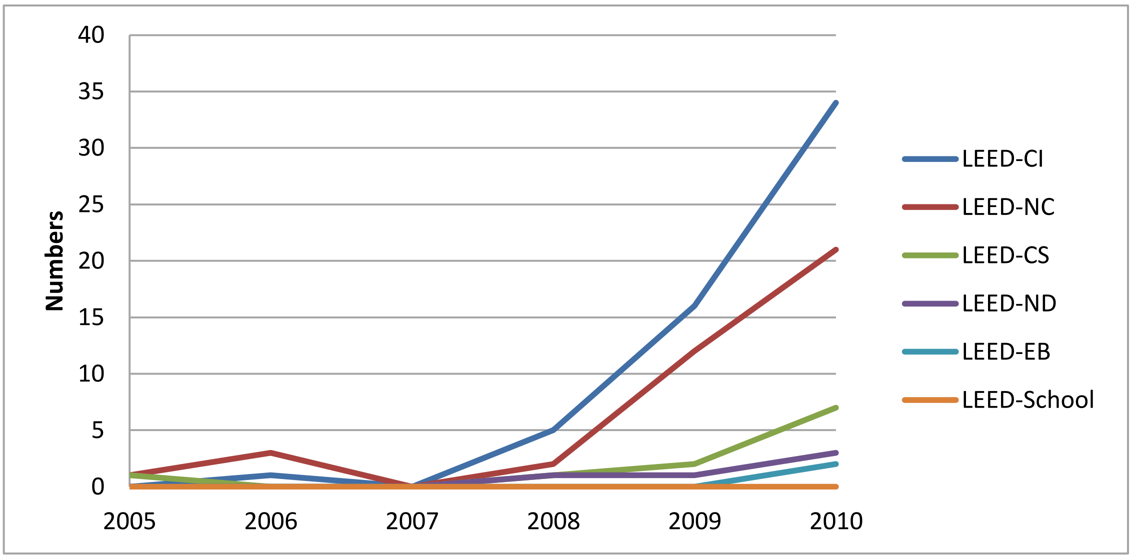
Figure 3.3 Number of registered projects in different LEED systems



Source: CSUS 2012

Figure 3.4 shows the certified projects from 2005 to 2010. Different from the results of registered projects, LEED-CI has the most certified projects other than LEED-CS or LEED-NC, and no project passed any of the systems in 2007. Till 2010, no project had passed the LEED-school certification. This figure also shows a good growth trend of LEED certified projects in China (Tian et al. 2012).

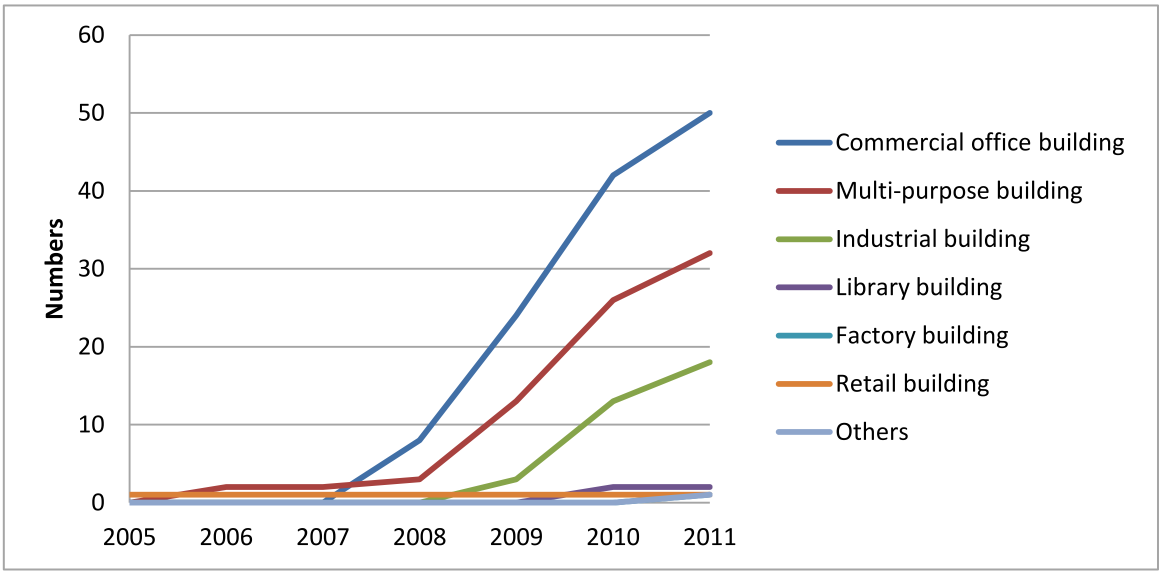
Figure 3.4 Number of certified projects in different LEED systems



Source: CSUS 2012

Tian et al. (2012) have summarized the public building types of certified projects. Among the 97 projects which can be found in Public LEED Project Directory, most of certified projects are commercial office buildings, followed by multi-purpose buildings. Factory buildings and retail buildings have a small proportion of the certified projects (Figure 3.5).

Figure 3.5 Distribution of LEED certified projects by building types

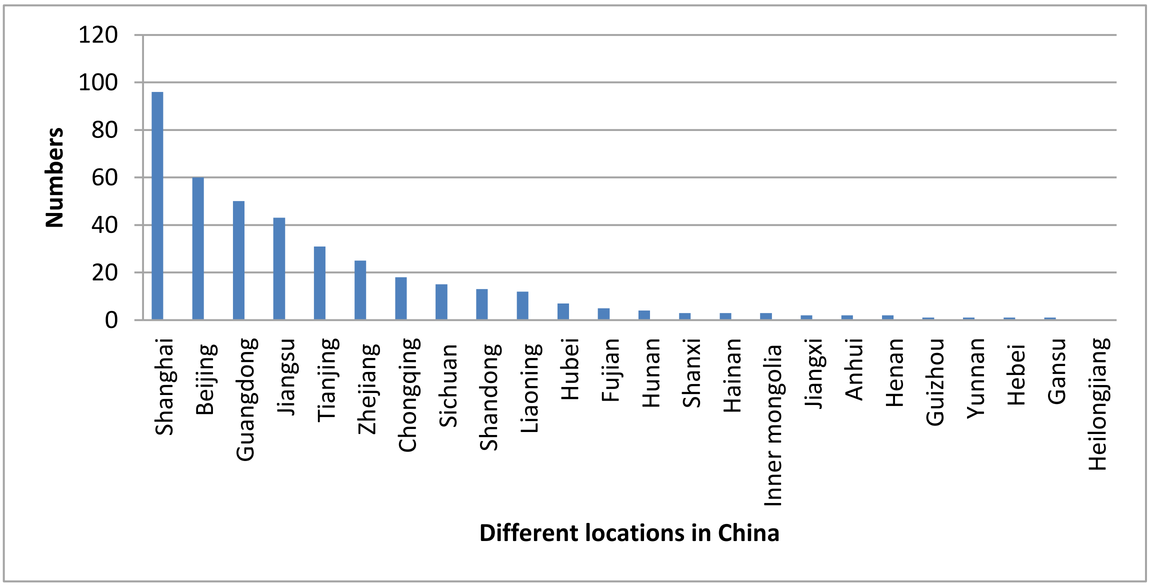


Source: CSUS 2012

With the increasing attention on LEED nowadays in China, some professionals also present their criticism and concern about the adoption of LEED in China. Chen and Lee (2013) stated that LEED focuses on the application of materials while it lacks the reviews on the actual operation stage the project and many of the LEED certified buildings can hardly be green in operation stage due to improper use. Another criticism comes from the cultural difference. It states that US people emphasis on high comfort, which led to high energy consumption. The so called energy efficient building based on the US standard may consume more energy than the normal building in China (Kai & Wang 2011). Toloken (2008) stated that sustainable building should take the whole building life cycle into consideration and this part is lack on LEED.

From the literature review on the current LEED projects in China, it is easy to find that there is an obvious difference in the number of registered projects between the economically developed areas and the developing areas. Most of the LEED registered projects are located in the economically developed areas, especially the metropolitans, like Beijing, Shanghai, Guangzhou and Shenzhen. Figure 3.6 shows the LEED registered projects in different areas. Shanghai, Beijing and Guangdong province (including two metropolitans of Guangzhou and Shenzhen) are the top three areas with the most number of the projects. Following by these three are the Jiangsu, Tianjing, Zhejiang, which are part of the Yangtze River Delta Economic Zone, also an economically developed area. While for other provinces, especially those in the developing areas, there are few LEED registered or certified projects.

Figure 3.6 Registered LEED projects by provinces in 2011



Source: Tian et al. 2012

The situation is similar for the certified projects according to Tian et al. (2012). Shanghai owns 40% of the certified LEED projects, followed by Beijing and Guangdong.

iii) The development of China specific sustainable assessment tools

Recently, these SATs have been used in China and attract attention from the industry and the general public. However, there are problems about the application of these tools, especially during regional adaptation (Sev 2011). In the developed countries, sustainability is concerned with maintaining standards of living while reducing environmental impacts (Cole 2005), but the living standards in developing countries are always lower (Sev 2011). Thus, it would be difficult for the developing countries to deal with first and only environmental issues and ignore the economic and social issues. Indeed, social and economic concerns in developing countries, like China, are often more of a priority than in developed countries (Sev 2011). Libovich (2005) supported this viewpoint by stating that the social and economic problems are still at the top agenda of these countries. Gibberd (2005) also suggested that social and economic aspects should be addressed before environmental issues.

Besides, there is another problems associated with the adaptation of these tools in China. As discussed before, the majority of the SAT have been developed nationally and consider the issues where they have emerged. In that case, when they are adapted for use or even used directly in other countries, problems emerge. One problem for regional adaptation is the assessment indicators should reflect national, regional and cultural varieties if they are to be feasible and applicable (Sev 2011). Some assessment indicators vary from country to country. Take the application of LEED in China for example, the high development density or community connectivity is required by one criteria 'Development Density and Community Connectivity'. The attitudes toward the land development between the two countries are quite different. The United States have relatively more land and less people, but China has relatively less land and much more people. China focuses on preventing develop too much and lack of land, while the United State focuses on preventing developing too sparse and becoming inconvenient to use. From this point, it can be seen, to apply the LEED in China's own project can cause some incorporation problems (Kai & Wang 2011). Consequently, more care and precision should be given to the assessment indicators for qualitative assessment to reduce the misinterpretation (Sev 2011).

Under such a situation, China started to develop its own green building assessment tools in order to fill the gap while adopting international tools. The first rating assessment system for assessing sustainable housing is the *Technical Assessment Handbook for Ecological Residence*. It was introduced in 2001 to improve environmental quality of residential buildings (Huang & Li 2006). There are major five parts in this handbook as Table 3.4 shows.

Table 3.4 The assessment details in Technical Assessment Handbook for Ecological Residence

Categories	**Indicators**
Planning and design	Site selection, transportation, green, noise, sunshine and light, etc.
Energy	Energy efficiency in main building, energy efficiency in HVAC system, renewable energy, etc.
Indoor environmental quality	Indoor air quality, noise, light, heat, etc.
Water	Water supply and drainage system, sewage system, landscape water use, rainwater recycle, etc.
Material and resources	Green building material; recycle material, waste disposal, etc.

Source: Huang & Li 2006

In 2003, the *Green Olympic Building Assessment System (GOBAS)* was introduced by Tsinghua University. It was originally developed for the construction of Olympic stadium and other buildings only. GOBAS was later adopted by the Beijing Municipal Construction Commission as the Beijing local green building standards (Green Olympic Building Research Center, 2003).

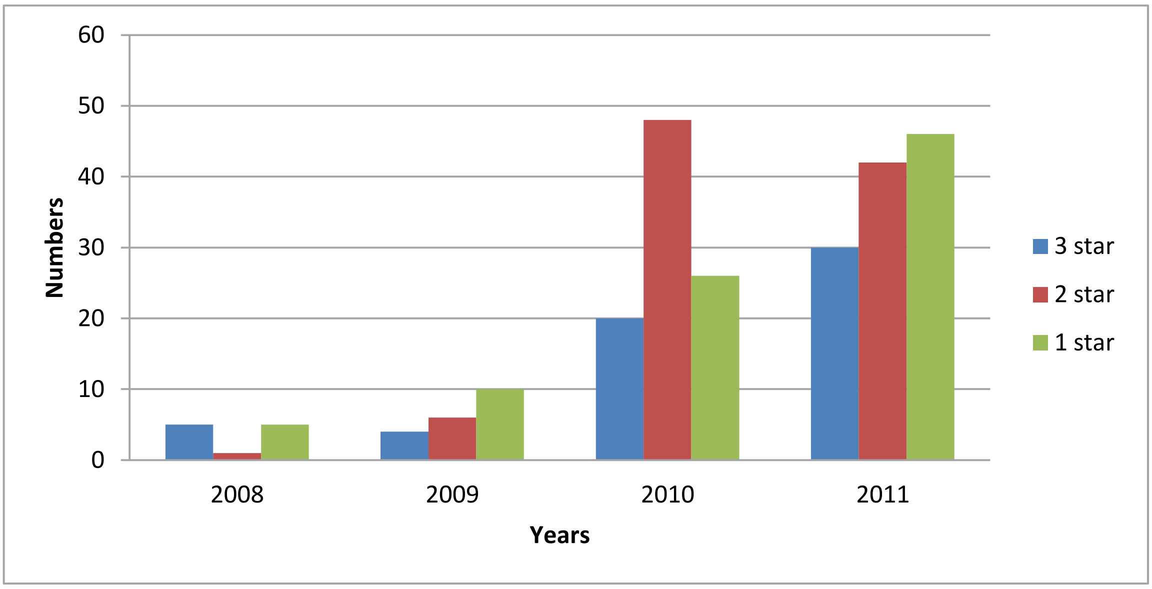
Followed by the GOBAS, a national three star green building evaluation standard called the *Evaluation Standards for Green Buildings (ESGB)* was launched in China in 2006. It uses scoring and a checklist to assess building performance. Indicators are classified into three groups of control items, general items and preference items. The assessment was divided into six groups and they are land saving and outdoor environment, energy saving and energy utilization, water saving and water utilization, material saving and material utilization, indoor environmental quality, and operation management. The evaluation results are presented into three levels of star rating ranging from one-star to three-star (Ye et al. 2013). ESGB was developed as a national building assessment tool and different provinces and municipalities have modified the ESGB by taking into consideration of local climate, resource, economic and culture. Till now, there are 15 provinces and municipalities which have their local standards with similar pattern of ESGB (Tian et al. 2012).

To satisfy all types of buildings, some specific standards are developed for detailed ESGB. The ESGB for industrial buildings was launched in August 2010 to evaluate the industrial buildings on their design, construction and operation. The ESGB for Hospital at a trailing stage since July 2011 and the ESGB for Office Buildings and High-rise Buildings are being developed.

iv) The application of local sustainable assessment tools

Since the launch of the ESGB, more and more projects apply for it. Till September 2011, there were 243 projects passing the ESGB certification. Figure 3.7 shows the distribution of the ESGB certified projects from 2008-2011 and the number is growing year by year (Tian et al. 2012).

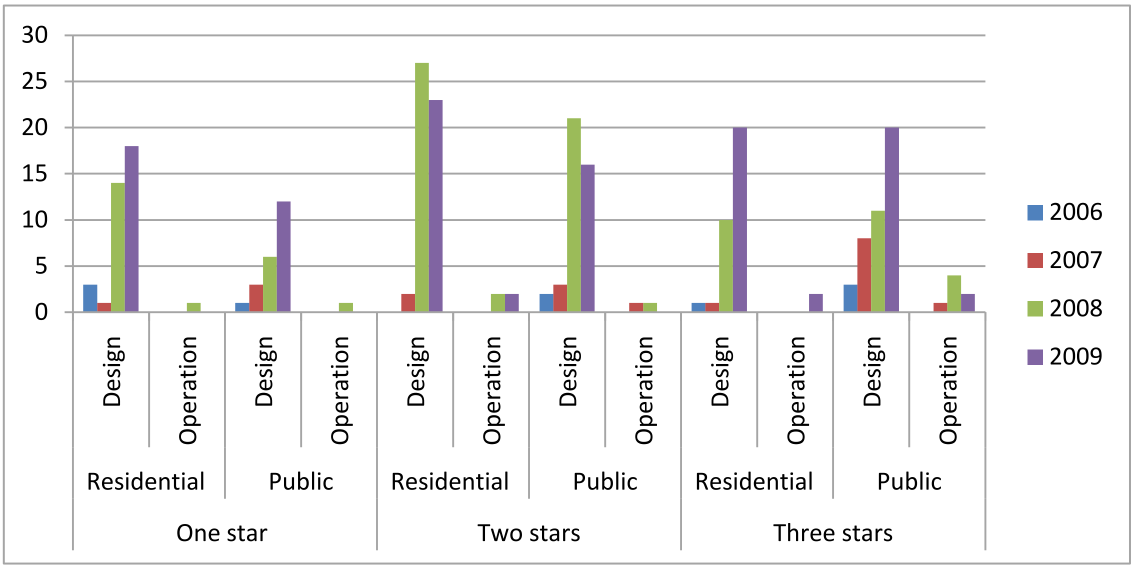
Figure 3.7 Distribution of the ESGB certified projects



Source: Tian et al. 2012

Since 2006, 127 residential buildings (52.3%) and 116 public buildings (47.7%) received ESGB certification. Figure 3.8 shows the distribution of different types of buildings by certification levels. In Figure 3.8 'Design' means the green building design certification, while 'operation' means the green building operation certification. It is obvious that for the two types of buildings, the numbers for design certification is much higher that the operation at all star rating levels. Figure 3.8 also indicates that, among the one star and two star certified buildings, there are more residential buildings than public buildings, while for three stars certified buildings, there are more public buildings than residential buildings.

Figure 3.8 Distribution of ESGB certificated buildings by building types and levels



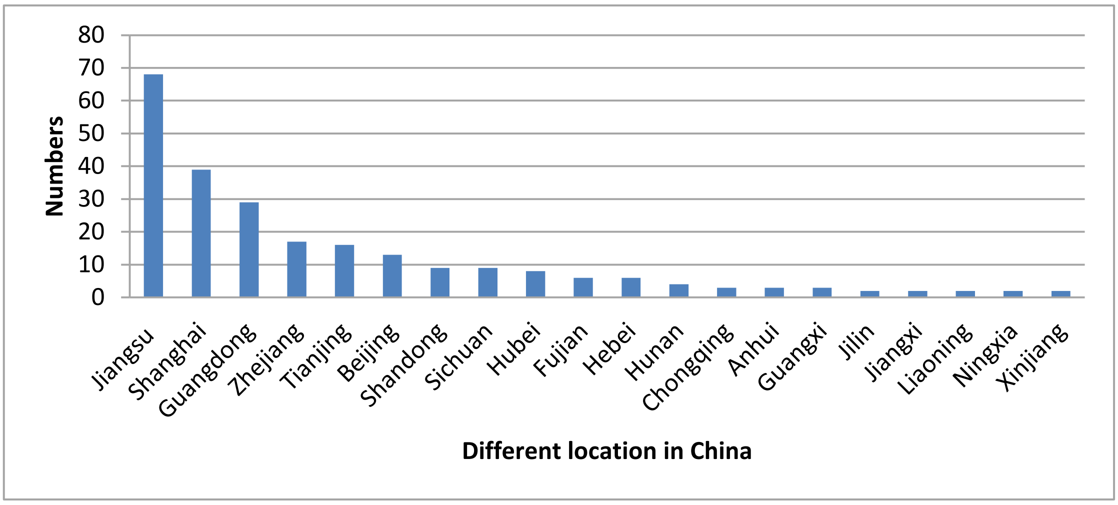
Source: CSUS 2012

The certification of ESGB is conducted by the Green Building Label Management Office, which is founded by the Science and Technology Promotion Center of Housing and Urban Development Ministry and the Green Building Council, as well as the Green Building Research Center in Chinese Society for Urban Studies. Both these authorities have the right to make evaluation of 1 Star, 2 Star or 3 Star buildings nationwide. From 2010, both the 1 Star and 2 Star levels can be evaluated by the local authorities, but the 3 Star still needs to be certified by the two authorities discussed above. Till 2011, there were 27 provinces and municipalities with capacity to make the evaluation (CSUS 2012).

In addition, there are some incentives for ESGB promotion. The development of the green buildings in China is dominated by the government and promoted by the related authorities such as: Green Building Research Center in Chinese Society for Urban Studies and Green Building and Energy Professional Committee. The Ministry of Housing and Urban-Rural Development issued the "China Green Building Platform for Action" in May 2011, which proposed the economic incentive policies for green buildings (CSUS 2012). In the meantime, some local governments issued a series of incentive approaches such as in Tianjin a "pilot construction project management approach for green building" was issued in Tianjin in 2007. The incentive scheme provides 50,000 Yuan to projects which met the green building construction standards (Tian et al. 2012). In the Jiangsu province, the Suzhou Industrial Park was awarded 1,000,000 Yuan, 200,000 Yuan and 50,000 Yuan, respectively for the ESGB 3 Star, 2 Star, and 1 Star projects (Zhou et al. 2010). In the Shenzhen Bao'an District, the government launched the "Bao'an District grant funds use plan for green building pilot project "(CSUS 2012). The subsidies are mainly used to build the pilot green building projects in Bao'an District and an average of 500,000 Yuan subsidy for each project. In Shanghai the government gives the ESGB two-star and above construction projects up to 5 million Yuan from 2011. Wuhan also offers Municipal Construction Committee awards for projects which get the ESGB two-star and three-star rating (Kai & Wang 2011; Tian et al. 2012).

The level of economic development also has some impact on the ESGB certification. Similar to the situation of LEED application in China, the numbers of certified buildings are concentrated in the economically developed regions, like: Shanghai and Guangdong. While in some relatively economically backward areas there are only a few certified projects. Figure 3.9 shows the regional distribution of ESGB certified projects.

Figure 3.9 Distribution of ESGB certified projects by provinces by 2011



Source: Tian et al. 2012

Compared with the regional distribution of LEED, the Jiangsu Province has the most ESGB certified projects instead of Beijing. Shanghai and Guangdong are still the top 2 and 3 and have a considerable number of certified projects.

3.5 A critique of environmental building assessment tools

The tools discussed in Sections 3.3 and 3.4 represent some of the most popular international tools in China as well as some of the tools developed by China that are used in the construction industry as an instrument to communicate product information and environmental awareness to stakeholders in the industry. The LCA thinking has been incorporated in current assessment tools in different ways. For example, BREEAM uses a rank to evaluate embodied energy of building elements. CASBEE take the different stages into consideration, e.g. construction, operation.

The development of these tools varies a great deal, ranging from tools for individual building components to a whole building assessment. They consider environmental issues with local, regional and, in some cases, even global perspectives. Initially, these tools focused on environmental impacts, but this has now been extended to the wider domain to include social and economic impacts in the assessment process.

According to Cole (1998) the specific definition of the term “building performance” is complex since different stakeholders in the building sector have differing interests and requirements. Economic performance, health and comfort related issues, social stability, biodiversity conservation, and so forth are all significant when environmental building performance is considered. This viewpoint is supported by Ding (2008) as she states that assessment methods should be required to assess building performance across a broader range of environmental considerations as the environmental issues become more urgent and more comprehensive. However some of the current sustainable assessment tools use only a single criterion such as energy use, indoor comfort or air quality to indicate the overall performance of a building (Cooper1999; Kohler 1999).

Kaatz et al. (2006) supported this view and stated that current environmental assessment tools are green building assessment tools which assess building performance against a pre-determined set of environmental criteria but the assessment methods should go beyond this to address a broader set of environmental, social and economic issues.

One of the aspects which still lack attention is financial return. Some assessment tools such as BREEAM, LEED and HK-BEAM have not taken financial aspects into consideration in the evaluation framework (Ding 2008). This will be an obstacle to the development of sustainable buildings, as some environmentally friendly buildings would cost a fortune. Lack of due consideration to financial return would contradict the ultimate principle of building investment, as sustainable projects become less attractive to developers with less economic returns. Incorporating economic aspects into the evaluation system can make it more attractive for the construction market.

There is another concern about the effectiveness of building sustainable assessment methods as they are typically concerned with their consequences on buildings as completed products. However, more attention is now also paid to the impacts in the building process throughout the building's life cycle (Shen & Wang 2002; Kaatz et al. 2005). According to WCED (1998) environmental, economic and social criteria, which encompass the building performance, will have different impacts at various stages of a development. Van Paumgartten (2003) stated that the performance of both economic and environmental aspects of a development can be maximized through the incorporation of sustainable principles into the building process.

Kaatz et al. (2006) suggested that the use of sustainable assessments will enhance the ability to impact the design and construction practice and challenge the existing norms and values of those responsible for the delivery of buildings. As a result, it would be essential to assess impacts of a development for the building process during the building life cycle (Shen & Wang 2002; Kaatz et al. 2006). This is beyond the current narrow technical focus and provides opportunities for the subsequent development of these tools, which include a more conscious use of such methods to influence the quality of a building project through the building process.

Besides, majority of the tools are designed to support decision making during the design stage of a building. The impairment for the pre-design criteria assessed and incorporated at the earlier stage will make sustainable building assessment method more useful (Ding 2008). The use of sustainable assessment methods as design guidelines is not sufficient; they also need to be applied in a stage well before design.

More importantly, for the sustainability agenda to be maintained, a holistic building life-cycle must be considered.

The building life-cycle is usually portrayed as inception, design, construction, operation and demolition (Shen & Wang 2002). Building environmental assessments will need to be considered throughout these stages during entire life span of a development (Blengini & Carlo 2010). Through a closer integration of building assessment into the building process, sustainability principles can be explicitly integrated with a building's objective and goals economically and harmony. As activities during these phases will influence the building performance in various magnitudes in terms of economic, social and environmental aspects, environmental building assessment tools may not be used solely to evaluate the quality of building performance but rather, it should also be used to transform the contents of methods by incorporating the principles of sustainable development directly into the building development process through information exchange and knowledge transfer. As a result, it will help to influence the ways the buildings are designed, constructed, used and demolished. The structure of the building process influences the available opportunities for exploiting economies of scale. The incorporation of sustainability measures into the building process are often more effective (Van Bureren & De Jong 2007). Greater emphasis should be placed on the process and transformation that occur within a building system to reflect sustainability values (Shen & Wang 2002; Shen et al. 2005; Kaatz et al. 2006).

Moreover, a full life-cycle of a building must be extended to include upstream acquisition of raw materials and downstream disposal to landfill or reuse or recycling of materials and these are largely ignored in the assessment of environmental performance in buildings (EPA 2003). However, the current environmental building assessment tools seldom consider the impacts associated with the process of manufacturing products and transporting them to the site, ongoing operations and maintenance, and the disposal of waste at the end-of-life (Sev 2011; Ng et al. 2013; Wallhagen et al. 2013). Even though some of the research considers one or several stages in building process, few of them considered all the stages in a life cycle perspective. For example, Bilec et al. (2010) have done a research on developing a life-cycle assessment modelling of construction processes for buildings and the research focused only on the construction phase. Besides, there are other research studies which focus on only the operation phase (Scheuer et al. 2003), or end-of-life stage for commercial buildings (Guggemos & Horvath 2003). Even looking at some of the commonly used tools around the world, they are also focused on one or several stages of a building but not the entire life cycle. Table 3.5 summarizes the applicable of environmental assessment tools in various stages of a building life cycle. Majority of them have the LCA thinking to some extent. However, they have not been sufficiently assessing building performance in a whole life cycle perspective. Table 3.5 shows the stages that current assessment tools are considered, and the lack of consideration of all stages in a building life cycle has led to the research problem in this research.

Table 3.5 Sustainable assessment tools and their applicable phases

Tools	**Building stages**				**References**
	Inception & Design	**Construction**	**Operation**	**Demolition**	
Green Star	★				Chang & Chou 2010
LEED	★	★			Haapio & Viitaniemi 2008
BREEAM	★	★	★		Haapio & Viitaniemi 2008
EcoProfile			★		Haapio & Viitaniemi 2008
CASSBE	★	★	★		JaGBC & JSBC 2006

The impacts during the life cycle of a project are highly inter-dependent, as one phase can influence one or more of the other phases (Shen 2002). Each phase in a building life cycle plays an important role in achieving different aspects of sustainability for a project. Inception phase is the first step of a potential project for its sustainability performance to be assessed; design phase provides an opportunity to bring together all the sustainability performance considerations and realize the sustainable strategy for the project; construction phase is the period during which all the sustainable aspirations for the project may be put in place; operation phase is the stage when the major positive effects of a project on the social and economic aspects occur; and demolition phase offers an opportunity to plan for reuse and recycling. Therefore, when the sustainability performance of a construction project is examined, all the phases during the building life cycle should be taken into consideration (Thomson et al. 2011; Wallhagen et al. 2011).

Considering the situation of construction industry in China, the ESGB as well as the application of international tools also have shortages especially related to the LCA thinking and TBL. Similar with the situation in other countries, environmental performance is also the also the focus of concern in China but economic and social issues are largely ignored. Most of the green certificated projects in China are focused only on environmental performance. With the growing attention on the building's financial return and social well-being, more efforts are needed to incorporate the TBL thinking in the whole decision making process.

Besides, only a few of the assessment tools take all stages in building life cycle into consideration. There are two categories in the ESGB certification process, one for design and the other for operating. Most of the ESGB certificated projects receive awards during the design stage, and relatively few projects receive their award for the operating stage. Only a few consider the construction or demolition stage. With regard to the application of international tools in China, there are also only a few consider the whole building life cycle as discussed previously in this section.

Another issue needing to be considered is that current approaches to environmental control and management are highly qualitative (Chen et al. 2005), especially in construction stage. A search of the Civil Engineering Database of the American Society for Civil Engineers and the EICompendex database found that only 2% of all papers on environmental management in construction provide quantitative methods (Chen et al. 2005). In some evaluation tools, both quantitative and qualitative performance criteria are included. The indicators such as energy consumption, water consumption and GHG emission are quantifiable whereas some subjective issues such as environmental quality, sustainable site are qualitative. Combining the quantitative and qualitative data to aid decision making in building evaluation is a topic worth exploring in sustainable assessment.

Regional variation is another significant factor to be considered in the development of SATs. The different climate conditions, building techniques and materials, and local economic conditions all influence the SATs (Kohler 1999). Most of the tools focus only on local scale and do not allow for national or regional variations (Ding 2008). The SBTool is the first international SAT and it is criticized for establishing scoring weights subjectively by individual countries when evaluating their buildings (Crawley &Aho 1999). These tools need modification before they can be used in China. Besides, some organizations also developed a subset of their tool for other countries in order to meet the demand of the market, such as DGNB-China which was founded in 2009 (CSUS 2012). This is a tool developed by DGNB specifically for China's market.

Further criticism of the current SATs states that most of the assessment systems are relative, not absolute, by assessing building performance against a set of pre-determined criteria and their corresponding weights determined by subjective judgments (Cooper 1999). The subjective nature of the tools has attracted much criticism due to lack of realistic basis (Retzlaff 2009). Kohler (1999) goes on to comment that current assessment tools hide the real mass and energy flows which are critical in the determination of effective environmental impacts. They do not help to reveal the carrying capacity of the environment. Thus, no real comparison can be made to compare the impacts created by buildings during their life cycle.

As for the China's tools ESGB and GOBAS, they are based on qualitative scoring which was criticised by Li et al. (2010) as being subjective which make it difficult to provide in-depth and comparable results. Besides, they are often served as a post-construction evaluation tool for determining the acceptance of completed work, which is hard for conducting any improvement (Li et al. 2010).

3.6 Summary

Building sector plays an important role in sustainable development. Meanwhile, sustainable building assessment models and tools are the key to regulate and promote the sustainable building all over the world. Different sustainable assessment models and tools are reviewed in this chapter. The application of the representative international tool- LEED and the China's own tool - ESGB were also compared and analysed in this chapter. With strong regional characteristics, including climate, economic situation, values and other issues, sustainable assessment tools are unlikely to be adopted directly in different regions. More importantly, current assessment tools seldom consider the three pillars –environmental, economic and social aspects in all stages in building life cycle. Consequently, there is a critical need to develop a tool which considers the three pillars in building life cycle and develops based on China's own situation. This research aim is to analyze buildings' environmental, economic and social performance in different stages. In order to analyze these three pillars in different stages, building processes and activities should be analyzed later. In the following chapter, the building stages and activities as well as the building performance related to the stages will be discussed.

CHAPTER 4

BUILDING PROCESS AND BUILDING LIFE CYCLE PERFORMANCE

4.1 Introduction

According to Thomson et al. (2011, pp143), increasing sustainability assessment of buildings is required for "understanding the social, economic and environmental impacts associated with the way that buildings and their support systems are designed, built, operated, maintained and ultimately disposed." However, the lack of fully integrated assessment tools has resulted in the lack of a holistic assessment approach for a building life cycle. In the previous chapter, the current sustainable assessment tools have been analysed as well as the approaches for sustainable building assessment. As the research is focused on sustainable building assessment in different stages in building life cycle, this chapter will analyse the building phases and building performance in these phases, which makes this research necessary, timely and feasible. Environmental, economic and social impacts in different stages will also be analysed.

4.2 Building phases and activities

A construction project will have various impacts economically, socially and environmentally at different stages of a building's life cycle (Shen & Wang 2002). Kaatz et al. (2006) stated that a better understanding of building phases and their related activities is required in order to incorporate sustainability across the different life cycle stages of the project. Thomson et al. (2011, pp 144) stated that "project life cycle represents an important context as it reflects the consecutive and interlinked stages of the object under consideration." The factors impacting on sustainability performance of a building may vary according to the project process. Therefore, when sustainability performance of a construction project is examined, project stages and hence the major activities in each phase must be specified first, so that factors influencing the project's characteristics of each stage can be identified.

In the past decades, many research studies have discussed stage division of a building. The RAIA Plan of Work, published in 1964, was one of the first industry documents to advocate process thinking (RAIA 1973). The document was presented in a standard method of operation for the construction of buildings and was accepted as an operational model throughout the building industry since its introduction. According to this document, a construction project is divided into five stages - pre-design, design, mobilization, construction and post-construction.

Donald (1992) suggested that from concept to implementation, the stages of a construction project may fall broadly into consistent patterns. However, the construction time as well as the emphasis and unique characteristic of each project may influence the stage division of a building. According to Donald (1992) a construction project may be more efficient to be divided into six basic phases - concept and feasibility studies, engineering and design, procurement, construction, start-up and implementation, and operation or utilization.

Ritz (1994) described that a construction project usually starts with a conceptual phase, followed by definition, execution, start-up, and demolition. In 1994, the Building Services Research and Information Association (BSRIA) was compiling environmental code of practice for buildings and their services, the life cycle of a construction project was divided into fifteen parts and seven stages, which are pre-design, design, preparing to build, construction, occupation, refurbishment and demolition (BSRIA 1994).

Kibert (1994) divided the life cycle of a construction project into six stages, namely, planning, development, design, use, maintenance and deconstruction. Similarly, Shen and Wang (2002) suggested a five-stage division, which are inception, construction, commission, operation, and demolition. This division was also adopted by Ding and Shen (2010) in their research on using a building process approach to assess sustainability performance of built projects. Erlandsson and Borg (2003) stated that building life cycle should include raw material extraction, manufacturing, on-site construction, operation (including maintenance) and end-of-life/demolition. Figure 4.1 summarizes stage division of a building in a timeline. From Figure 4.1 majority of the research works cover the EoL stage since 1994, except Thomson et al. (2011). Their research is about mapping sustainability assessment with the project life cycle and the stage division is based on the RIBA Plan of Work (2007).

As mentioned above, there are many different stage-divisions of a construction project across its life cycle (refer to Figure 4.1). Among these different ways of stage division, some include all the activities of a construction project (BSRIA 1994; Kibert 1994; Shen & Wang 2002; Erlandsson & Borg 2003; Zvadskas et al. 2011; Wu et al. 2012), while some are only up to the operating stage (RAIA 1973; Donald 1992; Ritz 1994; Thomson et al. 2011). Sev (2011) has criticized that the way of building division which do not include the end of life stage are contrary to the concept of building life-cycle. Among these divisions, the major difference is the dividing points and the sequences of some major activities. Zvadskas et al. (2011) supported this viewpoint by stating that a building life cycle may have a lot of versions, and the main difference may be on the division points of some of the activities.

Figure 4.1 The divisions of building phases

No. of Stages	Building phases	References
5	Pre-design, design, mobilization, construction and post-construction	RAIA 1973
5	Concept and feasibility studies, engineering and design, procurement, start-up and implementation, and operation or utilization	Donald 1992
5	Conceptual phase, definition, execution, start-up, and demolition	Ritz 1994
6	Pre-design, design, preparing to build, construction, occupation, refurbishment and demolition	BSRIA 1994
6	Planning, development, design, use, maintenance and deconstruction	Kibert 1994
5	Inception, construction, commission, operation, and demolition	Shen & Wang 2002
5	Raw material extraction, manufacturing, on-site construction, operation and end-of-life/demolition	Erlandsson & Borg 2003
7	Brief, design, construction, maintenance, facilities management, demolition and utilisation	Zvadskas et al. 2011
5	Preparation, design, pre-construction, construction and use	Thomson et al. 2011
4	Building materials production, construction, operation, and demolition	Wu et al. 2012

In the construction industry, four or five stage divisions seem to be more acceptable in research studies (Ding & Shen 2010; Thomson et al. 2011; Wu et al. 2012). Ding and Shen (2010) used five stage divisions in developing a building process model to assess sustainability performance of built projects. The five stage division includes inception, construction, commissioning, operation and demolition and are used to develop the SDV model for assessing sustainable performance of built projects. Thomson et al. (2011) stated a five stage division in their research about mapping sustainability assessment with the project life cycle, which includes preparation, design, pre-construction, construction and use. Wu et al. (2012) used a four stage division in their research about energy consumption and GHG emission of office building in China and the stages include building materials production, construction, operation and demolition. Zhang et al. (2013) mentioned about transportation, construction, operation and maintenance, and demolition stages in their research on life cycle assessment of air emission in construction process.

The divisions mentioned above, all map the different phases according to their own research use in the industry. Sometimes they will make some adjustments to the stage division according to their own research purposes. In the research of Ramesh et al. (2010) about life cycle energy analysis of buildings, the life cycle energy consumption was analysed in three stages of initial, operating and demolition stage. In 2011, Zvadskas et al. (2011) stated a seven stage division brief, design, construction, maintenance, facilities management, demolition and utilisation.

Considering the aim of this research is about establishing a sustainable assessment model in building life cycle, developing a sustainable building requires emphasis on all stages of the building's life cycle (Sev 2011). The social, economic and environmental impacts need to be assessed in different stages in a life cycle by covering impact issues referring to each stage. For a five stage division, the inception and design stage can be combined into one, as there are limited activities at the brief stage. These two have similar sustainable impacts in the project life span. After the inception and design, the construction, operation stages take place. Demolition is the end-of-life stage of the project.

Therefore, this research will adopt a four-stage division for the study which includes inception and design, construction, operation and demolition. It meets the requirement that "the life time should be utilised to define the starting point and end point of the life-cycle" (Erlandsson & Borg 2003). Table 4.1 summarizes the stage-division of a construction project across its life cycle and the major activities in each stage.

Table 4.1 The stage-division of a construction project across its life cycle and the major activities in each stage

Life cycle stages	**Major activities**
Inception & design	Identify project aims and objectives
	Establish project proposal
	Undertake feasibility studies
	Undertake preliminary and detail design
Construction	Mobilize resources
	Transport resources to site
	Undertake construction and installation activities (Shell and core, finishes and decoration, services, etc.)
Operation	Building handover to user
	Undertake routine maintenance (regular, scheduled and ad hoc repair or replace)
	Undertake minor or major refurbishment
Demolition	Undertake demolition activities
	Transport waste to treatment centre or landfill

Source: Gangolells et al. 2009

The four stages have obvious impacts in the attainment of sustainability performance (Table 4.1). In the inception and design phase, it evaluates a construction project from environmental, technical, economic, and social aspects to ensure that the attainment of sustainability performance will start from an outset of a building's life cycle. It brings together all the sustainability performance considerations and identifies sustainable strategies for a project.

In the construction phase, it implements the sustainable technology and puts all the sustainable aspirations in place for the project. Gangolells et al. (2009) conducted a research about predicting the severity of environmental impacts related to the construction process of residential buildings. They state that some of environmental impacts, such as waste generation and water consumption, have extremely significant impacts during the construction stage of a building.

In the operation phase, major energy consumption occurs along with GHG emissions. According to Gaglia et al. (2007) some major environmental impacts emerge in the operation stage and they include energy consumption, resources consumption and pollution discharge. In addition, operation costs account for a considerable part of total cost of a building during its life span (Flanegan & Norman 1989).

In the demolition phase, it offers an opportunity for considering reuse and recycling, thus, reducing extraction of raw materials and the associated energy consumption. Shen and Wang (2002) stated that the demolition stage of a construction project has some negative contribution to the environment and they include waste disposal, landfill, etc. The demolition cost and compensation to stakeholders are also important components of the building life cycle cost.

4.3 The evaluation of environmental, economic and social impacts related to the building process

As discussed in Section 4.2, building life cycle can be divided into different phases as building is a process rather than a product (Sev 2011). According to WCED (1998) environmental, economic and social criteria will have different impacts at various stages of a development. Van Paumgartten (2003) stated that the performance of both economic and environmental aspects of a development can be maximized through the integration of sustainable principles into a building process. Kaatz et al. (2006) suggested that the use of environmental assessments will enhance its ability to impact on the design and construction practice in challenging the existing norms and values to those who are responsible for the delivery of buildings. As a result, it is important to assess impact of a development on the entire building process (Shen & Wang 2002; Kaatz et al. 2006).

4.3.1 Inception and design phase

At the inception and design stage, as it is at the beginning of a project, it plays an important part in improving building performance. It is increasingly recognized as vital for the efficient commissioning and effective operation and maintenance of a construction project (Dodoo et al. 2010). This is the stage that environmental sustainability performance may be decided through the selection of site location, materials and technologies. The inception and design stage is valued in building performance because the decisions made here influence all downstream processes.

The inception and design stage involves identifying project aims and objectives, developing proposal, undertaking feasibility study and preliminary and detail design. This stage is usually with little physical works, thus, there is limited direct contribution during this stage from viewpoints of economic, social and environmental aspects (Shen et al. 2010). However, this stage provides an opportunity to bring together all the sustainability performance considerations from the outset and realize sustainable strategies for the project (Wang et al. 2005). The proposal development and feasibility study can incorporate the sustainability considerations, requirements, and strategies of a construction project.

During the inception and design stage of building, major decisions are made regarding the building type, occupancy, form, dimensions, and type of structural system. All these have significant impact on the final form, constructability, cost, and overall performance of a building. It is a complex process involving many activities and stakeholders. The process is based on the interaction among all different stakeholders such as developers, consultants, managers, administrators, etc. The decision made at this stage will have long-term impacts on its sustainability performance over the following stages of its life cycle.

Actually, the most important decisions regarding a building's sustainable features are made during the inception and design stage, as decisions made at this stage influence all downstream processes (Shen et al. 2010). During this stage, system efficiency and sustainability of heating, cooling, mechanical ventilation and water systems are also considered. The equipment use and performance will have significant impacts on other stages, especially during operation, which means this stage will determine whether the project will achieve sustainability performance and attain the objective efficiently or not.

Some research studies have demonstrated the importance of inception and design stage on a building's sustainable performance. According to Kats et al. (2003) a slight increase in upfront costs of about 2% to support sustainable design, on average, results in life cycle savings of approximately 20% of total construction costs; which is more than ten times the initial investment. Another study by Wang et al. (2005) also revealed that simply making buildings of simple shapes and the correct orientation can reduce energy consumption by 30-40% with no extra cost. Since buildings have considerable impacts on the environment, it has become necessary to pay more attention to environmental performance in building design.

Shen et al. (2010) conducted a research project feasibility study. They stated that the inception and design stage is a key to successful implementation of sustainable and socially responsible construction management practice. The major economic impact in this stage includes demand and supply analysis, market forecast, investment plan, etc. Though there is only a small part of capital is input at the inception and design stage, the assessment and analysis of marketing, cost profit financing will have crucial impacts on the total economic sustainability performance. The social impacts at this stage may include influence of the project on the local social development, provision of employment opportunities, public services (Shen & Wang 2002; Shen et al. 2010).

4.3.2 Construction phase

The construction phase of a building refers to a series of construction activities, including the construction and installation of building materials or products, until buildings are completed (Gong et al. 2012). The diesel fuels used by heavy equipment at construction site and in transportation, as well as electricity used for power pools and lighting are all included in this stage (Wu et al. 2012).

The building construction stage mainly analyses the energy, resource consumption, GHG emission and other environmental impacts in relation to transportation and construction activities. The construction phase accounts for a total of 8-20% of energy consumption in a building life cycle (Ortiz et al. 2009a). Although the contribution of environmental impacts in the construction phase is small compared with values of the whole life cycle, this phase cannot be neglected because of the immediate negative impacts on the environment due to the excessive consumption of building materials, water consumption and improper waste management on site and generation of pollutants during site operation (Ortiz et al. 2010).

Yang (2003) indicated that environmental impact of the construction phase is much less than the operation phase. However, Li et al. (2010) stated that the impact of the construction phase may be more intensive due to the shorter period of construction compared with the operation phase. This problem is even more intensive in China due to country's rapid urbanization since the early 1980s (Li et al. 2010). The growing number of construction projects in China every year has caused serious damage to the environment as well as the health and well-being of people on site and nearby residents. Considering this situation, China's policy makers have come up with some regulations such as a ban on construction activities before and during the process to control construction dust to impact on air quality (Li et al. 2010).

On-site construction activities usually result in soil and ground contamination, surface and underground water contamination, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, impacts on wildlife and natural features, and archaeology impacts (Chen et al. 2005). The list of construction-related environmental aspects has been classified by different institutions and researchers. Based on the work of eco-management and audit scheme (EMAS) (2001) and the research studies of Gangolells et al. (2007) and Shen et al. (2010), the list of environmental aspects covers:

- Emissions to atmosphere
- Releases to water
- Production of solid and other wastes requiring landfill for disposal
- Use and contamination of land
- Resource consumption
- Local issues (noise, vibration, odour, dust, etc.)
- Impact on the community and the local traffic
- Risks of environmental accidents
- Effects on biodiversity

Economically, the construction costs at this stage include cost for labour, plant and materials. This is what the building occupiers, managers and others consider first other than environmental and social benefit in reality (Vatalis et al. 2011). A literature review shows that people are concerned about the additional cost of green buildings. Tagaza and Wilson (2004) estimated that the additional capital costs for green buildings range from 1% to 25% more than traditional buildings. Green materials and using green construction technologies contribute to the higher costs during the construction stage (Hwang & Tan 2010). According to Zhang et al. (2011), buildings with green materials cost approximately 3% to 4% more than traditional projects. The long time needed for implementing green construction technologies also result in higher construction cost (Hwang & Ng 2013). This is because buildings with green technologies are often time consuming to build. More time is also required for random checks and more site visits are also needed for the project team.

The higher costs of a project directly affect the project managers as well as stakeholders as they need to consider the budget of the project (Hwang & Ng 2013). It becomes an obstacle to building green (Rehma & Adeb 2013). However, Vatalis et al. (2011, pp 379) stated that "the potential economic benefits may be difficult to see in the construction phase but there are returns of investment in the operation and restoration phase." As the questions of economic assessment of the sustainable buildings in this stage are raised, further research is needed to discuss the economic impacts during construction. To some degree, assessing the economic impacts of buildings in all stages can help the stakeholders have a clearer picture of the economic cost and benefits before decision making.

From a social perspective, the construction stage is a critical component of the labour market as it generates employment opportunities (Zhao et al. 2012). However, it has been criticised also as a high-risk profession, where poor occupational health and safety is associated with project construction (Zhao et al. 2012). Jones et al. (2006) undertook a research on corporate social responsibility of the UK construction industry and the result indicates that the fatal accidents involving workers in construction companies are generally much higher than any other industry. The main causes of these accidents include falls from height, the operational errors involving site transport and equipment. The research conducted by the Health and Safety Executive in the UK shows that construction site economical loss due to the occupational accidental and health damage accounts for approximately 8.5% of the project cost (Qu 2007). In

Australia, the incidences of injury in construction industry are 50% higher than all other industries combined (Petrovic-Lazarevic et al. 2007). In that case, the employment and the safety are considered as the two major social impacts during construction stage (Huang et al. 2012). According to Hwang and Low (2012) the activities in project during the construction stage have some negative impacts on the neighbourhood nearby. The locations around the occupants, as well as some transportation facilities may be affected by the road blocks and other activities during construction.

4.3.3 Operation phase

The operation stage is the phase where the needs of users are met. The operational activities include cooling, heating, and ventilation as well as the lighting and water supply (Wu et al. 2012). No matter how sustainable a building may have been in its design and construction, it can only remain so if it is operated responsibly and maintained properly. Though the initial design can fix many issues and influences opportunities for future improvements, designers cannot control what happens after a building is completed. It is in the operation phase that green practices such as air quality enhancement take place and it accounts for more than 83% of inventoried environmental burdens except waste generation (Scheuer et al. 2003).

According to Gaglia et al. (2007), three major environmental impacts emerge in operation stage include energy consumption, resources consumption and pollution discharge. The energy consumption includes electricity consumption and gas consumption. The electricity consumption mainly includes the HVAC system, lighting system, and socket and power equipment. Resource consumption includes water resource consumption; raw materials for maintenance, refurbishment and renovation. Pollution discharge mainly includes GHG emission; waste water and human waste.

Several studies showed that compared with other stages, the operation phase accounts for 80% of the total energy consumption, while the corresponding figure for building material production phase is 15% and 5% for the other phases in the 50-year building lifecycle (Scheuer et al. 2003; Liu et al. 2010). In temperate or cold regions, the major part of the life cycle energy use for buildings is in the operating phase (Winther & Hestnes 1999). For a cold region, such as Swedish conditions, Adalberth (2000b) states that for houses built in the 1990s about 85% of the life cycle energy use, and 70–90% of the pollutant discharge, were the result of the operation phase. Major efforts to reduce energy consumption include improvement of the lighting and HVAC facilities used during building operation phase (Gustavsson et al. 2010).

Except for the energy consumption, the operation stage is also the phase with the highest resource consumption with approximately 80-90% of the life cycle's total, while the construction phase accounted for a total of 8-20% and the demolition phase represented less than about 2-5% (Adalberth et al. 2001; Peuportier 2001; Koroneos & Kottas 2007; Huberman & Pearlmutter 2008; Ortiz et al. 2009a and b). That's to say, life cycle distribution of energy and resource consumption are concentrated in the operation phase of a building.

In economic terms, operation stage costs account for approximately 55% of the total cost over a life span of 40 years (Flanegan & Norman 1989). The significance of operation costs, such as those for utilities consumption, hiring management staff and up keeping of facilities is well recognized (Lai 2010). According to Lai et al. (2008), the operation costs include those for maintaining an in-house team, hiring outsourced contractors, purchasing spare parts and materials, replacing facility installations, and paying utility bills.

Commercial buildings are commonly constructed with quality fabrics and facilities include air-conditioning systems, lifts, fire services, etc. to satisfy the increasing demand of users, which brings increasing operational and maintenance costs to building life cycle (Lai 2010). In order to evaluate the operational costs of buildings, some necessary data and assumptions are needed, including initial capital costs, maintenance and repair costs, management costs, operation period and discounted rates (Manioğlu & Yılmaz 2006).

Pertaining to social aspect, occupants' health and comfort, stakeholder relations and occupier satisfaction and productivity are the major concerns in operation stage. The occupants' health and comfort are closely related to the sick building syndrome and building related illness and environmental sensitivity. The definition of human health as defined by the World Health Organization (WHO 1946) as "health is a state of complete physical, mental and social well-being, not merely the absence of disease or infirmity." The following are common illnesses related to users of buildings:

- Sick building syndrome (SBS)

  The symptoms listed by WHO are eye, nose and throat irritation; sensation of dry mucous membranes and skin; erythema; mental fatigue; headaches; high frequency of airway infection and cough; hoarseness, wheezing, itching and unspecified hypersensitivity; and nausea and dizziness.

- Building related illness (BRI)

  Building related illnesses, as defined by the U.S.A. National Research Council in 1987, are illnesses arising from exposure to indoor contaminants that cause specific clinical syndrome. The nature of the illness is dependent on the contaminant present within the building. For example, exposure to bio-aerosols can cause illnesses such as humidifier fever and hypersensitivity pneumonitis, whereas exposure to the Legionella bacteria precipitates Legionnaires' disease. These symptoms are not alleviated by exit from the building. The most effective mitigation strategy for building related illness is to trace the illness to a specific contaminant and remove the source from the building (Samet & Spengler 1991).

Achieving occupant comfort is the result of a collaborative effort of environmental conditions, such as indoor air temperature, illumination, radiant temperature, sound, relative humidity, air quality and air movement and others. Improving those perspectives during building operation stage can improve quality and productivity of users (Lai 2010). Thus, the occupiers' satisfaction and productivity is another important concern in this stage of a building life cycle.

In addition, the stakeholder relations need to be considered in social aspects in building operation stage (Matos & Silvestre 2013). According the Hall and Vredenburg (2003), one of the greater difficulties for dealing with sustainability is that it involves a wider range of stakeholders. They usually have contradictory interests and wishes, which increase ambiguity. To some degree, only when the stakeholders' relation has been dealt with properly, the goal of sustainable building can be achieved.

4.3.4 Demolition phase

When a construction project approaches the end of its useful life, demolition will take place. According to Gong et al. (2012), the demolition phase is at the end of the building life cycle and it includes the relevant processes concerned with the recovery and utilization of the dismantled building and abandoned building materials. Liu and Pun (2006) state that the building demolition can be viewed as the reverse process of building construction as the issues involved in a demolition project are fundamentally identical or similar to those in the construction of a project. Increasing building demolition activities are anticipated as numerous construction activities is occurring all over the world due to constant new developments every year (Pun et al. 2006).

The demolition period of a construction project is considered to make little if any positive contribution but can leave some negative impact on the environment (Shen & Wang 2002). According to Scheuer et al. (2003), the wastes produced by demolition as well as the waste disposal to the landfill have negative impact on the environment. The demolition activities represent about 2-5% of resource consumption and 0.4% of the total energy consumption. The demolition waste is considered as one of the major waste flows in the world (Huang et al. 2013). In Australia, 30-40% of the solid waste comes from construction and demolition waste, which is nearly one tonne per person annually (Pun et al. 2006). Gao et al. (2001) state that the huge amounts of demolition waste indicate that building demolition has become one of the major sources of environmental impact.

Non-recycled waste cause the loss of construction materials and take up land space for final disposal (Moffatt & Kohler 2008). Broadly speaking, recycling and disposal of demolition waste also impact on the conservation of resources. With the recycling and reuse of demolition waste, it reduces the extraction of raw materials used for new construction material production which saves energy as well (Huang et al. 2013).

From economical point of view, the major impacts include demolition cost, compensation to stakeholders, etc. The demolition costs mainly include administration cost, labour cost, plant and waste disposal cost (Pun et al. 2006). These costs are always different due to different demolition technology used (Pun et al. 2006). Besides, the materials dismantled from the project will always have economic value and they can be reused, recycled or reproduced for future construction projects (Klang et al. 2003).

Socially, the community safety and security are all important issues in demolition phase. The activities in the demolition stage will induce safety issues both to the public and the demolition workers. Community satisfaction also needs due consideration during demolition stage. According to Shen and Wang (2002), the demolition stage is important for the local communities to improve local investment in environment. A proper disposal plan offers assurance to the client, local communities and the government.

4.4 Assessing building performance from a life cycle perspective

As discussed above, building life cycle can be divided into several phases and each phase plays an essential role in building sustainability. Previously, many research works have focused on several or one of the building phases. Some researchers looked at end-of-life options for commercial buildings (Guggemos & Horvath 2003); other research has focused at construction phase of buildings (Bilec et al. 2010); some research has put the emphasis on the operation phase (Scheuer et al. 2003). However, little research has considered all the stages in a life cycle perspective. The impacts during the life cycle of a project are highly inter-dependent, as one phase can influence one or more of the other phases (Wu et al. 2012).

Each phase in a building life cycle plays an important role in achieving sustainability for a project. Inception and design phase provides an opportunity to bring together all sustainability considerations from the outset and realize sustainable strategy for the project. It is the first step of a potential project for its sustainability performance to be incorporated and improved. The construction phase is the stage during which all sustainable aspirations for the project may be put in place. The operation phase is the stage when the major positive effects of a project on the environmental, social and economic aspects occur; and finally the demolition phase offers an opportunity to plan for reuse and recycling (Thomson et al. 2011; Wu et al. 2012). Therefore, when sustainability performance of a construction project is examined, all the phases of a building life cycle should be taken into consideration.

This viewpoint is supported by Blengini and Carlo (2010) and they state that an overall judgement on building sustainability should encompass all the life cycle phases". Another reason is that different players in building industry value different things. According to Cole (1998), the definition of building performance varies according to the different interest groups involved in building development. Using an overall rating score to assess a building's performance is hard to satisfy all stakeholders. In that case, the performance scores for various stages become necessary. Therefore, this research will not only consider the performance of the whole building, but also the performance of every single stage of a building life cycle. Based on the discussion above, the sustainable impacts in different stages are identified and summarized in Table 4.2.

In the Table 4.2, the major indicators of environmental, economic and social impacts are summarized by stages. These indicators are selected based on the discussion in Section 4.3. The environmental, economic and social impacts in each stage of building life cycle are analysed, and the major indicators are chosen based on the discussion. Based on these indicators, the building performance in each phase of different stages can be assessed.

Table 4.2 Summary of the building stages and the relevant sustainable impacts

Development stages	**Major activities**	**Impacts**		
		Environmental	**Economic**	**Social**
Inception & design	Identify aims/ objectives Develop project proposal, Undertake feasibility studies, Undertake preliminary and detail design	Site selection, biodiversity, natural habitat	Land cost, loan payment consultant fees	Cultural and heritage protection, infrastructure and public facilities, neighbourhood
Construction	Mobilize resources, Transport resources to site,	Atmosphere emissions, release to water, landfill, use and contamination of land, resource	Construction costs (labour, plants and materials), professional fee	Employment opportunity, safety on site, property integrity

	Undertake construction and installation activities (Shell and core, finishes and decoration, services, etc.)	consumption, local issues, impact on the community and the local traffic, risks of environmental accidents, effects on biodiversity		
Operation	Management, operation & maintenance	Resource consumption, energy consumption, water consumption, pollutant emissions	Operation cost, maintenance cost, salary, utility bills	Occupants' health and comfort, stakeholder relations, occupier satisfaction and productivity
Demolition	Demolition & disposal	Waste disposal, landfill, operation of demolition	Waste disposal fees, labour cost, deployment of staff, land redevelopment, valued residues	Community satisfaction , safety and security

To assess the indicators in three pillars in different stages, different assessment methods need to be considered. According to the discussion in Chapter 2, the common used environmental assessment approaches include LCA approach and consumer-based approaches. In the consumer-based approaches, there are EF, CF and WF. EF track human pressures on the planet in terms of resources and GHG emissions on ecological assets. CF track human pressures on the planet in terms of GHG emission, while WF tracks in terms of water volumes. All these three approaches are applied in building industry in the past decades. For example, Ferng (2001) proposed an improvement to the construction method based on the EF method; Airaksinen and Matilainen (2011) evaluated the CF of an office building; Li et al. (2011) conducted a research on CF of a large public building during its life cycle.

Compared with the series of consumer-based approaches, LCA is an objective and feasible tool to analyse the energy, emission, resources and other environmental indicators in building life cycle. Based on Section 2.4.1, a number of research studies have used LCA approach to evaluate environmental indicators in building life cycle. Keoleian et al. (2000) evaluated life cycle energy use, GHG emission of a residential building based on the LCA approach. Junnila and Horvath (2003) evaluated the electricity and heat use as well as resource consumption during building operation stage based on LCA approach. Junnila et al. (2006) used LCA approach to evaluate the energy consumption, GHG emission and resource consumption of two office buildings in their construction, usage and EoL stage. Many other research studies which use LCA for environmental assessment can be found in Table 2.2.

As the LCA approach can assess many indicators in different building stages, it is well accepted in the construction industry as an environmental assessment approach nowadays. In addition, there are limitations for the consumer-based approaches in this research, as they are mainly focused on water, GHG emission, land, etc. It cannot cover majority of the environmental assessment indicators in each stage of building life cycle as presented in Table 4.2. Based on the discussion, the LCA approach is chosen as the environmental assessment approach in this research.

In economic assessment of a building, LCC is a technique which enables comparative cost assessments to be made over a specified period of time. Except for LCC, there are some other methods for cost accounting, including TCA and FCA. The differences among these three are that TCA and FCA cover a broader concept. TCA covers broader range of direct, indirect, contingent and less quantifiable cost, and FCA covers external social cost more than TCA (see Figure 2.3). In terms of LCC, different types have been developed including conventional LCC, environmental LCC and societal LCC. Similarly, the difference between the conventional LCC and the other two is the number and type of 'contingency' costs and the broader environmental and social costs.

In this research, the environmental and social aspects will be evaluated independently. To avoid double counting, the conventional LCC is adopted in this research for economic analysis in building life cycle.

With respect to social aspects, different approaches including SIA, social benchmarking, social footprint, etc. are discussed in Chapter 2. SIA is used to assess or estimate the social impacts for both qualitative and quantitative indicators. Social benchmarking can assess how well a project meets its objectives and how they could be more effective. Social footprint is a measurement for quantifying the social sustainability performance of an organization. As discussed in Chapter 2, social benchmarking needs regulation and policy support, social footprint focuses on a broader range of impacts. To assess the social indicators in Table 4.2, SIA is suitable at project level. As the social indicators are qualitative, an appropriate qualitative method will be discussed further in this research to support the SIA assessment.

4.5 Summary

This chapter discussed the building phases in life cycle and the sustainable impacts in different phases. Pervious research works on model development of sustainable building performance are also discussed. Based on the discussion above, it is necessary and feasible to assess building sustainable performance in different phases from life cycle perspective. In the following chapter a research method will be developed to identify the assessment indicators in each pillar in different phases, as well as the approach to establishing the model.

CHAPTER 5

RESEARCH METHODOLOGY AND DATA COLLECTION

5.1 Introduction

Based on the literature review, the shortcomings in current building assessment tools in China demand a life cycle assessment model for China. In this chapter, the research design and methodology are discussed to explain how this research is conducted. Both qualitative and quantitative methods are adopted in this research. Questionnaire survey and semi-structured interviews are used for data collection, and case study is used for model verification.

5.2 Research methodology

The primary aim of the research is to develop an assessment model to assess building performance from a life cycle perspective. Therefore, selecting an appropriate research methodology is critical for the success of the research. According to Arif et al (2012) research methodology is typically concerned with the logic of research enquiry particularly with investigating the potentialities and limitations of certain types of techniques or procedures. Guba and Lincoln (1994) stated that both the ontological and epistemological stance of the researchers has influence on the response of methodological questions. Creswell (2007) indicated that "ontology concerns with what is believed in constituting social reality whilst epistemology concerns with the claims of what is assumed to exist can be known." In that case, as the truth and reality are social constructs, both the truth and reality from the collective opinion of the participants need to be considered by researchers (Fellow & Liu 2005). Quantitative, qualitative and mixed methods are the three types of approaches usually used to conduct research

(Williams 2007). Brannen (1992, pp 5) pointed out that "quantitative approach is usually selected for the research requiring numerical data, while the qualitative approach is usually for the textual data, and the mixed methods approach for both numerical and textual data."

5.2.1 Qualitative methods

Qualitative method refers to collecting and interpreting information about some phenomenon without concern for quantities (Patton 1990; Thomas 2003). Patton (1990) stated that the qualitative research is always based on documenting information from literature review and data collection includes participant observation, in-depth interviewing, detailed description, and case studies. This method permits the researchers to study selected issues in depth and detail. He went on to state that "qualitative methods are particularly oriented toward exploration, discovery, and inductive logic. Another reason for using qualitative methods is that for particular outcomes no acceptable, valid and reliable quantitative measures exist. Qualitative data can put flesh on the bones of quantitative results and bring the results to life through in-depth case elaboration."

Leedy and Qrmood (2001) supported this viewpoint by stating that the qualitative methods are used to develop a better understanding of complex situations. Some types of qualitative methods are used often in research, such as case studies, ethnographies, and experience narratives. (Leedy & Qrmood 2001; Thomas 2003). Table 5.1 summarizes the advantages and limitations of these qualitative methods.

Table 5.1 Summary of advantages and limitations of qualitative methods

Types	Contents	Advantages	Limitations
Case study	Case study typically consists of a description of an entity and the entity's actions and also offers explanations of why the entity acts as it does.	It can reveal the way multiplicities of factors have interacted to produce the unique character of the entity that is the subject of the research.	It is hard to apply the generalizations, principles or situations from one to another with considerable risk of error.
Ethnography	Ethnography, as a special kind of case study, is the chief method used by cultural anthropologists.	It can reveal characteristics shared among members of group–characteristics that render the group's culture distinctive, thereby helping consumers of the research understand how and why one group differs from another.	Conclusions drawn from the ethnographic study of one group can be applied to other groups only at considerable peril because of the unique conditions that may determine the pattern of life in each setting.
Experience narrative	It refers to an event as described by a person who was involved in the described episode, either as active participant or as an observer.	It enables readers to participate vicariously in other people's thoughts and emotions that are associated with events the readers would never directly experience in their own lives.	Experience narratives are not effective devices for revealing how characteristics are distributed throughout a population.

Source: Thomas 2003

From the table, the benefits of using qualitative methods enable more flexible participation and reveal the multiplicities of ways. The critiques about the qualitative methods are about the errors and risks about the results' application.

5.2.2 Quantitative methods

Section 5.2.1 discusses the content of qualitative methods as well as advantages and limitations of the different methods. In other words, qualitative methods involve a researcher describing a kind of characteristics of people and events without comparing events in terms of measurement of amounts. According to Patton (1990, pp 13), quantitative methods, on the other hand, "require the use of standardized measures so that the varying perspectives and experiences of people can be fit into a limited number of predetermined response categories to which numbers are assigned". Therefore, quantitative methods are systematic, standardized, and easily presented in a short space with numbers and statistics and are succinct, parsimonious, and easily aggregated for analysis (Thomas 2003). It always starts with a problem statement and involves strategies of inquiry include experiment and surveys, and data collection on pre-designed/determined instruments (Patton 1990; Creswell 2003; Thomas 2003).

King et al (1994) indicated that the quantitative measurement and analysis are easily replicable by other researchers based on numerical measurement of specific aspects of phenomena, when the quantitative methods abstract from particular instances to seek general description or to test causal hypotheses. Thomas (2003) presented four types of quantitative studies and they are: survey, experiment, correlation study and liberal-feminist study. They also have their own advantages and limitations. Table 5.2 summarizes the advantages and limitations of some of the quantitative methods. For example, surveys are useful to reveal the current status of a target variable within a particular entity, but it fails to show the unique way that the target variable fits into the pattern. Correlation study provides statistical techniques for calculation and provides more precise information, but it is only as good as the data on which it is based.

Table 5.2 Summary of advantages and limitations of quantitative methods

Types	Contents	Advantages	Limitations
Survey	A method for collecting quantitative information about items in a population	Useful to reveal the current status of a target variable within a particular entity	Fails to show the unique way that the target variable fits into the pattern
Experiment	It is a method to help people decide between the hypotheses or	The strengths of experiment include its capacity to demonstrate	The limitations of experiment include lack of generalizability and

	explanation	cause-and-effect relationships. It is useful to test theories and hypotheses about how physical processes work under particular conditions	external validity
Correlation study	It is a scientific study in which a researcher investigates associations between variables.	Provides statistical techniques for calculating and provides more precise information	It is only as good as the data on which it is based

Source: Thomas 2003

Based on the discussion in Sections 5.2.1 and 5.2.2, the qualitative and quantitative methods all have their own advantages and limitations in research. In order to adopt their good points and avoid the shortcomings, the mix methods are discussed in next section.

5.2.3 Mixed method strategies

King et al. (1994) stated that most research does not fit clearly into one category - qualitative or quantitative - or the other. The best often combines features of each. In a research project, some data may be collected that is amenable to statistical analysis, while other equally significant information is not. Thomas (2003) stated that each research method is suited to answering certain types of questions but not appropriate to answering other types. The best answer frequently results from using a combination of both qualitative and quantitative methods.

Triangulation is a method developed in 1979 as convergence across qualitative and quantitative methods (Jick 1979; Creswell 2009). Jick (1979, pp 607) noted that the "effectiveness of triangulation rests on the premise that the weaknesses of each single method will be compensated by the counterbalancing strengths of another." This is based on the assumption that the multiple and independent measures do not share the same strengths and limitations. The U.S. AID Evaluation Special Study series (1989) had over 60 projects to show how both qualitative and quantitative data can be combined, and how researchers can combine direct fieldwork, secondary data, project documents, interviews, and observations to draw conclusions. By the early 1990s, the mixing idea started to consider the actual integration or connection between the quantitative and qualitative data instead of just convergence (Patton 1990). Further, qualitative and quantitative data can be merged into one large database or the results can be used side by side to reinforce each other (Crewell & Clark 2007). Creswell (2009) summarized how the mixed method (triangulating method) works based on the quantitative and qualitative methods and details are presented in Table 5.3.

Table 5.3 Characteristic of quantitative, qualitative and mixed methods

Quantitative methods →	**Mixed methods**	← **Qualitative methods**
• Pre-determined • Instrument based questions • Performance data, attitude data, observational data and census data • Statistical analysis • Statistical interpretation	• Both pre-determined and emerging methods • Both open-and closed-ended questions • Multiple forms of data drawing on all possibilities • Statistical and text analysis • Across database interpretation	• Emerging methods • Open-ended questions • Interview data, observation data, document data, and audio-visual data • Text and image analysis • Themes, patterns interpretation

Source: Creswell 2009

From the table, the mixed methods combine the advantages of both the quantitative and qualitative methods and have a wider applicability. Quantitative methods mainly deal with the performance data, attitude data, observational and census data, while qualitative methods primarily deal with interview data, observation data, document data and audio-visual data. Combining with these two types of methods, mixed methods are able to deal with multiple forms of data including all the possibilities. Thus, both the statistical and text analysis can be done with mixed methods.

5.3 Data-collection processes and instruments

When people speak of research methods, they often refer to processes and instruments used for gathering information. Some of the important processes and instruments include content analyses, observations, interviews, questionnaires, inventories and case studies (Thomas 2003). These different processes have their own strengths and weaknesses.

Content analysis is the most suitable way for finding the host of research questions but it is time consuming. Observation, including direct and mediated observation, helps researchers watch and/or listen to events, then have a record. However, the accuracy of the observations is often questioned. Questionnaires enable researchers to collect a large quantity of data in a relatively short period of time, but the low response rate has often plagued the researchers, which is similar to inventories. Compared with questionnaire survey, interviews provide the researchers with greater flexibility and personal control, but the researcher's presence may bias responses (Thomas 2003). A detailed analysis with respect to advantages and limitations of different data-collection processes are summarized in Table 5.4.

Table 5.4 Advantages and limitations of different data-collection processes

Processes	Content	Advantage	Limitation
Content analysis	Content analysis is the process to search through one or more communications to answer questions that the investigator brings to the search.	It is suitable for gathering information about what communications contain. It is the only appropriate method for answering a great host of research questions.	Content analysis is time-consuming and laborious in relation to the amount of information obtained. The accuracy and comprehensiveness of the results of an analysis are dependent greatly on researchers.
Observations	Observations involve	For direct observation, it	For direct observation, it

	watching and/ or listening to events, then recording what occurred. It can be either direct or mediated.	provides information from spontaneous and unexpected events with no special equipment required. For mediated observation, the auditory and visual record can help the researchers review important aspects.	is often difficult for the observer to produce an immediate, accurate record. For mediated observation, the accuracy of the observer's report is still questionable as it depends greatly on people's subjective inference.
Questionnaires	Questionnaires involve a set of questions that participants in a survey are asked to answer. It is always used for collecting the facts and opinions.	They enable a researcher to collect a large quantity of data in a relatively short period of time and can gather a wide variety of information from respondents. Data can be collected from peoples in distant places, and the researcher need not be present at the time.	A significant disadvantage of questionnaire survey is low respondent rate. If the researcher is not present to supervise the participants, participants can easily ignore the form.
Interview	Interviews usually involve a researcher orally asking questions from individuals to answer orally. Traditionally it has been conducted face-to-face, but it can also be conducted via phones and internet.	Interviews provide the researcher with greater flexibility and personal control than do questionnaires. In comparison to direct observation, interviews are more efficient for collecting information about people's knowledge, personal backgrounds, and opinions.	Provides indirect information filtered through the views of interviewees. Provides information in a designated place rather than the natural field setting. Researcher's presence may bias responses. Not all people are equally articulate and perceptive.
Inventories	It refers to a printed document on which participants in a research project are asked to report their attitudes or preferences	Its strength and weakness is similar to the questionnaire.	

Sources: Thomas 2003; Creswell 2009

5.4 Research methods used in the construction industry

In the past decades, the research methods mentioned in Section 5.2 are widely used in construction industry and help the researchers conduct their research and find the value of new things. Matipa et al. (2009) conducted a questionnaire survey throughout Ireland to ascertain the extent to which IT systems were being used as part of a total life cycle cost analysis. They indicate the reason for choosing questionnaire as the data collection method included "the type of population, most of the population could not find time for an interview, as well as the increasingly expensive nature of alternative means of data collection" (Matipa et al. 2009, pp 83).

Fiedler and Deegan (2007) used a series of in-depth interviews with individuals from building and construction companies as well as environmental groups to document a review of environmental collaborations in the Australian building and construction industry. Prior theory, mentioned by Perry (1998) is also used to provide a focus for the data collection phase in semi-structured interviews. He identified several motivations to drive the collaboration of particular environmental groups and building and construction companies on specific projects with in-depth interviews. Similarity, Hong et al. (2012) use semi-structured interviews to explore the applicability of construction partnering in Mainland China. Their research starts with document analysis to identify the favourable conditions and potential difficulties in implementing partnering in China. After that, a series of semi-structured interviews are conducted to confirm their consumption. A group of academic experts and industrial practitioners are chosen to solicit the perception of the benefits and obstacles of the application of partnering in China.

Except for using a single research method, some researches adopted two or more methods for data collection. Tam et al. (2012) conducted a questionnaire survey and semi-structured interviews to examine the factors affecting the implementation of green buildings for the Hong Kong construction industry. The research starts with a pilot questionnaire survey to 10 practitioners, and followed by face-to-face interviews to receive comments and feedback to further improve the readability and suitability of the questionnaires. After that, the main survey was conducted and 145 responses had been collected. The advantage of the way of combining questionnaire surveys and interviews is that they can make better use of both methods and provide more interaction. A similar approach has been adopted by Varnas et al. (2009). They used questionnaire survey combined with interview to explore the current practices, problems and opportunities of green procurement of construction contracts in Sweden. In the research, the questionnaire aims at achieving an overall picture of the application of environmental preferences in the procurement of construction contracts, and interviews were used to achieve a deeper understanding of the reasons for applying these environmental aspects. In other words, the questionnaires provide a broad base and the interviews provide deeper discussion.

These two research studies used interviews after the questionnaire survey as supplement, in some other research; interviews can be also used with the questionnaire survey at the same time. Per Anker and ElvarIngi (2013) conducted a research to explore the implementation of building information modelling (BIM) in the Nordic countries of Europe. The data collection was conducted in two countries; one was Iceland and the other was Denmark. The questionnaire survey was conducted in Iceland and the interviews were conducted in Demark. After that, the two analyses were discussed jointly and explored how learning from implementation of BIM in one country can be used in another country.

Arif et al. (2012) used case studies and semi-structured interviews to assess the implementation of waste management practices in Indian construction industry. They stated that case studies can be treated as conducting an in-depth investigation into a research topic, as the empirical enquiry that investigates contemporary occurrences within its real life context is particularly useful when boundaries between phenomenon and context are clearly evident. King (1994) stated semi-structured interview in his book as ‘the qualitative research interview’ as the qualitative interview is particularly appropriate where a study focuses on the meaning of particular phenomena to the participants.

Besides two method combination, some researchers have used more than two methods for data collection. Häkkinen and Belloni (2011) used document review, interviews and case studies to address the actual barriers and drivers for sustainable buildings. Their research started with a critical review and web-based enquiry of the current barriers and drivers. Then, interviews were used to define the need for the changes, followed by the case studies to study the possibilities to improve the sustainable building processes and the benefits of sustainable buildings. These three methods worked closely to complete this research. Similarity, Lam et al. (2011) proposed a green specification framework for modelling established green specification systems in Hong Kong. It also started with literature review to support the components of the proposed framework and then used questionnaire survey and interviews to collect the data for the framework. Research conducted in such form often uses literature review as foundation or inspiration, then uses the questionnaire survey, interview or case study to verify their assumptions, collect data, and draw inferences.

Table 5.5 summarizes some of the methods used in current research on construction industry. The one or several methods chosen in the research works are all based on their own research aims and objectives. From the table, some research studies use only one method, such as questionnaire survey or interviews; some use two or three together. Combining the methods together to conduct the research can help to adopt the good points and avoid the shortcomings.

Table 5.5 Research methods used in construction industry

Methods	Research studies	References

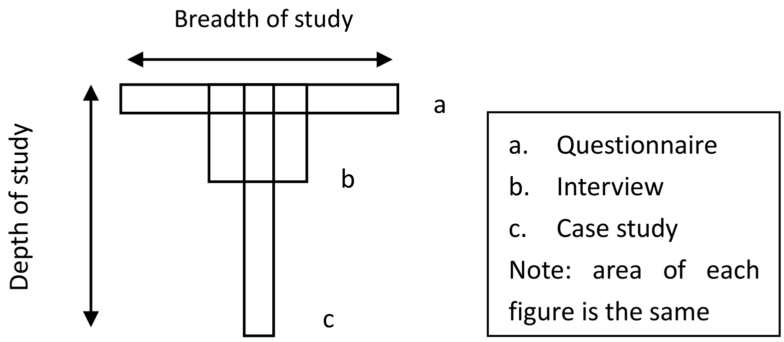
Questionnaire survey	Ascertains the extent to which IT systems were being used as part of a total life cycle cost analysis in Ireland	Matipa et al. 2009
Interviews	Documented a review of environmental collaborations in the Australian building and construction industry	Fiedler & Deegan 2007
Interviews	Explored the applicability of construction partnering in Mainland China	Hong et al. 2012
Questionnaire survey Interview	Explored the current practice, problems and opportunities of green procurement of construction contracts in Sweden	Varnas et al. 2009
Questionnaire survey Interview	Examined the factors affecting the implementation of green buildings for the Hong Kong construction industry	Tam et al. 2012
Questionnaire survey Interview	Explored the implementation of building information modelling (BIM) in the Nordic countries of Europe	Per Anker and ElvarIngi 2013
Interviews Case study	Assessed the implementation of waste management practices in Indian construction industry	Arif et al. 2012
Document review Interviews Case study	Addressed the actual barriers and drivers for sustainable buildings	Häkkinen & Belloni 2011
Literature review Questionnaire survey Interviews	Proposed a green specification framework by modelling after established green specification systems in Hong Kong	Lam et al. 2011

5.5 Research design

To choose the most suitable type of research method in this research, it is important to consider the full range of possibilities of data collection. The advantages and disadvantages of particular methods (see Table 5.1, 5.2), error sources, possible bias, strengths of triangulations etc. should all be considered in the adopted research design.

Fellows and Liu (2008) stated some common used methods for construction and these include questionnaire, interview and case study. All these methods have their own advantages and limitations. In current research works, these methods serve alone or together to help conducting a research (Table 5.5). Figure 5.1 shows that questionnaire is broad but not deep enough, while case study is deep but yields narrow results. Creswell (2003, pp 15) stated that case study explores "in depth a program, and even an activity, a process, or one or more individuals". The interview falls in between them. Choosing any one of them may cause a broad but shallow study at one extreme or a narrow and deep study at the other.

Figure 5.1 Breadth v depths in research



Source: Fellows & Liu 2008

This research aims at developing a sustainable assessment model from life cycle perspective in China. All three pillars in building sustainability are considered in this research. Firstly, the gaps in sustainable building assessment are identified, followed by the development of research aims and objectives. Comprehensive literature review is conducted to discuss the sustainable development and the triple bottom line approach. The assessment approaches in relation to three pillars of sustainability are also discussed. After that, the sustainable building and sustainable building assessment models and tools are reviewed in order to offer an insight into green building assessment. The building processes and building life cycle performance are also reviewed as this offers a theme for this research.

Based on the literature review, there are gaps in developing a sustainable building assessment model in different stages of building life cycle, especially in China. To get the primary data for green building assessment in China and the data for model development, the questionnaires are used to collect information from a big sample.
All the information collected from the questionnaires, like the current situation, identified key indicators for the model to be used as the foundation of the data analysis. Questionnaires are always used to collect the broad information. In order to have in-depth discussion and more open idea for some issues generated in the questionnaire survey, interview is needed in the research (Thomas 2003; Fellows & Liu 2008; Creswell 2009). It can offer an opportunity to the participants to explain more information which is hard to get from questionnaire survey.

Semi-structured interviews were chosen in this research to gain enough interaction, notably, feedback information from the providers. These two methods are adopted for data collection for the research. As presented in Figure 5.1, the combination of these two methods will help to collect both broad and in-depth data. In this research, broad data is needed to get the general opinion about the green building as well as its assessment in China, which makes the questionnaire survey necessary. The indicators generation also need a large database to make it adequate and avoid bias. Considering some open-ended information is needed, as well as some in-depth discussion, interviews are also necessary in this research.

When adopting these research methods, different forms are used. Questions in the questionnaire surveys usually appear in two primary forms – open or closed. Interviews usually vary in three forms – structured, semi-structured and unstructured. According to Fellows and Liu (2008), these forms can generally be categorised as either one-way or two-way communication. One-way communication methods include postal questionnaires, completely structured interviews, diaries, scrutiny of documents and observations by the researchers, while two-way methods permit feedback and gathering of further data via probing and include semi-structured interviews and participant observation. These are also regarded as linear data collection methods (one-way communication) and non-linear methods (two-way communication). Rogers and Kincaid (1981) asserted that linear methods focus on transfer of data/information whilst non-linear methods are more conducive to the transfer of meaning. In another words, linear methods fail to provide interaction in data collection, more likely one-off approaches.

In this research, both linear and non-linear methods will be used for data collection, including closed questions in questionnaire survey and semi-structured interviews. Using closed questions is due to the fact that it can provide large data in relatively short time period. For the information target in questionnaire survey, closed questions can be more precise and more targeted. For deep discussion in interviews, semi-structured interviews are needed to permit feedback and gathering of further data. Some open-ended questions in questionnaire survey also provide interaction with data collection.

The assessment indicators for the model are chosen based on the results of questionaries and semi-structured interviews integrated with the former literature review conducted in Chapter 4. The model is developed based on these assessment indicators. After the model is proposed, case study is used to verify the model. Multiple sources such as direct or participant observations, interviews and archival documents are needed for the data collection for a case study (Williams 2007).

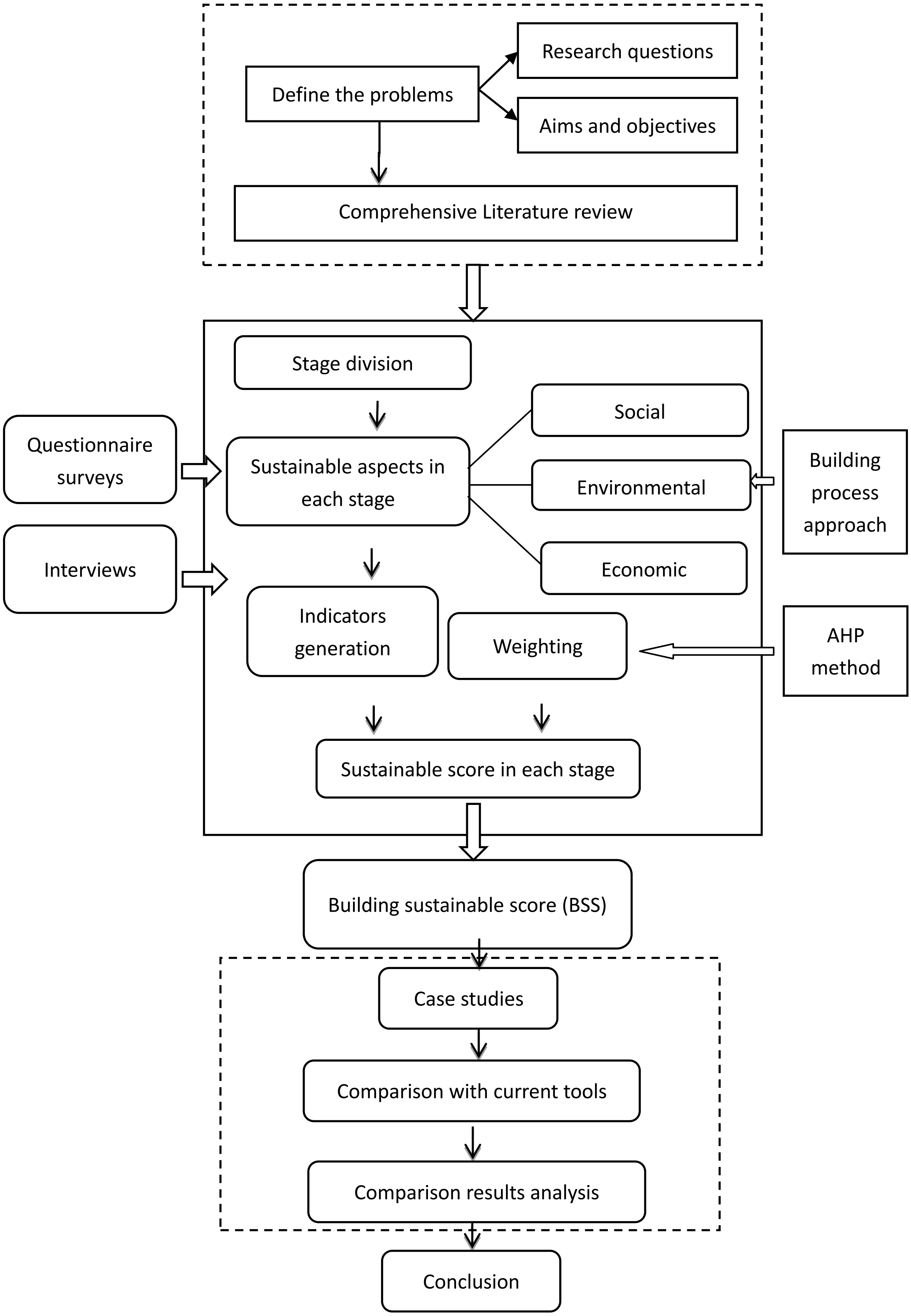
To sum up, this research uses the mixed qualitative and quantitative method in data collection process. It starts with qualitative research to identify the research gaps as well as developing the aims and objectives of the research and generates the conceptual assessment framework, followed by the data collection, as well as the model development and case study. For data collection, both questionnaire survey and interview are conducted, which include the qualitative and quantitative questions. Therefore, the data collected in this survey can be both broad and also deep enough. It avoids the shortcomings of using either one method separately and integrates the advantages of both methods. Figure 5.2 shows the flowchart of this research.

5.6 Summary

In this chapter, different research methods have been analyzed. After comparing their advantages and limitations, as well as taking the characteristics of this research into consideration, mixed methods (triangulation) are used in this research. The questionnaire surveys and interviews have been employed for data collection for model development. Questionnaires serve as foundation for the data needed for model establishment, while interviews focus on some deeper and unsolved questions in the questionnaire survey.

The next chapter will discuss the process of data collection in this research. The data collected from the questionnaire survey and interviews are analyses in the next chapter. A model will be established after data analyses. Case studies will be used for model verification.

Figure 5.2 Research flowchart



CHAPTER 6

DATA ANALYSIS AND DISCUSSIONS

6.1 Introduction

The previous chapter described the research methods. This chapter presents the process of data collection and the results of data analysis. The results have been analyzed in correlation with the literature review in previous chapters. The aim of this chapter is to report on the results of data analysis and draw conclusions from the results which have been used to develop the decision model for environmental building assessment at the later stage.

This chapter includes the analysis from industry questionnaire survey and semi-structured interviews. The basic structure of the chapter is transforming those quantitative and qualitative data into useful information. The current situation of green building and sustainable assessment tools in China is discussed. After that, the stage division and the associated sustainable impacts in different stages of a building are analyzed.

6.2 Data collection process

Based on the reviews and analysis of the current literature, a model which considers the three pillars in sustainability in building life cycle is needed for construction in China. In order to establish such a model, the assessment indicators need to be identified first. In addition, the local data of the current situation of green building in China also provided valuable information for this research. Consequently, the industry survey was designed to collect the primary data from China's construction market, which included a questionnaire survey and semi-structured interview. This data collection process was under the ethics approval of the University of Technology, Sydney (UTS), with the approval number 2011-450A. The information letter was sent together with the invitation to the participants of the survey and interview. The consent forms were signed by all the interviewees.

6.2.1 Questionnaire survey

The questionnaire survey was conducted to get information about the assessment indicators as well as the current situation of green building and assessment in China from professionals in the construction industry and to collect data for developing the model. Professional is usually defined as someone who has experience or skill in a particular job or activity in the construction industry. Therefore the selection criteria for professionals in this research include people working directly in the construction industry or their jobs are closely related to the construction industry. They need to have some years of working experience. However people with experience of working with sustainable building will have the priority.

This research aims at establishing an assessment model for green building assessment in China. This model focuses on using the three pillars to assess building performance at different stages of a building life cycle. Therefore, the building stages needed to be stated first in the survey. In addition, obtaining the assessment indicators is the major objective in the survey. The questionnaire survey was conducted for the data collection.

The survey contained a pilot study and a main survey, and they were conducted online. Villoria Saez et al. (2013) stated three major advantages for conducting a questionnaire online:

- Efficiency: electronic mails are the most efficient tools used between stakeholders involved in the construction process
- Confidentiality: online survey is more confidential to ensure at all times the privacy of the responses
- Questionnaire length: online survey provide greater flexibility for the respondent to develop and review their ideas

The wider coverage is another advantage for online survey. In addition, the questionnaire survey was conducted in China, which is far from Australia. It would be costly and time consuming to use mail, so the questionnaire survey was conducted online.

i) Survey sample

According to Fellows and Liu (2008, pp 159), "the objective of sampling is to provide a practical means of enabling the data collection and processing components of research to be carried out whilst ensuing that the sample provides a good representation of the population." In order to get the proper information, a suitable sample should be chosen in the survey. The sampling error is often ignored by the researchers when determining the size of sample. They also sometimes fail to address possible biases of respondents.

The first task for the sampling method is to define the population which is critical as the population defines the set of entities from which the research sample is drawn (Eisenhardt 1989). There are three major types of sampling methods in the sampling frame, including random sampling, judgmental sampling and non-random sampling (Fellows & Liu 2008). In random sampling, equal chance is offered to each member of the population. Judgmental sampling means judgment is used to determine which items of the population should form the sample. Non-random samples, including systematic sampling, stratified sampling and cluster sampling, are appropriate where a population occurs in groups.

Given an extremely large population, judgmental sampling may be used. Judgments help to choose which items of the population should form the sample. In this research, experienced professionals in construction industry or closely connected with construction industry, such as the officer who was in charge of green building evaluation in a government agency, were chosen as the sample in this research. However, such sampling method may introduce bias.

This research is related to the building performance, which depends greatly on the subjective opinion of stakeholders, especially the social impacts. To avoid the bias, different occupations in the construction industry needed to be included in the survey sample. The different professionals were recruited for the questionnaire survey included developers, design consultants, contractors, government agencies and academics. They were chosen as the target group as they have experience and knowledge of green buildings and have the professional capability to give good advice. Moreover, they represented different positions and points of view to express their idea on the sustainable building assessment in China. The sample size and sample location had also been determined before the survey.

This survey was planned to be conducted mainly in Guangdong Province. The reason for choosing Guangdong province as the major object was due to its highly developed economy in China nowadays. Shenzhen, as the Special Economic Zone located in Guangdong province, has been a pilot in green building development. Professionals there have more opportunity to be in contact with the green building projects and green building assessment. Their experience and field of vision would have a positive influence on the survey results. The participants included government officers, architects, structural engineers, developers, contractors, and equipment engineers, cost engineers and academics. Those professionals came from different companies and institutes. Some of them came from private companies and some of them came from government institutions. The different backgrounds they had also influenced their views on green buildings.

ii) Sample size

There are four main properties for sample size, and they are consistent, unbiased, efficient and sufficient (Fellows & Liu 2008). The variance of a consistent estimator decreases as the sample size increases. Sample size is essential to gain an unbiased result. Construction industry is well-known for the poor response to questionnaire surveys and obtaining a response rate of 20-30% is considered to be acceptable (Akintoye 2000; Dulaimi et al. 2003). Czajia and Blair (2005) have introduced a method for sample size calculation and it has been applied to several construction researches. The following equation comes from Czaja and Blair (2005):

$$SS = \frac{z^2 \times p(1-p)}{c^2} \tag{6.1}$$

Where:
SS= sample size
z = standardize variable
p = percentage picking a choice, expressed as a decimal
c= confidence interval, expressed as a decimal

For this research, assuming a confidence interval (c) of $\pm$10%, a value of 95% was established for confidence level (significance level of α = 0.05, z =1.96). Sample size is at least 311. Therefore, approximately 2500 participants were set up as a goal sample size for this questionnaire survey.

iii) Questionnaire development

The questionnaire was developed to have a deeper insight into the current sustainable building assessment in China and gained further information for model development. The questionnaire contained three parts - personal details, general questions, and model development. Part one is personal details, includes 5 questions gender, age, location, work experience and qualifications. This is to obtain background information of participants and for recording and data classification. Part two contains general questions; including 5 questions about the current situation of green building and green building assessment in China. In the previous literature review, the current situation of green building assessment is discussed. The purpose of this part is to gain a clearer picture of the current situation in China and to provide motivation for the development of the model.

Part three is for model development and includes 10 questions about the stage division of building life cycle, the key issues in assessing environmental, economic and social performance, etc. (see Appendix D). In Chapter 4, the stage division of a building life cycle is discussed. Whether it is suitable for the China situation still needs to be verified. As the sustainable building assessment has strong regional characteristic, incorporating the local experts' opinions for the stage division become important. Assessment indicators are other important issues which needed to be discussed in this survey. The experts' opinions in assessment indicators helped to make the model more adaptable in China's situation.

iv) Pilot study

After the questionnaire was developed, the pilot study needed to be conducted before the main survey. The aim of the pilot study was to find out whether these questions were clear, how long it took for the participants to finish, whether they answered in proper way, etc. It helped to identify some problems and polish the final questionnaires.

The pilot study started from February 2012 and lasted for two weeks; 35 professionals had been recruited for this study. This pilot study was aimed to test the questions and revise them before the main survey. The 35 professionals came from different parts of China, southern China, northern China, eastern China, western China and central

China. They were recruited from website, acquaintance referral as well as supervisor's help. The questionnaires had been sent to them via email as attachment as well as web link, so they can fill out either the word document or online directly.

Generally, the results for the pilot study were good. The time for them to fill this questionnaire was around 15 to 20 minutes. However, there were still some problems found in this study. Some of the questions were too vague or had different meanings. They were revised after this had been pointed out by the participants. In the final survey, the feedback of pilot study such as the logic relation of each question was incorporated.

v) Main survey

The main questionnaire survey was conducted online, and 479 were completed satisfactorily. The main survey started at 20/2/2012, and ended at 3/5/2012. It took more than two months. About 482 professionals participated in this survey (three incomplete were treated as invalid). These professionals were recruited from different part of China, mainly in Guangdong province. The link of the online survey was sent to about 1,000 people originally, some of the participants had forwarded this link to their contacts. The response rate may not be calculated exactly due to the link having been forwarded to the participants' colleagues.

The contact details of these professionals were collected from website and industry recommendation. Some of participants introduced their contacts in the same field to participate. The participants needed to have some years' experience in construction industry or closely connected with construction industry. The experts from the firms which have experience with sustainable building or sustainable building assessment, as well as the government agency which had taken charge of the ESGB certification were given priority in this survey.

The questionnaires had been sent to participants via email both by attachments or web link. Similar to the pilot study, the participants could fill the form either in word documents or online directly. The whole data collection process took more than two months, mainly in Shenzhen, Guangzhou and other cities in Guangdong province. The questionnaire survey was accessible online, so the professional could participate in it wherever they are. According to the discussion in Section 5.5.1, the participants needed to be well distributed to avoid bias.

6.2.2 Interview

The participants in the semi-structured interview had been recruited from the questionnaire survey. The people who were willing to take part in the interview left their contact details for the face-to-face interview. A total of 20 professionals agreed and participated in the interviews. As discussed before, the questions in the questionnaire survey had limitation and it is hard for the participants to present the details and depth information. Thereby, the interviews were used as the supplement to collect data.

Among the 20 professionals who participated in this interview, there were 4 designers, 4 government officers, 3 consultants, 4 contractors, 2 academics, 3 developers. 55% of them were 36-45 years old and had extensive experience. Table 6.1 shows the background of the participants.

Table 6.1 The component of the participants

Professionals	Age (Years)				Total
	26-35	36-45	46-55	>55	
Designers	1	3	0	0	4
Government officers	0	1	2	1	4
Consultants	1	2	0	0	3
Contractors	0	2	2	0	4
Academics	0	1	1	0	2
Developers	0	2	1	0	3
Total	2	11	6	1	20

The interviews started from June 2012 and lasted about 4 weeks. They started after the pre-analysis of the questionnaire survey. They were aimed at collecting more in-depth information from the participants. Due to the travel funding, only the professionals in Guangdong province had been chosen.

All the participants read the information letter and signed the consent form before they started the interview. The interviews were conducted in their office by appointment. It was face to face and lasted 1 to 1.5 hours for each person. Notes and tape recording were kept for record. The questions in semi-structured interview were based on the results of the questionnaire survey. The questions about stage division and indicators generation were important for model development. The sample semi-structure interview questions can be found in Appendix E.

6.3 Data analysis - questionnaire survey

479 valid questionnaires had been collected in the questionnaire survey. The sample included a group of stakeholders from different fields including developers, design consultants, contractors, government agencies, academic and others. Others included lawyers, property managers, secretaries and construction workers. These six groups

had professional knowledge and experience in the green building research and their opinion on sustainable assessment models and tools contributed a lot to this research. The samples also covered a broad range of age and work experience as well as regions.

The questionnaire survey contained three major parts which include background, general questions about sustainable building assessment in China, and data for model development. A sample of the questionnaire survey has been included in Appendix D. In the following section, the general background of the questionnaire survey will be discussed.

6.3.1 General background

The background information of survey participants were summarized in Table 6.2. From the table, 64% of the participants were male. It is obvious that the building industry is still a male dominated industry. The number of male respondents is nearly double the number of female respondents. The female respondents were approximately 27% of the male respondents and they are under-represented in particular in 'design consultants'.

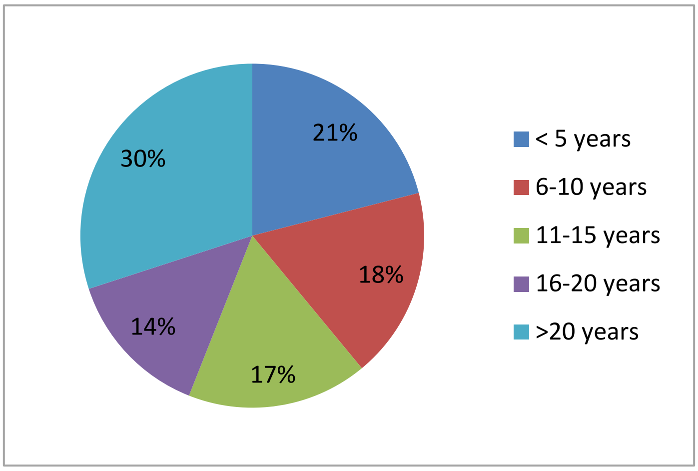
From the regional distribution in Table 6.2, 83.4% of the participants were from Southern China, and there were still 16.6% of the participants from other regions of the country. According to the discussion in Section 6.1, Southern China was chosen in this survey due to its developed economy and experts there have much experience with sustainable buildings compared to other parts of China such as the west. China is a vast country and the situation in the Southern part cannot represent the whole country. Therefore, the model which was based on the data collected in Guangdong Province would hardly represent the situation of the whole country. However, this model can be used as a base. When it is applied to other parts of China, regional adaptation collaborative is needed to adjust some assessment indicators.

Table 6.2 Summary of general background of participants in questionnaire survey

	Male		Female		Total	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
By Age						
<25 years old	22	4.6	19	4.0	41	8.6
26-35 years old	105	21.9	64	13.4	169	35.3
36-45 years old	94	19.6	55	11.5	149	31.1
46-55 years old	69	14.4	32	6.7	101	21.1
>55 years old	15	3.1	4	0.8	19	3.9
Total	305	63.7	174	36.3	479	100
By Professional						
Developers	27	5.6	15	3.1	42	8.7
Design consultants	129	26.9	34	7.1	163	34.0
Contractors	66	13.8	42	8.8	108	22.6
Government agencies	44	9.2	46	9.6	90	18.8
Academics	11	2.3	18	3.8	29	6.1
Others	28	5.8	19	3.9	57	9.7
Total	305	63.7	174	36.3	479	100
Note: Others include: lawyers, property managers, secretaries, construction workers etc.						
By Regions						
South China	247	51.5	153	31.9	400	83.4
East China	31	6.5	7	1.5	38	8.0
North China	8	1.7	7	1.5	15	3.2
Central China	9	1.9	4	0.8	13	2.7
West China	10	2.1	3	0.6	13	2.7
Total	305	63.7	174	36.3	479	100
By Work experience						
<5 years	52	10.8	47	9.8	99	20.6
6-10 years	58	12.1	30	6.3	88	18.4
11-15 years	50	10.4	31	6.5	81	16.9
16-20 years	46	9.6	20	4.2	66	13.8
>20 years	99	20.7	46	9.6	145	30.3
Total	305	63.7	174	36.3	479	100

Besides, in this survey approximately 30% of the participants in this study have had more than 20 years' work experience. The years of work experience from the participants were well distributed (Figure 6.1). This could avoid the bias coming from the working experience, as the professionals with less work experience may have a different opinion to those who have much longer work experience.

Figure 6.1 experience distribution



From Table 6.2 approximately 34% of the participants were design consultants and 22.6% of the participants were contractors. Table 6.3 shows the age distribution by gender and professional. 35% of the participants in this survey were aged between 26 to 35 years old. Among them there were also more male than female participants. Male numbers in the age group of 26 to 35 years was approximately double the number of female. In this age group, the majority of the male participants were the design consultants whilst female participants were working for contractors, etc.

Table 6.3 Age distribution by gender and professionals

	< 25		26-35		36-45		46-55		>55	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Devel	0	1	7	5	12	7	7	2	1	0
Design	7	2	50	11	39	10	26	11	7	0
Contra	3	7	22	18	22	14	18	3	1	0
Gover	2	0	13	15	14	20	11	11	4	0
Acade	1	3	3	6	3	2	3	3	1	4
Others	9	6	10	9	4	2	4	2	1	0
Total	22	19	105	64	94	55	69	32	15	4
%	4.6	4.0	21.9	13.4	19.6	11.5	14.4	6.7	3.1	0.8

Note:
Devel: Developers
Design: Design consultants
Contra: Contractors
Gover: Government agencies
Acade: Academics
Others include: lawyers, property managers, secretaries, construction workers etc.

The experience distribution varies on the professions of the participants. Table 6.4 shows their experience by professions; it can be found that the 40% of the developers, as well as the 39% of the government agencies have more than 20 years' work experience. In contrast to them, the 43% of the design consultants have 6-15 years' work experience, and 32% have more than 20 years' work experience.

Table 6.4 Experience distribution by professionals

Professionals / Experience	Devel	Design	Contra	Gover	Acade	Others
< 5 years	5	26	26	10	8	24
6-10 years	5	38	18	14	5	8
11-15 years	8	32	18	15	4	4
16-20 years	7	15	23	16	3	2
>20 years	17	52	24	35	9	8
Total	42	163	109	90	29	46
%	9	34	23	19	6	9

6.3.2 Sustainable building development in China

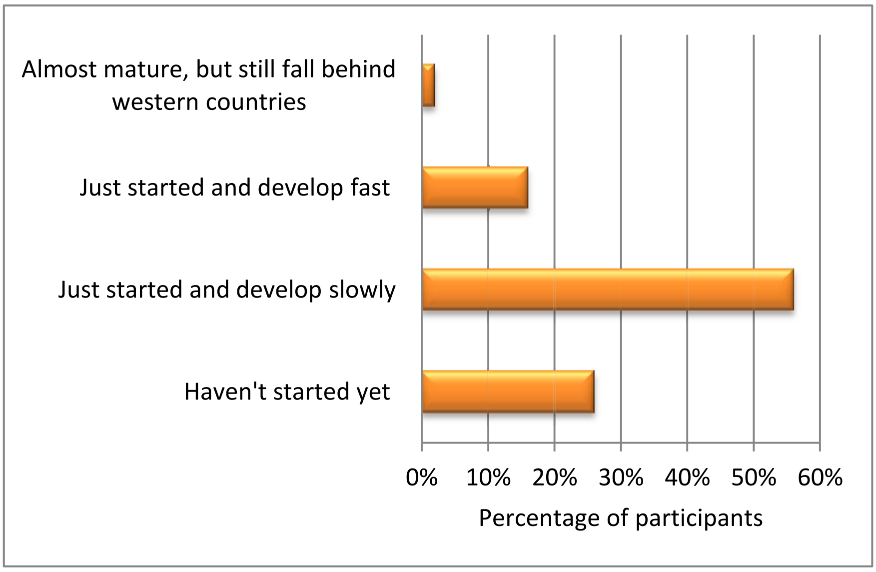
After investigating the general background of the participants, the questionnaire survey included five questions on the current situation of sustainable building development and sustainable building assessment in China. In the literature review, the gaps and shortages of current sustainable building assessment, especially in China are examined. However, these are all based on the former documents. Since the construction industry developed fast in China (Kai & Wang 2011), it is important to get the primary information of the update data of the sustainable building situation for this research.

Three questions were designed in this part (details included in Appendix D). The participants were asked to compare the situation of green building in China with the western countries. For the people who thought the green building development in China had fallen behind the western countries, they were asked to give the possible reasons. The ways to improve the current situation in China were also asked.

The participants in this survey come from different fields in construction industry, and they have different concerns and requirements about sustainable building development in China. Getting their opinions about the current limitation of sustainable building as well as the ways to improve the sustainable building in China can supplement and/or improve the information from the literature review.

Among the answers to the question about the sustainable building development in China (Figure 6.2), about 56% of the participants thought the current situation of green building in China has just started and has developed slowly, while 26% of the participants though it even has not started yet.

Figure 6.2 The current situation of sustainable building development in China



The reasons for this circumstance have also been analyzed in this study. For those who thought the green buildings in China 'are still falling behind the western countries', they were asked to choose the possible reasons for it and rank them. As for those who thought the green building in China is 'very mature and takes the lead', they were asked to ignore this question. Some of the major causes for the slow uptake of green building in China have been developed from the literature (Huang & Li 2006; Kai & Wang 2011; Tian et al. 2012; CSUS 2012), such as:

- lack of professional consciousness
- technology constraint
- lack of fund
- building material constraint
- and others

In this question, the participants were ask to rank the level of importance of those causes from 1 to 5 (1=most, 5 = least).

The Relative Importance Index (RII) is used in this study to assess the relative importance of the indicators. In this question, RII is used to rank the causes for slow uptake of green building in China.

$$\text{RII} = \frac{\sum a_i x_i}{A * N} \quad (6.2)$$

Where a_i = constant expressing the weight of the i^{th} response,
x_i = level of the response given as a percentage of the total response for each factor,
A = highest weight,
N = total number of respondents.

The value of RII ranges from 0 to 1; a higher RII indicates that a particular factor is more significant than the other. The RII for groups was determined by averaging the RIIs of all individual factors within the same category. The RII results are shown in Table 6.5:

Table 6.5 Causes for the slow development of green building in China

Factors	RII					Aver RII	Rank
	Devel	Design	Contra	Gover	Acade		
Lack of professional conscious	0.87	0.87	0.86	0.84	0.85	0.86	1
Technology constraint	0.69	0.69	0.69	0.72	0.68	0.69	2
Lack of investment	0.54	0.57	0.65	0.62	0.52	0.58	3
Building material constraint	0.41	0.42	0.46	0.44	0.39	0.42	4
Other	0.19	0.15	0.17	0.18	0.12	0.13	5

Note: Other include high cost, conceptual misunderstanding, etc.

From the Table 6.5, professional conscious is the most important reason for hindering the development of green building in China from all fields of professionals, followed by technology constraint and lack of investment. ‘Lack of professional conscious’ here means the green building has not attracted enough attention from all different stakeholders in the building industry and they include developers, consultants, construction managers, etc. The different professionals may have different concerns in some points, but when considering the reasons for the obstacle to current green building development, they have the similar idea that the professional conscious is the most important one. What causes this problems and how to overcome it needs deep discussions in a following interview.

Technology constraint is the second important reason for the slow development of green building in China. It means the green building technology still needs improvement. In addition, lack of investment is another reason according to this survey. According to Kai and Wang (2011), there are some misunderstandings of green building as they are costly but of less benefit. Thus, the developers are not willing to spend their money on it. However, according to the discussions in Chapter 3, the sustainable building will bring more benefits in the long term.

6.3.3 Ways to improve the current situation of green building development in China

How to improve the current situation of green building assessment in China? Several options can be useful. There are some options adopted from literature (Lu 2010; Kai & Wang 2011; CSUS 2012; Chen & Lee 2013), such as:

- Establish a complete legal system
- Develop an assessment system which is suitable for China
- Improve professionals’ consciousness on building sustainability
- Develop eco-friendly materials
- Others

The participants were asked to rank the five options according to their own experience and knowledge. The structure of this question is similar as the last one.

Table 6.6 the ways to improve the green building situation

Factors	RII					Aver RII	Rank
	Devel	Design	Contra	Gover	Acade		
Establish a complete legal system	0.85	0.73	0.83	0.83	0.86	0.82	1
Develop an assessment system which is suitable for China	0.70	0.72	0.70	0.75	0.54	0.68	2
Improve professionals' conscious on building sustainability	0.60	0.60	0.64	0.56	0.55	0.59	3
Improve professionals' conscious on building sustainability	0.49	0.44	0.45	0.42	0.45	0.45	4
Others	0.18	0.01	0.21	0.20	0.12	0.14	5

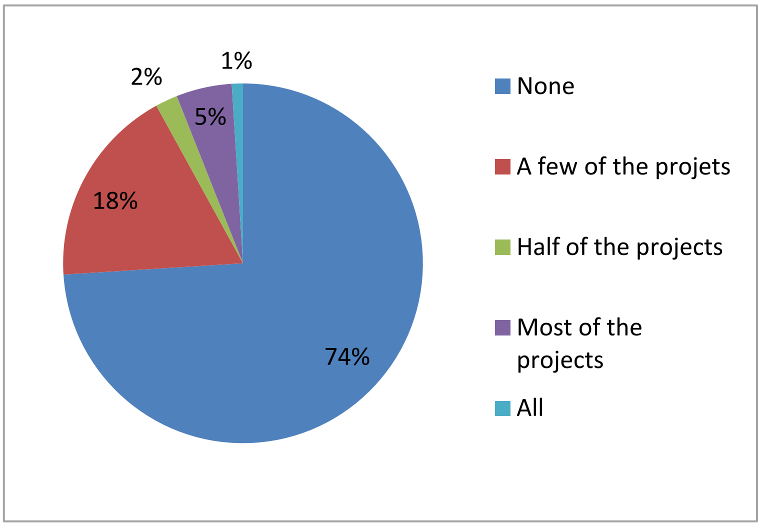
Note:
Others include public lecture, market incentives, public service activities and etc.

'Establishing a complete legal system' becomes the first choice of people, followed by the 'developing an assessment system which is suitable for China'. The importance of a complete legal system attracts the attention of all the professionals in the building industry. As the discussion in Chapter 3, there are a series of legal systems and standards in China, and they are from nationwide to regional. The voice of a complete legal system reflects that the legal system of green building is still not perfect.

6.3.4 Opinion about the sustainable assessment tools in China

Figure 6.3 shows the percentage of the participants about their experience on the sustainable assessment tools used. 74% of participants have not used any sustainable assessment tools before, whilst 18% believe that only a few of the projects they participated in have used some kind of sustainable assessment tools. It indicates that most of the participants are not familiar with any sustainable assessment tools.

Figure 6.3 the projects which used sustainable assessment tools among the projects they participated in



From the comparison analysis of age distribution (Table 6.7), it can be found that participants who have used the sustainable assessment tools before are concentrated in the 26-45 age groups.

Table 6.7 Participants who used the SA tools before by age

Used SAT \ Age	< 25	26-35	36-45	46-55	>55	Total
Not used before	26	122	114	81	14	357
Only a few projects	11	38	21	14	4	88
Half of the projects	0	0	5	2	0	7
Most of the projects	3	8	9	4	1	25
All the projects	1	1	0	0	0	2
Total	41	169	149	101	19	479

Note: SAT: sustainable assessment tools

The professional backgrounds also influence people's choice. From the Table 6.8 below, 52% of the professionals with experience in the SATs are the design consultants.

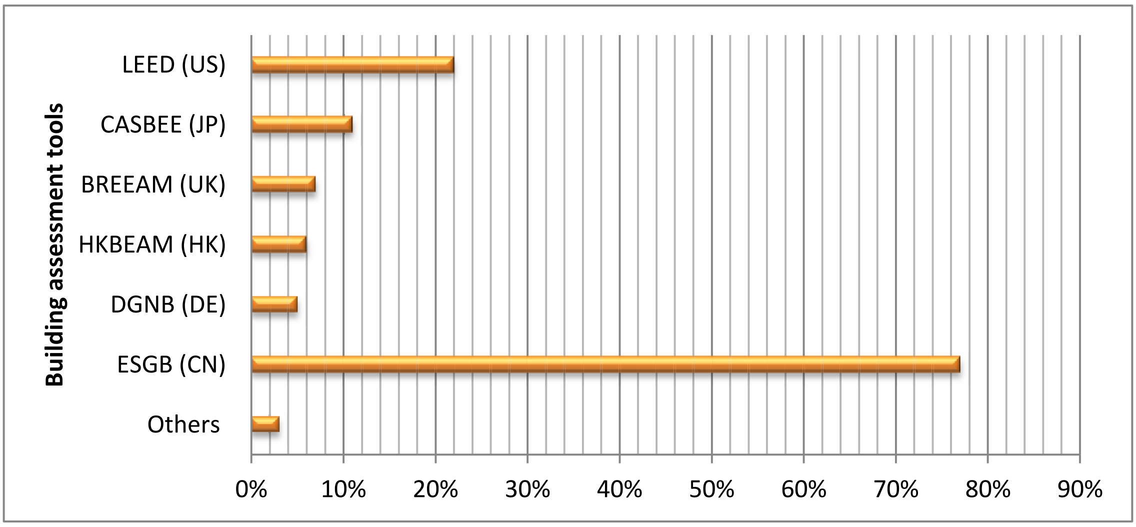
Table 6.8 Experience in SAT by occupation

Used SAT \ Occupation	Devel	Design	Contra	Gover	Acade & others	Total
Not used before	33	97	81	78	68	357
Only a few projects	5	48	18	7	10	88
Half of the projects	1	5	1	0	0	7
Most of the projects	2	10	8	2	3	25
All the projects	1	1	0	0	0	2
Total	42	161	108	87	81	479

6.3.5 The most widely used sustainable assessment tools in China

From the survey replies, about 26% of the participants have used the SATs before while 74% of the participants have no experience with the SATs (Figure 6.3). As shown in Figure 6.4, among these 122 participants who have had experience with the SATs, 77% of the participants chose ESGB, 22% of the participants chose LEED, 11% of participants chose CASBEE, 7% of the participants chose BREEAM. It indicates that the ESGB was still the most widely used of the SATs in China, and followed by LEED (Figure 6.4). LEED was the first tool which entered into the Chinese market and has occupied a considerable market as a foreign SAT.

Figure 6.4 The most widely used SATs in China



The professional backgrounds also influence people’s choice. From the Table 6.9, majority of professional who have experience in ESGB and LEED are the design consultants, followed by the contractors.

Table 6.9 The SATs which professionals used

	Devel	**Design**	**Contra**	**Govern**	**Acade**	**Others**	**Total**
LEED (US)	2	16	3	2	1	4	28
CASBEE (JP)	1	7	4	1	0	1	14
BREEAM (UK)	1	6	1	0	0	1	9
HKBEAM (HK)	0	5	0	1	1	1	8
DGNB (DE)	0	4	3	0	0	0	7
ESGB (CN)	6	51	23	5	4	5	95

Notes:
Others include lawyers, property managers, secretaries, construction workers etc.

6.3.6 Building life cycle stages

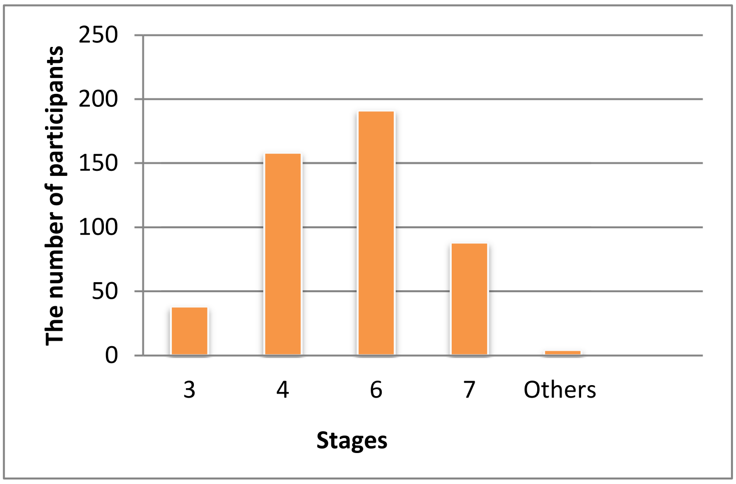
Based on the literature review, there are a lot of ways of building stage division (see Chapter 4). Some cover the building life cycle from cradle to grave, some do not. The previous researches on building performance assessment by former researchers chose different types of division according to their own purposes and regions. As discussed in Chapter 4, the four stage division is a proper way for the sustainable assessment in a building life cycle, which includes inception and design, construction, operation and demolition. With regard to the influence from regional difference to the building performance assessment, conducting an industry survey to investigate the common acceptance stage division by the professionals in China is important. Therefore, in this section, the participants were asked to select the most suitable staging of building life cycle according to their experience and knowledge.

As discussed in Chapter 4, the building life cycle could be divided from three stages to seven stages. The most commonly used stages in the literature are:

- 3 stages - Design, construction, and operation
- 4 stages - Inception& design, construction, operation and demolition
- 6 stages - Inception, design, procurement, construction, implementation, operation
- 7 stages - Pre-design, design, preparing to build, construction, occupation, demolition

The participants were asked to choose from these four kinds of divisions or to express their own idea in 'others'. The results were summarized in Figure 6.5 below. Others include less than 3 stages and more than 7 stages.

Figure 6.5 The stage division



Among 479 professionals, about 40% chose 6 stages division, and followed by 33% of 4 stages division. It is discrepancy from the four stage division based on the literature review. In order to find the reasons and get more objective information, further questions were asked in the interviews in the next section.

Based on the discussion in Chapter 4, the different stages in building life cycle have different sustainable impacts. This makes the assessment in every single stage become important. This viewpoint is also supported by the survey results. Almost 95% of the participants thought that every single stage plays an important role and they all need to be considered in assessing buildings' sustainable performance. Table 6.10 shows the importance of assessing building performance in every single stage. 71% of the participants think it is very important or even more than very important to assess building performance in every single stage. This figure shows the professionals in China have revealed the importance of assessing the building performance in different stages of building. Combining with the discussions in the literature review in Chapter 4, the environmental, economic and social impacts are different in every single stage of building life cycle and they cannot replace each other easily. Therefore, assessing building performance in each stage of its life cycle makes the assessment more precise and more acceptable by the stakeholders.

Table 6.10 Importance of assessing building performance in every single stage by professional

	Extremely important (%)	**Very important (%)**	**Important (%)**	**Not very important (%)**	**Not extremely necessary (%)**
Developers	2	3	3	1	0
Design consultants	10	13	10	1	0
Contractors	5	12	5	0	0
Government officials	6	8	4	1	0
Academics	2	2	1	1	0
Others	4	4	2	0	0
Total	29	42	25	4	0

6.3.7 The pillars of sustainable impacts

In order to establish an evaluation model for sustainable performance of buildings, the first step is to find out the pillars which need to be considered in a buildings' sustainability. Based on the discussion on Chapter 2, three pillars which include environmental, economic and social impacts are needed to be considered according to the theory development and former researchers' work. As discussed before, the regional differences have great impact in the building sustainable assessment, and this research is aimed at developing an adaptable model to assessment building performance in China. The professionals in China may or may not have the same idea as the literature review, thus getting information from the professionals in China's building industry is important.

From the survey results, 350 participants (73.1%) chose environmental, economic and social impacts as the key impacts on a buildings' sustainable performance, which is in accord with the literature review. In addition, 76 participants indicated other impacts, such as: culture impacts, esthetics, life style, technology impact. These could be considered as part of social impacts or environmental impacts. Thus, these three impacts will be chosen as the three key impacts to evaluate building sustainable performance in the model in accordance with the literature review.

6.3.8 Identifying indicators for the assessment of building performance

This section is designed to identify the indicators for the assessment of building performance. As discussed before, this research aim is to assess building performance in every stage of building life cycle. Therefore the assessment indicators should be identified first. In this survey, participants were asked to rank the relevant indicators based on their experience and knowledge. The Relative Importance Index (RII) was adopted to analyze the results. The indicators chosen were based on their relative importance. The indicators can be finalized by incorporating with the results of the literature review. The follow-up interviews also helped to finalize the indicators generation.

i) The indicators for environmental impacts

Based on the literature review in Chapter 4, there are many indicators which are chosen for assessing buildings' environmental impacts, such as energy consumption, resource consumption, emission. In this questionnaire survey, the indicators for option have been chosen based on the indicators appearing in high frequency in current literature, including energy consumption, resource consumption, emission, land contamination, waste generation, noise, dust, transport issue, landfill.

The participants were asked to rank them. While coding their answer, 0 means not chosen, 1 means chosen as the first, 2 means chosen as the second, 3 means chosen as the third, 4 as chosen as the fourth, 5 means chosen as the fifth and so on. The total weighting for each factor is calculated and a relative importance index (RII) is constructed reflecting the level of importance of these factors.

The value of RII ranges from 0 to 1; a higher RII indicates that a particular factor is more significant than others. The RII for groups was determined by averaging the RIIs of all individual factors within the same category. The rankings of these indicators are summarized in Table 6.11.

The relative importance of these indicators is presented in Table 6.11. The environmental assessment indicators in the order of importance from high to low include resource consumption, energy consumption, waste generation, emission, water, land contamination, transport issue, landfill, and dust. Considering the complexity of the model, the top five assessment factors are chosen for the model development. The five factors for environmental impacts are resource consumption, energy consumption, waste generation, emission, and water

Table 6.11 Indicators for assessing the buildings' environmental impacts

Indicators	RII					Average RII	Rank
	Devel	Design	Contra	Gover	Acade		
Energy consumption	0.62	0.75	0.65	0.49	0.65	0.632	2
Resource consumption	0.69	0.67	0.66	0.53	0.62	0.634	1
Emission	0.38	0.41	0.36	0.39	0.37	0.38	4
Land contamination	0.17	0.23	0.24	0.23	0.19	0.21	6
Waste generation	0.43	0.42	0.47	0.57	0.46	0.47	3
Water consumption	0.29	0.25	0.25	0.37	0.28	0.29	5
Dust	0.08	0.04	0.09	0.13	0.07	0.08	9
Transport issue	0.15	0.10	0.08	0.12	0.15	0.12	7
Landfill	0.21	0.14	0.22	0.18	0.20	0.19	8

ii) The factors for social impacts

In social aspect, the most important indicators for social impacts are chosen with the similar method. Table 6.12 presents the RII for indicators in the social impact as well as their ranking.

Table 6.12 Indicators for assessing the buildings' social impacts

Indicators	RII					Aver RII	Rank
	Devel	Design	Contra	Gover	Acade		
Quality of the livability	0.69	0.68	0.72	0.61	0.64	0.67	2
Health and social wellbeing	0.76	0.75	0.78	0.74	0.71	0.75	1
Community satisfaction	0.44	0.52	0.46	0.54	0.48	0.49	3
Esthetics	0.25	0.23	0.25	0.22	0.27	0.24	5
Cultural identity	0.33	0.27	0.25	0.28	0.29	0.27	4
Protection of ancient architecture	0.17	0.16	0.2	0.21	0.18	0.18	6
Convenience surrounding	0.27	0.27	0.25	0.26	0.29	0.27	4
Facilities	0.09	0.09	0.09	0.10	0.09	0.09	7

According to the Table 6.12, the assessment indicators for social impacts in the order of importance from high to low are health and social wellbeing, quality of the livability, community satisfaction, convenience surrounding, cultural identity, esthetics, protection of ancient architecture, facilities. As the discussion in section 4.4 in the Chapter 4, the selection of sustainable assessment indicators needs to consider the applicability, practicability. Therefore based on the results in Table 6.12 as well as the practicability and applicability of the model, the health and social wellbeing, community satisfaction, quality of the livability, convenience surrounding and facilities are chosen for model development.

According to the literature review in Chapter 2 and 4, the economic indicators are assessed with the LCC approach. All the economic indicators in building life cycle will be assessed according to this approach.

6.3.9 Summary for questionnaire survey and inspiration for the interview

In this section, 479 questionnaires are analyzed. It starts with the general background. The samples in this study are recruited from distributed professionals in the construction industry in China. The well distributed samples in different groups of stakeholders, genders, as well as age and experience help to avoid bias to generate information for model development.

After that, the current situation of sustainable building and sustainable building assessment in China are discussed. Though the current situation is discussed based on the literature in the previous chapter, to get the primary data from the industry is valuable to establish the model (see Chapter 2). Based on the discussion in section 6.2.2 and 6.2.3, the sustainable building in China has just started and has developed slowly and the 74% of the professionals have no experience with the current SAT. Among the groups which have used the SATs before, the ESGB and LEED are the most widely used the SATs in China. This also supports the discussion in Chapter 2.

Based on the discussion in the questionnaire survey, developing an assessment system which is suitable for China is recognized to be important to improve this situation by the professionals. The third part of the questionnaire survey is for model development. Finding the proper stage division is the first step for model development in this research. According to the survey results, the six stages division which includes inception, design, procurement, construction, implementation and operation are chosen by 40% of the professionals, which is more than the four stage division which includes inception and design, construction, operation, and demolition chosen by 33% of the professionals. This result is different from the literature review in Chapter 4. More discussion is conducted in the interview to find the reason.

After the stage division, the three pillars which are environmental, economic and social aspects are generated for sustainable assessment of a building. As for the assessment indicators for three pillars in each stage, the construction stage is chosen as a sample here. RII is adopted to rank the relative importance of a series of indicators in each pillar. The most important indicators are chosen for model development, the applicability and practicability are also considered when choosing the indicators. The results are compared with the literature review in the section 4.3 in Chapter 4.

In summary, the questionnaire survey helps to verify the importance and feasibility of this research. The building stage division, pillars of building assessment impacts as well as the assessment indicators for construction stage of building have been generated. The results which are different from the literature review, such as the six stage division will be discussed further in next part of data collection. Interview will also help to finalize the assessment indicators in all other stages after the stage division.

6.4 Interview

As discussed in the Section 6.2, some of the topics in the results on the questionnaire survey are contrary to literature review, such as stage division and some of them could not lead to enough discussion at that stage such as the assessment indicators in every building stage. Therefore the second part of data collection took place. A group of professionals were recruited for the deeper discussion in the interview. Among the people who expressed their willingness to take part in the personal interview, the experts with experience in sustainable building assessment were given priority. Their location was also considered due to the time and cost budget.

6.4.1 Background of interview

The interviews were conducted from May to June 2012 after analyzing the questionnaire survey. The interviewees were recruited voluntarily. When conducting the questionnaire survey, there was a form at the end of the questionnaire to ask the professionals who were willing to participate in the second part of the data collection to leave their contact details and available time. The interviews were conducted in Guangzhou and Shenzhen, two large cities in Southern China. Due to the limited time and research budget, some professionals have not been chosen due their location being far from these two cities.

In addition, similarity to the questionnaire survey, the professions of the participants need to be well distributed to avoid bias. Finally, 20 experts were recruited for this interview chosen from 37 volunteers. Among the interviewees, there are 4 designers, 4 government officers, 3 consultants, 4 contractors, 2 academics, 3 developers. 55% of them are 36-45 years old with extensive experience. Table 6.13 summarizes the components of the participants.

Table 6.13 The components of the participants

Professionals \ Age	26-35	36-45	46-55	>55	Total
Designers	1	3	0	0	4
Government officers	0	1	2	1	4
Consultants	1	2	0	0	3
Contractors	0	2	2	0	4
Academics	0	1	1	0	2
Developers	0	2	1	0	3
Total	2	11	6	1	20

A set of semi-structured questions were designed for the interviewees. There were two parts to the questions in the interview. The first part of the interview was used to get more information about the problems of sustainable building development and the use of current assessment tools in China. Some indicators and reasons were discussed in the questionnaire survey, but deeper and open discussions were conducted in interview. According to the discussion in Chapter 5, the questionnaire was short on providing more personal thought, deeper discussion; thus this part in interview could be a supplement to the results of questionnaire survey.

The second part of the interview was about model development. The two major targets in this part were identifying the stage division in this research, and finalizing the assessment indicators in each stage of building life cycle. As discussed at the end of the section 6.2, the results in the questionnaire survey about stage division were different from the literature review, the interviewees were asked to present their opinion about the stage division and compare the four and six stage division. After the stage division, the assessment indicators for each stage were finalized. The results of interview were analyzed via factor analysis and software Nvivo. More detailed information about the questions for the semi-structured interview can be found in Appendix E

6.4.2 The problems of sustainable building development in China

In the questionnaire survey, the current situation of sustainable building development in China was criticized as ‘China is just started and has developed slowly’. The reasons for this situation stated by 479 questionnaire participants were ‘Lack of professional conscious’ and ‘Technology constraint’. These results were supported in interviews. According to the results of question 1, 90% of the interviewees thought the sustainable building development was developed slowly since it started. 70% of the participants indicated that the sustainable building in China was still on its beginning stage. The most frequently used words in the answer of the Q1 include slow, beginning, attach less attention.

According to the results of question 2, 65% of the participants thought the public knowledge and need were the major obstacles for sustainable building development. They expressed that the sustainable building was still a new concept to the public in China. As there is less demand of people to buy or rent the buildings which are green, there is less demand for the developers to pay attention to the buildings’ sustainability. Thus there is not enough market demand for the sustainable building, which has hindered the progress. The most frequently used words in the answer of the Q2 include less demand, misunderstands, cost more.

A manager in Shenzhen Green Building Association expressed the similar problems. She said: “In my opinion, the problem is that the green building is still not widely known by the public. When we do some promotion, like organizing people to visit the existing green buildings and organizing the green building seminars, I feel that the green building is lack of the public awareness. For one thing, the public is still not familiar with the new type of building, I mean new to the Chinese people; for another, they are afraid that the green building will cost more money.” Sometimes the public also has some misunderstandings about the green buildings. From a consultant’s words, “to some clients, green building just means ecofriendly, which associated with higher cost and longer construction period. They cannot get any economic benefit right away.” With this misunderstanding “the developers find there is little market for the green buildings, so they have little enthusiasm.”

i) The difference between urban and rural area

There was another interesting phenomenon in the interview that the professionals were more optimists about the green buildings in urban area. An academic from Shenzhen University said “most of the green buildings are located in the metropolis, such as Shanghai, Beijing and Shenzhen.” He further stated that “the sustainable buildings we talk about nowadays are more concern about the buildings in cities and ignore the buildings in rural areas.”

A government officer in Guangzhou Bureau of Land Resources said “Actually, the buildings in rural area are quite different from those in cities. Some of them are kind of ‘sustainable’. For example, some houses in rural area use some local materials, which are already environmental friendly.” Therefore the way to promote the green buildings in cities would be useless in rural area. Some participants suggested in further development of sustainable building assessment, these differences between urban and rural needed to be taken into consideration.

ii) Too much emphasis on green technologies

‘Green technologies’ was one of most frequently used words in interview. 40% of the participants mentioned the overfilling of the green technologies in an inappropriate way. This would not help the building gain better performance in their operation stage; on the contrary, some of these technologies would bring even higher operation cost. A structure engineer in China Construction Design International (CCDI) stated that:

“LEED certificate is popular in building industry in China (see Figure 6.4), especially for the commercial buildings, many developers put too much emphasis on the green technologies in order to get a higher certificated in LEED. However, some of the technologies are not appropriate when applied in China.”

One consultant also pointed out: “people put too much emphasis on the green techniques, but lack of an overall concept. For example, the reclaimed water system has been strongly advocated several years ago for the green buildings. Many green buildings have installed this kind of systems. The problem is the operation cost for the water treatment is too expensive and even more expensive than buying fresh water. So the majority of the systems have fallen into disused. Actually this is a kind of waste and contra to the original intention of sustainable.” Another academic said: “From my point of view, the shortage of the sustainable building is people still don’t implement its true meaning. Sustainable buildings do not mean how many green techniques you use in the building, but whether the buildings are ecofriendly, economically viable and accepted by the public.”

iii) Haven’t taken building life cycle into consideration

Some interviewees mentioned building assessment in different stages. In their opinion, people have not taken every stage in life cycle into considerations. One design consultants said: “Our clients always put too much emphasis on the design stage but ignore the other stages of building. Actually, in order to achieve the goal of sustainable development, we should pay attention to each stage of buildings, like operation. Many buildings which are designed to be sustainable are found to cost more in operation. It is a ‘waste’ rather than ‘save’ indeed.”

iv) Other restrictions

The current economic condition is another restriction for the development of green buildings in China. One government official said: “you can’t force a people who cannot afford a shelter to pursue a better life. If the people still struggle for a place to live, it would be hard for them to consider whether it is environmental friendly or not.” One of the driving forces for the sustainable building is market demand. Only after economic development to a certain extent can the sustainable building become a need for the public.

Another restriction comes from the industry itself. Take the design consultants for example; they have little decision-making power. One design consultant said: “Unless the clients required, we won’t consider green buildings ourselves. Honestly speaking, the workload for the designers in China is very heavy; we have few time or energy to consider more than the immediate work.”

6.4.3 The current used sustainable assessment tools in China

In the questionnaire survey, the ESGB was the most used tools follow by LEED, which was treated as a most popular foreign tool. The results were supported by the interview. Among the 20 interviewees, the ESGB and LEED were the most frequently used words when they mentioned the SATs in China. According to a manager in Shenzhen Green Building Association, “The most famous tools now should be the ESGB, the local one, and the LEED from US. The LEED is the most widely accepted foreign tool in China, because it is the first foreign tool that enters the Chinese market, and it has good reputation.” LEED was particular popular in business use. A design consultant in CCDI said: “LEED, as an international tool, is preferred by some major developed companies. Its popularity is good for the promotion of company.” But LEED also has some shortcomings when applied in China. LEED, as an US assessment tool, is based on the situation of another country, which is quite different from China. The different lifestyle and different values make it hard to use the same standard to evaluate the situation in other place. “For example, LEED require high green technique, which will lead the participants to pursuit the high-tech blindly. Its score items involve too much US product catalogue, it is too commercial and lack systematic,” indicated by an interviewee.

6.4.4 The stage division in building life cycle

In the questionnaire survey, about 40% of participants had chosen the 6 stages division, followed by 33% participants who had chosen 4 stages division (see Figure 6.5). It is a discrepancy from the information of the literature review. In order to get more objective information, further questions had been asked in the interviews. In question 7, participants were asked about the most suitable stage division in building life cycle due to their knowledge. Question 8 discussed the six stage division chosen by most people in the questionnaire survey.

In question 7, 80% of the interviewees said there should be inception/production, design, construction, operation/commission/maintenance, and EoL (demolition). This answer is similar to the four stages division which includes inception and design, construction, operation and demolition.

In question 8, the interviewees were asked about their opinions about the six stages division include inception, design, procurement, construction, implementation, operation. 70% of the interviewees did not agree with it. Some of them expressed some possible reasons for this answer. According to an academic in Shenzhen University, “One possible reason might be the knowledge from text book about the stage division. But from my point of view, the six stage division (inception, design, procurement, construction, implementation, and operation) even does not consider the stage in end of life of building. I don't think it is a suitable answer for stage division." A design consultant agreed with this idea, "the six stages division is the right way of division for building process; the only problem is that it lacks the EoL stage."

But there are still 20% of professionals who agreed with the six stages division in the interview. In order to find the reason, they were asked about the reason for the choice. Some of them ignored the final stage (demolition), as a developer's words, "Actually, we always ignore the demolition stage by ourselves, once the building has been completed, our mission is done. Seldom people track it latter or keep that in mind. So demolition stage has always been ignored. But in academic research it should be considered." Another contractor indicated the similar information, "I guess it is due to the reason that people seldom consider the last stage in China. Building are demolished very fast, some buildings are last for ten or twenty years. It is quite different from the buildings in western country. Building there can stand for 50, 70 or even 100 years." As the academic said, "Actually, in the way of 6 stage division, it misses the 'demolition' which is the final part of building life cycle. The whole building life cycle is the key point in this study, so demolition cannot be ignored. Besides, the 'procurement' and 'implementation' can be grouped into 'construction' when considered the sustainable performance."

Based on the discussion in Chapter 4, the stage division from inception to demolition is more appropriate as it includes a starting point and end point of the building life-cycle. All these four stages have distinctive and unreplaceable impacts on environment, economic and society. Though the six stage division gained support in the questionnaire survey, it lacks the EoL stage of building, which is important for sustainable impact assessment. Incorporated with the literature review in chapter 4, for the purpose of sustainable performance assessment, the four stage division which includes inception and design, construction, operation, and demolition is used in this research.

6.4.5 The assessment indicators in three pillars in different stages

As the research aims to assess building performance in different stages, it is essential to identify the indicators in different stages in three pillars. In the questionnaire survey, assessment indicators have been generated based on China's situation. As the four stages division in building life cycle has already been settled in the above section, the assessment indicators are discussed in the interview in every stage.

From the questions 10 to 12 of the interview, the participants were asked to identify the assessment indicators in the three stages. Their answers were also compared with the literature review in Table 4.4 in Chapter 4. Incorporating with the survey results and literature review, the assessment indicators for the four stages are presented in Table 6.14.

The indicators present in each stage are in conjunction with the characteristics and activities at each stage. In inception and design stage, proposal and design take place with limited physical impact to the environment and society. But it provides an opportunity to bring together all the sustainability performance considerations from the outset and realize sustainable strategies for the project. The sustainable indicators in this stage represent the sustainability considerations, requirements, and strategies of a construction project.

In the construction stage, a series of construction activities is always associated with environmental pollution, employment opportunity and some safety issues. The operation stage, which always lasts several decades to meet the users' need, consumes a lot of energy and resources with high emissions. The occupant's feeling and safety are the major concerns in this stage. The demolition stage is always associated with the recovery and utilization of the dismantled building and abandoned building materials. The demolition waste is the major environmental indicator and cannot be ignored. Like the reverse process of building construction, the safety and the community satisfaction is the major concern in this stage.

Table 6.14 the assessment indicators for different stages in three pillars

Stages \ Pillars	Environmental	Economic	Social
Inception & design	• Sustainable site • Heritage conservation • Sustainable material • Sustainable design	• Land cost • Professional fee • Other costs &charges	• Impact on community • Urban integration • Proximity to facilities • Cultural issue
Construction	• Resource • Energy • Waste • Water • Emissions	• Construction costs • Professional fee • Other costs &charges	• Impact on community • Health & safety of work environment
Operation	• Emissions • Resource • Energy • Water	• Operating cost • Cleaning cost	• Occupants' health and comfort • Stakeholder relations • Occupier satisfaction and productivity
Demolition	• Waste • Emission	• Demolition cost • Salvage value • Other costs &charges	• Health& safety • Community satisfaction

6.5 Summary

This chapter starts with the discussion about the current situation in China, 479 participants in a questionnaire survey and 20 professionals in an interview expressed the problems in China in depth. The slow development of sustainable building and sustainable building assessment in China, as well as the call for a suitable assessment tool, which is in accord with the results in the literature review, highlight the significance of this research. The current assessment tools are also analyzed in this survey. The ESGB, as the national tool in China, is the most used tool, while the LEED is the most popular of the international tools, which is in accord with the literature review in Chapter 2.

Most importantly, the stage division is decided upon as well as the key indicators in each stage in three pillars. These aspects are the basis for the model development in the coming chapters. Based on the discussions in the questionnaire survey and interview, as well as the literature review in chapter 4, the stage division in building life cycle in this research is stated as: inception & design, construction, operation and demolition. The assessment factors in three pillars in each stage are also resolved. In chapter 7, the analysis model will be built based on these issues. The way to quantify and qualify these indicators will also be discussed in the following chapter.

CHAPTER 7

DEVELOPING A BUILDING SUSTAINABLE SCORE MODEL FOR ASSESSING BUILDING PERFORMANCE FROM A LIFE CYCLE PERSPECTIVE

7.1 Introduction

Based on the literature review and industry survey, a model for assessing building sustainability performance has been established and presented in this chapter. The model is titled the Building Sustainable Score (BSS). The process of developing indicators is discussed and followed by the assessment detail of these indicators. Both the quantitative and qualitative methods were used for the indicators evaluation. Based on the literature review on current assessment method of these indicators, several methods were selected in this research. The major environmental indicators were quantified by LCA, whilst economic indicators were quantified by LCC. Social indicators were assessed by using a value score. The specified methods for these indicators have been discussed by stages. After that, the weighting of each indicator was identified. The analytic hierarchy process (AHP) method was adopted for identifying the importance of the indicators in relation to each other.

7.2 The conceptual model

In Chapter 6, assessment indicators for the three pillars in each stage of a building's life cycle have been identified. Based on these key indicators, the conceptual model of Building Sustainable Score (BSS) has been established and presented in Figure 7.1.

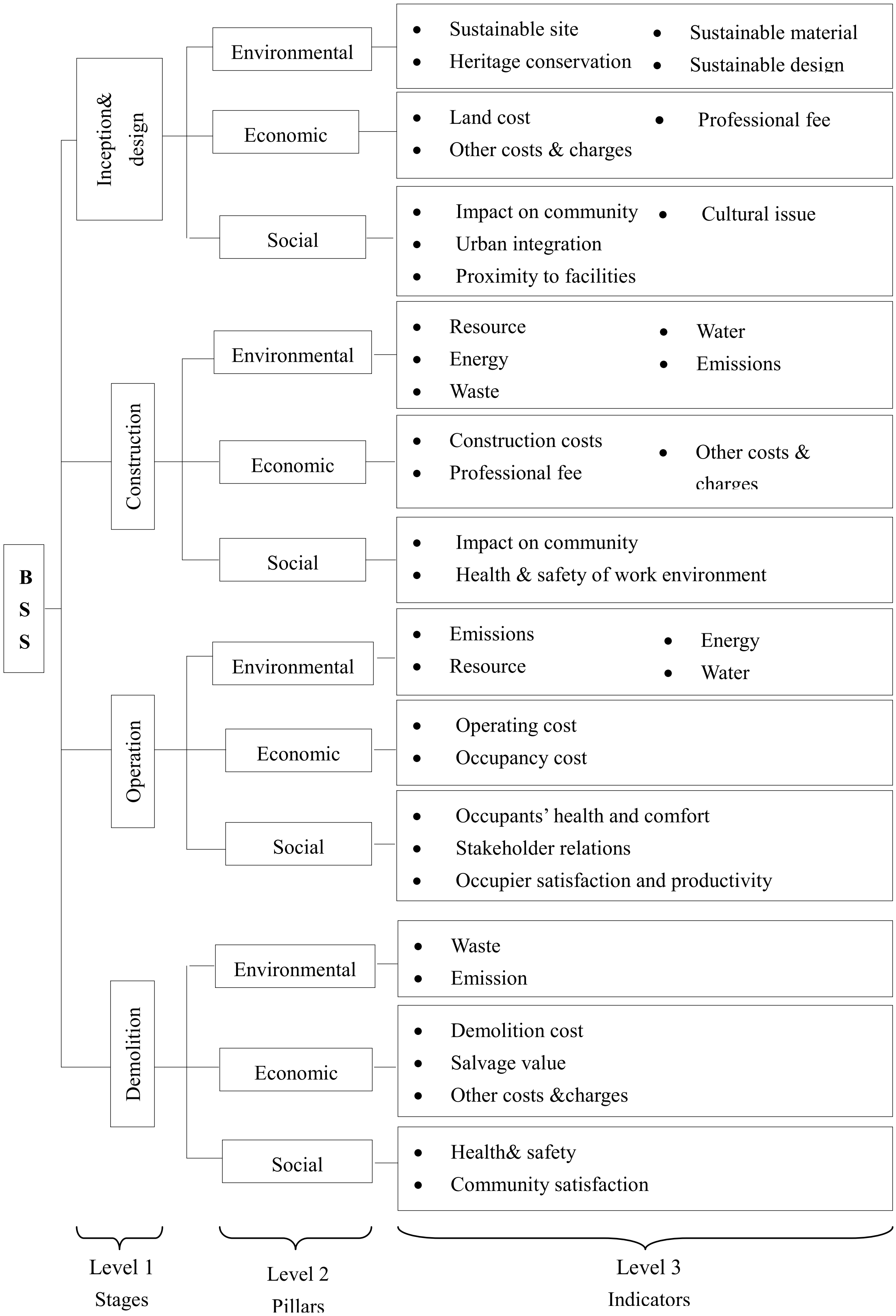
The assessment model consists of four sub-models; each sub-model will reflect sustainable performance of one of the building life cycle phases:

- Inception and design
- Construction
- Operation
- Demolition

Each sub-model analyzed environmental, economic and social impacts and finally they were combined into a single decision model for decision making. The sub-model for analyzing environmental, economic and social impacts was established at each stage, and each model will reflect sustainability impacts related to the major activities at each stage.

Figure 7.1 presents a conceptual model for the BSS. There are three levels in the BSS model. The first level contains stages of a building life cycle. The building life cycle is defined into four stages and they are inception and design, construction, operation and demolition. The second level presents the three pillars for each stage. In each stage, the three pillars in sustainability include environmental, economic and social impacts. The third level presents the assessment indicators. The selection of these indicators is discussed in Chapter 6. The evaluation of these indicators is discussed in this chapter. Both qualitative and quantitative methods are used for assessing the indicators.

Figure 7.1 The conceptual model for BSS



7.3 Evaluation of indicators

7.3.1 Assessment details of indicators

After the conceptual model, the assessment methods for the indicators identified in Figure 7.1 needs to be designed before the model establishment. In the previous studies, researchers identify different methods for assessing the indicators. Ding and Shen (2010) undertake a study of assessing sustainability performance of built projects. They identified a method of assessing subjective issues of environmental criteria. A scale of 1-5 was used to value the environmental risk and social benefits. The level of scale was used to express the level of benefits to a group of stakeholders, include architect, surveyor, contractor, engineer, project manager and clients.

Similarly, Alwaer and Clements-Croome (2010) assess the building suitability with a linear ranking scale. In their study, the key performance indicators related to sustainable building are identified. A consensus-based model, named the Sustainable Built Environment Tool (SuBETool) is established for multi-criteria decision making. It is a kind of rating framework and can become a rating tool with the participation of a third party. It needs the stakeholders to adopt it with consideration of their region and local conditions to define the selective criteria, priority levels and setting of weights, context and performance benchmarks. The three pillars including environmental indicator groups, socio-cultural indicator groups and the economic indicators groups are assessed by the level of performance and priority level, which is defined by the participation of stakeholders.

A linear ranking scale from -2 to +5 is identified for the building suitability score in their study. There are five levels for this ranking scale with the performance from excellent to unsatisfactory. The authors also provide reasons for the level from -2 to +5 instead of -5 to +5 or any others. They indicate that it “provides a scale where the focus in sustainability assessment is based on more positive than negative attributes”

(Alwaer & Clements-Croome 2010, pp 806). They want to use this as a way to encourage those involved in sustainability projects to achieve better design results.

Gangolells et al. (2009) introduce a systematic approach for environmental impact assessment at the pre-construction stage. In their study, nine categories of environmental aspects and the corresponding twenty indicators are developed with the help of expert panels. The assessment indicators are identified as related to the construction process. In assessing these indicators, their scale, probability and duration of the impact are evaluated by a panel of experts from various professional fields. A four-interval scale is developed for each of the three dimensions which are composed of the significance of the indicators, and the overall significance rating score is multiplied by these three dimensions. In their research, numerical rating score of 0, 1, 3 and 5 are established for the sustainability of the indicators. Two years later, Gangolells et al. (2011) further use these four level rating scores to predict the significance of environmental impacts related to the construction process of residential buildings.

The researches above mainly discussed the subjective method for the assessment indicators. The objective issues can be assessed based on a LCA approach (Ding & Shen 2010). If the energy criterion is taken for example, the initial and recurrent embodied energy as well as the energy used during the operation and demolition are estimated. In the construction stage, the energy estimated includes embodied energy of construction material and the energy consumed on site. In the operation stage, the energy estimated includes embodied energy of material used for maintenance and repair and the energy used for fixtures and fitting.

Li et al. (2010) also state a quantitative assessment method of the environmental impact of construction activities based on a LCA approach. The environmental impacts are categorized into three categories in their research and they include ecosystems, natural resources and human health. Inventory analysis is adopted for quantifying for example the material, energy and emission. After that, the inventory data are translated into damages to ecosystems, human health and resources and further express the overall impact using a single value.

In assessing the economic criterion, the discounted cash flow approach is used by Ding (2005) to bring costs and benefits into an equivalent monetary value. Ding and Shen (2010) also calculate money value in economic life span with the discounted cash flow approach. The net present value (NPV) is used by the construction industry to decide whether or not to go ahead with a project (Perkins 1994).

Incorporated with the discussion in Chapter 2 and Chapter 4, LCA, LCC and value score are used to assess these indicators. According to the discussion, the subjective issues are quantified using value scores that aim at maximizing their subjective attributes. The objective aspects of environmental issues are using LCA, while the economic aspects are using LCC. The assessment details of these indicators in four stages are shown in Tables 7.1- 7.4.

Table 7.1 summarizes the criteria and method for the assessment indicators in the inception and design stage. In the table, the criteria of each indicator are worked out. The indicators are selected based on the literature review of research studies and the analysis of assessment details of sustainable building assessment tools both locally and internationally. For example, sustainable site is one of the environmental indicators in the inception and design stage. The criteria for this indicator include whether it is green field or brown field and whether it considers the habitat conservation. The details for other indicators in this stage can be seen from Table 7.1.

Table 7.1 The assessment details of indicators in the inception and design stage

Pillars	Indicators	Criteria	Methods
Environmental	E_1- Sustainable site	• Green field or brown field Green field is a new construction project; brown field is usually a contaminated site that has been rehabilitated. • Habitat conservation To determine whether the new project will impact the local flora or fauna and then cause damage to the local biodiversity: - Destroy the inhabitancies of local animals - Destroy the vegetation cover - Destroy the native plant species	Value score (VS)
	E_2- Heritage conservation	Whether the site selection would impact the ancient architecture: • Whether there is ancient architecture nearby • How old is the ancient architecture • How would the ancient architecture be affected (demolish wholly or partly)	VS
	E_3- Sustainable material	Whether the material chosen for construction and operation is sustainable • Contain reused or recycled materials • Eco-friendly material e.g. low reflection glass	VS
	E_4- Sustainable design	Whether the design of the project meets the requirement of sustainability: • Architecture design Meet the building floor area ratio, green ratio • HVAC design Harmless gas emissions, high efficiency, low noise equipment	VS
Economic	C_1- Land cost	The cost for land	LCC
	C_2- Professional fee	The consultant fee for feasibility study Design fee: • Consultant fee • Design fee • Construction plan review fee	LCC
	C_3- Other cost &charges	Other cost & charges include: • government charges • rates • taxes	LCC

Social	S_1- Impact on community	• Local Roads and Footpaths Include: the number of footpaths; roadside drains and culverts • Appearance of public area • Include parks and gardens, street cleaning, landscaping design • Encouragement of employment of local residents within the building • Promotion of and linkage to local service providers • Accessible communication channels with building stakeholders	VS
	S_2- Urban integration	It refers to the liveable environment where the project is planned to be built, as well as the safety appliance install and aesthetic. • The liveable environment, include land, soil. • The safety appliance installed • Aesthetic implication (such as: compliance with precinct theme, building scale)	VS
	S_3- Proximity to facility /Accessibility	Traffic management Include traffic flow, road signage • Close to the amenities Include close to the school, close to the hospital • Parking facilities • Connections to designated green spaces • Wheelchair access • Proximity to child-minding facilities	VS
	S_4- Cultural issue	• Recognition of indigenous people through allocation of cultural space and communication of site or community history • Consideration of gender equity and minority group requirements • Preservation of heritage values • Value of artwork as % of fit out	VS

Table 7.2 summarizes the criteria and method for the assessment indicators in the construction stage. The criteria of each indicator in three pillars in the construction stage are worked out. For example, the energy consumption in this stage contains the embodied energy and energy consumed on site. The environmental indicators in this stage are evaluated by LCA. The economic aspects in this stage mainly include the

cost for construction. Take the construction cost for example, it includes cost for labour, cost for construction material, cost for utilities, cost for equipment (rent, buy), and financing and services cost. LCC is used for evaluating the economic indicators. The details of other indicators can be found in Table 7.2.

Table 7.2 The assessment details of indicators in the construction stage

Pillars	**Indicators**	**Criteria**	**Methods**
Environmental	E_5- Resource	Construction materials used in the construction process, like: • Cement • Steel • Sand • Timber • Glass	LCA
	E_6- Energy	Energy consumed in the construction process, like electricity, etc. • Embodied energy • Energy on site	LCA
	E_7- Waste	Construction waste consists of unwanted material produced directly or incidentally by the construction process. • The amount of waste generated in the construction process • The amount of waste be land filled • The amount of waste can be reused	LCA
	E_8- Water	Water consumption during the construction process • Water consumption in construction activities • Water consumption by the site workers	LCA
	E_9- Emissions	The Greenhouse Gas (such as: carbon dioxide, methane, nitrous oxide, etc.) emission during the construction process. • Materials transport to site • Emission when producing construction material • Emission in the construction activities	LCA
Economic	C_4- Construction cost	The total cost, direct and indirect, include: • Cost for labour • Cost for construction material • Cost for utilities • Cost for equipment (rent, buy) • Financing and services cost	LCC
	C_5- Professional fee	The consultant fee for the construction supervision	LCC
	C_6- Other cost & charges	• Government charges • Recycling cost	LCC

		• Finance costs • Landfill costs	
Social	S_5- Impact on community	• Views affect by the construction site • Public area occupied by the construction techniques • Neighbourhood influence by the noise and other pollutions • Employment opportunity	VS
	S_6- Health & safety of work environment	Health & safety of site workers • Information for all workers on their rights and responsibilities that affect health and safety at work.	VS

Table 7.3 summarizes the criteria and method for the assessment indicators in the operation stage. Similarly, LCA is used for the environmental indicators, LCC is used for evaluating the economic indicators and VS is used for evaluating the social indicators. The criteria for each indicator can be found in Table 7.3.

Table 7.3 The assessment details of indicators in operation stage

Pillars	Indicators	Criteria	Methods
Environmental	E_{10}- Energy	It refers to the consumption of energy or power in the operation stage	LCA
	E_{11}- Water	It refers to the consumption of water in the operation stage • Water for office use • Water for afforest station • Water supply for air conditioner	LCA
	E_{12}- Resource	Resource consumption during operation stage • Papers and other office supplies • Toilet supplies	LCA
	E_{13}- Emission	GHG emissions associated with buildings operation are mainly coming from: • Electricity consumption • Consumption of fossil fuels on-site for the production of electricity, hot water, heat, etc. • On-site waste water treatment • On-site solid wastes treatment • Industrial processes housed in the buildings Fossil fuels include for example: natural gas, propane, etc.	LCA
Econom	C_7- Operation cost (utilities bills)	Operational expenses for energy, water, and other utilities. Those are based on consumption, current rates, and price projections. Bill of quantities	LCC

		• Energy cost • Water cost • Other utilities • Maintenance, repair and custodial cost	
	C_8- Occupancy cost	Occupancy costs are those costs related to occupying a space including: • Rent • Real estate taxes, personal property taxes • Insurance on building and contents • Cost for refurbishment	LCC
Social	S_7- Occupants' health and comfort	• The sick building syndrome, building related illness and environmental sensitivity. • Livability – the degree of excellence or satisfactory character of life quality of building users • Adequate public liability and service provider insurance • Awareness and training of emergency evacuation and accident first aid procedures for all floor wardens • A first aid station accessible to all building users	VS
	S_8- Stakeholder relations	• Monitoring of stakeholder concerns, views and provisions • Transparency and disclosure of landlord/tenant contracts and marketing agreements • Supportive use and occupation guidelines for tenants • Appropriate training for security and public relations personnel	VS
	S_9- Occupier satisfaction and productivity	• Quality of communal service area e.g. toilets, kitchen facilities • Complementary usage of building • Occupant productivity in terms of satisfaction and physical wellbeing • Wheelchair access	VS

Table 7.4 summarizes the criteria and method for the assessment indicators in the demolition stage. The environmental assessment indicators in this stage are evaluated by LCA. Take the emission in demolition for example; the emission in demolition process, transportation should all be assessed. The details for other indicators can be found in Table 7.4.

Table 7.4 The assessment details of indicators in demolition stage

Pillars	Indicators	Criteria	Method
Environmental	E_{14}- Waste	Demolition waste is waste debris from destruction of a building. The debris varies from insulation, electrical wiring, rebar, wood, concrete, and bricks. It also may contain lead, asbestos or different hazardous materials. • The amount of waste, include: concrete, bricks, wood, etc. • Landfill	LCA
	E_{15}- Emission	• GHG emissions in the demolition process • GHG emissions in the transportation • GHG emissions inventories from demolition debris reuse, recycling, and disposal activities • Emissions of non-CO2 GHGs in the manufacture	LCA
Economic	C_9- Demolition cost	Estimate the demolition cost by buildings' structure • The way of demolition • The features of buildings, like: structure, area, etc. • The amount of debris has to be removed • Labor cost • Cost for equipment rental • Costs for any permits, licenses and insurance policies	LCC
	C_{10}- Salvage value	Salvage value is the estimated resale value of an asset at the end of its useful life.	LCC
	C_{11}- Other costs& charges	Other costs & charges include: government charges, rates and tax • Government charges • Rates and tax	LCC
Social	S_{10}- Health and safety	• The health of staff on site and people nearby (depend on the demolition methods, techniques and equipment employed) • Health and safety risk assessment	VS
	S_{11}- Local impacts	• The views, appearance of local communities via the demolition process. • available and efficiency of public transport - whether occupying public road and facilities	VS

The table above shows the definition as well as assessment detail of each indicator in the three pillars in each stage. The quantification and qualification of the indicators are based on these criteria. In the next section, the evaluation of indicators will be discussed in detail. The way of conduction of VS, LCC and LCA are also discussed.

7.3.2 Indicator Evaluation

Among the 37 indicators, 15 are environmental indicators, 11 economic indicators, and 11 social indicators. The different methods including LCA, LCC and VS are discussed in detail in this section for the indicators' assessment.

i) Value score

Based on the discussion in Section 7.3.1, there are different methods for sustainability measure of the subjective indicators. For example, a four level rating score range from 0, 1, 3, 5 (Gangolells et al. 2009); a five level value score of 1-5 (Ding & Shen 2010) and another five level value score from -2 to +5 (Alwaer & Clements-Croome2010). Among these three types of values score, the four levels and the five levels of 1-5 do not contain the negative level. As discussed in Chapter 3, the building industry brings many negative impacts such as environmental, economic and social. It would be insufficient to have a value score just having the positive aspects. In that case, the values in the range from -2to +5 from Alwaer and Clements-Croome (2010) is adopted in this research. There are five levels in it:

- $+4 \leq +5$ Best practice (Excellent performance)
- $+3 \leq +4$ Very good practice reflecting stable conditions in terms of sustainability
- $1.5 \leq +3$ Good Performance
- $0 \leq 1.5$ Current standard (Minimum acceptable performance) or typical practice for the particular building type and region, or also due to the difficulty in obtaining data
- -1 to -2 Unsatisfactory performance (Deficient) which is not likely to meet the accepted regulations, design criteria and industry norms, or the indicator performance gives a negative impact on the environment in social, economic and environmental terms

When this approach is applied, the score can be derived by an expert panel from the stakeholders of the buildings, which offers stakeholders' participation in the building performance assessment. In the previous study, similar methods have been used by former researchers. For example, Ding and Shen (2010) use a team of construction professionals to express the level of impact scale of environmental criteria. Gangolells et al. (2009) conduct a questionnaire survey among a panel of experts to collect the scale, duration and probability of the environmental indicators. Alwaer and Clements-Croome (2010) also invite the stakeholders to use their model with consideration of their region and local condition to represent the value score of the suitability. Therefore for this research, the VS with the range from -2 to +5 are used for qualitative evaluation.

ii) LCC

LCC is adopted for the economic analysis in this research based on the discussion in Chapter 2 and Section 7.3.1 in this chapter. The monetary value of cost will be analyzed in each stage. In assessing the economic criterion only the costs are measured in the four stages of the building life cycle. The discounted cash flow approach is used to calculate money value in the economic life span.

In conducting the discount cash flow approach, the discounted rate needs to be determined in accordance with the market economy. Neale and Wagstaff (1985) conduct a research about discounted cash flow and life cycle costing for construction projects in the UK. The different discounted rate of 10%, 20% and 30% are used to conduct the sensitive study to compare two projects. Ding (2005) also use three discounted rates 5%, 10% and 15% to conduct the sensitive study to analyse different design options of a project. Ding and Shen (2010) use the discounted rate of 5% to analyse the economic criterion of a 40-year life span building. In this research, the discounted rate is based on the market condition by taking into consideration inflation, loan on investment, etc., and a discount rate of 5% is used for the study.

To calculate the cost of building in life cycle, the economic life span for structure as well as the elements of the building should be identified first. Based on the discussion in Chapter 2, many of the existing research studies on LCC in China are based on the international literature (Ouyang et al. 2009; Zhang & Xiao 2009; Ying & Neng 2010; Ouyang et al. 2011). The economic life span of the building components are based on the Table 2.9 in Chapter 2. The costs for replacement and repair in operation stage depend on the economic life span of the components.

iii) LCA

As discussed in the literature review, LCA is the most appropriate framework for the identification, quantification, of the inputs, outputs, and the potential environmental impacts of building (Junnila et al. 2003). Inventory analysis is a process that quantifies the input of a production system, such as energy, material (Li et al. 2010). In this research, the inventory analysis has been established to quantify the objective indicators in environmental assessment.

Three major types of data are required for inventory analysis:

- Project data, including project location and the quantifies of material used
- Equipment data, including the type, amount and running-time of equipment, and the average electricity and fuel consumed by this equipment
- Ancillary material data, include the material used for replace and repair

As discussed in Chapter 3, the construction industry requires large quantities of material and in turn, results in the consumption of energy and release of the GHG emission. Hannond and Jones (2008, pp 87) state that “energy and pollutant emissions such as carbon dioxide may be regarded as being ‘embodied’ within materials”. The embodied energy can be viewed as the quantity of energy require to process, and supply to the construction site. Likewise, the embodied carbon emission can be viewed as the quantity of emission related to the material supply chain or life cycle. This is taken to include raw material extraction, processing and transportation to the construction site. Hammond and Jones (2008) develop an open-access database of both embodied energy and carbon initially for the construction industry. Nowadays, the Inventory of Carbon & Energy (ICE) (Hammond & Jones 2011) is widely used in the construction industry (Broun & Menzies 2011; Hernandez & Kenny 2011; Monahan & Powell 2011; Sodagar et al. 2011; Sandberg & Brattebø 2012). This database is English based and it may vary from the China's condition due to the different raw materials and production process. The exact amount of embodied energy and emission may be different from the real data, but it can still provide an intuitive judgment based on these calculations. Therefore, the coefficient for embodied energy and emission based on the Inventory of Carbon & Energy (ICE) will be used for the quantifying of the embodied energy and carbon emission for the research.

a) Emission

The GHG emission in a building project mainly comes from material production, construction, operation and demolition activities. In this research, only CO_2 is taken into consideration. In construction stage, CO_2 emission comes from raw material extraction, material production, transportation and the construction activities on site. The embodied emission is based on material used, e.g. cement, steel, timber, glass, etc. The amount of material used in the building was derived from the bill of quantities, architecture and engineering drawings, and the architect's specifications. The coefficients are adopted from the data from the ICE. Besides embodied emission, the emission in construction includes the emission from the equipment and their power. The emission in construction stage can be quantified based on the above data.

In operation stage, CO_2 emission mainly comes from the operation of the equipment and maintenance. It is based on the electricity consumed by the lighting, HVAC and other equipment. In demolition stage, CO_2 emission comes from the demolition activities, machine and the material recycle.

b) Energy

Energy consumption includes energy consumed in construction, operation and demolition stages. Based on the Tables 7.1-7.4, the energy consumed in construction and operation is calculated in this research. Energy consumed in construction stage includes embodied energy and energy used to operate the construction equipment, and the other activities on site. Embodied energy is also based on the material used. The coefficients are adopted from the database from ICE. Similar to embodied emission, the data derived from the bill of quantities will be used as the base for embodied energy.

As for the energy consumed on site, the first step is to summarize the number of machines used on site and their power, then get the amount of electricity consumed by the equipment. The second step is to summarize the number of site workers and their daily electrical consumption, then get the amount of electricity consumed by the site daily life. These two parts are the major sources for energy consumption in construction stage.

Energy consumed in operation stage is mainly from the electrical and HVAC systems. The data is derived from the architect's specifications. In China, this kind of information is contained in the specifications. The operational energy for the building life span (e.g. 50 years) can be estimated by the equipment data, include the type, amount and running-time of equipment, and the average electricity and fuel consumed by this equipment. Similarly the energy consumed during demolition stage will be assessed in a similar approach.

c) Water

Water consumption mainly comes from construction and operation stage. Water consumption in construction stage includes the embodied water (also known as virtual water) and the water consumed in construction activities. Similar to the embodied energy, embodied water refers to the water used to acquire raw materials (excavation), manufacture and transport to the building site. In this research, only the embodied water for manufacturing material onsite, such as concrete, is considered. The calculation is based on the ratio of ingredients. Water consumed on site includes water consumption for site activities, water consumption for machines, water consumption for daily life of site workers, and water for firefighting purposes.

Water consumption for site activities depends on the quantity of water needed for the construction processes. Similarly, water consumption for machines depends on the number of items of equipment, and the type, amount and running-time of the equipment. Water consumption for the daily life of site workers depends on the number of workers and their daily consumption of water. The water consumption for firefighting purposes depends on the local data. Water consumed in operation stage is mainly for office use, daily use, water for fire station and so on.

d) Waste

A huge volume of waste would be generated in the building life cycle. The waste in construction and demolition (C&D) stage of building accounts for a large part of it (Villoria Sáez et al. 2012). A variety of authors have developed methodologies to quantify the C&D waste produced in both new construction and demolition works (Wang et al. 2004; Lu et al. 2011; Yuan & Shen 2011; Villoria Sáez et al. 2012).

Bossink and Brouwers (1996) estimated the C&D waste by the waste generation rate (WGR). They conducted their study with some residential buildings in The Netherlands, and state that 1-10% (in weight) of the building materials delivered on site becomes waste. Cochran et al. (2007) also analyzed the waste of residential and non-residential buildings in USA by percentage by weight. They stated that the percentage of the composition of waste in eight categories include 56% concrete, 13% wood, 11% drywall, 8% miscellaneous debris, 7% asphalt roofing materials, 3% metal, 1% cardboard, and 1% plastic. Tam et al. (2007) analyzed four categories of C&D waste in Hong Kong; they were concrete, steel boards, timber board, and bricks and blocks. They stated the wastes contain about 13.3% for the private housing. The conclusion in their study shows the private housing and private commercial buildings generated higher wastage level compared with other types of buildings.

Kofowoeola and Gheewala (2009) conducted a study in Thailand about the C&D waste from building. They stated that the waste generation of 21.38 kg/m^2 for residential construction and 18.99 kg/m^2 for non-residential construction. Solís-Guzmán et al. (2009) quantified the C&D waste based on the budget data of the project. The model developed by them estimated the volume of waste by categories and by projects. They stated that the waste for new construction is 0.3076 m^3/m^2, and the waste for demolition is 1.2676 m^3/m^2. Similarity, Llatas (2011) presented a model for C&D waste also based on the budget data of the project. In this model, a rate of 0.1388 m^3/m^2 is generated for residential building.

In general, most of the authors estimated the C&D waste by building types and focused on several categories of waste (Cochran et al. 2007; Tam et al. 2007; Llatas 2011). Amnon Katz et al. (2010) did not separate the waste by building types, but instead focused on the accumulation of construction waste generated in the construction process. In their research, the total amount of waste from the site was estimated at 0.2 m^3/m^2 floor area. In this research, the inventory approach was adopted to quantify the amount of construction and demolition waste. Based on the research of Chen et al. (2007), the amount of construction and demolition waste could be estimated by gross floor area and types of structure. The construction wastes include the waste onsite and the garbage on site produced by workers. The waste onsite is normally estimated by gross floor area and coefficient, for example Lu et al. (2008) assumed that 2t waste is produced by 100 m^2 construction area in their research on quantifying the construction waste for a building in China, and the garbage on site was estimated by the number of workers onsite and the garbage produced by the workers. The coefficients for demolition waste can be found in Table 7.5.

Table 7.5 Coefficients for demolition waste (kg/m^2) in China

Structures		Steel waste	Concrete waste	Brick waste	Glass waste	Combustible waste	Total
Residential building	Mixed	13.8	894.3	400.8	1.7	25.0	1335.5
	Reinforced concrete	18.0	1494.7	233.8	1.7	25.0	1773.1
	Brick	1.4	482.2	384.1	1.8	37.2	906.7
	Steel	29.2	651.3	217.1	2.6	7.9	908.1
Commercial building	Mixed	18.4	863.4	267.2	2.0	27.5	1178.4
	Reinforced concrete	46.8	1163.8	292.3	1.9	37.7	1542.5
	Brick	1.8	512.7	417.5	1.7	32.1	965.8
	Steel	29.2	651.3	217.1	2.6	8.0	908.2

Source: Chen et al. (2007)

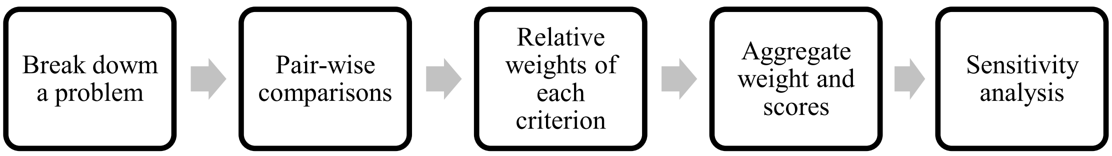
7.4 Weighting of the indicators

Weighting is needed to present the preference of some indicators against others. There are many ways to generate weighting for each indicator. Generally, it can be divided into two categories, one is the objective category, and the other category is the subjective category (Yang et al. 2010). Indicators in the objective category can be weighted using methods such as the principal component analysis method, factor analysis method, grey incidence method, entropy value method, rank sum ratio method, and numerical values can be calculated for each indicator (Yang et al. 2010). However, these methods do consider neither the decision makers' concerns nor the experts' experience, which is essential in the purpose of evaluation of weighting.

The indicators in the subjective category can be valued using methods such as Delphi, analytic hierarchy process (AHP), simple rank order and ratio weighting (Yang et al. 2010). These methods allow the decision maker to provide expect judgment on the relative importance of the indicators. Delphi, as one of the commonly used method in this group, is a systematic interactive forecasting method by an expert panel. It leads to group decision but it can be very time consuming as it needs two or more rounds to generate consensus of opinions. Group decision is important as it avoids the subjective judgment from individual perception. Another method in this group is the AHP method. It is a systemic decision-making framework solving multi-criteria decision problems of choice and prioritization, which was developed by Saaty (1990). Compared with Delphi, the AHP method can also be used to generate group decisions but with only one round. As such it requires less time and lower cost in the process (Vidal et al. 2011). In considering the time and process of the study, AHP has been used to derive weightings for indicators in the model.

AHP, as a step-by-step framework, provides a mathematical solution to determine weightings and priority by using pair-wise comparisons. The five general stages are as follows:

Figure 7.2 The flow of AHP method



Sources: Saaty 1998

After breaking down a problem into hierarchy criteria, Saaty (1998) proposed a priority matrix to make pair-wise comparison. A scale of 1-9 is used to define the relative importance of an element i compared to element j (Table 7.5).

Table 7.6 Fundamental scale for developing priority matrix

Intensity of importance	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values

Source: Saaty 1998

Take 3 elements for example, element A_1, A_2, A_3 and pair-wise comparison matrix are established as follows:

Table 7.7 Pair-wise comparison matrix for elements A_1, A_2, A_3

A_{ij}	A_1	A_2	A_3	
A_1	a_{11}	a_{12}	a_{13}	Upper
A_2	.	a_{22}	a_{23}	right hand
A_3	a_{ij}	.	a_{33}	

Entry a_{ij} is the relative importance of an element A_i compared to element A_j. For the upper right hand matrix triangle, a_{ij} needs to be defined by the expert panel, while the lower left hand matrix triangle is the reciprocal of upper right hand: $a_{ij} = 1/a_{ji}$

According to Yang et al. (2010), there are two ways to produce a group decision. The first method involves members to meet as a group and generates consensus for their opinions. This method is more time consuming and sometimes difficult to operate due to the geographical locations of members. The other method uses a geometric mean in combining individual comparison matrices. Aczél and Saaty (1983) demonstrated that the geometric mean was an appropriate method to combine individual opinion into group judgment in AHP, since it keeps the reciprocal property of the judgment matrix. This research has used the geometric mean for group decision and has been conducted in two steps:

i) A questionnaire is designed with a 9 scale form to collect the individual comparison matrix

In this research, the BSS model includes four sub-models of BSS_i, BSS_c, BSS_o and BSS_d. Each sub-model combines the pillars of environmental, economic and social into an overall sustainable value. The weighting for the assessment indicators need to be generated here. Experts panel are used to collect the data for the individual comparison matrix. The questionnaire for the expert panel can be found in Appendix F. The individual comparison matrix can be listed as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (7.1)$$

For example, there are three indicators in environmental aspects in inception and design stage, indicators A_1 , A_2, A_3 and the pair-wise comparison matrix is established as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad (7.2)$$

ii) Combine the individual comparison matrix to make group decision

As discussed above, the weighting is calculated by the pair-wise comparison matrix by an expert panel. To avoid the bias caused by the different experts and balance the difference caused by the panels' own interest, participants were chosen from different professions, including designers and contractors.

As a panel of experts will be chosen for the assessment, suppose there are k experts who have filled questionnaires to weight n indicators.

$$A = \begin{bmatrix} \sqrt[k]{a_{11}{}^{1} \times a_{11}{}^{2} \times, \ldots\ldots, \times a_{11}{}^{k}} & \sqrt[k]{a_{12}{}^{1} \times a_{12}{}^{2} \times, \ldots\ldots, \times a_{12}{}^{k}} & ,\ldots\ldots, & \sqrt[k]{a_{1n}{}^{1} \times a_{1n}{}^{2} \times, \ldots\ldots, \times a_{1n}{}^{k}} \\ \sqrt[k]{a_{21}{}^{1} \times a_{21}{}^{2} \times, \ldots\ldots, \times a_{21}{}^{k}} & \sqrt[k]{a_{22}{}^{1} \times a_{22}{}^{2} \times, \ldots\ldots, \times a_{22}{}^{k}} & ,\ldots\ldots, & \sqrt[k]{a_{2n}{}^{1} \times a_{2n}{}^{2} \times, \ldots\ldots, \times a_{2n}{}^{k}} \\ , & , & ,\ldots\ldots, & , \\ . & . & . & . \\ . & . & . & . \\ \sqrt[k]{a_{n1}{}^{1} \times a_{n1}{}^{2} \times, \ldots\ldots, \times a_{n1}{}^{k}} & \sqrt[k]{a_{n2}{}^{1} \times a_{n2}{}^{2} \times, \ldots\ldots, \times a_{n2}{}^{k}} & ,\ldots\ldots, & \sqrt[k]{a_{nn}{}^{1} \times a_{nn}{}^{2} \times, \ldots\ldots, \times a_{nn}{}^{k}} \end{bmatrix}$$

$$=\lambda_{max} W \tag{7.3}$$

λ_{max} is the maximum eigen value of a comparison matrix.

W is the corresponding eigenvector, the components in W are the weightings for each of the indicators.

iii) Consistency test

After the calculation of the eigenvalue, the consistency test is needed to test whether the result is acceptable for this assessment.

$$\text{Consistency ratio C.R.} = \frac{C.I.}{R.I.} \tag{7.4}$$

C.I. is the consistency index; the formula for C.I. is as follows:

$C.I. = \frac{\lambda_{max}-n}{n-1}$ (7.5)

λ_{max} is the maximum eigenvalue of a comparison matrix

N is the number of indicators.

R.I. is the random index, Saaty (1990) provided the R.I. in Table 7.7. For n=1–11, the sample is 500, for n=12–15, the sample is 100.

Table 7.8 Random index (R.I.) in AHP

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty 1990

In that case, the consistency ratio can be calculated. Saaty (1990) stated that a C.R. less than 0.1 is acceptable, otherwise, a new comparison matrix is needed to weight the indicators.

7.5 Building sustainable score (BSS) model

In this research, a mathematical model has been developed to aid decision making in the building industry. The assessment model consists of four sub-models. Each sub-model represents the sustainability of one stage of the building life cycle.

The BSS is a score for the four stages and it is a step function which assumes different values at different stages of a project life cycle.

$$\text{BSS} = \sum_{i=1}^{4} w_i \, BSS_i \quad (7.6)$$

BSS_i represents the sustainable score in each stage – inception and design, construction, operation and demolition. In each stage, the sustainable score consist of environmental, economic and social scores using the following formula:

$$\begin{cases} BSS_i = f\{E_{i,}C_{i,}S_i\} \\ BSS_c = f\{E_{c,}C_{c,}S_c\} \\ BSS_o = f\{E_{o,}C_{o,}S_o\} \\ BSS_d = f\{E_{d,}C_{d,}S_d\} \end{cases} \tag{7.7}$$

Take building sustainable score in inception and design stage as an example:

E_i Represents the environmental score in inception and design stage

C_i Represents the economic score in inception and design stage

S_i Represents the social score in inception and design stage

$$\begin{cases} E_i = \sum_{k=1}^{n} w_k E_i^k \\ C_i = \sum_{k=1}^{n} w_k C_i^k \\ S_i = \sum_{k=1}^{n} w_k S_i^k \end{cases} \tag{7.8}$$

E_i^k Represents the environmental score of one indicator

C_i^k Represents the economic score of one indicator

S_i^k Represents the social score of one indicator

w_k Represents the weighting of each indicator

K Represents the indicators

Based on the discussion above, the model BSS can be presented as:

$$\begin{cases} BSS_i = \sum_{k=1}^{n} w_k E_i^k + \sum_{k=1}^{n} w_k C_i^k + \sum_{i=1}^{n} w_k S_i^k \\ BSS_c = \sum_{k=1}^{n} w_i E_c^k + \sum_{k=1}^{n} w_i C_c^k + \sum_{k=1}^{n} w_i S_c^k \\ BSS_o = \sum_{k=1}^{n} w_i E_o^k + \sum_{k=1}^{n} w_i C_o^k + \sum_{k=1}^{n} w_i S_o^k \\ BSS_d = \sum_{k=1}^{n} w_i E_d^k + \sum_{k=1}^{n} w_i E_d^k + \sum_{k=1}^{n} w_i S_d^k \end{cases} \tag{7.9}$$

And BSS $= BSS_i + BSS_c + BSS_o + BSS_d$

The BSS is calculated by weighted summation. Weighted summation is a simple and often used evaluation method (Janssen 1992). The appraisal score is calculated for each indicator followed by summing of the weighted scores for all criteria.

The indicators contain both quantitative and qualitative scores with different units. To make these scores comparable, they must be transformed into a common dimension or into a common dimensionless unit. In that case, standardization is essential in this model. The scores are transformed into standardized scores using the function below.

The following equation is adopted in this research (Janssen 1992):

$$\widehat{x_{ji}} = \frac{x_{ji} - \min_i x_{ji}}{\max_i x_{ji} - \min_i x_{ji}} \quad (7.10)$$

$\widehat{x_{ji}}$ Represents the standardize x_{ji}

$\min_i x_{ji}$ Represents the lowest score

$\max_i x_{ji}$ Represents the highest score

This procedure scales these scores according to their relative position on the interval between the lowest and highest score. This will be discussed further in the next chapter along with the case studies.

After that, the final score for each stage as well as the whole building can present the performance of the building sustainability. The higher the score the better the sustainable performance of a building is. The detailed presentation of the model can be found in the next chapter.

7.6 Summary

The Building Sustainable Score (BSS) has been established in this chapter. LCA, LCC and value score are adopted for evaluation of indicators. Four sub-models are established for each building stage. In each stage, the sustainable score consists of environmental, economic and social score. The BSS represents the sustainable score of the overall performance. The weightings for the model are generated based on the group AHP method. The stakeholders' participation is contained in this model, which makes the model more customer-friendly.

In the next chapter, three case studies are chosen for model verification. The BSS model is applied in three different scenarios. The sustainable performance of the case studies in different building stages as well as the overall results is discussed.

CHAPTER 8

CASE STUDIES AND MODEL VERIFICATION

8.1 Introduction

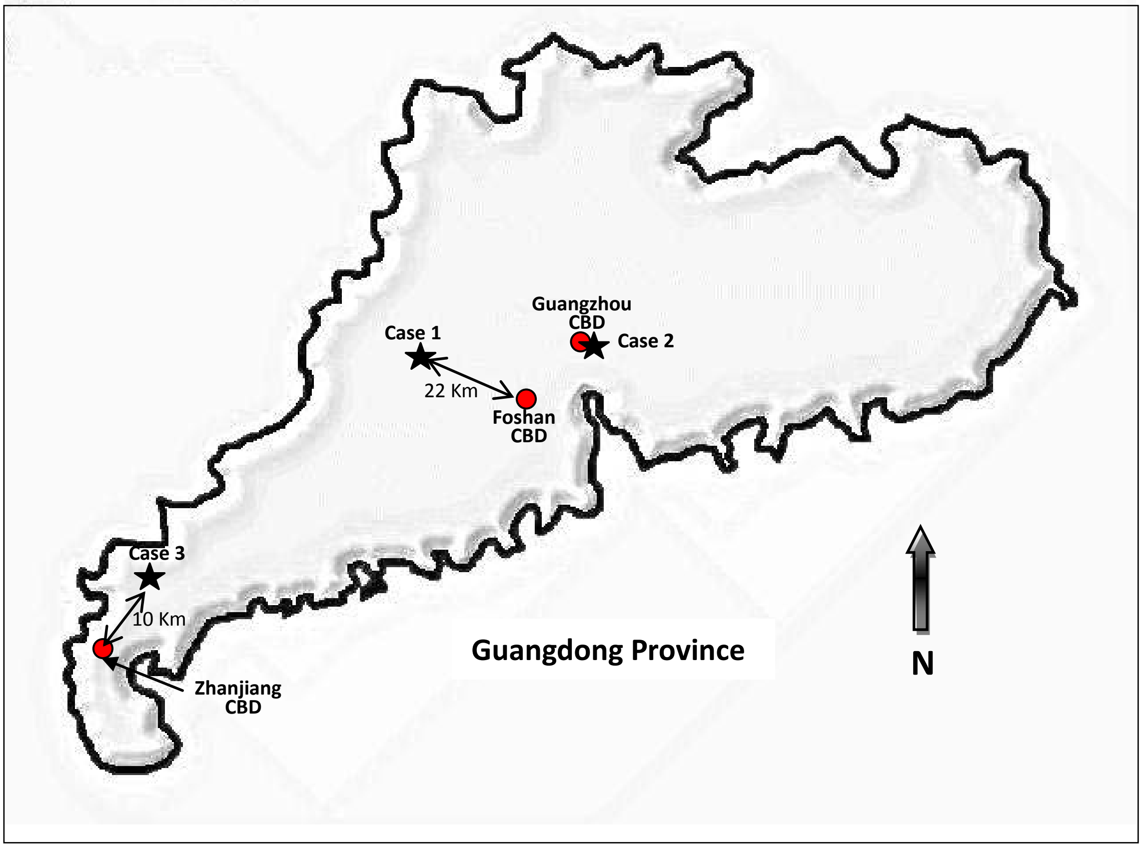
After the model establishment in Chapter 3, three case studies are chosen for model verification in this chapter; a low rise office building in suburban industrial area, a medium rise office building in the CBD and a medium rise green building in a new development area. The three case studies are analysed based on the BSS model. In this chapter, the sustainable performance of the three case studies in every stage of the building life cycle as well as the overall performance will be analysed. Quantitative methods and qualitative methods are used for assessing the indicators. The details of the calculation processes for the indicators are discussed in this chapter. Expert panels were recruited for the AHP survey for generating weighting for the study. The results of the BSS are also compared with the LEED and ESGB for further discussion. The value and innovation of this model are also discussed in this chapter.

8.2 Background information of the three case studies

The information of the projects for the case study was collected from some design institutes in Guangdong Province, China. They provided the drawings, bills of quantities, specifications. In order to choose the suitable cases for model verification, some preconditions were needed for screening the cases, such as location, size, and type of the project. Consistency with the industry survey, Guangdong province was chosen as the target location of the case study. Different types of projects were needed to make the comparison analysis. Finally, three cases were chosen from seven projects which have initially been obtained from the design institutes for case studies in this research. The three projects are all reinforced concrete frame structures.

The three projects were located in three different cities in Guangdong province. Case 1 was a low rise office building in a suburban industrial area located in Foshan City; Case 2 was a high rise office building in CBD in Guangzhou City; Case 3 was a medium rise green building in a new development area in Zhanjiang City. Figure 8.1 shows the location of the three case studies.

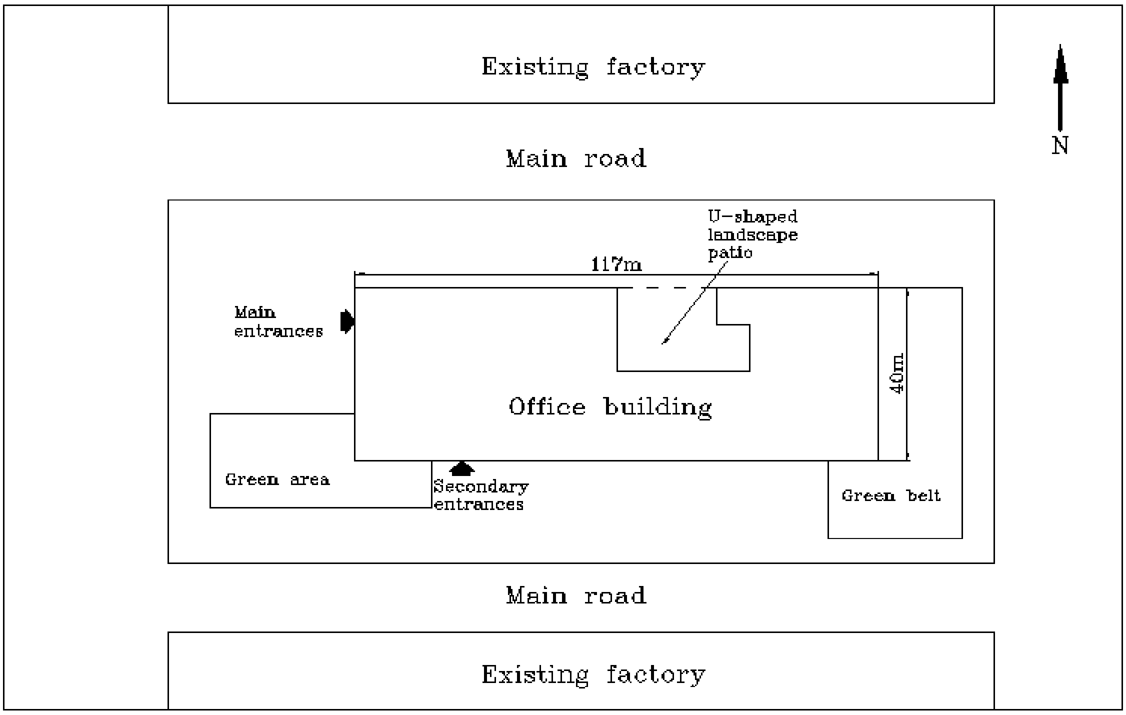
Figure 8.1 The location of the three case studies in Guangdong Province, China



8.2.1 Case Study No 1: A low rise office building in a suburban industrial area

The building site was located in Foshan City of Guangdong Province in China. It was located in a suburban industrial area 22 kilometres away from the CBD (Figure 8.1). The building was located in the north-eastern part of the site, with two sides of the site near the main road. It has a 30 meter green belt on the east and north sides with willow, coniferous pine and poplars growing. The traffic entrance was located on the southeast corner of the site, to organize freight traffic during construction and office traffic during operation. In the south part of the land, there was outdoor parking and a green area. The building had a u-shaped landscape patio. Figure 8.2 presents the general layout of this building.

Figure 8.2 The general layout of Case Study No 1



The project had one basement and three levels above ground floor. The project was design for 50 years; it had a Class 1 fire-resistance rating, and seismic intensity scale of 7 based on the Chinese standard. The total land area was 16,287.08m^2, gross floor area of 10,928.86 m^2, ground floor area of 9,889.39 m^2, and underground floor area of 1,093.47m^2(for more detailed information see Table 8.1).

In the design, the building has included the concept of sustainability in the design. This project uses low-reflective glass, metal plates and other facade materials to control the light pollution. Besides, it selects environmentally friendly, renewable raw materials and local materials, and uses more green areas to improve the environmental quality.

Other sustainable designs are listed as follows:

For the HVAC systems, the design includes:

- Selection of efficient and low-noise devices
- All vibrating equipment is equipped with vibration damping devices to prevent vibration or noise spreading to other rooms
- Acoustic treatment to all inner surface walls of HVAC plant room with acoustic doors
- Vibrating equipment is isolated within the structure

For the electrical system, the design includes:

- Selecting energy-efficient and environmentally friendly dry-type transformers and selecting a reasonable load rate
- Selecting plastic pipe instead of steel pipe, especially the flame retardant PVC pipe.
- Installing flue gas purification treatment before altitude emissions.

8.2.2 Case Study No 2: A medium rise office building in the CBD

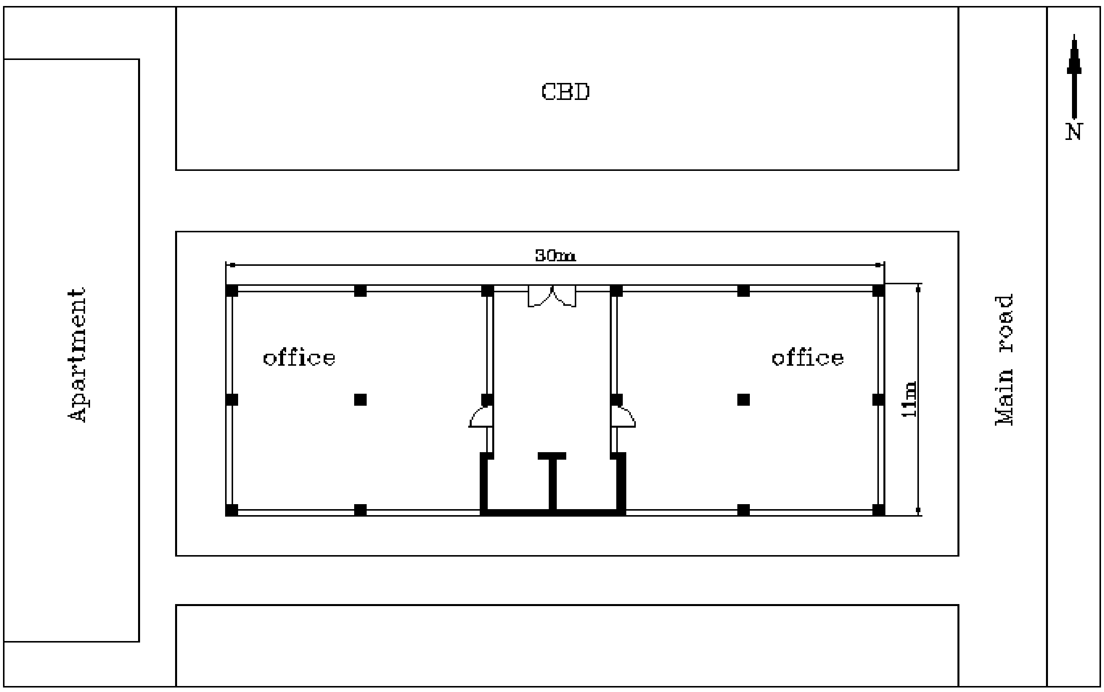
This project was located in CBD of Guangzhou City. It was a high rise office building with 16 floors. In the east, it was adjacent to the city's main road; in the west, it was near the residential area in the CBD; in the north, there was the well-developed financial and commercial centre.

The total land area is 2,163m^2, gross floor area of 5,471m^2, average room floor area of 320m^2, floor area ratio is 2.5. The building is 60 meters in height and is for office use. Construction was commenced in April 2011 and completed in August 2013 (see Table 8.1).

The project used the shear wall-frame structure and the roof used the in-situ reinforced concrete floor slab structure. It was a reinforced concrete frame structure with pile foundations. The designed economic life span was 50 years. Part of the facade used a curtain wall to enhance the modern aesthetics of the building (see Figure 8.2). Granite finishes was applied with the curtain wall to complement each other.

The building used a central cooling and heating system. The water-cooled screw chillers were used for the cooling system. For the open plan, the low-velocity air conditioning systems were applied, while the fan-coil unit air-conditioning systems with independent fresh air supply was applied in the separate office suites. The exhaust systems were applied to the place with no direct natural ventilation, or the aisle exceeds 60m. The water supply for this project comes from the city water supply network. The sewage was discharged into the sewer network after treatment.

Figure 8.3 The general plan of Case Study No 2



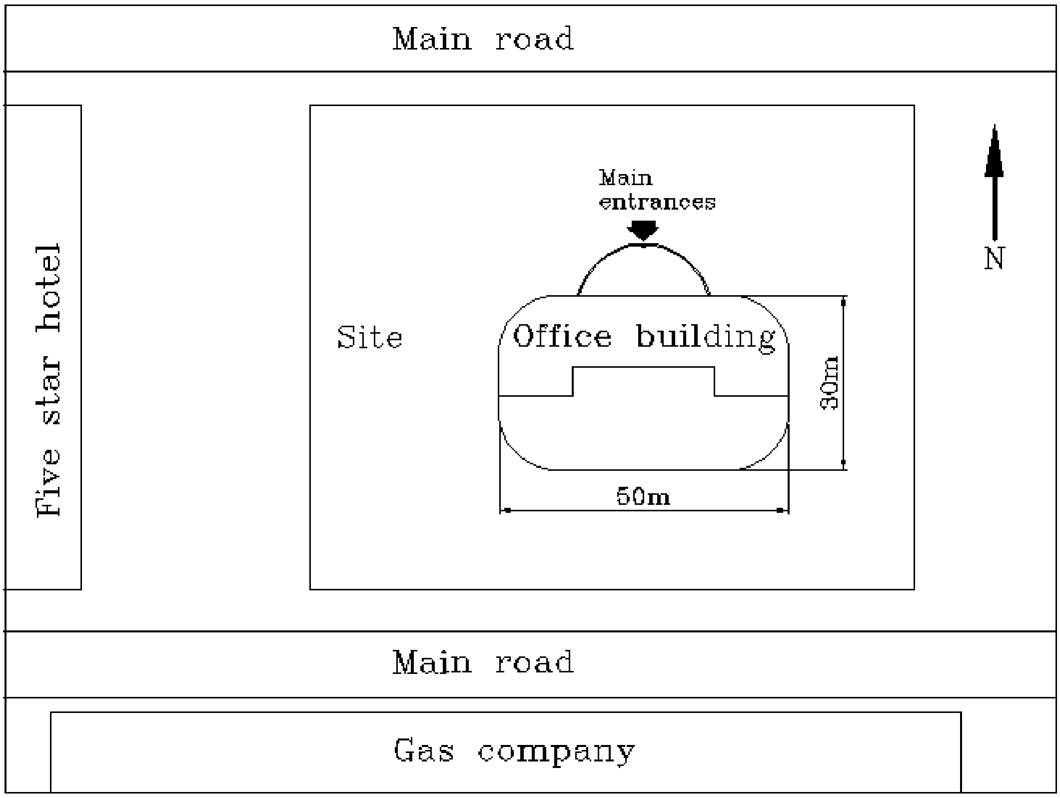
8.2.3 Case Study No 3: A medium rise green building in a new development area

Case 3 was a high rise green building in a new development area in Zhanjiang City in Guangdong Province. The construction started on March 2008 and was completed in August 2011. It is located between two main streets. There was an open area on the east side, a gas company is 20 meters to the south, and a five star hotel 140 meters to the west.

This project had an environmental impact analysis about the site to make sure it would not affect the farmland, forest, wetland, natural water and other protected areas nearby. It set ESGB two star as the goal in its inception and design stage. A series of green technologies have been considered in this project, such as solar energy, green area, maximize natural ventilation and natural lighting, low embodied energy materials used for the retaining structures, rainwater and water reuse, intelligent control and management, recycle building materials and so on. Around the project, there are two bus stops within 500 meters and four bus lines to other places. With these public transportation facilities, the car usage can be minimized.

A green garden has been set up on the roof of the building. The garden has multi-layer trees and shrubs, including five categories of plants. The area of green roof is 1,262m^2 and the green ratio is 22.93%. Figure 8.4 shows the general plan of the project.

Figure 8.4 The general plan of Case Study No 3



This project also uses permeable ground to collect water and protect the environment. The green area in the site, as natural infiltration facilities, is treated as permeable ground. There are plenty of green spaces in the site area to improve the local environment of the community.

Some energy saving technology is used in this project, such as exhaust heat recovery technology, solar hot water systems, solar photovoltaic systems and so on. In the external structure design, a series of actions are adopted, include using aerated concrete blocks in the building envelope, using extruded polystyrene insulation board. Aluminium Low-E insulating glass is used for exterior windows. Low-E double hollow glass is energy-saving glass itself, with good light transmittance and better heat transfer coefficient and shading coefficient at the same time. It also has good air tightness and water tightness.

The exhaust heat recovery technology is another sustainable measure in this project. As the building is located in southern China with a humid climate, the air conditioning season is long. In that case, the heat recovery equipment with the heat exchange mode is selected in this project. The heat recovery fresh air ventilator can pre-cool fresh air with the recovery cooling.

For energy saving, solar hot water systems are also installed in this project. An air source heat pump is used as an alternative heat supply. It uses a built-in electric heater in a hot water tank as heating equipment for the air source heat pump. Solar collectors are installed on the available area of the roof, about $56m^2$, and the volume for the water tank is $100m^3$. The solar photovoltaic systems are used in this project. There are 96 Mon crystalline photovoltaic cell assembly installed on the roof to provide the lighting.

Some water saving measures are also used here, such as a rainwater harvesting and recycling system, reclaimed water system, water-saving irrigation system, high performance water pump system, and selecting water-saving appliances.

For the rainwater harvesting recycling system, the rainwater is harvested from the rooftop to the outdoor rainwater cisterns, and then the water will be used for watering plants and cleaning after treatment. The reclaimed water system is used to collect the water from the pool by gravity and used for green plants and cleaning after treatment. The water-saving irrigation system uses low-pressure pipes and drippers or other emitters to water the roots of the plants directly in a stable, sustained way. High performance water pumps system use inverter technology to control the amount of flow.

Table 8.1 Design detail of the three case studies

	Case Study No 1	**Case Study No 2**	**Case Study No 3**
Building type	Low rise Reinforcement concrete frame	High rise Reinforcement concrete frame	Green building (ESGB 2 Stars) Reinforcement concrete frame
Year of construction	2008	2006	2008
Year of completion	2010	2008	2011
Intended use	Office	Office	Office
Site area	16, 287 m^2	2,163m^2	20,762m^2
Gross floor area	10, 929 m^2	5,471 m^2	28,349 m^2
Number of floor	3 above ground and 1 basement car park	16 above ground and 1 basement car park	20 above ground and 2 basement car park
Designed life span	50 Years	50 Years	50 years
Location	Suburban industrial areas	CBD	New development zone
Green features	Green area outdoor	Not indicated	Green roof & green belt outdoor
Engagement of sustainable consultant	/	/	Yes
Recycled material	Not indicated	Not indicated	10.3%
Energy saving material	Low-E glass	/	Low-E glass
Water recovery system	/	/	Yes
Solar hot water systems	/	/	Yes
Solar photovoltaic systems	/	/	Yes
Rainwater harvesting & reuse system	/	/	Yes

Sources: Specification and design document of the three case studies

8.3 Assessment details of case studies

The sustainable indicators in the three case studies are evaluated. From an economical point of view, the costs in every stage are quantified based on the LCC method. Estimation takes place in the demolition stage. Environmentally, the subjective indicators include sustainable site, heritage conservation are qualified in a value score which is collected by surveying the key design team members in each case. The objective indicators, like energy consumption and GHG emission are all quantified based on a LCA approach with inventory analysis. For the social aspect, the indicators are also qualified by a value score based on surveying the key design team member.

8.3.1 Economic assessment - LCC approach

According to the discussion in Chapter 7, the economic assessment is based on the LCC method. The discounted cash flow approach is used to bring the operation cost into an equivalent monetary value. The operation period is 50 years (see Table 8.1). According to the literature review in Chapter 2 (Section 2.4.2), different discount rates are chosen by former researchers based on their research content. As discussed in Chapter 7 (Section 7.3.1), the discount rates range from 5% to 30%. In this research, 5% is used as it is commonly used by the research in China (Ouyang et al. 2009; Zhang & Xiao 2009; Ding & Shen 2010). The economic life span for each component of the buildings is based on Table 2.9 in Chapter 2.

The capital costs for the projects are based on their project budgets. The operating costs contain salary, energy bill, water bill, security cost and cost for replacement and repair. The cost for replacement and repair is estimated by their economic life span, capital cost and discounted rate. For example, the economic life for a steel fire-rated door is 20 years and the construction cost for the door is ¥3,055.8. The door will be replaced every 20 years for a building life span of 50 years. The replacement cost for the door in the 50 years can be calculated as:

$$¥3{,}055.8/(1+5\%)^{20} + ¥3{,}055.8/(1+5\%)^{40} = ¥61{,}116.00$$

The energy bill and water bill are estimated by the unit price and the consumption. The electricity consumption is estimated by the type, amount and running-time of equipment, and the average electricity consumed by the equipment. The water consumption is estimated by the daily usage for the office building. Salary is estimated by the personnel composition and the average salary for different positions. Security cost is estimated by the security equipment and the salary for the security.

The cleaning cost is estimated according to the price catalog of the local cleaning company. The demolition cost is calculated based on the Cost Manual for Construction Project, China Water Power Press, May 2005 1st Edition. For more calculation details see Table I1-I6 in Appendix I. Table 8.2 summarizes the results of economic assessment for the three case studies.

Table 8.2 Summary of economic assessment for the three case studies

Stage	Indicators	Cost (¥) per GFA		
		Case Study No 1	Case Study No 2	Case Study No 3
GFA (m^2)		10,929	5,471	28,349
Inception & design	Land cost	5,250.03	16,946.69	7,200.00
	Professional fees	191.53	200.00	217.94
	Other costs & charges (government charges & rates)	41.86	62.32	54.76
Construction	Construction cost	1,981.22	2,069.44	2,113.40
	Professional fees	113.19	130.00	134.40
	Other costs & charges (preparation fees & taxes)	52.47	63.61	57.83
Operation (50 years)	Operating cost	41,253.86	64,447.55	40,983.86
	Cleaning cost	550.69	822.82	614.78
Demolition	Demolition cost	396.24	413.89	422.68
	Other costs & charges	79.25	90.56	84.46

From the Table 8.2, the three cases have different characteristics in their economic aspects. The land cost for the three cases are different due to their different location. The one in the CBD is higher than the one in the suburban industry area. As the three cases are located in different cities in Guangdong province and constructed in different time, no exact comparison can be made and these figure can just for reference only. The construction cost for the three cases also have some differences. The construction cost for Case 3 is higher than the other two; this might be because of the green technology and material it used. These green technology and materials used in the construction stage have their benefits in the coming stage. The operation cost for Case 3 is the lowest among these three cases. Case 2 as an office building in the CBD has the highest operating cost and cleaning cost. The possible reason may be the higher labour cost and the higher density of usage.

Table 8.3 shows a discounted cash flow for the three projects. Some of the construction materials have a 20 or 15 years life span. They will be replaced in every 20 or 15 years and repaired in every 10 years. Some of the materials have a 30 years life span, and are replaced after 30 years. Take the glass windows for example; they are replaced every 20 years and the glass is repaired every ten years in 10% of cases.

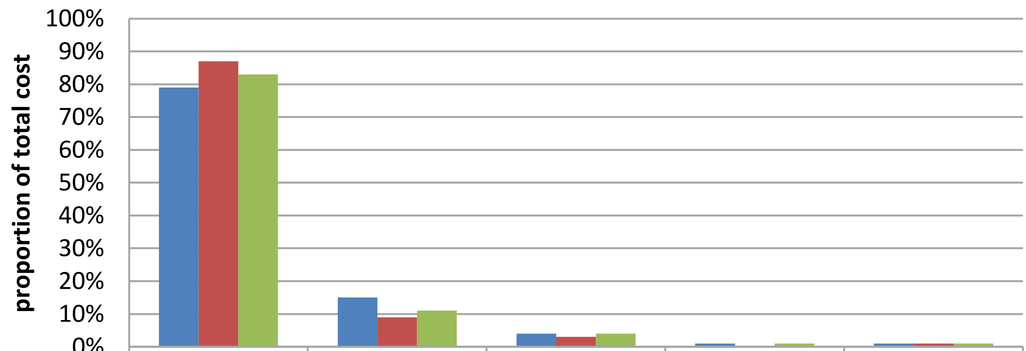
Table 8.3 The discounted cash flow of operating cost for the three projects (¥)

	10 years	**20 years**	**30 years**	**40 years**	**50 years**
Case Study No 1 (per GFA)	27.69	306.53	73.96	162.39	24.64
Case Study No 2 (per GFA)	18.01	303.65	85.73	80.66	16.11
Case Study No 3 (per GFA)	20.86	351.61	99.27	93.40	18.66

Figure 8.5 shows the major components in building life cycle costing in the three case studies. From Figure 8.5, operating cost, land cost and construction cost are the three major components of building life cycle cost in the three cases. The operating cost is far more than other costs in the building life cycle followed by the land cost. The operating cost for Case 2 - medium rise building in the CBD - accounts for the largest proportion

in the life cycle cost (87%) compared with the low rise building in the Suburban industrial area (79%) and the green building in the new development area (83%). The land cost for Case 1 accounts for the largest proportion (15%) as it has a large land area outside building.

Figure 8.5 The LCC component of Case Study No 1, 2, and 3



	Operating cost	Land cost	Constrcution cost	Demolition cost	Cleaning cost
Case 1	79%	15%	4%	1%	1%
Case 2	87%	9%	3%	0%	1%
Case 3	83%	11%	4%	1%	1%

8.3.2 Environmental assessment – The value score and LCA approach

i) The LCA approach for quantitative indicators

The quantitative measurement is based on the criteria of indicators in Chapter 7. LCA is applied to the quantitative indicators such as energy consumption, material consumption, CO_2 emission. According to Section 7.3.1 in Chapter 7, three types of data are collected for LCA:

- Project data, including the quantity of material used. The material consumption is based on it. The ingredients of construction material are also calculated based on their composition. The detailed calculation can be found in Table I7 in Appendix I.
- Equipment data, including the type, amount and running-time of equipment. For the electrical equipment, the average electricity consumed is collected. The energy consumed on site is calculated based on these data.

- Ancillary material data, which includes the material used for replacement and repairs.

a) Energy consumption

Based on the discussion in Chapter 7, the energy consumption mainly includes the energy consumed in the construction stage and operation stage. The energy consumed in the construction stage includes embodied energy and energy consumed on site. The embodied energy is calculated based on the Inventory of Carbon & Energy (ICE) (Hammond & Jones 2011). Formula 8.1 shows the calculation of embodied energy. The amount of embodied energy used in construction stage is the product of the amount of material and energy coefficient.

$$EE = M \times e \tag{8.1}$$

EE – Embodied energy

M – The amount of material

e – Energy coefficient

The amount of material used in the building was derived from the bill of quantities, architecture and engineering drawings, and the architect's specifications. The coefficients are adopted from the ICE database for both embodied energy and embodied CO_2 emission calculation. The reasons for using the ICE database are discussed in Section 7.3.2. The ICE database is developed by Hammond and Jones (2008) as an open-access database of both embodied energy and carbon initially for the construction industry. As an English based database, it may vary from the China's condition due to the different raw materials and production process. Therefore, the exact amount of embodied energy and emission may be different from the real data. But it can still provide an intuitive judgment based on these calculations. Therefore, the coefficient for embodied energy and emission based on the Inventory of Carbon & Energy (ICE) will be used for the quantifying of the embodied energy and carbon emission.

The energy consumed onsite is calculated based on the type, amount and running-time of equipment on site, and the average electricity consumed by the equipment. This data comes from the explanation documents. The energy consumed in the operation stage is calculated based on the type, amount and running-time of equipment used in the operation stage.

Take Case 1 for example; Table 8.4 shows the energy consumed on site. A similar calculation is applied to the other two cases. In the operation stage, the power of equipment, such as HVAC and lighting is based on the case's explanation documents. The energy consumption is also calculated based on the power and amount of equipment. Detailed calculations are included in Table I8-9 in Appendix I.

Table 8.4 Energy consumed on site in construction stage for Case Study No 1

Equipment	Power (KW)	Amount	Total
Crane	35	2	70
Concrete mixer	15	2	30
Steel cutting machine	2	3	6
Steel bending machine	2	3	6
Hoist	6	1	6
AC welder	12.5	1	12.5
Woodworking circular saw	3	1	3
Plug-shaker	1.1	2	2.2
Electro slag welding	35	1	35
Lighting	/	/	15
Life on site	/	/	12
Total			197.7

b) Water consumption

The water consumption calculated in this research includes the water consumed in the construction and operation stage. The water consumed on site includes the water consumed for construction activities, the water consumed by the equipment, the water consumed for the daily life for the workers and the water consumed for firefighters.

Take Case 1 for example; the calculation for water consumed in the construction stage is as follows: (Note: the formula and coefficient used in these calculations are all based on the Construction Water Evaluation Specification in China).

Water consumption on site (per day) $q_1=K_1\Sigma Q_1N_1K_2$ (8.2)

K_1 coefficient of unanticipated water consumption in construction, take 1.15

Q_1 the work load per day, assume 350 m^3 concrete a day

N_1 the water consumed per m^3 concrete, assume 0.4 m^3 is needed (assumed the concrete is ready-mixed concrete, just take the natural conservation into consideration

K_2 balance coefficient, take 1.5

$q_1=1.15\times350\times0.4\times1.5= 241.5\ m^3$

Water consumed by equipment $q_2=K_1\Sigma Q_2N_2K_3$ (8.3)

K_1 coefficient of unanticipated water consumption, take 1.1

Q_2 the number of equipment, assumed 2 pressure test pumps

N_2 water consumed by the equipment, take 1.2 m^3

K_3 balance coefficient by equipment, take 1.1

$q_2=1.10\times2\times1.2\times1.10= 2.9\ m^3$

Water consumed by workers on site $q_3=P_1N_3K_4$ (8.4)

P_1 peak number on construction site, take 700

N_3 water consumption per person 0.04 m^3

K_4 balance coefficient, take 0.8

$q_3=700\times0.04\times0.8= 22.4\ m^3$

$q1 + q2 + q3 = 266.8m^3$

Water for fire protection:

According to the city database, fire water takes 10L/s, so the q4=288 m^3

The water consumption per day Q = q1+ q2+ q3+ q4 = 554.8 m^3

Water consumption in construction stage = 554.8 m3/day × 180 day= 99,864 m^3

The water consumed in the operation stage includes office use, equipment use and irritation. The daily usage for the office use, equipment use and other uses are estimated based on the design document. The water consumed in the operation stage is calculated by the daily usage plus the operating period.

c) Materials

The material used for the construction stage is calculated from the bills of quantities. Take the concrete structure for example, the volume and type of concrete is derived from the bills of quantities. Based on the proportion of composition and the known density, the weight of the materials can be calculated.

d) Waste

The solid waste generated in the construction process is estimated by the project data and the coefficient from local guidelines (Li 2011). The solid waste generated on site include construction and demolition waste. The construction waste is estimated by the gross floor area and the waste per square meter. According to Li (2011), 2t of waste is assumed to be produced by 100 m^2 of construction area. The solid waste at the demolition stage is also estimated from the project data and the coefficient, which is based on the research conducted by Chen et al. (2007). They conducted research about the demolition waste in China; see the Table 7.5 in Chapter 7.

e) CO_2 emissions

The CO_2 emissions at the construction and operation stages are estimated in this research. The emission in the construction stage is estimated by the quantities of the materials and the coefficient of the emission. The quantities of material are based on the bills of quantities. The coefficients of CO_2 emission are based on the ICE.

The calculation process shows in spreadsheet (see Table I7 in Appendix I). The emission in the operation stage is based on the energy consumption in operation and the coefficient. Li (2011) conducted a research about energy conservation and emission reduction policies for China. According to Li (2011), the carbon emission for an office building is 0.43 $kgCO_2/kWh$. In the demolition stage, the carbon emission can be estimated by the bill of quantities and coefficient. According to Li (2011), the coefficient for CO_2 emission for demolition of a building is as below:

Table 8.5 The coefficient for carbon emission in demolition stage

Measures	Coefficient
Deconstruction	$7.78kg/m^2$
Earthworks	$0.62kg/m^2$
Machinery	2.85kg/t

Source: Li 2011

The detailed calculation for carbon emission can be found in Appendix I.

ii) Value score approach for qualitative indicators

For the qualitative indicators, value scores are adopted here. Expert panels are chosen for the value score collection. The experts who have been closely connected with the projects are recruited for the survey. They are contacted via email and invited to participate in the scoring process. Several experts are connected with each project; there are 7 for Case 1, 6 for Case 2 and another 7 for Case 3. A panel for each case was selected based on their professional background, knowledge about green building assessment and the project. As a result five experts were selected for each case.

A questionnaire was designed for the expert panels and was send via email as an attachment. The qualitative indicators were listed in the questionnaire survey as well as their criteria. The criteria of indicators were based on the Table 7.1-7.4 in Chapter 7.

They were asked to value the score from -2 to +5 for the qualitative indicators, include some environmental indicators and the social indicators in next section. It took about a month to collect the data.

The expert panel was asked to value the performance of each indicator from -2 to +5. As discussed in the Chapter 7 of model development, the value score is in the range from -2 to +5:

- +4 ≤ + 5 Best practice (excellent performance)
- +3 ≤ + 4 Very good practice reflecting stable conditions in terms of sustainability
- 1.5 ≤ + 3 Good performance
- 0 ≤ 1.5 Current standard or difficulty in obtaining data
- –2 ≤ –1 Unsatisfactory performance

Their opinion was combined for the final score using the following formula (Alwaer & Clements-Croome (2010)).

$$A_1 = \frac{A_1^1+A_1^2+A_1^3+A_1^4+A_1^5}{5} \qquad (8.5)$$

The results of value scores for indicators at the inception and design stage are included in Table 8.3. Table 8.3 summarizes the results of environmental assessment for the three case studies. The results of qualitative indicators are present in the value score, while the quantities for the quantitative indicators are calculated in their own unit.

From Table 8.3, the quantities of the environmental indicators in the construction, operation and demolition stage are calculated in their own unit. Compared with the energy consumption in the construction stage, the consumption in the operation stage are much more for all the three cases. Similarly, the carbon emission in the operation stage is also far more than in the construction stage. Due to the limitation of the available information, the discounting of energy consumption, water consumption and

CO_2 emission during the 50 years are not discussed in this research. Comparing the results of the three cases in Table 8.3, it is easy to find that Case 3 has the better environmental performance than the other two cases in all four stages in the building life cycle. With the better selection of sustainable material, design and site, Case 3 has lower energy consumption, water consumption as well as carbon emission in the construction as well as the operation stage.

Table 8.6 Summary of environmental assessment for the three case studies

Stages	Indicators	Unit	Total (per GFA)		
			Case Study No 1	Case Study No2	Case Study No3
Inception & design	Sustainable Site	/	4.2	3.2	4.6
	Sustainable material	/	3.2	3.9	4.8
	Sustainable design	/	2.8	4.7	4.8
	Heritage conservation	/	2.2	3.2	3.8
Construction	Energy	MJ	8,077.26	7,480.46	4,605.26
	Water	kg	79.78	94.56	80.12
	Material	kg	1,911.63	1,766.64	1,003.61
	Waste	kg	31.53	66.32	28.47
	Emissions (CO_2)	kg CO_2	543.69	542.72	369.93
Operation (50 years)	Energy	MJ	51,417.17	70,260.06	27,592.88
	Water	kg	116.20	151.71	133.34
	Material	kg	192.01	408.52	86.16
	Emissions	kg CO_2	6,507.63	8,538.82	3,326.55
Demolition	Waste *	kg	1542.5	1542.5	1383.62
	Emission	kg CO_2	13.85	13.43	11.26

* The waste for Case 1 and 2 is the same because they use the same coefficient to estimate the demolition waste (Table 7.5 in Chapter 7). Case 3 is estimated based on the information of the ESGB application document.

8.3.3 Social assessment - The value score approach

In social assessment, value score was also used here. The professionals related to the projects were recruited for the questionnaire survey, and it was conducted with the qualitative environmental indicators at the same time (see the previous section). It was conducted together with the qualitative indicators in environmental aspects with the same procedure. The results for the three cases are show in Table 8.4 and Figure 8.7.

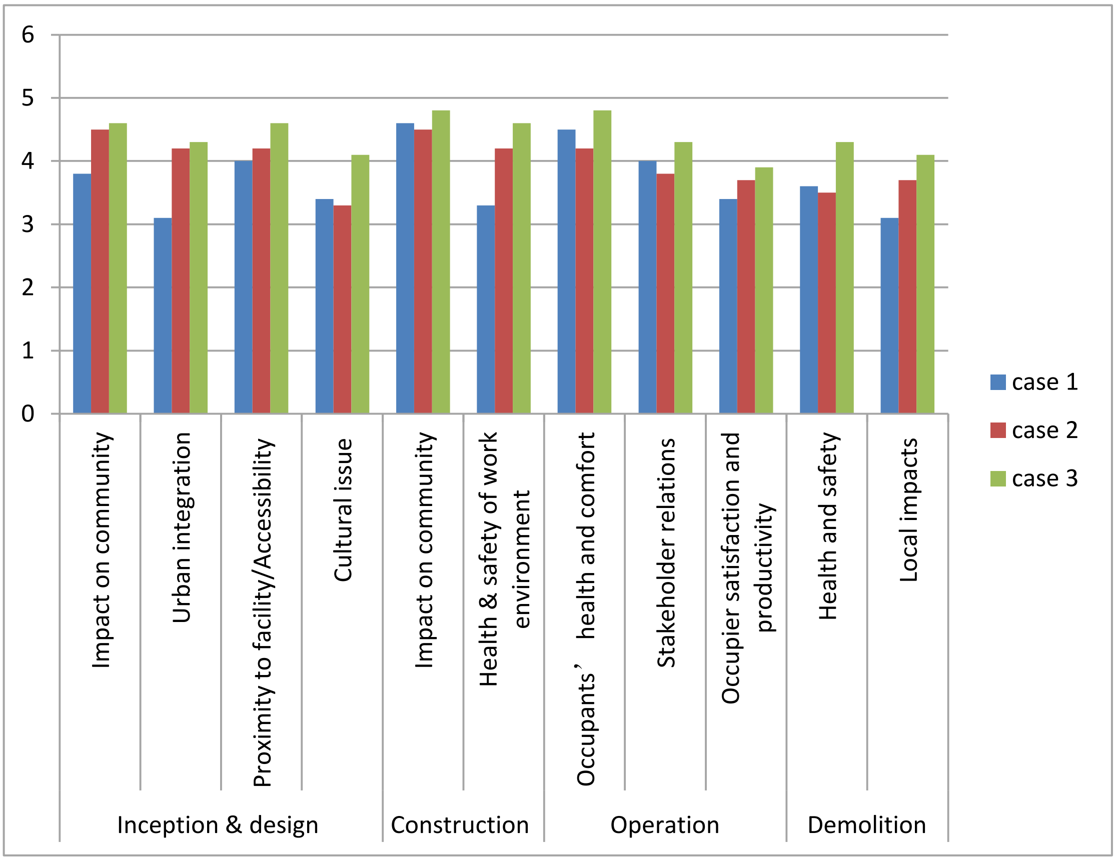
Table 8.7 Summary of social assessment for the three case studies

Stages	Indicators	Value score		
		Case Study No 1	**Case Study No 2**	**Case Study No 3**
Inception & design	Impact on community	3.8	4.5	4.6
	Urban integration	3.1	4.2	4.3
	Proximity to facility/Accessibility	4.0	4.2	4.6
	Cultural issue	3.4	3.3	4.1
Construction	Impact on community	4.6	4.5	4.8
	Health & safety of work environment	3.3	4.2	4.6
Operation	Occupants' health and comfort	4.5	4.2	4.8
	Stakeholder relations	4.0	3.8	4.3
	Occupier satisfaction and productivity	3.4	3.7	3.9
Demolition	Health and safety	3.6	3.5	4.3
	Local impacts	3.1	3.7	4.1

From Table 8.4 and Figure 8.7, in the inception and design stage, Case 1 gets the lowest score in three indicators including impact on community, urban integration and proximity to facility/accessibility. Case 2 get the lowest score in cultural issues. Case 3 has a better performance than the other two in the inception and design stage. Case 1 has the worst performance in this stage due to it being in a suburban industry area which is far from the public facilities. In the construction stage, Case 2 has the lowest score in impact on community. As Case 2 is in the CBD area, the construction process may have great impact to the nearby community than the other two cases. In the operation stage, Case 2 has the lowest score in the indicators including occupants' health and comfort and stakeholder relations, while Case 1 has the lowest score in occupier satisfaction and productivity. The possible reasons for this are that Case 2 is an office building in the

CBD area with high density which would impact on people's comfort. In the demolition stage, Case 1 has the lowest score in local impacts while Case 2 has the lowest score in health and safety.

Figure 8.6 The value score of social impacts for the three case studies



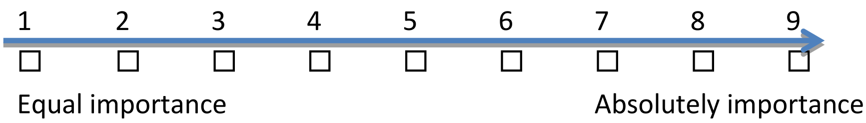
8.4 Weighting system in the BSS model

After the evaluation of each sustainable indicator for the three case studies, the weighting for these indicators is calculated in a group AHP matrix. As all the assessment indicators are quantified or qualified in different units, standardization is needed here in order to combine them in the BSS model. Based on the weighting summation, the BSS scores are calculating for each case. As a result, the BSS results of the three case studies are comparable as well as their performances in each stage.

8.4.1 AHP method

Based on the discussion in Chapter 7, an AHP was used for generating weighting for indicators. An expert panel was recruited to collect the data for pair-wise comparison. This was conducted on August 2013 when case studies were taking place. The experts were recruited from the design institutes which have been closely connected with these projects. Five experts were chosen for the AHP analysis due to their participation in these projects. The same panels were used for the value score for all the cases. The sample questionnaire for the AHP group can be found in Appendix F. Take the two environmental indicators in the inception and design stage for example, in order to get the pair-wise comparison; the questions were designed as follows:

In order to assess the environmental impacts in inception stage of building, please indicate the importance degree of 'Brown/green field' over 'Local flora & fauna' with '√'?



There were four indicators in environmental aspects in the inception and design stage, so 6 questions were asked to get the upper right hand results in the matrix. With their answers, one matrix for environmental indicators in inception and design is as follows:

$$A_1 = \begin{bmatrix} 1 & 1/6 & 1/7 & 3 \\ 6 & 1 & 3 & 5 \\ 7 & 1/3 & 1 & 3 \\ 1/3 & 1/5 & 1/3 & 1 \end{bmatrix}$$

As discussed in Chapter 7, the matrix for group AHP is used in this survey, thus the matrix for group answers for environmental indicators in inception and design stage is:

$$A=\begin{bmatrix} \sqrt[5]{1\times1\times1\times1\times1} & \sqrt[5]{\frac{1}{6}\times3\times3\times\frac{1}{7}\times\frac{1}{4}} & \sqrt[5]{\frac{1}{7}\times\frac{1}{6}\times6\times\frac{1}{6}\times\frac{1}{6}} & \sqrt[5]{3\times4\times4\times4\times4} \\ \sqrt[5]{6\times\frac{1}{3}\times\frac{1}{3}\times7\times4} & \sqrt[5]{1\times1\times1\times1\times1} & \sqrt[5]{3\times\frac{1}{4}\times4\times4\times\frac{1}{2}} & \sqrt[5]{5\times\frac{1}{7}\times7\times7\times5} \\ \sqrt[5]{7\times6\times\frac{1}{6}\times6\times6} & \sqrt[5]{1\times1\times1\times1\times1} & \sqrt[5]{1\times1\times1\times1\times1} & \sqrt[5]{3\times2\times2\times5\times7} \\ \sqrt[5]{\frac{1}{3}\times\frac{1}{4}\times\frac{1}{4}\times\frac{1}{4}\times\frac{1}{4}} & \sqrt[5]{\frac{1}{5}\times7\times\frac{1}{7}\times\frac{1}{7}\times\frac{1}{5}} & \sqrt[5]{\frac{1}{3}\times\frac{1}{2}\times\frac{1}{2}\times\frac{1}{5}\times\frac{1}{7}} & \sqrt[5]{1\times1\times1\times1\times1} \end{bmatrix}$$

Matlab was used to calculate the maximum eigen value $\lambda_{\max}$ and the corresponding eigenvector W, the components in W are the weightings for each of the indicators.

maxeigval = 4.2132

w =

0.20

0.32

0.41

0.07

After the calculation of the eigenvalue, the consistency test is needed to test whether the results are acceptable for this assessment. Saaty (1990) stated that a C.R. less than 0.1 is acceptable, otherwise, a new comparison matrix is needed to weight the indicators.

Consistency index *C.I.* = $\frac{\lambda_{max}-n}{n-1} = \frac{4.2132-4}{4-1} = 0.071$

Consistency ratio C.R. = $\frac{C.I.}{R.I.} = \frac{0.071}{0.9} = 0.078 < 0.1$

Therefore the result is acceptable.

Similarity, 12 matrixes were established to calculate the weighing based on the survey results. The weighting for the indicators in environmental aspects in the inception and design stage is summarized in Table 8.5.

Table 8.8 Weighting for environmental indicators in inception and design stage

	Sustainable site	Sustainable material	Sustainable design	Heritage conservation	W	C.R.
Sustainable site	1	0.5569	0.3309	3.7764	0.20	0.078 < 0.1
Sustainable material	1.7956	1	1.4310	2.8094	0.32	
Sustainable design	3.0219	0.6988	1	3.3470	0.41	
Heritage conservation	0.2648	0.3560	0.2988	1	0.07	

Similarly, weighting for other indicators were calculated and are summarized in Table 8.6. The detailed process can be found in Appendix H.

Table 8.9 Weighting for indicators in the three pillars and four stages

Stages	Pillars	Indicators	Weighting
Inception & design	Environmental	Sustainable site	0.20
		Sustainable material	0.32
		Sustainable design	0.41
		Heritage conservation	0.07
	Economic	Land cost	0.64
		Professional fee	0.29
		Other costs &charges	0.07
	Social	Impact on community	0.34
		Urban integration	0.42
		Proximity to facilities	0.13
		Cultural issue	0.11
Construction	Environmental	Energy	0.38
		Water	0.09
		Resources	0.37
		Waste	0.11
		Emissions	0.06
	Economic	Construction cost	0.66
		Professional fee	0.25
		Other costs & charges	0.09
	Social	Impact on community	0.73
		Health & safety of work environment	0.27
Operation	Environmental	Energy	0.43
		Water	0.22
		Resources	0.27
		Emissions	0.08
	Economic	Operating cost	0.77
		Occupancy cost	0.23

	Social	Occupants' health and comfort	0.58
		Stakeholder relations	0.14
		Occupier satisfaction and productivity	0.28
Demolition	Environmental	Waste	0.84
		Emission	0.16
	Economic	Demolition cost	0.80
		Other costs & charges	0.20
	Social	Health and safety	0.48
		Local impacts	0.52

The weighing was applied in the model for the score generation. After the calculation of weight, the building sustainable score of the case study was evaluated by weighted summation. The score was calculated by first multiplying each value by its appropriate weight follow by summing of the weighted scores for all indicators.

8.4.2 Model calculation

The assessment indicators are measures on different measurement methods and units. The qualitative environmental indicators and social indicators are measured in value scores, while the quantitative environmental indicators and economic indicators are measured in their own units. Thus, they must be standardized to a common dimensionless unit before weighted summation can be applied.

This research used interval standardization (see Formula 7.10 in Chapter 7). Before standardization the social and qualitative environmental indicators (the higher the better) obtain a positive sign, while the cost and quantitative environmental indicators (the lower the better) obtain a negative sign. As a consequence, the high score is attached to the low environmental burden, low cost but high social benefits. The Table 8.7 shows the results after standardization. The BSS was calculated by using the weighted summation method.

Table 8.10 Building sustainable score in the inception and design stage of the three case studies

Pillars	Indicators	Case Study No 1			Case Study No 2			Case Study No 3			Weighting
		Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	
Economic	Land cost* (¥)	85,507,200.00	5250.03	1	36,655,700.00	16946.69	0	149,488,200.00	7200.00	0.83	0.64
	Professional fees (¥)	2,093,200.00	191.53	1	1,094,200.00	200.00	0.68	6,178,381.06	217.94	0	0.29
	Other costs & charges (¥)	457,500.00	41.86	1	340,966.00	62.32	0	1,552,391.24	54.76	0.37	0.07
				1.00			0.20			0.56	
Environmental	Sustainable Site	4.2		0.71	3.2		0	4.6		1	0.20
	Sustainable material	3.2		0	3.9		0.44	4.8		1	0.32
	Sustainable design	2.8		0	4.7		0.95	4.8		1	0.41
	Heritage conservation	2.2		0	3.2		0.63	3.8		1	0.07
				0.15			0.57			1.00	
Social	Impact on community	3.8		0	4.5		0.88	4.6		1	0.34
	Urban integration	3.1		0	4.2		0.92	4.3		1	0.42
	Proximity to facility/Accessibility	4.0		0	4.2		0.33	4.6		1	0.13
	Cultural issue	3.4		0.25	3.3		0	4.1		1	0.11
				0.03			0.73			1.00	
BSS_I				1.18			1.50			2.56	

Building sustainable score in each pillar (magenta)
Building sustainable score in each stage (yellow)

The land cost of Case 2 is much higher than Case 1 is due to their location, Case 1 is in suburban industrial areas while Case 2 is in CBD. The standardization is based on the Equation 7.10, the 1 being the best outcome and 0 being the worst outcome. Take the indicator 'sustainable site' for example; the value score for the three case studies are 4.2, 3.2, and 4.6. The standardization for Case 1 is as:

$$\hat{x} = \frac{4.2-3.2}{4.6-3.2} = 0.71$$

Therefore, after the calculation, BSS_I for Case 1 is 1.18, Case 2 is 1.50 and Case 3 is 2.56. The total score for each stage is 3. This figure indicates Case 3 performs better in this stage than the other two.

Table 8.11 Building sustainable score in construction stage of the three case studies

Pillars	Indicators	Case Study No 1			Case Study No 2			Case Study No 3			Weighting
		Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	
Economic	Construction cost (¥)	21,652,770.57	1,981.22	1	11,321,911.24	2,069.44	0.33	59,912,776.6	2,113.40	0	0.66
	Professional fees (¥)	1,237,000.00	113.19	1	711,230.00	130.00	0.21	3,810,105.60	134.40	0	0.25
	Other costs & charges (¥)	573,400.00	52.47	1	348,010.31	63.61	0	1,639,422.67	57.83	0.52	0.09
				1.00			0.27			0.05	
Environmental	Energy (MJ)	88,276,358.33	8,077.26	0	40,925,610.24	7,480.46	0.17	130,554,635.05	4,605.26	1	0.38
	Water (kg)	871,883.99	79.78	1	517,359.33	94.56	0	2,271,208.64	80.12	0.98	0.09
	Materials (kg)	20,892,211.12	1,911.63	0	9,665,272.98	1,766.64	0.16	28,451,301.57	1,003.61	1	0.37
	Waste (kg)	344,580.00	31.53	0.92	362,840.00	66.32	0	806,980.00	28.47	1	0.11
	Emissions (kgCO2)	5,941,991.38	543.69	0	2,969,196.46	542.72	0.01	10,487,254.55	369.93	1	0.06
				0.19			0.12			1.01	
Social	Impact on community	4.6		0.33	4.5		0	4.8		1	0.73
	Health & safety of work environment	3.3		0	4.2		0.69	4.6		1	0.27
				0.24			0.19			1.00	
BSS_C				1.43			0.58			2.05	

BSS_C for Case 1 is 1.43, Case 2 is 0.58 and Case 3 is 2.05. The figure indicates that Case 3 has the best sustainable performance in the construction stage followed by Case 1, while Case 2 has the worst performance among these three. One possible reason why Case 2 has the worst performance is due to its location. Case 2 is in the CBD of Guangzhou city. The construction process would have great impact on the local community for both environmental and social impacts. When the three pillars are considered separately, the results are quite different. In the economic aspect, Case 3 has the lowest score in this stage. One of the possible reasons is that the sustainable material and some green technology cost more money in construction.

Table 8.12 Building sustainable score in operation stage of the three case studies

Pillars	Indicators	Case Study No 1			Case Study No 2			Case Study No 3			Weighting
		Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	
Eco	Operating cost (¥)	450,863,419.56	41,253.86	0.99	352,592,568.39	64,447.55	0	1,161,851,447.00	40,983.86	1	0.77
	Cleaning cost(¥)	6,018,489.95	550.69	1	4,501,666.19	822.82	0	17,428,398.22	614.78	0.76	0.23
				0.99			0			0.95	
Environ	Energy**(MJ)	561,938,227.29	51,417.17	0.44	384,954,848.16	70,260.06	0	782,230,533.7	27,592.88	1	0.43
	Water (kg)	1,270,000.00	116.20	1	830,000.00	151.71	0	3,780,000.00	133.34	0.52	0.22
	Materials (kg)	2,098,470.73	192.01	0.67	2,235,032.49	408.52	0	2,442,604.42	86.16	1	0.27
	Emissions (kgCO2)	71,121,838.25	6,507.63	0.39	46,715,878.49	8,538.82	0	94,304,273.83	3,326.55	1	0.08
				0.62			0			0.89	
Social	Occupants' health and comfort	4.5		0.5	4.2		0	4.8		1	0.58
	Stakeholder relations	4.0		0.4	3.8		0	4.3		1	0.14
	Occupier satisfaction and productivity	3.4		0	3.7		0.6	3.9		1	0.28
				0.35			0.17			1.00	
BSS_O				1.96			0.17			2.84	

In the operation stage, Case 3 has the best performance. The benefits as a green building become apparent in this stage. Both the environmental and social performance is better than the other two projects. The economic performance is a little bit lower than in Case 1. Case 2 has the worst performance among these three projects. The energy consumed in the operation stage of Case 2 is much higher than Case 1; this is due to its higher occupant's density. The higher utilization also cause other difference like higher water consumption for example. The high operating cost, high energy consumption all make it far from a green building.

Table 8.13 Building sustainable score in demolition stage of the three cases

Pillars	Indicators	Case Study No 1			Case Study No 2			Case Study No 3			Weighting
		Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	Quantities / Score	Per GFA	Standardization	
Eco	Demolition cost (¥)	4,330,554.11	396.24	1	2,264,382.25	413.89	0.33	11982555.32	422.68	0	0.80
	Other costs & charges (¥)	866,108.00	79.25	1	495,439.25	90.56	0	2,394,356.54	84.46	0.54	0.20
				1.00			0.26			0.11	
Env	Waste***(kg)	16,857,982.5	1542.5	0	8,439,017.5	1542.5	0	39,224,314.25	1383.62	1	0.84
	Emission (kgCO2)	151,345.80	13.85	0	73,501.65	13.43	0.16	319,216.95	11.26	1	0.16
				0			0.03			1.00	
Soc	Health and safety	3.6		0.14	3.5		0	4.3		1	0.48
	Local impacts	3.1		0	3.7		0.60	4.1		1	0.52
				0.07			0.31			1.00	
BSS_D				1.07			0.60			2.11	

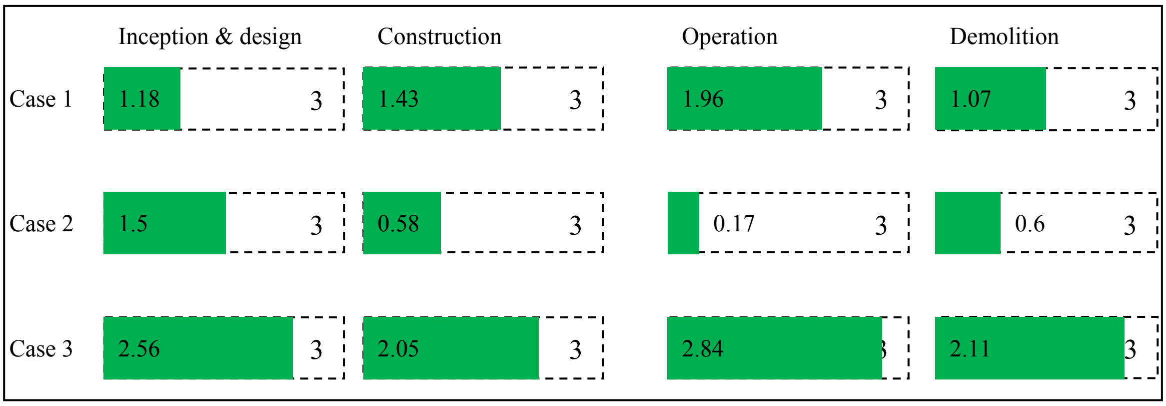
In the demolition stage, Case 3 also has the best performance compared with the other two. Taking the three pillars separately into consideration, Case 3 has the best environmental and social performance, while Case 1 has the best economic performance. One of the possible reasons for the poor behaviour in the economic aspect for Case 3 may be the external material and technology used for building 'green'. But similarity with the other stages, Case 3 has a much better performance in environmental and social aspects.

Table 8.14 Building sustainable score for the three case studies

Stages	Case Study No 1				Case Study No 2				Case Study No 3			
	Eco	**Env**	**Soc**	**Total**	**Eco**	**Env**	**Soc**	**Total**	**Eco**	**Env**	**Soc**	**Total**
Inception & design	1.00	0.15	0.03	1.18	0.20	0.57	0.73	1.50	0.56	1.00	1.00	2.56
Construction	1.00	0.19	0.24	1.43	0.27	0.12	0.19	0.58	0.05	1.01	1.00	2.05
Operation	0.99	0.62	0.35	1.96	0	0	0.17	0.17	0.95	0.89	1.00	2.84
Demolition	1.00	0	0.07	1.07	0.26	0.03	0.31	0.60	0.11	1.00	1.00	2.11

Table 8.10 summarizes the building score for the three case studies as well as the performance in every stage in the building life cycle. It clearly states the advantages and disadvantages of each case in three pillars in each stage. For example, Case 1 has much better performance in the economic aspect than the other two in the inception and design stage. Case 3, as a green building, may spend much more than the others in the inception and design stage, thus it get the lowest economic score in this stage. The total score for each stage is 3, Figure 8.8 shows the BSS score of different stages in the three case studies.

Figure 8.7 The score of different stages in the three case studies

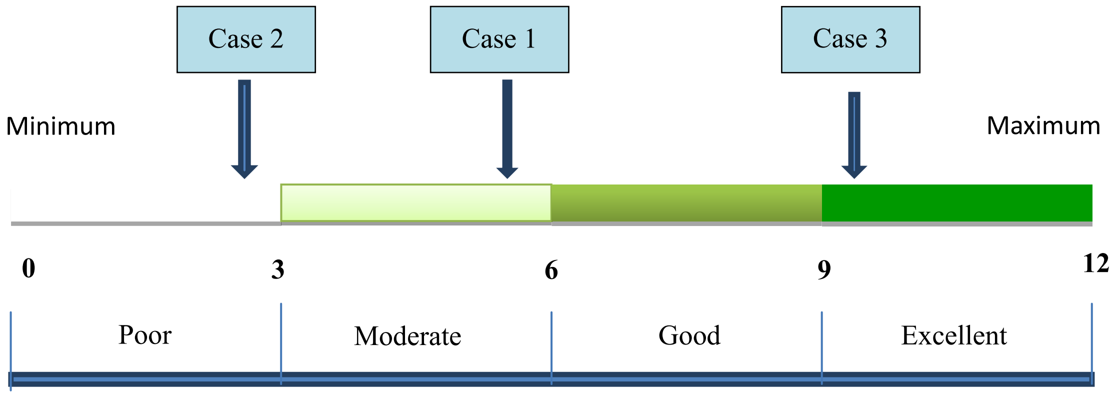


The full score for BSS model is 12. It can be divided for four levels:

- 0-3 Poor
- 3-6 Moderate
- 6-9 Good
- 9-12 Excellent

According the results in Table 8.10, Case 3 has an excellent sustainability performance, Case 2 has a poor sustainability performance, while Case 1 is moderate (see Figure 8.8).

Figure 8.8 BSS for the three case studies



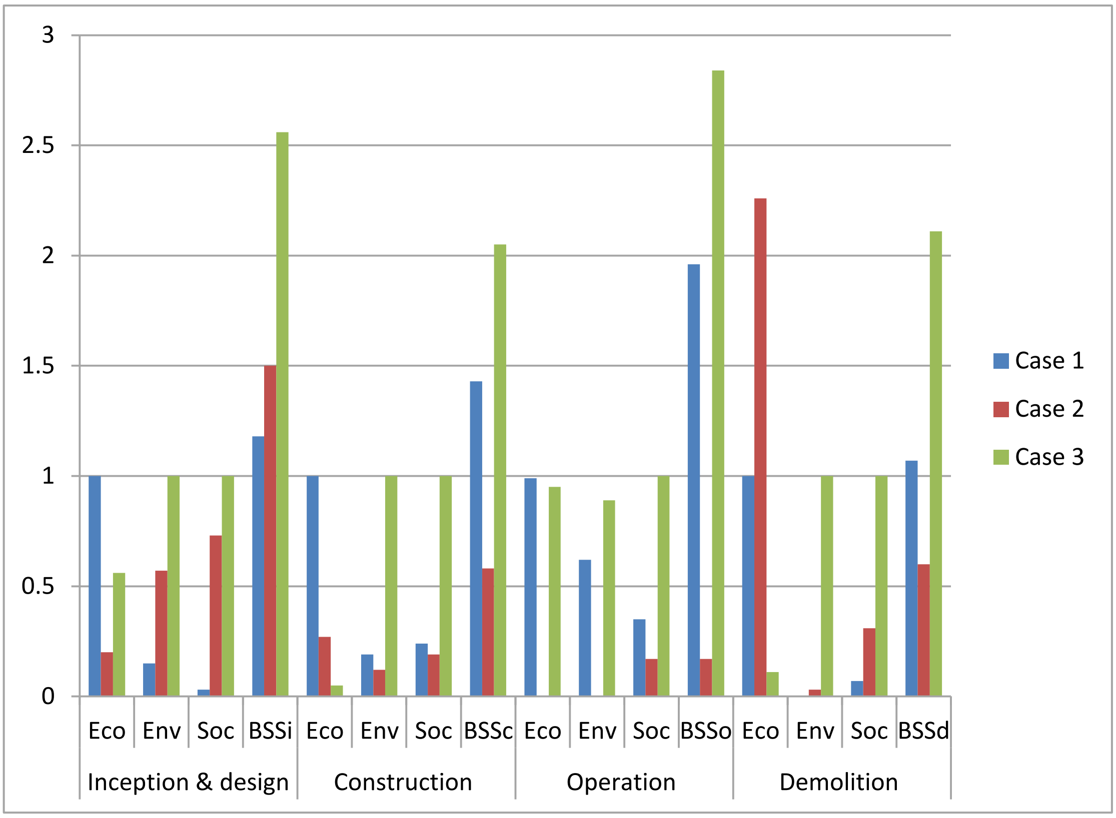
One of the advantages of BSS is that it can show the sustainable performance in three pillars in every building stage; the comparison of the three case studies in each pillars and stages are shows in Figure 8.9. In the inception and design stage, Case 1 has the best performance in the economic aspect, but gains the lowest score in the environmental score. In the construction stage, Case 3 has the lowest score in economic aspects, shows it cost more to build than other cases, but it has better performance than the other two in both environmental and social aspects.

In the operation stage, Case 2 gains the lowest score from all the three aspects in sustainability. Case 3 gains the highest score in environmental and social aspects, while a little less than Case 1 in economic aspect. In demolition stage, Case 2 has the best performance in economic aspects. Case 1 has the worst performance in environmental aspects and social aspects. But in general, Case 1 is still better than Case 2 in total sustainable score in demolition stage, due to the weighting.

In inception and design stage, their sustainable performance Case 1 < Case 2 < Case 3. In construction stage, their sustainable performance shows Case 2 < Case 1 < Case 3.

The operation stage and demolition are similar with the construction stage. While in construction stage, Case 1 and Case 3 are much better than Case 2.

Figure 8.9 The sustainable score in four stages and three pillars in three case studies



As the performance assessment is in stages, necessary redesigning or other actions can be taken before the actual construction. For example, Case 3 has a low score in environmental performance in demotion (0.11, see Table 8.10). In order to improve this situation, more recycle and reusable construction material can be chosen in the early stage. Case 3 also has a low score in economic performance in construction stage. It means the construction costs are high. Some action can take place in the early stage to reduce the construction cost including considering the design, structure and material selection. In addition, different from other assessment tools, it offers a direct expression of the environmentally impact in each stage as the actual amount of these indicators are calculated.

8.5 The results compared with other assessment tools

8.5.1 Assessing the three projects using LEED

In order to have a more objective evaluation of BSS, comparative studies have been taken with other popular tools here. LEED and ESGB have been chosen because LEED is the most popular international tool and ESGB is the most widely used local tool in China according to the industry survey results in Chapter 6.

LEED evaluates a project mainly in 7 categories; sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation and design process, and regional priority credits. In the comparative analysis, the LEED has been used to assess the three projects (see Appendix J). The results for each case are shown in Table 8.15. Case 3, as a green project, has gained 51 in total, which is qualified as silver. Neither Case 1 nor Case 2 can be certified by LEED as they are both lower than 40. Different from the results in BSS, the LEED score for Case 1 and Case 2 are quite close, Case 2 is even better than Case 1. From the quantitative and qualitative analysis in BSS evaluation, it is clear that Case 2, as an medium rise office building located in CBD, consumes much more energy, material and others as well as more emission than Case 1. However, the criteria in LEED are inflexible, once a project cannot meet the requirements, it gets zero point. In that case, it is hard to see the difference between different cases if they are not good enough to be certified.

Table 8.15 LEED evaluation for the three case studies

	Case Study No 1	**Case Study No 2**	**Case Study No 3**
Sustainable sites	15	17	19
Water efficiency	0	0	6
Energy and Atmosphere	0	0	16
Material and Resources	0	0	2
Indoor environmental quality	6	5	8
Innovation and design process	0	0	0
Regional priority credits	0	0	0
Total	21	22	51

From the Appendix J and Table 8.15, it can be found that Case 2 gains higher points than Case 1 in the criteria sustainable site. The requirement for the indicator development density and community connectivity in the criteria sustainable site is the degree of development density or community connectivity. Both of the two issues are required for a well-developed area. In that case, Case 2 located in the CBD area has much more advantage than Case 1 located in suburban industry area. But this result is not in line with China's own situation. The United States has relatively more land and less people, China has relatively less land and much more people. The attitudes toward the land development between the two countries are quite different. China focuses on preventing too much development due to a lack of land, while the Unite states focus on preventing developing too sparsely and becoming inconvenient to use. Similarity with this criterion, other criteria, like bicycle storage and changing room, certified wood, all have strong local characteristic of the US. From this point, it can be seen that, to apply the LEED in China's own projects can cause biases.

It can also be found in Table 8.15 that the score for Case 3 is high in Water, Energy & Atmosphere whilst Case 1 and 2 are zero. The water criterion includes 3 credits, Water Efficient Landscaping, Innovative Wastewater Technologies and Water Use Reduction. Case 3 installed water-saving irrigation system, water consumption for irrigation and it reduced the water for landscaping by 50% (this information is from their application material for ESGB). Besides, Case 3 installed a reclaimed water system and selected a high performance water pump system, and selected water-saving appliances. It met the requirement of these three credits, so Case 3 got 6 points in water creation. In contrast, Case 1 and Case 2 did not install this kind of system and do not offer any information that they have some water saving system; so it is set as zero score at this time.

In the energy and atmosphere criterion, 6 credits include, On-site Renewable Energy, Enhanced Commissioning, Enhanced Refrigerant Management, Measurement and Verification and Green Power. In the credit Optimize Energy Performance, Case 3 got 9 points as it saved 51.3% (this information is from their application material for the ESGB), while the other two do not offer any information about the energy saving. In the credit On-site Renewable Energy, Case 3 got 5 points as solar energy provided 8% of on-site energy. No on-site renewable energy was reported for Case 1 and Case 2. None of the three cases got points in the credits Enhanced Commissioning, Enhanced Refrigerant Management and Measurement and Verification. Case 3 has the solar photovoltaic systems so that it got 2 points in Green Power.

The material criterion includes 7 credits, Building Reuse, Construction Waste Management, Materials Reuse, Recycled Content, Regional Materials, Rapidly Renewable Materials and Certified Wood. Case 3 gained 1 point in Construction Waste Management as it saved 50% of the construction waste, and it gained another 1 point in Recycled Content as 10.3% of construction material are recycled (this information is from their application material for the ESGB). None of the three cases gain points in the credits like Certified Wood, Rapidly Renewable Materials, and Regional Materials.

The detailed assessment process for LEED can be found in Appendix J.

8.5.2 Assessing the three projects using ESGB

The three projects are also assessed with ESGB. The numbers of criteria which can meet the requirement in the ESGB Checklist of each case are assessed. The details of the ESGB amassment can be found in Appendix J. From the assessment results, Table 8.16 states Case 3 gains 2 stars and Case 1 and Case 2 gain no stars. ESGB assesses building performance in six categories; land saving & outdoor environment, energy saving & utilization, water saving &water resource utilization, materials saving & material resources utilization, indoor environmental quality, Operation management.

From the results of BSS, Case 1 has better sustainable performance than Case 2 (Figure 8.9). The ESGB cannot show much difference between these two cases as neither of them can gain grades. Besides, all the indicators are evaluated by checklist; none of the quantitative data can be assessed in ESGB, which will cause imprecise evaluation.

In the results of BSS, all the stages in buildings are evaluated. Though Case 2 has worse performance in total, it gains a better score in inception and design stage (Figure 8.10). It indicates that even if a project has good sustainable performance in inception and design stage it doesn’t mean it will be a sustainable building. To be a real sustainable building needs not only the sustainable design but also much effort in following stages.

Table 8.16 The grades for the three case studies

Criteria	Case Study No 1	Case Study No 2	Case Study No 3
Land saving & outdoor environment (Total 6 items)	4	1	5
Energy saving &utilization (Total 10 items)	4	3	8
Water saving & Water resource utilization (Total 6 items)	3	2	5
Materials saving &material resources utilization (Total 8 items)	3	3	6
Indoor environmental quality (Total 6 items)	2	2	5
Operation management (Total 7 items)	4	4	5
Prior items (Total 14 items)	0	1	6
Grade	-	-	★★

8.6 The benefits of BSS

Based on the discussion of the three case studies, the BSS model offers an opportunity to assess the environmental, economic and social performance of a building in every stage of its life cycle. The BSS model differs from other sustainable assessment tools or models which only focus on the environmental aspects; BSS considers the life cycle cost of the target project as well as its impact to the local society. This characteristic can help stakeholders get a clearer picture when they use it to assess the project. With the three pillars all being assessed, the building project can achieve the 'sustainability' as discussed in Chapter 2.

The BSS model also takes all stages in the building life cycle into consideration. From the sustainable performance in the early stages such as inception and design to the performance in the end-of-life stage can all be analyzed in this model. The case studies also verify the environmental, economic and social criteria, which compose the building performance, have different impacts at various stages of a development. The BSS model reveals the sustainability performance at various stages of three pillars so that resources can focus on the stage that has the most significant impacts in need of improvement.

Different from the previous assessment tools or models, the BSS offers a different approach to building assessment. A more comprehensive assessment process will be provided to the target projects. Most of the indicators can be quantified which fill the gap of the fuzzy and uncertainty of the checklist of many of the previous assessment tools. The combination of quantitative and qualitative indicators makes the results more comprehensive because it also takes the stakeholders' opinion into consideration. Before the BSS model, the three pillars and building life cycle assessment was more like a buzz word than a real assessment process. Few models or tools take these two aspects together into consideration. Based on the results of case studies, it can be found that with the BSS score, a more precise vision can be put on the building assessment process.

Based on the assessment of the three case studies from a life cycle perspective, some changes can be recommended to improve the performance of Case 1 and 2. For example, some green design can be applied to Case 2 to reduce the operating cost and improve its sustainable performance in the operation stage. In Case 1, some recycle and renewable material can be used in this project to improve the environmental performance in the demolition stage. Consequently, using the BSS to assess building performance at an early stage of a development can help to improve the project in a life cycle perspective.

There are still some limitations of data availability and applicability of the case study. The data for case study come from three projects in Guangdong province. Regional variations like climate and economic conditions will make it hard to generalize comprehensive results. However it can be used as a working model that can be modified to suit.

8.7 Summary

In this chapter, three case studies are used to verify the BSS model. Their environmental, economic and social performances are assessed in every stage in the building life cycle. With consideration of economic and social issues, the BSS model makes the 'sustainability' more stable than the former environmental assessment models or tools. In addition, the building performances in every single stage are assessed, so that stakeholders can choose the plan according to their requirements. Necessary redesigning or other action can take place to improve the situation in an early stage. The three case studies verify the practicability and feasibility of this model. This research presents a way to combine the quantitative indicators and qualitative indicators in the assessment process. The process of weighting and generating values scores have made the stakeholders' participants into the assessing process. Compared with the previous SATs, the BSS presents a different perspective to building assessment, and makes the assessment results more comprehensive.

CHAPTER 9

SUMMARY AND CONCLUSIONS

9.1 Introduction

This chapter summarizes the findings of this research. In the literature review, the current SATs were criticized as being inefficient and insufficient to consider all three pillars in sustainability in the building life cycle. A model which reveals the sustainability performance at various stages is needed by the construction industry in China. An industry survey was conducted for data collection. Both questionnaire survey and semi-structure interview were conducted in the building industry. They were intended to screen the assessment indicators for the model establishment and to analyze the real situation of sustainable building and sustainable building assessment in China. The building sustainable model aims to assess building performance in the three pillars, include environmental, economic and social performance in every stage in building life cycle is established based on the assessment indicators generated from the data collection and analysis. Three projects were chosen for case study and model verification. In this chapter, the major findings in the research process are discussed.

9.2 Summary of research

In the Chapter 1, the research questions and problems are identified. The current environmental assessment tools are criticized as being ineffective and inefficient in addressing the sustainability issues with regards to the increasing attention paid to building performance. In addition, sustainable building assessment has strong regional differences, the application of the international tools in China still has some shortcomings. China's own tool – ESGB is criticized as it does not sufficiently consider economic and social issues in the building life cycle. Moreover, the life cycle concept has not received sufficient attention in building assessment.

As the goal of sustainable construction is to balance environmental protection with economic growth and social well-being, the assessment tools should cover not only the environmental impact, but also the economic and social perspective. As suggested in the literature, environmental, economic and social impacts associated with project development vary at different stages throughout its life cycle. Consequently, assessing and incorporating sustainability performance into the building life cycle process from initial stage to end-of-life are essential. Given the previous discussions on the importance of incorporating environmental, economic and social assessments into the building life cycle, this research aims at developing a decision model to facilitate whole of life assessment that aids decision making.

9.3 Review of aims and objectives

9.3.1 Reviewing current environmental building assessment tools

The first objective in this research is finding the gap in current environmental building assessment methods. In Chapter 3, the different building assessment models and tools are discussed, as well as their application in China. Many countries have their own SATs and the development of the tools varies a great deal, ranging from tools for individual building components to a whole building. Most of them only consider the environmental aspects and none of them consider all stages in the building life cycle. The criticisms arise as the assessment methods should be required to assess building performance across a broader range of environmental, economic and social issues due to the definition of the term "building sustainability". Incorporating economic aspects into the evaluation system can make the assessment methods more attractive for the construction market.

In addition, based on the reviews of current assessment methods, more attention should be paid to the impacts in the building process throughout the building's life cycle. As the environmental, economic and social issues have different impacts at various stages of the building life cycle, assessing the building performance in different stages becomes important. Therefore, the performance of sustainable aspects of a development can be maximized through the incorporation of sustainable principles into the building process. Incorporating the assessment in different stages of building can enhance the ability to impact the design and construction practice.

9.3.2 Reviewing building processes and phases of a building

These criticisms indicate the need for a more comprehensive assessment model to assess building performance in the building life cycle, and it leads to the second objective in this research which is identifying building processes and phases of a building. In Chapter 4, different ways of stage division have been reviewed. It varies from 4 to 7 stages with different division points. Among these different ways of stage division, some include all the activities of a construction project, while some are only up to the operation stage (see Figure 4.1). In the construction industry, four or five stage division is more acceptable in research studies based on the discussion in Chapter 4. The divisions chosen by the researchers all map the different phases according to their own research uses in the industry.

One of the aims of this research is to establish a sustainable assessment model in the building life cycle. All stages of the building's life cycle are required for developing a sustainable building. For a five stage division the inception and design stage can be combined into one as there are limited activities at the briefing stage. These two have similar sustainable impacts in the project life span. After the inception and design, the construction, operation stage takes place. Demolition is the end-of-life stage of the project. As a consequence this research adopts a four-stage division for the study which includes inception & design, construction, operation and demolition. It meets the requirement to have the starting point and end point of the life-cycle.

9.3.3 Reviewing the environmental, economic and social impacts related to building processes

Based on the four stages division, the third objective of this research is investigating the environmental, economic and social impacts related to the building process. The three pillars are discussed in Chapter 4 according to the different stages in a building life cycle. Firstly, the major activities related to the different stages are identified. Secondly, the evaluation of sustainability performance is related to the major activities in the building process.

At the inception and design stage, little physical work takes place, so there is a limited direct contribution to sustainability aspects. However, it is valued in building performance as the decisions made here influence all downstream processes. This initial stage provides an opportunity to bring together all the sustainability performance considerations from the outset and incorporate the sustainability considerations, requirements, and strategies of a construction project. This is the stage that environmental sustainability performance can be decided through the selection of site location, materials and technologies. The local social development, public services and other social aspects could be influenced by the project. From an economical point of view, though there is only a small part of the capital input at the inception and design stage, the assessment and analysis of marketing, cost, profit and financing will have crucial impacts in the total economic sustainability performance.

In the construction stage, a series of construction activities happen, including the construction and installation of building materials or products. These activities are always associated with heavy energy consumption and GHG emission. The diesel fuels used by equipment at construction site and in transportation, as well as electricity used for power tools and lighting are all included in this stage. The contribution of environmental impacts in this stage also includes the excessive consumption of building materials, water consumption and improper waste management on site and generation of pollutants during site operations. From a social point of view, the construction stage is a critical component of the labour market as it generates employment opportunities. The occupational health and safety as well as impacts on the neighborhood are all associated with project construction. In economic aspects, the construction costs at this stage include cost for labour, plant and materials, which the stakeholders consider as a first consideration rather than environmental and social benefit in reality.

The operation stage is the phase when the needs of occupants are met. The major activities in this stage include cooling, heating, and ventilating as well as lighting and water supply. The major environmental impacts which emerge in this stage include energy consumption, resource consumption and pollution discharge. These environmental burdens account for the largest part among the building life cycle. In the economic aspect, the significances of operation stage costs such as those for utilities consumption, hiring management staff and up keeping of facilities are well recognized. In the social aspect, occupants' health and comfort, stakeholder relations and occupier satisfaction and productivity are the major concerns in operation stage.

The demolition stage is the end of the building life cycle and it includes the relevant process concerned with the recovery and utilization of the dismantled building and abandoned building materials. It is considered having little positive contribution but some negative impacts on the environment. The wastes produced by demolition as well as the wastes disposal to landfill are the major environmental impacts in this stage. In economic aspect, the major impacts include demolition cost and compensation to stakeholders. Socially, the community safety and security are all important issues in the demolition stage.

Based on the discussion in Chapter 4, building life cycle can be divided into several phases and each phase plays an important role in building sustainability. Previously, many researches have focused on one or several but not all of the building phases. In this research, all the stages in the building life cycle are analyzed. As regional variation is a significant characteristic for developing SATs, industry survey needs to be conducted in the construction industry in China to get the primary data for model development. Based on the discussion in Chapter 4, the different climate conditions, building techniques and materials and local conditions all influence the SATs.

9.3.4 Reviewing the current condition of green building design and construction in China

Though the stage division and three pillars associated with each stage are discussed in the literature review, it is still needed to be verified by an industry survey to make the model adaptable for local conditions. In addition, the assessment indicators needed to be generated in the industry survey to establish the BSS model. In order to generate the assessment indicators for model development, the fourth objective is to conduct an industry survey to collect data for generating indicators. Questionnaire surveys and semi-structure interviews have been used for data collection.

Based on the results of questionnaire survey, the reasons for the hindered development of green building in China are believed by the survey participants as a lack of professional consciousness, followed by technology constraints. Considering the ways to improve the current situation of green building development in China, establishing a complete legal system and developing an assessment system which is suitable for China gain the most support in the survey. The survey results also show that most of the participants are not familiar with any SATs yet. Even after incorporating the literature review, there is still a big gap in SATs in China and a strong need for the local SATs.

In order to develop a sustainable assessment model which is suitable for China's situation, the building stage divisions as well as the assessment indicators are generated in the survey and the literature. In contrast to the literature review, the six stage division which includes inception, design, procurement, construction, implementation and operation gained most support in the questionnaire survey. In order to find the reasons and get more objective information, further questions were asked in the interviews. In the interviews, the experts pointed out the end-of-life stage should be considered in the building life cycle when conducting sustainable assessment, which was lacking in the six stage division. Incorporated with the discussion in literature review, the four stage division from inception to demolition is more appropriate as it includes a starting point and end point of the building life cycle.

In addition, the assessment indicators for the building performance assessment were identified in the survey as well as in the literature. The assessment indicators in three pillars in each stage are identified and presented in Table 6.14 in Chapter 6.

9.3.5 Reviewing the model development and verification

After the indicators generation, the assessment model is established. This is the fifth objective in this research. The model assesses building performance on a triple bottom line approach and it is titled the Building Sustainable Score (BSS). Both the quantitative and qualitative methods are used for the indicators evaluation. The BSS is calculated by weighted summation. The analytic hierarchy process (AHP) method is adopted for identify the importance of the indicators against each other. As the indicators contain both quantitative and qualitative scores with different units, standardization is applied to transform the results into a common dimension and make these scores comparable.

In the BSS model, four sub-models are established for each building stage. In each stage, the sustainable score consist of environmental, economic and social score. The BSS represents the sustainable score of the overall performance. Theoretically, this model can represent performance of the target project in the three pillars in every stage. In order to verify whether this model can be applied efficiently and assess the building performance as expected, case studies were conducted in this research. Three cases were chosen for model verification. This is the last objective in this research. Based on the results of the case studies, comparable scores are generated for the three cases in the three pillars in every stage. The advantages and disadvantages for each case in three pillars in every stage are clearly identified. As the performance assessment is done in stages, necessary redesigning or other actions can be taken before the actual construction.

The results of the BSS were also compared with the LEED and ESGB for further discussion. Based on the results, it is demonstrated that the BSS offers a different approach to building assessment. A more comprehensive assessment process could be provided to the target projects. Most of the indicators can be quantified which fills the gap of the fuzziness and uncertainty of the checklist of many of the previous assessment tools. The combination of quantitative and qualitative indicators makes the results more comprehensive. It also takes the stakeholders' opinion into consideration.

9.4 The outcome of the BSS model

The BSS model can show the sustainable performance in every building stage. From the early stage such as inception and design to the end-of-life stage can all be analyzed in this model. As discussed in the literature review, the different building stages may have different sustainable performances. Assessing the sustainable performance in every stage can offer the stakeholders a deep insight into the impacts of various stages. Therefore, necessary redesigning or other actions can be taken before the actual construction.

In addition, the BSS offers an opportunity to assess the environmental, economic and social performance of a building. The BSS is different from other SATs or models which only focus on the environmental aspects; BSS considers the life cycle cost of the target project as well as their impacts on the local society. This characteristic can help stakeholders get a clearer picture when they use it to assess the project. With the three pillars all being assessed, the building project can achieve the 'sustainability'.

As the case studies show, the environmental, economic and social criteria, which compose the building performance, have different impacts at various stages of a development. The BSS model reveals the sustainability performance at various stages of three pillars so that resources can be focused on the stage that has the most significant impacts.

9.5 Contribution to knowledge

This research provides a different approach for sustainable building assessment. It verifies that the sustainable assessment is necessary and feasible to apply to different stages in the building life cycle. Different from other SATs or models which provide an overall performance of the target project, the BSS model provides the sustainable performance including environmental, economic and social impacts in each stage in the building life cycle.

In addition, the sustainable indicators in the BSS model are evaluated in different ways. Economic and most of the environmental indicators are quantified in different units in this research, whist the social indicators are qualified in a value score. This research offers a way to combine the quantitative and qualitative data in the sustainable building assessment. The combination of quantitative and qualitative indicators makes the results more comprehensive. It also takes the stakeholders' opinion into consideration.

Before the BSS model, the three pillars and building life cycle assessment is more like a 'buzz' word than a real assessment process. Few models or tools take these two aspects together into consideration. The BSS provides a more precise vision on the building assessment process.

9.6 Research limitations

According to the discussion in Chapter 1, the boundary conditions of building performance evaluation traditionally have been the building itself. However, this boundary must change if buildings are to be made more accountable for their impacts. In this research, the boundary condition of building performance evaluation is national. The environmental, economic and social impacts are evaluated with a national scope in mind. However, China is a vast country, and the climate and economic condition vary from region to region. In the meantime, regional variety is a significant feature of the SATs. The industry survey and case studies in this research were conducted in Guangdong Province. The local economic condition and the climate all influence the opinions of the stakeholders in the survey, and thus influence the model development. Therefore, this research can be used as a general base. When the model is applied nation-wide or to other region in China, it needs some adjustment to meet the local requirements.

In addition, this research focuses on the commercial buildings, especially office buildings. The residential building and commercial buildings are quite different in many features. Both the residential building and commercial building play an essential role in sustainable development. Although the residential building does not have such high energy consumption and carbon emission, as much less extensive curtain wall, artificial lighting are applied in the residential buildings, the large numbers of residential buildings make it an important part which cannot be ignored. When the model is applied to residential building, adaptation is needed to match the conditions.

9.7 Recommendations for further research

Further research will include modifying the model for various regions/locations in China. The BSS can be used as a frame, and the assessment indicators can be revised according to the local conditions. The local economic condition and the climate all influence the assessment indicators and weighting. Consequently, in order to get a better promotion of the BSS model, more researches are needed to make a branch of models to meet the local requirements by province or large zone.

In the further research, the different location conditions, including climate, economic, culture will be taken into consideration when generating the assessment indicators. The local legal systems as well as the current green building specifications for provinces and cities in China will be also used as inputs. Some constantly emerging incentive structures in China can also offer some information. Based on the local conditions, a series of BSS models can be established. These BSS branches can form a powerful system for green building assessment in China. They can also offer a comprehensive database for further research.

Further research will also focus on the assessment of residential buildings as well as other building types. The residential buildings and commercial buildings are quite different in many features, but both of them play essential roles in sustainable development. This research can be used as a foundational base, and more effort will be put into the development of residential building assessment.

After the development of the residential building assessment as well as the different local branches of the BSS system, a broader concept can be developed of a green city based on this assessment system. The boundary of the research will exceed the buildings, and municipal planning will be taken into consideration, including transportation and urban facilities. Having one or two buildings to be sustainable is far from the goal of sustainable development. There is a need to incorporate the sustainable concept in the urban planning stage with the comprehensive assessment. These researches will need further effort.

In addition, the research and development of green construction products is another important part of green building promotion. During the research process, the recycling property of the products and facilities has been gaining increasing attention, especially in China. The careful combination of assessment system and efficiency products can bring out the best in each other. The products catalogues of some SAT are based on their own country. Take LEED for example, their products catalogue is based on the local condition of the US. When it is applied in China, the lack of adaptability may bring some troubles, such as the high operating fee. Besides, the follow-up work of the environmentally friendly products is always expensive. For example, the double layer hollow curtain walls have good energy saving properties, but the high cleaning cost limits their development. Therefore, to develop green construction products which are adaptable to the local market and combine the catalogue with the sustainable building assessment can fill the current gap in the construction market.

9.8 Conclusions

This chapter summarizes the research. It reviews the research questions and problems. The research aims and objectives are also reviewed. The aims and objectives set in the beginning of this research have been all achieved. The BSS model can assess the sustainable building performance in three pillars in every stage of the building life cycle. More assistance can be offered in the early stage of a project based on the results of this model. The limitation and boundary of this research are also discussed. Some directions of future research are pointed out. Further research will go beyond the current boundary. Not only will the different types of buildings and locations be taken into consideration, but also other facilities such as transportation in the urban planning. Therefore, based on the assessment system, more deep insight and early assistance can be provided to the decision makers before they approve and initiate a project.

References

Abraham, D. & Dickinson, R. 1998, 'Disposal costs for environmentally regulated facilities: LCC approach', *Journal of Construction Engineering and Management*, vol. 124, no. 2, pp. 146-54.

Aczél, J. & Saaty, T.L. 1983, 'Procedures for synthesizing ratio judgements', *Journal of Mathematical Psychology*, vol. 27, no. 1, pp. 93-102.

Adalberth, K., Almgren, A. & Petersen, E.H. 2001, 'Life cycle assessment of four multi family buildings', *Int J Low Energy Sustain Build*, p. p. 2.

Agyeman, J., Bullard, R.D. & Evans, B. (eds) 2003, *Just sustainabilities development in an unequal world*, London : Earthscan.

Airaksinen, M. & Matilainen, P. 2011, 'A Carbon Footprint of an Office Building', *Energies*, vol. 4, no. 8, pp. 1197-210.

Akadiri, P.O., Olomolaiye, P.O. & Chinyio, E.A. 2013, 'Multi-criteria evaluation model for the selection of sustainable materials for building projects', *Automation in Construction*, vol. 30, pp. 113-25.

Albuquerque, P., Bronnenberg, B.J. & Corbett, C.J. 2007, 'A spatiotemporal analysis of the global diffusion of ISO 9000 and ISO 14000 certification', *Management Science*, vol. 53, no. 3, pp. 451-68.

Ali, H.H. & Al Nsairat, S.F. 2009, 'Developing a green building assessment tool for developing countries – Case of Jordan', *Building and Environment*, vol. 44, no. 5, pp. 1053-64.

Allan, J.A. 1998, 'Virtual water: a strategic resource', *Ground water*, vol. 36, no. 4, p. 545.

Alnaser, N.W., Flanagan, R. & Alnaser, W.E. 2008, 'Model for calculating the sustainable building index (SBI) in the kingdom of Bahrain', *Energy and Buildings*, vol. 40, no. 11, pp. 2037-43.

Alvarenga, R.A.F.d., da Silva Júnior, V.P. & Soares, S.R. 2012, 'Comparison of the ecological footprint and a life cycle impact assessment method for a case study on Brazilian broiler feed production', *Journal of Cleaner Production*, vol. 28, pp. 25-32.

Alwaer, H. & Clements-Croome, D.J. 2010, 'Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings', *Building and Environment*, vol. 45, no. 4, pp. 799-807.

Anastaselos, D., Giama, E. & Papadopoulos, A.M. 2009, 'An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions', *Energy and Buildings*, vol. 41, no. 11, pp. 1165-71.

Andi & Minato, T. 2003, 'Design documents quality in the Japanese construction industry: factors influencing and impacts on construction process', *International Journal of Project Management*, vol. 21, no. 7, pp. 537-46.

Archaeos Projects 1999, *Preliminary Site Report of the Oriental Institute of the University of Vienna and Archaeos: Excavation Project at Tell Arbid, Sector D*, website, Archaeos, Inc., New York, viewed 04/09/2004.

Arif, M., Bendi, D., Toma-Sabbagh, T. & Sutrisna, M. 2012, 'Construction waste management in India: an exploratory study', *Construction Innovation: Information, Process, Management*, vol. 12, no. 2, pp. 133 - 55.

Australian Cost Management Manual, Volume 3, The Australian Institute of Quantity Surveyors.

Aviso, K.B., Tan, R.R., Culaba, A.B. & Cruz Jr, J.B. 2011, 'Fuzzy input–output model for optimizing eco-industrial supply chains under water footprint constraints', *Journal of Cleaner Production*, vol. 19, no. 2–3, pp. 187-96.

Baeten, G. 2000, 'The Tragedy of the Highway: Empowerment, Disempowerment and the Politics of Sustainability Discourses and Practices', *European Planning Studies*, vol. 8, no. 1, pp. 69-86.

Balaras, C.A., Droutsa, K., Dascalaki, E. & Kontoyiannidis, S. 2005, 'Heating energy consumption and resulting environmental impact of European apartment buildings', *Energy and Buildings*, vol. 37, no. 5, pp. 429-42.

Barbier, E.B. 2004, 'The concept of sustainable economic development', *Environmental Conservation*, vol. 14, no. 2, pp. 101-10.

Becker, H.A. 2001, 'Social impact assessment', *European Journal of Operational Research*, vol. 128, no. 2, pp. 311-21.

Becker, H.A. & Vanclay, F. 2003, *The International Handbook of Social Impact Assessment*, Edward Elgar Publishing Limited.

Beinat, E. & Nijkamp, P. (eds) 1998, *Multicriteria Analysis for Land-Use Management* Kluwer Academic Publishers.

Bendewald, M. & Zhai, Z. 2013, 'Using carrying capacity as a baseline for building sustainability assessment', *Habitat International*, vol. 37, no. 0, pp. 22-32.

Bennett, M. & James, P. 1997, 'Environment-related management accounting: current practice and future trends', *Greener Management International*, vol. 97, no. 17, pp. 32-52.

Berke, P.R. & Conroy, M.M. 2000, 'Are We Planning for Sustainable Development?', *Journal of the American Planning Association*, vol. 66, no. 1, pp. 21-33.

Beynon, M.J. & Munday, M. 2006, 'The elucidation of multipliers and their moments in fuzzy closed Leontief input-output systems', *Fuzzy Sets and Systems*, vol. 157, no. 18, pp. 2482-94.

Beynon, M.J. & Munday, M. 2008, 'Considering the effects of imprecision and uncertainty in ecological footprint estimation: An approach in a fuzzy environment', *Ecological Economics*, vol. 67, no. 3, pp. 373-83.

Beynon, M.J., Munday, M. & Roberts, A. 2005, 'Ranking sectors using fuzzy output multipliers', *Economic Systems Research*, vol. 17, no. 3, pp. 237-53.

Bicknell, K.B., Ball, R.J., Cullen, R. & Bigsby, H.R. 1998, 'New methodology for the ecological footprint with an application to the New Zealand economy', *Ecological Economics*, vol. 27, no. 2, pp. 149-60.

Bilec, M.M., Ries, R.J. & Matthews, H.S. 2010, 'Life-cycle assessment modeling of construction processes for buildings', *Infrastructure System*, vol. 16, no. 3, pp. 199-205.

Bilec, M.M., Ries, R.J., Matthews, H.S. & Sharrard, A.L. 2006, 'Example of a Hybrid Life-cycle Assessment of Construction Process', *Journal of Infrastructure System*, vol. 12, no. 4, pp. 207-45.

Blazey, P. & Gillies, P. 2008, 'Sustainable housing in Australia–fiscal incentives and regulatory regimes–current developments–policies for the future', *Macquarie Law*, pp. 2008-29.

Blengini, G.A. & Di Carlo, T. 2010, 'The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings', *Energy and Buildings*, vol. 42, no. 6, pp. 869-80.

Bogenstatter, U. 2000, 'Prediction and optimisation of life-cycle costs in early design', *Building Research & Information*, vol. 28, no. 5/6, pp. 376-86.

Bonilla, S.H., Almeida, C.M.V.B., Giannetti, B.F. & Huisingh, D. 2010, 'The roles of cleaner production in the sustainable development of modern societies: an introduction to this special issue', *Journal of Cleaner Production*, vol. 18, no. 1, pp. 1-5.

Boothroyd, P. (ed.) 1995, *Policy Assessment*, Wiley, Chichester, England.

Bossink, B. & Brouwers, H. 1996, 'Construction Waste: Quantification and Source Evaluation', *Journal of Construction Engineering and Management*, vol. 122, no. 1, pp. 55-60.

Bossink, B.A.G. 2002, 'A dutch public-private strategy for innovation in sustainable construction', *Construction Management and Economics*, vol. 20, pp. 633-42.

Boulay, A.-M., Hoekstra, A.Y. & Vionnet, S. 2013, 'Complementarities of Water-Focused Life Cycle Assessment and Water Footprint Assessment', *Environmental Science & Technology*, vol. 47, no. 21, pp. 1926-7.

Boyd, T. & Kimmet, P. 2005, 'The triple bottom line approach to property performance evaluation', *Pacific Rim Real Estate Society (PRRES) 11th Annual Conference*.

Brannen, J. (ed.) 1992, *Mixing Methods: Qualitative and Quantitative Research* Ashgate Publishing Limited

Brent, A. & Labuschagne, C. 2006, 'Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry (13 pp + 4)', *The International Journal of Life Cycle Assessment*, vol. 11, no. 1, pp. 3-15.

Broun, R. & Menzies, G.F. 2011, 'Life Cycle Energy and Environmental Analysis of Partition Wall Systems in the UK', *Procedia Engineering*, vol. 21, no. 0, pp. 864-73.

BSI (ed.) 2008, *Guide to PAS2050. How to Assess the Carbon Footprint of Goods and Services*, British Standards Institution, London, UK.

BSRIA 2009, *BREEAM or LEED — strengths and weaknesses of the two main environmental assessment methods*.

Buckley, J.J. 1989, 'Fuzzy input-output analysis', *European Journal of Operational Research*, vol. 39, no. 1, pp. 54-60.

Burdge, R. (ed.) 1994, *A Community Guide to Social Impact Assessment*, Wisconsin: Social Ecology Press.

Burdge, R.J. 1987, 'The social impact assessment model and the planning process', *Environmental Impact Assessment Review*, vol. 7, no. 2, pp. 141-50.

Bull, J.W. (ed.) 1993, *Life Cycle Costing for Construction*, Blackie Academic and Professional, Glasgow.

Cai, X., Wang, M. & Fu, Q. 2010, 'Calculation of energy consumption and carbon emission for building in China ', *Journal of Disaster Provention and Mitigation Engineering* vol. 30, no. 9, pp. 428-33.

Cary, J. & Pisarski, A. 2011, 'Social benchmarking to improve river ecosystems', *Water Science & Technology*, vol. 64, no. 5, pp. 1148-53.

Castanheira, G., Bragan, a., 2014, 'The Evolution of the Sustainability Assessment Tool : From Buildings to the Built Environment', *The Scientific World Journal*, vol. 2014, p. 10.

CDM 2010, *Waste Characterization Study*, in D.o. Environment (ed.)City of Chicago, Illinois, United States.

Chan, E.S.W. & Wong, S.C.K. 2006, 'Motivations for ISO 14001 in the hotel industry', *Tourism Management*, vol. 27, no. 3, pp. 481-92.

Chan, E.H.W., Qian, Q.K. & Lam, P.T.I. 2009, 'The market for green building in developed Asian cities—the perspectives of building designers', *Energy Policy*, vol. 37, no. 8, pp. 3061-70.

Chang, K.-F., Chiang, C.-M. & Chou, P.-C. 2007, 'Adapting aspects of GBTool 2005--searching for suitability in Taiwan', *Building and Environment*, vol. 42, no. 1, pp. 310-6.

Chang, K.-F. & Chou, P.-C. 2010, 'Measuring the influence of the greening design of the building environment on the urban real estate market in Taiwan', *Building and Environment*, vol. 45, no. 10, pp. 2057-67.

Chen, H. & Lee, W.L. 2013, 'Energy assessment of office buildings in China using LEED 2.2 and BEAM Plus 1.1', *Energy and Buildings*, vol. 63, no. 0, pp. 129-37.

Chen, Z., Li, H. & Wong, C.T.C. 2000, 'Environmental management of urban construction projects in China', *Journal of Construction Engineering and Management*, vol. 126, no. 4, pp. 320-4.

Chen, Z., Li, H. & Hong, J. 2004, 'An integrative methodology for environmental management in construction', *Automation in Construction*, vol. 13, no. 5 SPEC. ISS., pp. 621-8.

Chen, Z., Li, H. & Wong, C.T.C. 2005, 'EnvironalPlanning: Analytic network process model for environmentally conscious construction planning', *Journal of Construction Engineering and Management*, vol. 131, no. 1, pp. 92-101.

Chen, Z., Clements-Croome, D., Hong, J., Li, H. & Xu, Q. 2006, 'A multicriteria lifespan energy efficiency approach to intelligent building assessment', *Energy and Buildings*, vol. 38, no. 5, pp. 393-409.

Cheng, K., Pan, G., Smith, P., Luo, T., Li, L., Zheng, J., Zhang, X., Han, X. & Yan, M. 2011, 'Carbon footprint of China's crop production—An estimation using agro-statistics data over 1993–2007', *Agriculture, Ecosystems & Environment*, vol. 142, no. 3–4, pp. 231-7.

Cheung, S.O., Tam, C.M., Tam, V., Cheung, K. & Suen, H. 2004, 'A web-based performance assessment system for environmental protection: WePass', *Construction Management and Economics*, vol. 22, no. 9, pp. 927-35.

China Academy of Building Research, 1995, The National Standards for Energy Efficiency of Civil Buildings: for heating in residential buildings, http://igshpa.org/edit/UploadFile/2007127102330678.pdf

China Academy of Building Research, 2005, Design Standard for energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone, http://www.ib-china.com/jzjn/law/xiare.pdf

China Society for Urban Studies (CSUS), 2012, 'Green Building', China Architecture & Building Press (ed).

China Statistical Yearbook, 2011, National Bureau of Statistic of China

Christini, G., Fetsko, M. & Hendrickson, C. 2004, 'Environmental management systems and ISO 14001 certification for construction firms', *Journal of Construction Engineering and Management*, vol. 130, no. 3, pp. 330-6.

CIB & UNEP-IETC 2002, *Agenda 21 for Sustainable Construction in Developing Countries. A discussion document*, C.B.a.C. Technology, Pretoria.

Clements-Croome, D., 2004. Intelligent building design, management and operation. London: Thomas Telford

Clift, M. & Bourke, K. 1999, 'Study on whole life costing', *DETR Report*, no. 366/98.

Cole, R.J. 1998, 'Emerging trend in building environmental assessment methods', *Build Res Inf*, vol. 26, pp. 3-16.

Cole, R.J. 1999, 'Building environmental assessment methods:clarifying intentions', *Building Research & Information*, vol. 27, no. 4/5, pp. 230-46.

Cole, R.J. 2005, 'Building environmental assessment methods: redefining intentions and roles', *Building Research & Information*, vol. 35, no. 5, pp. 455-67.

Cole, R.J. & Howaes, N. 2005, 'Building environemental assessment tools: current and future roles', *World Sustainable Building Conference*, vol. September, Tokyo, pp. 27-9.

Cole, R.J. & Larsson, N.K. 1999, 'GBC '98 and GBTool: background', *Building Research & Information*, vol. 27, no. 4/5, pp. 221-9.

Cole, R.J. & Sterner, E. 2000, 'Reconciling theory and practice of life-cycle costing', *Building Research & Information*, vol. 28, no. 5/6, pp. 368-75.

Collados, C. & Duane, T.P. 1999, 'Natural capital and quality of life: a model for evaluating the sustainability of alternative regional development paths', *Ecological Economics*, vol. 30, no. 3, pp. 441-60.

Cooper, I. 1999, 'Which focus for building assessment methods - environmental performance or sustainability', *Building Research & Information*, vol. 27, no. 4/5, pp. 321-31.

Cochran, K., Townsend, T., Reinhart, D. & Heck, H. 2007, 'Estimation of regional building-related debris generation and composition: Case study for Florida, US', *Waste Management*, vol. 27, no. 7, pp. 921-31.

Crompton, P. & Wu, Y. 2005, 'Energy consumption in China: Past trends and future directions', *Energy Economics*, vol. 27, no. 1, pp. 195-208.

Creswell, J.W. (ed.) 2007, *Qualitative Inquiry and Research Design: Choosing among Five Approaches*.

Creswell, J.W. (ed.) 2009, *Research Design - Qualitative, Quantitative and Mixed Methods Approaches* SAGE Publications, Inc.

CSD-Commission on Sustainable Development 2001, New York.

De Plessis, C. 2007, 'A strategic framework for sustainable construction in developing countries ', *Construction Management and Economics*, vol. 25, no. January, pp. 67-76.

Development, W.C.o.E.a. 1986, 'Our common future', Oxford University, Oxford.
Dietzenbacher, E. 2006, 'Multiplier estimates: To bias or not to bias', *Journal of Regional Science*, vol. 46, no. 4, pp. 773-86.
Ding, G.K.C. 2005, 'Developing a multicriteria approach for the measurement of sustainable performance', *Building Research & Information*, vol. 33, no. 1, pp. 3-16.
Ding, G.K.C. 2008, 'Sustainable construction--The role of environmental assessment tools', *Journal of Environmental Management*, vol. 86, no. 3, pp. 451-64.
Ding, G.K.C. & Shen, L.Y. 2010, 'Assessing sustainability performance of built projects: a building process approach', *International Journal of Sustainable Development*, vol. 13, no. 3, pp. 267-77.
Dodoo, E.N.D., Van Waveren, C.C. & Chan, K.Y. 2010, 'Factors influencing project quality in the design phase of building projects: A case in the Department of Building and Engineering Services of Botswana', *Industrial Engineering and Engineering Management (IEEM), 2010 IEEE International Conference on*, pp. 651-5.
Dong, H., Geng, Y., Sarkis, J., Fujita, T., Okadera, T. & Xue, B. 2013, 'Regional water footprint evaluation in China: A case of Liaoning', *Science of The Total Environment*, vol. 442, no. 0, pp. 215-24.
Ebert, T., Ebig, N. & Hauser, G. (eds) 2011, *Green Building Certification Systems - Assessing Sustainability International System Comparison Economic Impact of Certifications* Aumuller Druck, Regensburg
Edwards, L.E. & John Pojeta, J. 1997, *Fossils, Rocks, and Time*, in U.S.D.o.t. Interior (ed.)U.S. Geological Survey
Edwards, B. (ed.) 1999, *Sustainable architecture: European directives and building design*, Architectural Press.
Edwards, B. & Turrent, D. (eds) 2000, *Sustainable housing: Principles and practice*, E & FN Spon, London and New York.
Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. 2006, *IPCC Guidelines for National Greenhouse Gas Inventories.* , IPCC, National Greenhouse Gas Inventories Programme, Japan
Eisenhardt, K.M. 1989, 'Building theories from case study research', *Academy of Management Review*, vol. 14, no. 4, pp. 532-50.
Elkington, J. (ed.) 1997, *Cannibals with forks: the triple bottom line of 21st Century business*, Oxford : Capstone.
EPA 1993, *Life cycle design guidance manual: environmental requirements and product system*.
Erlandsson, M. & Borg, M. 2003, 'Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs', *Building and Environment*, vol. 38, no. 7, pp. 919-38.
Essa, R. & Fortune, C. 2008, 'Pre-construction evaluation practices of sustainable housing projects in the UK', *Engineering, Construction and Architectural Management*, vol. 15, no. 6, pp. 514-26.

Esteves, A.M. & Vanclay, F. 2009, 'Social Development Needs Analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry', *Environmental Impact Assessment Review*, vol. 29, no. 2, pp. 137-45.

European Union 2001, *European Union. Regulation (EC) No. 761/2001 of the European Parliament and of the Council of 19 March 2001 allowing voluntary participation by organisations in a community eco-management and audit scheme (EMAS).*

Fan, L., Zhu, D. & Wang, Y. 2013, 'Economic Incentive Policy of Green Building in China', *International Journal on Advances in Information Sciences and Service Sciences,*, vol. 5, no. 10, pp. 847-54.

Fellows, R. & Liu, A. (eds) 2008, *Research Methods for Construction,* Blackwell Publishing Ltd.

Ferng, J.J. 2001, 'Using composition of land multiplier to estimate ecological footprints associated with production activity', *Ecological Economics*, vol. 37, no. 2, pp. 159-72.

Ferrao, P. & Nhambiu, J. 2006, 'The Use of EIO-LCA in Assessing National Environmental Policies under the Kyoto Protocol: the Portuguese Economy', *International Journal of Technology, Policy and Management*, vol. 6, no. 4, pp. 361-71.

Ferry, D.J.O. & Flanagan, R. 1991, *Life cycle costing: a radical approach*, Construction Industry Research and Information Association London

Fiedler, T. & Deegan, C. 2007, 'Motivations for environmental collaboration within the building and construction industry', *Managerial Auditing Journal*, vol. 22, no. 4, pp. 410 - 41.

Finnveden, G. & Moberg, A. 2005, 'Environmental systems analysis tools - An overview', *Journal of Cleaner Production*, vol. 13, pp. 1165-93.

Finsterbusch, K. (ed.) 1980, *Understanding Social Impacts: Assessing the Effects of Public Projects*, Sage Publications, Beverly Hills, CA.

Fitzsimons, J., Russell-Smith, J., James, G., Vigilante, T., Lipsett-Moore, G., Morrison, J. & Looker, M. 2012, 'Insights into the biodiversity and social benchmarking components of the Northern Australian fire management and carbon abatement programmes', *Ecological Management & Restoration*, vol. 13, no. 1, pp. 51-7.

Flanegan, R. & Norman, G. (eds) 1989, *Life-Cycle Costing: Theory and Practice*, Surveyors Publications, London.

Foran, B., Lenzen, M., Dey, C. & Bilek, M. 2005, 'Integrating sustainable chain management with triple bottom line accounting', *Ecological Economics*, vol. 52, no. 2, pp. 143-57.

Forsberg, A. & von Malmborg, F. 2004, 'Tools for environmental assessment of the built environment', *Building and Environment*, vol. 39, no. 2, pp. 223-8.

Fortuński, B. 2008, 'Does the environmental management standard ISO 14001 stimulate sustainable development? An example from the energy sector in Poland', *Management of Environmental Quality*, vol. 19, no. 2, pp. 204-12.

Fowler, K.M. & Rauch, E.M. 2006, *Sustainable building rating systems summary (PNNL Formal Report No. 15858)*, WA: Pacific Northwest National Laboratory. , Richland.

French, N. 2013, 'The discounted cash flow model for property valuations: quarterly in advance cash flows', *Journal of Property Investment & Finance*, vol. 31, no. 6, pp. 610 - 4.

Gäbel, K., Forsberg, P. & Tillman, A.-M. 2004, 'The design and building of a lifecycle-based process model for simulating environmental performance, product performance and cost in cement manufacturing', *Journal of Cleaner Production*, vol. 12, no. 1, pp. 77-93.

Gaiger, J. 1999, 'Constraints and Conventions: Kant and Greenberg on Aesthetic Judgement', *British Journal of Aesthetics*, vol. 39, no. 4, pp. 376-91.

Gaiger, J. 2001, 'The Philosophy and Politics of Abstract Expressionism', *British Journal of Aesthetics*, vol. 41, no. 4, pp. 455-7.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B. & Giljum, S. 2012, 'Integrating Ecological, Carbon and Water footprint into a "footprint Family" of indicators: Definition and role in tracking human pressure on the planet', *Ecological Indicators*, vol. 16, pp. 100-12.

Gangolells, M., Casals, M., Gassó, S., Forcada, N., Roca, X. & Fuertes, A. 2009, 'A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings', *Building and Environment*, vol. 44, no. 3, pp. 558-71.

Gangolells, M., Casals, M., Gassó, S., Forcada, N., Roca, X. & Fuertes, A. 2011, 'Assessing concerns of interested parties when predicting the significance of environmental impacts related to the construction process of residential buildings', *Building and Environment*, vol. 46, no. 5, pp. 1023-37.

Gao, W., Ariyama, T., Ojima, T. & Meier, A. 2001, 'Energy impacts of recycling disassembly material in residential buildings', *Energy and Buildings*, vol. 33, no. 6, pp. 553-62.

Gavronski, I., Ferrer, G. & Paiva, E.L. 2008, 'ISO 14001 certification in Brazil: motivations and benefits', *Journal of Cleaner Production*, vol. 16, no. 1, pp. 87-94.

Gibberd, J. 2005, 'Assessing sustainable buildings in developing countries - the sustainble buidling assessment tool', paper presented to the *World Sustainable Conference (SB05)*, Tokyo, 27-29 September 2005.

Glavic, P. & Lukman, R. 2007, 'Review of sustainability terms and their definitions', *Journal of Cleaner Production*, vol. 15, no. 18, pp. 1875-85.

Goedkoop, M. & Spriensma, R. 2001, 'The Eco-indicator 99-A damage oriented method for Life Cycle Impact Assessment: Methodology Report, PRé Consultants, Amersfoort (The Netherlands)'.

Gluch, P. & Baumann, H. 2004, 'The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making', *Building and Environment*, vol. 39, no. 5, pp. 571-80.

Gong, X., Nie, Z., Wang, Z., Cui, S., Gao, F. & Zuo, T. 2012, 'Life Cycle Energy Consumption and Carbon Dioxide Emission of Residential Building Designs in Beijing', *Journal of Industrial Ecology*, vol. 16, no. 4, pp. 576-87.

González, P., Sarkis, J. & Adenso-Díaz, B. 2008, 'Environmental management system certification and its influence on corporate practices: Evidence from the automotive industry', *International Journal of Operations and Production Management*, vol. 28, no. 11, pp. 1021-41.

Gramling, R. & Freudenburg, W.R. 1992, 'Opportunity-threat, development, and adaption', *Rural Sociology*, vol. 57, no. 2, pp. 216-34.

Granly, B.M. & Welo, T. 2014, 'EMS and sustainability: experiences with ISO 14001 and Eco-Lighthouse in Norwegian metal processing SMEs', *Journal of Cleaner Production*, vol. 64, no. 0, pp. 194-204.

Guggemos, A. & Horvath, A. 2003, 'Strategies of extended producer responsibility for buildings', *Infrastructure System*, vol. 9, no. 2, pp. 65-74.

Guggemos, A. & Horvath, A. 2005, 'Comparison of Environmental Effects of Steel- and Concrete-framed Buildings ', *Journal of Infrastructure System*, vol. 11, no. 2, pp. 93-101.

Guggemos, A. & Horvath, A. 2006, 'Decision-support tool for Assessing the Environmental Efffects of Constructing Conmmercial Building', *Journal of Architecture Engineering* vol. 12, no. 4, pp. 187-95.

Gu, Y.-r., Chang, Y. & Zhang, X. 2009, 'Study on Building Life-Cycle Assessment Model in China', *Management and Service Science, 2009. MASS '09. International Conference on*, pp. 1-4.

Guba, E.G. & Lincoln, Y.S. 1994, 'Competing paradigms in qualitative research', *Handbook of Qualitative Research*, pp. 105-17.

Haapio, A. & Viitaniemi, P. 2008, 'A critical review of building environmental assessment tools', *Environmental Impact Assessment Review*, vol. 28, no. 7, pp. 469-82.

Häkkinen, T. & Belloni, K. 2011, 'Barriers and drivers for sustainable building', *Building Research & Information*, vol. 39, no. 3, pp. 239-55.

Hall, J. & Vredenburg, H. 2003, 'The challenges of innovating for sustainable development', *Sloan Management Review*, vol. 45, no. 1, pp. 61-8.

Han, B. & Yang, D. 2006, 'Calculation and analysis of energy consumption of energy efficient buildings in heating period', *Architectural Design Management*, vol. 5, pp. 56-60.

Haroglu, H. 2013, 'The impact of Breeam on the design of buildings', *Proceedings of the ICE - Engineering Sustainability*, vol. 166, pp. 11-9

Hart, M. (ed.) 2000, Guide to sustainable community indicators, sec. edition, Altantic center for the environment.

Harvey, N. (ed.) 1998, *Environmental impact assessment: procedures, practice and prospects in Australia*, Oxford University Press.

Haughton, G. (ed.) 1999, *Environmental justice and the sustainable city*, Earthscan, London.

Hawken, P. (ed.) 1993, *The ecology of commerce: A declaration of sustainability*, Harper Collins, New York.

Hernandez, P. & Kenny, P. 2011, 'Development of a methodology for life cycle building energy ratings', *Energy Policy*, vol. 39, no. 6, pp. 3779-88.

Hobbs, B.F. & Meier, P. (eds) 2000, *Energy Decisions and The Environment - A Guide to the Use of Multicriteria Methods*, Kluwer Academic Publishers.

Hobbs, G., Adams, K. & Blackwell, M. 2011, 'Understanding and predicting construction waste', *Proceedings of the ICE - Waste and Resource Management'*, vol. 164, pp. 239-45.

Hoekstra, A.Y. 2009, 'Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis', *Ecological Economics*, vol. 68, no. 7, pp. 1963-74.

Hoekstra, A.Y. & Chapagain, A.K. 2008, *Globalization of Water: Sharing the Planet's Freshwater Resources*, Blackwell Publishing, Oxford, UK.

Hoekstra, A.Y. & Hung, P.Q. 2002, 'Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade', *Value of Water Research Report Series*, vol. 11.

Hollands, R. & Palframan, L. 2014, 'EIA and EMS integration: not wasting the opportunity', *Impact Assessment and Project Appraisal*, vol. 32, no. 1, pp. 43-54.

Holliday, C., Schmidheiny, S. & Watts, P. 2002, Walking the talk: The business case for sustainable development. Greenleaf Publishing, San Francisco

Hong, Y., Daniel, W.M.C. & Albert, P.C.C. 2012, 'Exploring the applicability of construction partnering in Mainland China', *Facilities*, vol. 30, no. 13/14, pp. 667-94.

Hu, Y. 2012, 'Energy conservation assessment of fixed-asset investment projects: An attempt to improve energy efficiency in China', *Energy Policy*, vol. 43, no. 0, pp. 327-34.

Huang, B., Yang, H., Mauerhofer, V. & Guo, R. 2012, 'Sustainability assessment of low carbon technologies–case study of the building sector in China', *Journal of Cleaner Production*, vol. 32, pp. 244-50.

Huang, T., Shi, F., Tanikawa, H., Fei, J. & Han, J. 2013, 'Materials demand and environmental impact of buildings construction and demolition in China based on dynamic material flow analysis', *Resources, Conservation and Recycling*, vol. 72, pp. 91-101.

Huang, Y. & Li, D. 2006, 'Analysis of the Instructive Ability of the Evaluation Criteria of the Ecological Residence in China -- From The Technical Assessment Handbook for Ecological Residence of China to Green Building Evaluation Criteria', *Hua Zhong Architecture*, vol. 24, no. 10, pp. 107-9.

Huberman, N. & Pearlmutter, D. 2008, 'A life-cycle energy analysis of building materials in the Negev desert', *Energy and Buildings*, vol. 40, no. 5, pp. 837-48.

Huijbregts, M.A.J., Hellweg, S., Frischknecht, R., Hungerbühler, K. & Hendriks, A.J. 2008, 'Ecological footprint accounting in the life cycle assessment of products', *Ecological Economics*, vol. 64, no. 4, pp. 798-807.

Hung Kit Lai, J. 2010, 'Operation and maintenance budgeting for commercial buildings in Hong Kong', *Construction Management & Economics*, vol. 28, no. 4, pp. 415-27.

Hunkeler, D., Lichtenvort, K. & Rebitzer, G. (eds) 2008, *Environmental Life Cycle Costing* Taylor & Francis Group, New York.

Hwang, B.-G. & Low, L.K. 2012, 'Construction project change management in Singapore: Status, importance and impact', *International Journal of Project Management*, vol. 30, no. 7, pp. 817-26.

Hwang, B.-G. & Ng, W.J. 2013, 'Project management knowledge and skills for green construction: Overcoming challenges', *International Journal of Project Management*, vol. 31, no. 2, pp. 272-84.

Hwang, B.G. & Tan, J.S. 2010, 'Green Building Project Management: Obstacles and Solutions for Sustainable Development', *Sustainable Development*.

Indrani, B. 1990, 'Testing for the rank ordering of the priorities of the alternatives in Saaty's ratio-scale method', *European Journal of Operational Research*, vol. 48, no. 1, pp. 148-52.

ISO, *Environmental management – life cycle assessment - principles and framework*, vol. ISO 14040, International Organisation for Standardization

ISO 14040 2006, Environmental management – Life cycle assessment – Principles and framework, International Organisation for Standardisation (ISO), Geneve

ISO 14044 2006, Environmental management – Life cycle assessment – Requirements and guidelines, International Organisation for Standardisation (ISO), Geneve

ISO 15686-5 :2008 Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing ISO15686-5 ISO15686-5 ISO15686

Jänicke, M. 2008, 'Ecological modernisation: new perspectives', *Journal of Cleaner Production*, vol. 16, no. 5, pp. 557-65.

Jabareen,Y. 2008, 'A New Conceptual Framework for Sustainable Development', *Environment, Development and Sustainability*, vol. 10, no. 2, pp. 179-92.

JaGBC & JSBC 2010, *CASBEE for new construction technical manual*, Japan.

Jeswani, H.K. & Azapagic, A. 2011, 'Water footprint: methodologies and a case study for assessing the impacts of water use', *Journal of Cleaner Production*, vol. 19, no. 12, pp. 1288-99.

Jiang, P. & Tovey, K. N. 2009, 'Opportunities for low carbon sustainability in large commercial buildings in China', *Energy Policy*, vol. 37, no. 11, pp. 4949-58.

Jiang, Y. 2005, 'Current building energy consumption in China and effective energy measures', *HV & AC*, vol. 35, no. 5, pp. 30-40.

Jick, T.D. 1979, 'Mixing Qualitative and Quantitative Methods: Triangulation in Action', *Administrative Science Quarterly*, vol. 24, no. 4, pp. 602-11.

Joshi, S. 1999, 'Product Environmental Life-Cycle Assessment Using Input-Output Techniques ', *Journal of Industrial Ecology*, vol. 3, no. 2-3, pp. 95-120.

Joubert, R.A., Leiman, A., De Klerk, H.M., Karau, S. & J.C., A. 1997, 'Fynbos (fine ash) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis', *Ecological Economics*, vol. 22, no. 2, pp. 123-40.

Jones, P., Comfort, D. & Hillier, D. 2006, 'Corporate social responsibility and the UK construction industry', *Journal of Corporate Real Estate*, vol. 8 no. 3, pp. 134 - 50.

Joseph, H.K.L. 2010, 'Building operation and maintenance: education needs in Hong Kong', *Facilities*, vol. 28, no. 9/10, pp. 475-93.

Junnila, S.I. 2006, 'Empirical Comparison of Process and Economic Input-output Life Cycle Assessment in Service Industries', *Environment Science and Technology* vol. 40, pp. 7070-6.

Junnila, S.I. & Horvath, A. 2003, 'Life cycle environmental effects of an office building ', *Journal of Infrastructure System*, vol. 9, no. 4, pp. 154-66.

Junnila, S.I., Horvath, A. & Guggemos, A. 2006, 'Life-cycle assessment of office buildings in Europe and the Unite States', *Journal of Infrastructure System*, vol. 12, no. 1, pp. 10-7.

Juslen, J. 1995, 'Social impact assessment: a look at Finnish experiences', *Project Appraisal*, vol. 10, no. 3, pp. 163-70.

Kaatz, E., Root, D. & Bowen, A. 2005, 'Broadening project participation through a modified building sustainability assessment ', *Building Research & Information*, vol. 33, no. 5, pp. 471-54.

Kaatz, E., Root, D., Bowen, P.A. & Hill, R.C. 2006, 'Advancing key outcomes of sustainability building assessment', *Building Research & Information*, vol. 34, no. 4, pp. 308-20.

Kai, Y. & Wang, Y.B. (ed.) 2011, ‘The Mode of Green Residential District’, China Architecture & Building Press

Kats, G., Alevantis, L., Berman, A., Mills, E. & Perlman, J. 2003, *The costs and financial benefits of green buildings*, CA.

Keoleian, G.A., Blanchard, S. & Reppe, P. 2001, 'Life-Cycle Energy, Cost, and Strategies for Improving a Single Family House', *Journal of Industrial Ecology*, vol. 4, no. 2, pp. 135-56.

Kellenberger, D. & Althaus, H.-J. 2009, 'Relevance of simplifications in LCA of building components', *Building and Environment*, vol. 44, no. 4, pp. 818-25.

Kilbert, C.J. 1994, 'Establishing principles and a model for sustainable construction', *1st International Conference on Sustainable Construction* Koskel, Tampa, Florida

King, N. 1994, 'The qualitative research interview', *Qualitative Methods in Organizational Research*.

Kirkham, R.J., Boussabaine, A.H. & Awwad, B.H. 2002, 'Probability distributions of facilities management costs for whole life cycle costing in acute care NHS hospital buildings', *Construction Management and Economics*, vol. 20 pp. 251-61.

Klang, A., Vikman, P.-Å. & Brattebø, H. 2003, 'Sustainable management of demolition waste: An integrated model for the evaluation of environmental, economic, and social aspects,' *Resources, Conservation and Recycling*, vol. 38, no. 4, pp. 317-34.

Kneifel, J. 2010, 'Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings', *Energy and Buildings*, vol. 42, no. 3, pp. 333-40.

Kofoworola, O.F. & Gheewala, S.H. 2009, 'Estimation of construction waste generation and management in Thailand', *Waste Management*, vol. 29, no. 2, pp. 731-8.

Kohler, N. 1999, 'The relevance of Green Building Challenge: An observe's perspective', *Building Research & Information*, vol. 27, no. 4/5, pp. 309-20.

Kohler, N. & Moffatt, S. 2003, 'Life-cycle analysis of the built environment', *Industry and Environment*, vol. 26, no. 2-3, pp. 17-21.

Koroneos, C. & Kottas, G. 2007, 'Energy consumption modeling analysis and environmental impact assessment of model house in Thessaloniki-Greece', *building and environment*, vol. 42, no. 1, pp. 122-38.

Kvale, S. (ed.) 1996, *Interviews - An Introduction to Qualitative Research Interviewing* Sage Publication, Inc.

Labuschagne, C. & Brent, A.C. 2006, 'Sustainable project life cycle management: the need to integrate life cycles in the manufacturing sector', *International Journal of Project Management*, vol. 23, pp. 159-68.

Lagodimos, A.G., Chountalas, P.T. & Chatzi, K. 2007, 'The state of ISO 14001 certification in Greece', *Journal of Cleaner Production*, vol. 15, no. 18, pp. 1743-54.

Lahr, M.L. & Stevens, B.H. 2002, 'A study of the role of regionalization in the generation of aggregation error in regional input-output models', *Journal of Regional Science*, vol. 42, no. 3, pp. 477-507.

Lai, J.H.K. & Yik, F.W.H. 2007, 'Monitoring building operation and maintenance contracts', *Facilities*, vol. 25, no. 5/6, pp. 238 - 51.

Lai, J.H.K., Yik, F.W.H. & Jones, P. 2008, 'Expenditure on operation and maintenance service and rental income of commercial buildings', *Facilities*, vol. 26, no. 5/6, pp. 242-65.

Lehtonen, M. 2004, 'The environmental-social interface of sustainable development: Capabilities, social capital, institutions,' *Ecological Economics*, vol. 49, pp. 199-214.

Lennie, J. 2005, 'An Evaluation Capacity-Building Process for Sustainable Community IT Initiatives Empowering and Disempowering Impacts', *Evaluation*, vol. 11, no. 4, pp. 390-414.

Lenzen, M. 2001a, 'Errors in conventional and input-output-based life-cycle inventories', *Journal of Industrial Ecology*, vol. 4, no. 4, pp. 127-48.

Lenzen, M. 2001b, 'A generalized input-output multiplier calculus for Australia', *Economic Systems Research*, vol. 13, no. 1, pp. 65-92.

Lenzen, M. & Murray, S.A. 2001, 'A modified ecological footprint method and its application to Australia', *Ecological Economics*, vol. 37, no. 2, pp. 229-55.

Li, J. 2008, 'Towards a low-carbon future in China's building sector—A review of energy and climate models forecast', *Energy Policy*, vol. 36, no. 5, pp. 1736-47.

Li, J. & Wang, X. 2012, 'Energy and climate policy in China's twelfth five-year plan: A paradigm shift', *Energy Policy*, vol. 41, no. 0, pp. 519-28.

Li, L., Tan, Z., Wang, J., Xu, J., Cai, C. & Hou, Y. 2011, 'Energy conservation and emission reduction policies for the electric power industry in China', *Energy Policy*, vol. 39, no. 6, pp. 3669-79.

Li, N., Wei, X., Ruan, F. & Wang, L. 2011, 'A Research on the Evaluation Framework of Carbon Footprint in Large-scale Public Building', *Measuring Technology and Mechatronics Automation (ICMTMA), 2011 Third International Conference on*, vol. 1, pp. 250-3.

Li, Q., Guo, R., Li, F. & Xia, B. 2012, 'Integrated inventory-based carbon accounting for energy-induced emissions in Chongming eco-island of Shanghai, China', *Energy Policy*, vol. 49, no. 0, pp. 173-81.

Li, X., Zhu, Y. & Zhang, Z. 2010, 'An LCA-based environmental impact assessment model for construction processes', *Building and Environment*, vol. 45, no. 3, pp. 766-75.

Li, Y. & Zhang, X. 2013, 'Web-based construction waste estimation system for building construction projects', *Automation in Construction*, vol. 35, no. 0, pp. 142-56.

Libovich, A. 2005, 'Assessing green building for sustainable cities', paper presented to the *World Sustainable Conference* Tokyo.

Liu, C. & Pun, S.K. 2006, 'A framework for material management in the building demolition industry', *Architectural Science Review*, vol. 49, no. 4, pp. 391-9.

Liu, M., Li, B. & Yao, R. 2010, 'A generic model of Exergy Assessment for the Environmental Impact of Building Lifecycle', *Energy and Buildings*, vol. 42, no. 9, pp. 1482-90.

Lu, N., Lu, L., Li, P., Ma, H. & Zhu, L. 2008, 'Calculation for urban construction waste output in China and forecasting method', *Journal of Changan University*, vol. 10, no. 3, pp. 79-82.

Liu, Y., Prasad, D., Li, J., Fu, Y. & Liu, J. 2006, 'Developing regionally specific environmental building tools for China', *Building Research and Information*, vol. 34, no. 4, pp. 372-86.

Llatas, C. 2011, 'A model for quantifying construction waste in projects according to the European waste list', *Waste Management*, vol. 31, no. 6, pp. 1261-76.

Lu, Q. 2010, 'DGNB of Germany: Generation 2 of Sustainable Building Assessment of The World', *World Architecture*, no. 1, pp. 105-7.

Lutzkendoef, T. & Lorenz D, P. 2006, 'Using an integrated performance approach in building assessment tools', *Building Research & Information*, vol. 34, no. 4, pp. 334-56.

Manioğlu, G. & Yılmaz, Z. 2006, 'Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort', *Energy and Buildings*, vol. 38, no. 3, pp. 266-72.

Marino, C., Nucara, A. & Pietrafesa, M. 2012, 'Proposal of comfort classification indexes suitable for both single environments and whole buildings', *Building and Environment*, vol. 57, no. 0, pp. 58-67.

Marszal, A.J. & Heiselberg, P. 2011, 'Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark', *Energy*, vol. 36, no. 9, pp. 5600-9.

Mateus, R. & Bragança, L. 2011, 'Sustainability assessment and rating of buildings: Developing the methodology SBToolPT–H', *Building and Environment*, vol. 46, no. 10, pp. 1962-71.

Matipa, W.M., Kelliher, D. & Keane, M. 2009, 'A strategic view of ICT supported cost management for green buildings in the quantity surveying practice', *Journal of Financial Management of Property and Construction*, vol. 14, no. 1, pp. 79-89.

Matos, S. & Silvestre, B.S. 2013, 'Managing stakeholder relations when developing sustainable business models: the case of the Brazilian energy sector', *Journal of Cleaner Production*, vol. 45, no. 0, pp. 61-73.

Matthews, D.H. 2003, 'Environmental management systems for internal corporate environmental benchmarking', *Benchmarking*, vol. 10, no. 2, pp. 95-106.

McElroy, M.W., Jorna, R.J. & van Engelen, J. 2008, 'Sustainability quotients and the social footprint', *Corporate Social Responsibility & Environmental Management*, vol. 15, no. 4, pp. 223-34.

McGraw-Hill Construction (ed.), 2008, *Building Information Modeling*.

Melchert, L. 2007, 'The Dutch sustainable building policy: A model for developing countries?', *Building and Environment*, vol. 42, no. 2, pp. 893-901.

Melnyk, S.A., Sroufe, R.P. & Calantone, R. 2003a, 'Assessing the impact of environmental management systems on corporate and environmental performance', *Journal of Operations Management*, vol. 21, no. 3, pp. 329-51.

Melnyk, S.A., Sroufe, R.P. & Calantone, R.J. 2003b, 'A model of site-specific antecedents of ISO 14001 certification', *Production and Operations Management*, vol. 12, no. 3, pp. 369-85.

Miller, R.E. & Blair, P.D. 1985, *Input - Output Analysis: Foundations and Extensions*, Prentice-Hall, New Jersey.

Ministry of Construction, 2001, Technical Guidelines for Green Construction, pp 457.

Ministry of Construction, 2005, Provisions on the Administration of Energy Conservation for Civil Building, http://www.chinacourt.org/flwk/show1/php?file_id=106168

Moffatt, S. & Kohler, N. 2008, 'Conceptualizing the built environment as a social-ecological system', *Building Research & Information*, vol. 36, no. 3, pp. 248-68.

Monahan, J. & Powell, J.C. 2011, 'An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework', *Energy and Buildings*, vol. 43, no. 1, pp. 179-88.

Mui, K.W. & Chan, W.T. 2005, 'Application of the Building Environmental Performance Model (BEPM) in Hong Kong', *Energy and Buildings*, vol. 37, no. 8, pp. 897-909.

Müller, M.O., Stämpfli, A., Dold, U. & Hammer, T. 2011, 'Energy autarky: A conceptual framework for sustainable regional development', *Energy Policy*, vol. 39, no. 10, pp. 5800-10.

Neale, C.W. & Wagstaff, G. 1985, 'Discounted Cash Flow and Life Cycle Costing for Construction Projects', *International Journal of Operations & Production Management*, vol. 5, no. 4, pp. 55 - 70.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. & Olsson, L. 2007, 'Categorising tools for sustainability assessment', *Ecological Economics*, vol. 60, no. 3, pp. 498-508.

Neuman, W.L. (ed.) 2011, *Social research methods : qualitative and quantitative approaches*, Boston : Allyn & Bacon.

Nguyen, B.K. & Altan, H. 2011, 'Comparative review of five sustainable rating systems', *Procedia Engineering*, vol. 21, pp. 376-86.

Ni, Y. 2011, 'Discussion on Residence Area Estimate System Taking Germany as an Example', *Chinese and Overseas Architecture*, no. 11, pp. 57-9.

Ng, S.T., Chen, Y. & Wong, J.M.W. 2013, 'Variability of building environmental assessment tools on evaluating carbon emissions', *Environmental Impact Assessment Review*, vol. 38, no. 0, pp. 131-41.

Ochoa-Franco, L.A. 2004, 'Life cycle assessment of residential buildings', Carnegie Mellon University, Pittsburge

Ofori, G., Briffett, C., Gang, G. & Ranasinghe, M. 2000, 'Impact of ISO 14000 on construction enterprises in Singapore', *Construction Management and Economics*, vol. 18, no. 8, pp. 935-47.

Ofori, G. & Ho, K.K. 2004, 'Translating Singapore architects' environmental awareness into decision making', *Building Research & Information*, vol. 34, no. 1, pp. 27-37.

Qiu, J., Wang, G. & Shang, J. 2007, 'Calibrated building energy simulation and its application in a high-rise commercial building', *Energy and Buildings*.

Oliveira, O.J.d. & Serra Pinheiro, C.R.M. 2009, 'Best practices for the implantation of ISO 14001 norms: a study of change management in two industrial companies in the Midwest region of the state of São Paulo - Brazil', *Journal of Cleaner Production*, vol. 17, no. 9, pp. 883-5.

Olsthoorn, X., Tyteca, D., Wehrmeyer, W. & Wagner, M. 2001, 'Environmental indicator for business: a review of the literature and standardisation methods', *Journal of Cleaner Production*, vol. 9, pp. 453-63.

Olubodun, F., Kangwa, J., Oladapo, A. & Thompson, J. 2010, 'An appraisal of the level of application of life cycle costing within the construction industry in the UK', *Structural Survey*, vol. 28 no. 4, pp. 254-65.

Ometto, A.R. & Roma, W.N.L. 2010, 'Atmospheric impacts of the life cycle emissions of fuel ethanol in Brazil: based on chemical exergy', *Journal of Cleaner Production*, vol. 18, no. 1, pp. 71-6.

Ortiz, O., Bonnet, C., Bruno, J.C. & Castells, F. 2009a, 'Sustainability based on LCM of residential dwellings: A case study in Catalonia, Spain', *building and environment*, vol. 44, no. 3, pp. 584-94.

Ortiz, O., Castells, F. & Sonnemann, G. 2009b, 'Sustainability in the construction industry: A review of recent developments based on LCA', *Construction and Building Materials*, vol. 23, no. 1, pp. 28-39.

Ouyang, J., Ge, J. & Hokao, K. 2009, 'Economic analysis of energy-saving renovation measures for urban existing residential buildings in China based on thermal simulation and site investigation', *Energy Policy*, vol. 37, no. 1, pp. 140-9.

Ouyang, J., Lu, M., Li, B., Wang, C. & Hokao, K. 2011, 'Economic analysis of upgrading aging residential buildings in China based on dynamic energy consumption and energy price in a market economy', *Energy Policy*, vol. 39, no. 9, pp. 4902-10.

Partidario, M.R. 2000, 'Elements of an SEA Framework - Improving the Added-value of SEA', *Environmental Impact Assessment Review*, vol. 20, no. 6, pp. 647-63.

Patrick, T.I.L., Edwin, H.W.C., Chau, C.K. & Poon, C.S. 2011, 'A sustainable framework of "green" specification for construction in Hong Kong', *Journal of Facilities Management*, vol. 9, no. 1, pp. 16-33.

Patton, M.Q. (ed.) 1990, *Qualitative Evaluation and Research Methods*, SAGE Publications, Inc.

Pearce, D., Barbier, E. & Markandya, A. (eds) 1990, *Sustainable development: Economics and environment in the third world*, Earthscan Publications, London.

Pearce, D. & Turner, R.K. (eds) 1990, *Economics of natural resources and the environment*, Johns Hopkins University Press, Baltimore.

Pelzeter, A. 2007, 'Building optimisation with life cycle costs–the influence of calculation methods', *Journal of Facilities Management*, vol. 5, no. 2, pp. 115-28.

Per Anker, J. & Elvar Ingi, J. 2013, 'Building information modelling in Denmark and Iceland', *Engineering, Construction and Architectural Management*, vol. 20, no. 1, pp. 99-110.

Perry, C. 1998, 'Processes of a case study methodology for postgraduate research in marketing', *The European Journal of Marketing*, vol. 32, no. 9/10, pp. 785-802.

Petrovic-Lazarevic, S., Perry, M. & RajanR. 2007, 'Improving occupational health and safety measures in the Australian construction industry', *Zagreb International Review of Economics and Business*, vol. 10, no. 1, pp. 17-34.

Peuportier, B.L.P. 2001, 'Life cycle assessment applied to the comparative evaluation of single family houses in the French context', *Energy and Buildings*, vol. 33, no. 5, pp. 443-50.

Peuportier, B., Thiers, S. & Guiavarch, A. 2013, 'Eco-design of buildings using thermal simulation and life cycle assessment', *Journal of Cleaner Production*, vol. 39, no. 0, pp. 73-8.

Phillips, R. 2008, *Plan of work: multi-disciplinary services*, Royal Institute of British Architects.

Põder, T. 2006, 'Evaluation of environmental aspects significance in ISO 14001', *Environmental Management*, vol. 37, no. 5, pp. 732-43.

Porte, C.d.l., Pochet, P. & Room, B.G. 2001, 'Social Benchmarking, Policy Making and New Governance in the Eu', *Journal of European Social Policy November*, vol. 11, no. 4, pp. 291-307

Potoski, M. & Prakash, A. 2004, 'Regulatory convergence in nongovernmental regimes? Cross-national adoption of ISO 14001 certifications', *Journal of Politics*, vol. 66, no. 3, pp. 885-905.

Prior, J., Raw, G.J. & Charlesworth, J.L. 1993, *Building research establishment environmental assessment method (UK BREEAM) Version 3/39 New Homes, Building Research Establishment (BRE)*, Garston, Watford.

Process Management of National Green Building Innovation Award, 2008, China Architect & Building Press.

Proietti, S., Desideri, U., Sdringola, P. & Zepparelli, F. 2013, 'Carbon footprint of a reflective foil and comparison with other solutions for thermal insulation in building envelope', *Applied Energy*, vol. 112, pp. 843-55.

Punch, K.F. (ed.) 2005, *Introduction to Social Research - Quantitative and Qualitative Approaches*, SAGE Publications.

Pun, S.K., Liu, C. & Langston, C. 2006, 'Case study of demolition costs of residential buildings', *Construction Management & Economics*, vol. 24, no. 9, pp. 967-76.

Qu, Y. 2007, 'CSR research about construction enterprises', *Construction Economy*, vol. 7, pp. 94-6.

Royal Australian Institute of Architects (RAIA), 1973, The RAIA Plan of Work.

Ramesh, T., Prakash, R. & Shukla, K.K. 2010, 'Life cycle energy analysis of buildings: An overview', *Energy and Buildings*, vol. 42, no. 10, pp. 1592-600.

Rao, P. 2004, 'Greening production: A South-East Asian experience', *International Journal of Operations and Production Management*, vol. 24, no. 3-4, pp. 289-320.

Rebitzer, G. & Hunkeler, D. 2003, 'Life cycle costing in LCM: ambitions, opportunities, and limitations. Discussing a framework', *International Journal of Life Cycle Assessment*, vol. 8, no. 15, pp. 253-6.

Reboratti, C.E. (ed.) 1999, *Territory, scale and sustainable development*, Zed Books, London.

Rehma, M. & Adeb, R. 2013, 'Construction costs comparison between ‘green’ and conventional office buildings', *Building Research & Information* vol. 41, no. 2, pp. 198-208.

Reijnders, L. & Van Roekel, A. 1999, 'Comprehensiveness and adequacy of tools for the environmental improvement of buildings', *Journal of Cleaner Production*, vol. 7, no. 3, pp. 221-5.

Retzlaff, R.C. 2009, 'The use of LEED in planning and development regulation ', *Journal of Planning Education and Research*, vol. 29, no. 1, pp. 67-77.

Ritz, G.J. (ed.) 1994, *Total Construction Project Management*, McGraw-Hill

Robèrt, K.H. 2000, 'Tools and concepts for sustainable development, how do they relate to a general framework for sustainable development, and to each other?', *Journal of Cleaner Production*, vol. 8, no. 3, pp. 243-54.

Robèrt, K.H., Schmidt-Bleek, B., Aloisi De Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P. & Wackernagel, M. 2002, 'Strategic sustainable development - Selection, design and synergies of applied tools', *Journal of Cleaner Production*, vol. 10, no. 3, pp. 197-214.

Robinson, J. & Tinker, J. (eds) 1998, *Reconciling ecological, economic, and social imperatives*, IDRC-International Development Research Center, and Lewis Publishers, Ottawa.

Reboratti, C.E. (ed.) 1999, *Territory, scale and sustainable development*, Zed Books, London.

Rodríguez, G., Alegre, F.J. & Martínez, G. 2007, 'The contribution of environmental management systems to the management of construction and demolition waste: The case of the Autonomous Community of Madrid (Spain)', *Resources, Conservation and Recycling*, vol. 50, no. 3, pp. 334-49.

Rondinelli, D. & Vastag, G. 2000, 'Panacea, Common Sense, or Just a Label? The Value of ISO 14001 Environmental Management Systems', *European Management Journal*, vol. 18, no. 5, pp. 499-510.

Rotmans, J., Van Asselt, M. & Vellinga, P. 2000, 'An integrated planning tool for sustainable cities', *Environmental Impact Assessment Review*, vol. 20, no. 3, pp. 265-76.

Rowland-Jones, R., Pryde, M. & Cresser, M. 2005, 'An evaluation of current environmental management systems as indicators of environmental performance', *Management of Environmental Quality*, vol. 16, no. 3, pp. 211-9.

Robinson, J. & Tinker, J. (eds) 1998, *Reconciling ecological, economic, and social imperatives*, IDRC-International Development Research Center, and Lewis Publishers, Ottawa.

Ruiz, M.C. & Fernández, I. 2009, 'Environmental assessment in construction using a Spatial Decision Support System', *Automation in Construction*, vol. 18, no. 8, pp. 1135-43.

Saaty, T.L. 1983, 'Introduction to a modeling of social decision processes', *Mathematics and Computers in Simulation*, vol. 25, no. 2, pp. 105-7.

Saaty, T.L. 1987, 'How to handle dependence with the analytic hierarchy process', *Mathematical Modelling*, vol. 9, no. 3–5, pp. 369-76.

Saaty, T.L. & Vargas, L.G. 2005, 'The possibility of group welfare functions', *International Journal of Information Technology and Decision Making*, vol. 4, no. 2, pp. 167-76.

Sachs, W. (ed.) 1993, *Global ecology and the shadow of development.* , Zed Books, London.

San-José Lombera, J.-T. & Garrucho Aprea, I. 2010, 'A system approach to the environmental analysis of industrial buildings', *Building and Environment*, vol. 45, no. 3, pp. 673-83.

Sandberg, N.H. & Brattebø, H. 2012, 'Analysis of energy and carbon flows in the future Norwegian dwelling stock', *Building Research & Information*, vol. 40, no. 2, pp. 123-39.

Saparauskas, J., Zavadskas, E.K. & Turskis, Z. 2011, 'Selection of facade's alternatives of commercial and public buildings based on multiple criteria ', International Journal of Strategic Property Management, vol. 15, no. 2, pp. 189-203.

Schade, J. 2007, 'Life cycle cost calculation models for buildings', *Proceedings of 4th Nordic Conference on Construction Economics and Organisation: Development Processes in Construction Management,*, Luleå.

Scheuer, C., Keoleian, G.A. & Reppe, P. 2003, 'Life cycle energy and environmental performance of a new university building: modeling challenges and design implications', *Energy and Buildings*, vol. 35, no. 10, pp. 1049-64.

Schwartz, M.T. & Billoski, T.V. 1990, 'Greenhouse hypothesis: effect on dinosaur extinction', in B.T. Jones & N.V. Lovecraft (eds), *Extinction*, Barnes and Ellis, New York, pp. 175-89.

SETAC 2008, *Standardisation efforts to measure greenhouse gases and 'carbon footprinting' for product*, no 87-88, The International journal of Life Cycle Assessment.

Sev, A. 2011, 'A comparative analysis of building environmental assessment tools and suggestions for regional adaptations', *Civil Engineering & Environmental Systems*, vol. 28, no. 3, pp. 231-45.

Sharma, A., Saxena, A., Sethi, M., Shree, V. & Varun 2011, 'Life cycle assessment of buildings: A review', *Renewable and Sustainable Energy Reviews*, vol. 15, no. 1, pp. 871-5.

Shen, L.Y., Lu, W.S., Yao, H. & Wu, D.H. 2005, 'A computer-based scoring method for measuring the environmental performance of construction activities', *Automation in Construction*, vol. 14, no. 3, pp. 297-309.

Shen, L.Y. & Tam, V.W.Y. 2002, 'Implementation of environmental management in the Hong Kong construction industry', *International Journal of Project Management*, vol. 20, no. 7, pp. 535-43.

Shen, L.Y., Tam, V.W.Y., Tam, L. & Ji, Y.b. 2010, 'Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice', *Journal of Cleaner Production*, vol. 18, no. 3, pp. 254-9.

Shen, L.Y. & Wang, J.Y. 2002, 'A model for assessing the feasibility of construction project in contribution to the attainment of sustainable development'.

Shen, L.Y., Wu, Y.Z., Chan, E.H.W. & Hao, J.L. 2005, 'Application of system dynamics for assessment of sustainable performance of construction projects', *Journal of Zhejiang University Science*, vol. 64, no. 4, pp. 339-49.

Simpson, R.W., Petroeschevsky, A. & Lowe, I. 2000, 'An Ecological Footprint analysis for Australia', *Australian Journal of Environmental Management*, vol. 7 pp. pp. 11-8. .

Sinden, G. 2009, 'The contribution fo PAS 2050 to the evolution of international greenhouse gas emission standards', *The International Journal of Life Cycle Assessment*, vol. 14, pp. 195-203.

Singh, S. & Bakshi, B.R. 2009, 'Eco-LCA: A tool for quantifying the role of ecological resources in LCA', paper presented to the *Sustainable Systems and Technology*, Phoenix, AZ, 18-20 May 2009.

Siti Uzairiah Mohd, T., Amaratunga, D. & Nazali Mohd, N. 2013, 'Social enterprise applications in an urban facilities management setting', *Facilities*, vol. 31, no. 5/6, pp. 238-54.

Sodagar, B., Rai, D., Jones, B., Wihan, J. & Fieldson, R. 2011, 'The carbon-reduction potential of straw-bale housing', *Building Research & Information*, vol. 39, no. 1, pp. 51-65.

Solís-Guzmán, J., Marrero, M., Montes-Delgado, M.V. & Ramírez-de-Arellano, A. 2009, 'A Spanish model for quantification and management of construction waste', *Waste Management*, vol. 29, no. 9, pp. 2542-8.

Spörri, C., Borsuk, M., Peters, I. & Reichert, P. 2007, 'The economic impacts of river rehabilitation: A regional Input-Output analysis', *Ecological Economics*, vol. 62, no. 2, pp. 341-51.

Spencer, R. & Mulligan, H. 1995, 'Sustainable development and the construction industry', *Habitat International*, vol. 19, no. No.3, pp. 279-92.

Spitzer, M., Pojasek, R., Robertaccio, F. & Nelson, J. 1993, 'Accounting and capital budgeting for pollution prevention. United States Environmental Protection Agency', paper presented to the *The Engineering Foundation Conference*, San Diego, CA.

Statistics, A.A.B.o. (ed.) 2003, *Australian Year Book*, Canberra.

Standing Committee of the National People's Congress, 1997, Energy Conservation Law of the People's Republic of China, http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/03/energy-conservation-law.pdf

Sterner, E. 2000, 'Life-cycle costing and its use in the Swedish building sector', *Building Research and Information*, vol. 28, no. 5/6, pp. 387-93.

Suh, S., Lenzen, M., Treloar, G.J., Hondo, H., Horvath, A., Huppes, G., Jolliet, O., Klann, U., Krewitt, W., Moriguchi, Y., Munksgaard, J. & Norris, G. 2004, 'System boundary selection in life-cycle inventories using hybrid approaches ', *Environment Science and Technology*, vol. 38, no. 3, pp. 657-64.

Tagaza, E. & Wilson, J.L. 2004, *Green buildings: drivers and barriers e lessons learned from five Melbourne developments*.

Tam, V.W.Y. 2008, 'On the effectiveness in implementing a waste-management-plan method in construction', *Waste Management*, vol. 28, no. 6, pp. 1072-80.

Tam, V.W.Y., Hao, J.L. & Zeng, S.X. 2012, 'What affects implementation of green buildings? An empirical study in Hong Kong', *International Journal of Strategic Property Management*, vol. 16, no. 2, pp. 115-25.

Taylor, C.N., Goodrich, C. & Bryan, C.H. 1995, 'Issues-oriented approach to social assessment and project appraisal', *Project Appraisal*, vol. 10, no. 3, pp. 142-54.

Thayer, R.J. (ed.) 1994, *Gray world, green heart: Technology, nature, and sustainable landscape*, John Wiley & Sons, New York.

The Ordinance for Energy Conservation of Civil Buildings, 2008, http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176550.htm

The Ordinance for Energy Conservation of Public Buildings, 2008, http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176549.htm

Thiry, M., Ayrault, M.B. & Grisoni, J.C. 2002, 'Ground-water silicification and leaching in sands - Example of the Fontainebleau sand (Oligocene) in the Paris basin'.

Thomson, C.S., El-Haram, M.A. & Emmanuel, R. 2011, 'Mapping sustainability assessment with the project life cycle', *Engineering Sustainability*, vol. 164, no. 2, pp. 143-57.

Thomas, R.M. (ed.) 2003, *Blending Qualitative and Quantitative Research Methods in Thesis and Dissertations* Corwin Press, California.

Tian, H., Zhang, H., Sun, D., Tang, M. & Liang, Y. 2012, 'Status and prospect on LEED verification of architecture project in China', *Construction Technology* vol. 41, no. 358, pp. 34-8.

Toloken, S. 2008, 'Plantronics takes LEED in creating China site', *Plastics News*, vol. 20, no. 31, pp. 16-.

Torres-Sibille, A.d.C., Cloquell-Ballester, V.-A., Cloquell-Ballester, V.-A. & Artacho Ramírez, M.Á. 2009, 'Aesthetic impact assessment of solar power plants: An objective and a subjective approach', *Renewable and Sustainable Energy Reviews*, vol. 13, no. 5, pp. 986-99.

Treloar, G.J. 1997, 'Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input-Output-based Hybrid Energy Analysis Method', *Economic Systems Research*, vol. 9, no. 4, pp. 375-91.

Treloar, G. J. 1998, A Comprehensive Embodied Energy Analysis Framework (Ph.D.). Deakin University.

Trust, C. 2008, *Guide to PAS2050-How to Assess the Carbon Footprint of Goods and Services*, F.a.R.A.a.B.S.I. Department for Environment.

Tukker, A. 2000, 'Life cycle assessment as a tool in environmental impact assessment', *Environmental Impact Assessment Review*, vol. 20, no. 4, pp. 435-56.

Turner, K., Lenzen, M., Wiedmann, T. & Barrett, J. 2007, 'Examining the global environmental impact of regional consumption activities - Part 1: A technical note on combining input-output and ecological footprint analysis', *Ecological Economics*, vol. 62, no. 1, pp. 37-44.

Tversky, A. & Kahneman, D. 1974, 'Judgment under uncertainty: heuristics and biases. Biases in judgments reveal some heuristics of thinking under uncertainty', *Science*, vol. 185, no. 4157, pp. 1124-31.

UNEP (ed.) 2003, *Sustainable building and construction*, Industry and Environment

UNCED – United Nations Conference on Environment and Development, 1992, <www.ciesin.org/TG/P1/TREATY/unced.html >.

US Interorganizational Committee, Principles and guidelines for social impact assessment in the USA, 1993.

USIC, Principles and guidelines for social impact assessment in the USA, Impact Assessment and Project Appraisal, vol. 21, no. 3, 2003, pp. 231–250.

Uygunoğlu, T. & Keçebaş, A. 2011, 'LCC analysis for energy-saving in residential buildings with different types of construction masonry blocks', *Energy and Buildings*, vol. 43, no. 9, pp. 2077-85.

Valdez, H.E., Chini, A.R. & Rinker, M.E. 2002, 'ISO 14000 standards and the US construction industry', *Environmental Practice*, vol. 4, no. 4, pp. 210-9.

Van Bureren, E. & De Jong, J. 2007, 'Establishing sustainability: policy successes and faliures', *Building Research & Information*, vol. 35, no. 5, pp. 543-56.

Vanclay, F. (ed.) 2002, *Social Impact Assessment*, vol. 4, Wiley, Chichester.

Vanclay, F. & Bronstein, D.A. (Eds.), 1995, Environmental and Social Impact Assessment, Wiley, Chichester, England.

Vanclay, F. 2004, 'The Triple Bottom Line and Impact Assessment: How Do TBL, EIA, SIA, SEA and EMS Relate to Each Other?', *Journal of Environmental Assessment Policy & Management*, vol. 6, no. 3, pp. 265-88.

Van der Ryn, S. & Cowan, S. (eds) 1995, *Ecological design*, Island Press.

Vandenberg, M., 2002, ‘How Victorian Businesses, Governments and Non-government Agencies are taking the Journey Towards the Triple Bottom Line’, *Scoping Study*, www.ethyka.com/tbl/resources

Van Paumgartten, P. 2003, 'The business case for high-performance green buildings: sustainability and its financial impact', *Journal of Facilities Management*, vol. 2, no. 1, pp. 26-34.

Varun, Sharma, A., Shree, V. & Nautiyal, H. 2012, 'Life cycle environmental assessment of an educational building in Northern India: A case study', *Sustainable Cities and Society*, vol. 4, no. 0, pp. 22-8.

Vatalisa, K.I., Manoliadis, O.G. & Charalampides, G. 2011 'Assessment of the economic benefits from sustainable construction in Greece', *International Journal of Sustainable Development & World Ecology* vol. 18, no. 5, pp. 377-83.

Vidal, L.-A., Marle, F. & Bocquet, J.-C. 2011, 'Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects', *Expert Systems with Applications*, vol. 38, no. 5, pp. 5388-405.

Villoria Sáez, P., del Río Merino, M. & Porras-Amores, C. 2012, 'Estimation of construction and demolition waste volume generation in new residential buildings in Spain', *Waste Management & Research*, vol. 30, no. 2, pp. 137-46.

Villoria Saez, P., del Río Merino, M., San-Antonio González, A. & Porras-Amores, C. 2013, 'Best practice measures assessment for construction and demolition waste management in building constructions', *Resources, Conservation and Recycling*, vol. 75, no. 0, pp. 52-62.

Wackernagel, M., Onisto, L., Bello, P., Linares, A.C., Falfán, I.S.L., García, J.M., Guerrero, A.I.S. & Guerrero, M.G.S. 1999, 'National natural capital accounting with the ecological footprint concept', *Ecological Economics*, vol. 29, no. 3, pp. 375-90.

Wackernagel, M. & Rees, W.E. 1996, *Our EcologicalFootprint: Reducing Human Impact on the Earth*, New Society Publishers, Philadelphia, PA, USA.

Wallhagen M, Glaumann M & U., W. 2008, ' What is a "green" building according to different assessment tools?', paper presented to the *Sustainable Building Conference [SB08]*, Melbourne, Australia.

Wallhagen, M., Glaumann, M., Eriksson, O. & Westerberg, U. 2013, 'Framework for Detailed Comparison of Building Environmental Assessment Tools', *Buildings*, vol. 3, no. 1, pp. 39-60.

Wallhagen, M., Glaumann, M. & Malmqvist, T. 2011, 'Basic building life cycle calculations to decrease contribution to climate change – Case study on an office building in Sweden', *Building and Environment*, vol. 46, no. 10, pp. 1863-71.

Wang, J.Y., Touran, A., Christoforou, C. & Fadlalla, H. 2004, 'A systems analysis tool for construction and demolition wastes management', *Waste Management*, vol. 24, no. 10, pp. 989-97.

Wang, W., Zmeureanu, R. & Rivard, H. 2005, 'Applying multi-objective genetic algorithms in green building design optimization', *building and environment*, vol. 40, no. 11, pp. 1512-25.

WCED (ed.) 1987, *Our common future*, Oxford University Press, Oxford.

Weidema, B.P. 2006, 'The Integration of Economic and Social Aspect in Life Cycle Impact Assessment', *International Journal of Life Cycle Assessment*, no. 1, pp. 89-96.

Weidema, B.P., Thrane, M., Christensen, P., Schmidt, J. & Løkke, S. 2008, 'Carbon Footprint', *Journal of Industrial Ecology*, vol. 12, no. 1, pp. 3-6.

White, A.L. & Becker, M. 1992, 'Total Cost Assessment: Catalyzing Corporate Self-Interest in Pollution Prevention', *New Solutions*.

Wiedmann, T., Lenzen, M., Turner, K. & Barrett, J. 2007, 'Examining the global environmental impact of regional consumption activities - Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade', *Ecological Economics*, vol. 61, no. 1, pp. 15-26.

Wiedmann, T. & Minx, J. (eds) 2008, *A definition of 'CarbonFootprint'*, Ecological Economics Research Trends, Nova Science Publishers, Hauppauge, NY, USA.

Wiedmann, T., Minx, J., Barrett, J. & Wackernagel, M. 2006, 'Allocating ecological footprints to final consumption categories with input-output analysis', *Ecological Economics*, vol. 56, no. 1, pp. 28-48.

Wong, S.H.L., Tam, W.C.K., Yim, A.H.L. & Ip, N.H.Y. 2006, *Monitoring of Solid Waste in Hong Kong: Waste Statistics for 2005*, in E.P. Department (ed.)Hong Kong, China.

Woodward, D. 1997, 'Life cycle costing -- theory ,information acquistion and application', *International Journal of Project Management*, vol. 15, no. 6, pp. 335-44.

Wood, R. & Garnett, S. 2010, 'Regional sustainability in Northern Australia --A quantitative assessment of social, economic and environmental impacts', *Ecological Economics*, vol. 69, no. 9, pp. 1877-82.

Wu, H., Yuan, Z., Zhang, L. & Bi, J. 2012, 'Life cycle energy consumption and CO2 emission of an office building in China', *The International Journal of Life Cycle Assessment*, vol. 17, no. 2, pp. 105-18.

Wu, Y. & Xu, R. 2013, 'Green building development in China-based on heat pump demonstration projects', *Renewable Energy*, vol. 53, no. 0, pp. 211-9.

Xing, Y., Horner, R.M.W., El-Haram, M.A. & Bebbington, J. 2009, 'A framework model for assessing sustainability impacts of urban development', *Accounting Forum*, vol. 33, no. 3, pp. 209-24.

Yan, D., Zhe, T., Yong, W. & Neng, Z. 2011, 'Achievements and suggestions of heat metering and energy efficiency retrofit for existing residential buildings in northern heating regions of China', *Energy Policy*, vol. 39, no. 9, pp. 4675-82.

Yan, K. & Yongbing, W. (eds) 2011, *The Mode of Green Residential District*, China Archetecture & Building Press.

Yang, Y., Li, B. & Yao, R. 2010, 'A method of identifying and weighting indicators of energy efficiency assessment in Chinese residential buildings', *Energy Policy*, vol. 38, no. 12, pp. 7687-97.

Ye, L., Cheng, Z., Wang, Q., Lin, W. & Ren, F. 2013, 'Overview on Green Building Label in China', *Renewable Energy*, vol. 53, no. 0, pp. 220-9.

Ying, H. & Neng, Z. 2010, 'Optimization of insulation thickness for external wall of residential buildings in cold regions of China based on Life Cycle Cost Analysis', *Industrial Engineering and Engineering Management (IE&EM), 2010 IEEE 17Th International Conference on*, pp. 227-30.

You, F., Hu, D., Zhang, H., Guo, Z., Zhao, Y., Wang, B. & Yuan, Y. 2011, 'Carbon emissions in the life cycle of urban building system in China—A case study of residential buildings', *Ecological Complexity*, vol. 8, no. 2, pp. 201-12.

Young, A. 1997, 'Is there really spare land? A critique of estimate of available cultivatable land in developing countries', *Environment, Development and Sustainability*, vol. 1, no. 1, pp. 3-18.

Young, J.W.S. 1997, 'A framework for the ultimate environmental index - Putting atmospheric change into context with sustainability', *Environmental Monitoring and Assessment*, vol. 46, no. 1-2, pp. 135-49.

Yuan, H. & Shen, L. 2011, 'Trend of the research on construction and demolition waste management', *Waste Management*, vol. 31, no. 4, pp. 670-9.

Zeng, S.X., Tam, C.M., Deng, Z.M. & Tam, V.W.Y. 2003, 'ISO 14000 and the construction industry: Survey in China', *Journal of Management in Engineering*, vol. 19, no. 3, pp. 107-15.

Zeng, S.X., Tian, P.C.M. & Tam, V.W.Y. 2004, 'Implementation of environmental management in the construction industry of China', *Architecture Science Review*, vol. 47, no. 1, pp. 19-26.

Zhang, X., Shen, L. & Zhang, L. 2013, 'Life cycle assessment of the air emissions during building construction process: A case study in Hong Kong', *Renewable and Sustainable Energy Reviews*, vol. 17, no. 0, pp. 160-9.

Zhang, X. & Xiao, Y. 2009, 'Research on the LCC Model of Energy-Saving Residential Building', paper presented to the *International Conference on Information Management, Innovation Management and Industrial Engineering*, Dec. 2009.

Zhang, Z., Wu, X., Yang, X. & Zhu, Y. 2006, 'BEPAS - A life cycle building environmental performance assessment model', *Building and Environment*, vol. 41, no. 5, pp. 669-75.

Zhao, Z.-Y., Zhao, X.-J., Davidson, K. & Zuo, J. 2012, 'A corporate social responsibility indicator system for construction enterprises', *Journal of Cleaner Production*, vol. 29–30, pp. 277-89.

Zhou, N., Levine, M.D. & Price, L. 2010, 'Overview of current energy-efficiency policies in China', *Energy Policy*, vol. 38, no. 11, pp. 6439-52.

Zimmerman, A. & Kilbert, C.J. 2007, 'Informing LEED's next generation with the natural step', *Building Research & Information*, vol. 35, no. 6, pp. 681-9.

Zorpas, A. 2010, 'Environmental management systems as sustainable tools in the way of life for the SMEs and VSMEs', *Bioresource Technology*, vol. 101, no. 6, pp. 1544-57.

Zuo, J., Read, B., Pullen, S. & Shi, Q. 2012, 'Achieving carbon neutrality in commercial building developments – Perceptions of the construction industry', *Habitat International*, vol. 36, no. 2, pp. 278-86.

Appendices

Appendices

Appendix A: Legal system for green building in China

Table A1 - Legal system of the construction industry in China

Name	Type	Year of issue	Issuing Department/ organization	Regional	Contents	References
Energy Conservation Law of China	Laws	1997	Standing Committee of the National People's Congress	Nation wide	• Energy conservation administration • Rational utilization and energy conservation • Progress in energy conservation technologies • Incentive measures • Legal liability	http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/03/energy-conservation-law.pdf
The Ordinance for Energy Conservation of Civil Buildings	Administrative Regulations	2008	State Council	Nation wide	• local energy conservation plan for civilian buildings • Specific funding for energy saving of civilian buildings • Energy conservation projects can enjoy tax exemption • Assessment criteria of building won't be endorse unless meet the energy conservation	http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176550.htm
The Ordinance for Energy Conservation of Public Buildings	Administrative Regulations	2008	State Council	Nation wide	• Examining the implementation of energy saving standards • Assessing the gross and per capita energy consumption • Examining the implementation of the proposals raised in the last auditing • Putting forward the new conservation proposals • Examining the implementation of annual energy conservation plan, and the actual consumption in contrast to the ration	http://www.mohurd.gov.cn/zcfg/xzfg/200808/t20080815_176549.htm

Provisions on the Administration of Energy Conservation for Civil Building	Ministry Rules	2005	Ministry of Construction	Nation wide	• Heat preserving and thermal insulation technologies and materials • Technologies for centralized heat supply and those for district heating supply • Applied technologies and equipment utilizing solar energy, terrestrial heat and other renewable energies, etc.	http://www.chinacourt.org/flwk/show1/php?file_id=106168
Process Management of National Green Building Innovation Award	Ministry Rules	2004	Ministry of Construction	Nation wide	• Land saving and outdoor environment • Energy saving and energy consumption • Water saving and water consumption • Material saving and material & resource consumption • Indoor environmental quality and operation management	China Society for Urban Science, Green Building 2008, p444, China Architect & Building Press

Table A2 - Green building related Standards, Codes and Guidelines in China

Name	Type	Year of issue	Issuing Department/ Organization	Region	Applicable building type	Criteria	Assessment method/base	References
Technical Standards for Performance Evaluation of Residential Buildings	National standard	2005	Ministry of Construction	Nation wide	Residential buildings in urban area	• Building applicability • Building security • Building durability • Building environmental • Building economic	• Checklist & scoring • Weight system	www.supnow.com/articles/guifanbiaozhun/biaozhun
Residential Building Norms	National standard	2005	Ministry of Construction	Nation wide	Construction, operation and maintenance of residential buildings in urban areas	• Basic stipulations • Outdoor environment • Structure • Indoor environment • Supporting facilities • Energy saving	• Checklist	http://www.lnyanfang.com/shownews.asp?id=465
Design Standards for Energy Conservation of Public Buildings	National standard	2005	Ministry of Construction	Nation wide	Office, commercial building, hotel and others	General provision, terminology, design coefficients for indoor energy conservation, architecture & thermal engineering design, heating, ventilation, lighting, etc.		http://www.czhzhl.com/UploadFiles/2007920204624658.doc
The National Standards for Energy Efficiency of Civil Buildings: for heating in residential buildings	Sector Standard	1995	Ministry of Construction	North China	Civil buildings	• Index of building heat loss • Index of heating coal consumption		http://igshpa.org/edit/UploadFile/2007127102330678.pdf

Design Standard for energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone	Sector Standard	2001	Ministry of Construction	Hot summer & Cold winter region	Residential buildings	• Index of heat loss • Index of cool loss • Annual cooling electricity consumption • Annual heating electricity consumption		http://www.ib-china.com/jzjn/law/xiare.pdf
Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone	Sector Standard	2003	Ministry of Construction	Hot summer & warm winter region	Residential buildings	• Index of heat loss • Index of cool loss • Annual cooling electricity consumption • Annual heating electricity consumption	Custom budget method	http://www.jskj.org.cn/show.aspx?id=2967&cid=285
Technical Guidelines for Green Building	Technical Guidelines and Manual	2005	Ministry of Construction & Ministry of Science and Technology	Nation wide	Residential buildings	• Criteria of green buildings • Technical outlines for planning and design • Technical outlines for construction • Technical outlines for intelligent building • Operation management for green buildings • Promoting industrialization of green building technologies		http://www.chinahouse.gov.cn/cyzc8/84173.doc
Technical Guidelines for Green Construction	Technical Guidelines	2001	Ministry of Construction	Nation wide	Construction & operation	• Construction management • Environmental protection	Based on ISO14000 & ISO 18000	Technical Guidelines for

	and Manual					• Material saving & use of resource • Water saving and use of water • Energy saving and use of energy • Land saving and site protection		Green Construction, Green Buildings 2008, p457
Outlines and Technical Principles for Green Building Quarter	Technical Guidelines and Manual	2001	Housing Industrialization Promotion Center & Ministry of Construction	Nation wide	Residential community	• Residential power system • Water environmental systems • Air environmental systems • Sound environmental systems • Light environmental systems • Thermal environmental systems • Afforest systems • Waste disposal and management systems • Green construction material systems	• Checklist • No weighting system	http://jijian.sdkd.net.cn/ReadNews.asp?NewsID=33, Liu Yu 2005 PhD thesis
Construction Outlines for Healthy Residential Building	Technical Guidelines and Manual	2001	State Housing Engineering Center & Ministry of Construction	Nation wide	Residential buildings	• Hunan environmental health • Natural environmental affinity • Residential environmental protection • Healthy environmental guarantee	• Checklist • No weighting system	http://house.sina.com.cn/2003-05-08/21788.html

Table A3 - Evaluation and rating systems in China

Name	Type	Year of issue	Issuing Department/ Organization	Region	Applicable building type	Criteria	Assessment method	References
Evaluation Standards for Green Building (ESGB)	National standard	2006	Ministry of Construction and the State Quality Supervision Bureau	Nation wide	Residential building & public buildings	• Land saving and outdoor environment • Energy saving and energy consumption • Water saving and water consumption • Material saving and material & resource consumption • Indoor environmental quality and operation management	• Checklist & scoring • No weight system	China Society for Urban Science, Green Building 2008, p444, China Architect & Building Press
Eco-housing Technical Assessment Manual	Evaluating and Rating systems	2003	The Chinese Society for Housing Industry	Nation wide	Residential buildings	• Environmental planning • Energy and environment • Indoor environment • Water environment • Material and resource	• Checklist • Quantification • Scoring • Weighting	Nie et al. 2003
Green Olympic Building Assessment System	Evaluating and Rating systems	2003	Tsinghua University	Beijing	Olympic construction	• Planning stage • Design stage • Construction stage • Operation stage	• Checklist • Scoring • Weighting	Jiangyi et al, 2003
Evaluation Standards for Green Buildings	Evaluating and Rating	2006	Ministry of Construction	Nation wide	Residential buildings &	• Land saving and outdoor environment	• Checklist • Scoring	China Society for Urban Science, Green Building

	systems		and the State Quality Supervision Bureau		public buildings (office buildings, commercial buildings and hotels)	• Energy saving and energy consumption • Water saving and water consumption • Material saving and material consumption • Indoor environmental quality • Operation management	• No weighting system	2008, p444, China Architect & Building Press
Process Management of Green Building Evaluation and Labeling (trial) & Implementation rules for Green Building Evaluation and Labeling (trial)	Labeling system	2007	Ministry of Construction	Nation wide	All building types	Label type: • Green building design label • Green building evaluation label		http://www.cin.gov.cn/hybd/08hy/lsjzbs/lsjzhyzl/200808/t20080807_176463.htm
Technical Guidelines for Energy Evaluation & Labeling of Civil Buildings	Labeling system	2008	Ministry of Housing and Urban & Rural Construction	Nation wide	New residential & public buildings, and existing buildings conducting energy saving reforms	• Certificate the residential and public building respectively • Qualify material and products • Two stages evaluation: by simulation and by actual measurement • Single buildings • Five levels grading	• Computing programs • Document check • On-site inspection • Performance test	http://www.cin.gov.cn/zcfg/jswj/jskj/200807/p020080703605488120121.doc

Appendix B: Information letter for personal interview

INFORMATION LETTER

Dear ………..

My name is Jiani Liu and I am a student at the University of Technology, Sydney.

I am conducting a research into environmental assessment tools of buildings and would welcome your assistance. You have been approached for this study because you can offer relevant information and experience about building performance and building processes. The research would involve a personal interview for about 45 minutes to answer questions in relation to the research topic. The purpose of the research is to develop a model to assess social and environmental performance of buildings on a life cycle perspective. The information from the interview will be solely for this research and will be kept confidentially in all publications.

If you are interested in participating in the interview, I would be grateful if you would contact me (tel. , email:jiani.liu-1@student.uts.edu.au) or my supervisor Grace Ding (Tel. +61 2 9514 8659, email: grace.ding@uts.edu.au).

You are under no obligation to participate in this research and can withdraw from the study at any time without giving a reason.

Yours sincerely,
Jiani

Name & Title	Ms Jiani Liu
UTS contact address	PO Box 123, Broadway, NSW, 2007, Australia
UTS telephone number	02 9514 9935
UTS email address	jiani.liu-1@student.uts.edu.au

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix C: Consent form for personal interview

UNIVERSITY OF TECHNOLOGY, SYDNEY

CONSENT FORM

UTS HREC approval reference No.2011-450A

I ____________________ agree to participate in the research project being conducted by Jiani Liu, of the University of Technology, Sydney for her PhD.

I understand that the purpose of the study is to develop a model to assess social and environmental performance of buildings on a life cycle perspective.

I understand that I have been asked to participate in this research because I can offer the relevant information and experience on understanding social and environmental impacts of building at different stages of a building. I understand my participation in this research will involve a personal interview for about 45 minutes to answer questions in relation to the research topic. The information from the interview will be solely for this research purposes and will be kept confidentially in all publications.

I am aware that I can contact Jiani Liu (Tel:[redacted], Email: jiani.liu-1@student.uts.edu.au) or her supervisors Grace Ding (Tel:95148659, Email: Grace.Ding@uts.edu.au) and Bijan Samali (Tel:95142023, Email: Bijan.Samali@uts.edu.au) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

____ ____/____/____

Signature (participant)

____ ____/____/____

Signature (researcher or delegate)

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix D: Questionnaire survey

The purpose of the research is to develop a model to assess social, economic and environmental performance of buildings on a life cycle perspective. This research has been approved by the UTS Human Research Ethics Committee. The clearance number is: UTS HREC REF NO. 2011-450A.

You can withdraw from the study at any time and without giving a reason. If you have any questions or requires, feel free to contact Jenny Liu: jiani.liu@uts.edu.au; or Grace Ding Grace.ding@uts.edu.au

Part 1: Details

1. **What is your gender?**
   ☐ Male ☐ Female

2. **Your age group is:**
   ☐ < 25 years old ☐ 26-35 years old ☐ 36-45 years old
   ☐ 46-55 years old ☐ > 55 years old

3. **Where do you work?**
   ☐ South China ☐ North china ☐ East China
   ☐ Central China ☐ West china

4. **How many years have you been in the building industry?**
   ☐ < 5 years ☐ 6-10 years ☐ 11-15 years
   ☐ 16 - 20 years ☐ More than 20 years

5. **What is your profession?**
   ☐ Developer ☐ Architect ☐ Structure engineer
   ☐ Service engineer ☐ Cost engineer ☐ Constructer
   ☐ Sub-constructer ☐ Academic ☐ Government officer
   ☐ Other _______

6. **During the projects you participated in, how many of them have used the current sustainable assessment tools?**
   ☐ None ☐ a few of the projects ☐ half of the projects
   ☐ Most of the projects ☐ All

7. **Which tools have you used before? (You can choose more than one)**
   ☐ LEED (US) ☐ CASBEE (Japan) ☐ BREEAM (UK)
   ☐ HKBEAM (HK) ☐ GBAS (CN) ☐ Others_______

8. **According to your knowledge, which dimensions should be considered in the building sustainability: (You can choose more than one)**
   ☐ Environmental impacts ☐ Economic impacts ☐ Social impacts
   ☐ Others ______

9. **Compared to the western countries, please identify the current situation of green building in China:**
   ☐ Haven't started yet
   ☐ Just started and develop slowly
   ☐ Just started and develop fast
   ☐ Almost mature, but still fall behind western countries
   ☐ Very mature and takes the lead

10. **If you think the green buildings in China still fall behind the western countries, please choose the possible reasons for it and rank them:**
    a. Professional conscious b. Technology constraint c. Lack of fund
    d. Building materials constraint e. Others ______

11. **How can we improve the green building in China, please rank the following options:**
    a. Establish a complete legal system
    b. Develop an assessment system which is suitable for China
    c. Improve professionals' conscious on building sustainability
    d. Develop eco-friendly materials
    e. Others________

Part 2: General questions

12. **There are many different stage-division of a construction project across its life cycle, please choose the reasonable one according to your knowledge:**
    ☐ Inception, design, construction, operation and demolition
    ☐ Inception, construction, commission, operation, and demolition
    ☐ Planning, development, design, use maintenance and deconstruction
    ☐ Concept and feasibility studies, engineering and design, procurement, construction, start-up and implementation, and operation or utilization
    ☐ Pre-design, design, preparing to build, construction, occupation, refurbishment and demolition
    ☐ Other______________

13. **Do you think all the stages play the equal role in building sustainability?**
    ☐ Totally the same ☐ Mainly the same ☐ Mostly different ☐ Totally different

14. **Place a number against each stage from most to least important in sustainable performance:**
   1 = Least important
   5 = Most important

Inception	
Design	
Construction	
Operation	
Demolition	

15. **Pleases identify the importance of assessing building performance in every single stage:**
   ☐ Extremely important ☐ Very important ☐ Important
   ☐ Not so important ☐ Not important

Part 3: Model development

16. **Place a number against the importance of environmental, economic and social impacts in building performance in each stage:**
   1 = Least important
   5 = Most important

	Inception	Design	Construction	Operation	Demolition
Environmental impact					
Economic impact					
Social impact					

17. **Please choose the top five most important indicators in environmental impacts?**
   a. Energy consumption b. Resource consumption c. Emission
   d. Land contamination e. Waste generation f. Noise
   g. Dust h. Transport issue i. Landfill
   j. other _______

18. **Please rank the importance of the following indicators in economic impacts:**
   a. Cost b. Budget c. Investment
   d. Compensation e. Remaining value f. Local economy
   g. Others _________

19. **Please rank the importance of the following indicators in social impacts:**

a. Quality of the liveability b. Health and social wellbeing c. Aesthetics
d. Community satisfaction e. Cultural identity f. Facilities
g. Protection of ancient architecture h. Others _________

20. Do these indicators play equally in different stages?

☐ Totally the same ☐ Most the same ☐ Half the same ☐ Most the different
☐ Totally different

21. What make livable buildings? Please choose the top five most important impact criteria from the following options:

a. Thermal comfort in winter
b. Thermal comfort in summer
c. Indoor air quality
d. Acoustic comfort
e. Visual comfort
f. Influence of the user
g. Building related outdoor qualities
h. Safety and incident risks

22. Please choose the top five most important criteria for the building esthetics:

a. Art in architecture
b. Harmonious surrounding
c. Landmark design
d. Unique style
e. Cultural identity
f. Accepted by the public
g. Others _____

23. In your opinion, what makes a livable community? Please choose the top five most important impact criteria from the following options:

a. Space efficiency
b. Public accessibility
c. Capability of conversion
d. Vehicle comfort
e. Building-related outdoor qualities
f. Shopping facilities
g. School facilities
h. Others_________

Appendix E: Sample questions of semi-structure interview

Q1 Have you heard about the sustainable building? How do you think about it?

Q2 In your opinion, what's the reason for the shortage of sustainable building in China?

Q3 Do you familiar with the sustainable assessment tools? Which one is the most popular in China now?

Q4 In your opinion, whether the current tools are perfect for China's situation or can the current tools meet the market demand?

Q5 Do you have any suggestions to the green building assessment tools, especially for China?

Q6 How do you think about building life cycle? Do you think it is necessary to assess building performance in the life cycle perspective?

Q7 Due to your knowledge, what is the best stage division in building life cycle? For example, there are several types of stage division: 'Design, construction, and operation', 'Inception, design, construction, operation and demolition', 'Inception, design, procurement, construction, implementation, operation' and 'Pre-design, design, preparing to build, construction, occupation, demolition'.

Q8 From the questionnaire survey which I conducted before, I found that most people chose the 'Inception, design, procurement, construction, implementation, operation'. What do you think about that?

Q9 Shall we talk about the meanings of assessing building performance in each stage in buildings? Do you think it is necessary?

Q10 From my literature review, I found most of the current tools focus on environment impacts. In your opinion, are there any other aspects should be considered in building assessment?

Q11 Do you have any suggestion for assessing the social aspect?

Appendix F: AHP survey sample

Please use a scale of 1-9 to define the relative importance of the element A compared to element B

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values

The lower left hand matrix triangle is reciprocal of upper right hand

A/B	Sustainable site	Sustainable material	Sustainable design	Heritage conservation
Sustainable site	1			
Sustainable material		1		
Sustainable design			1	
Heritage conservation				1

A/B	Land cost	Professional fees	Other costs & charges
Land cost	1		
Professional fees		1	
Other costs & charges			1

A/B	Impact on community	Urban integration	Proximity to facilities	Cultural issue
Impact on community	1			
Urban integration		1		
Proximity to facilities			1	
Cultural issue				1

A/B	Energy	Water	Resources	Waste	Noise	Emissions
Energy	1					
Water		1				
Resources			1			
Waste				1		
Noise					1	
Emissions						1

A/B	Land cost	Professional fees	Other costs & charges
Land cost	1		
Professional fees		1	
Other costs & charges			1
A/B		Impact on community	Health & safety of work environment
Impact on community		1	
Health & safety of work environment			1

A/B	Energy	Water	Resources	Emissions
Energy	1			
Water		1		
Resources			1	
Emissions				1

A/B	Operating cost	Occupancy cost
Operating cost	1	
Occupancy cost		1

A/B	Occupants’ health and comfort	Stakeholder relations	Occupier satisfaction and productivity
Occupants’ health and comfort	1		
Stakeholder relations		1	
Occupier satisfaction and productivity			1

A/B	Waste	Noise	Emission
Waste	1		
Noise		1	
Emission			1

A/B	Demolition cost	Salvage value	Other costs &charges
Demolition cost	1		
Salvage value		1	
Other costs &charges			1

A/B	Health and safety	Local impacts
Health and safety	1	
Local impacts		1

Appendix G: Value score survey sample

Please indicate the value score for the qualitative indicators from -2 to +5 according to the levels below.

- $+4 \leq +5$ Best practice (Excellent performance)
- $+3 \leq +4$ Very good practice reflecting stable conditions in terms of sustainability
- $1.5 \leq +3$ Good Performance
- $0 \leq 1.5$ Current standard (Minimum acceptable performance) or typical practice for the particular building type and region, or also due to the difficulty in obtaining data
- -1 to -2 Unsatisfactory performance (Deficient) which is not likely to meet the accepted regulations, design criteria and industry norms, or the indicator performance gives a negative impact on the environment in social, economic and environmental terms

Stages	Indicators	Criteria	Score
Inception and design	Sustainable site	• Green field or brown field Green field is a new construction project; brown field is usually a contaminated site that has been rehabilitated. • Habitat conservation To determine whether the new project will impact on local flora or fauna and then cause damage to the local biodiversity: - Destroy the inhabitancies of local animals - Destroy the vegetation cover - Destroy the native plant species	
	Heritage conservation	Whether the site selection would impact on ancient architecture: • Whether there is ancient architecture nearby • How old is the ancient architecture • How would the ancient architecture be affected (demolish wholly or partly)	
	Sustainable material	Whether the material chosen for construction and operation is sustainable • Contain reused or recycled materials • Eco-friendly material e.g. low reflection glass	
	Sustainable design	Whether the design of the project meets the requirement of sustainability: • Architecture design Meet the building floor area ratio, green ratio • HVAC design Harmless gas emissions, high efficiency, low noise equipment	
	Impact on community	• Local roads and footpaths Include: the number of footpaths; roadside drains and culverts • Appearance of public area • Include parks and gardens, street cleaning, landscaping design	

		• Encouragement of employment of local residents within the building • Promotion of and linkage to local service providers • Accessible communication channels with building stakeholders	
	Urban integration	It refers to the liveable environment where the project is planned to build, as well as the safety appliance install and aesthetic. • The liveable environment, include land, soil • The safety appliance installed • Aesthetic implication (such as compliance with precinct theme, building scale)	
	Proximity to facility/ Accessibility	Traffic management Include traffic flow, road signage • Close to the amenities Include close to the school, close to the hospital • Parking facilities • Connections to designated green spaces • Wheelchair access • Proximity to child-minding facilities	
	Cultural issue	• Recognition of indigenous people through allocation of cultural space and communication of site or community history • Consideration of gender equity and minority group requirements • Preservation of heritage values • Value of artwork as % of fit out	
Construction	Impact on community	• Views affect by the construction site • Public area occupied by the construction techniques • Neighbourhood influence by the noise and other pollutions • Employment opportunity	
	Health & safety of work environment	Health & safety of site workers • Information for all workers on their rights and responsibilities that affect health and safety at work.	
Operation	Occupants' health and comfort	• The sick building syndrome, building related illness and environmental sensitivity. • Livability – the degree of excellence or satisfactory character of life quality of building users • Adequate public liability and service provider insurance • Awareness and training of emergency evacuation and accident first aid procedures for all floor wardens • A first aid station accessible to all building users	
	Stakeholder relations	• Monitoring of stakeholder concerns, views and provisions • Transparency and disclosure of landlord/tenant contracts and marketing agreements • Supportive use and occupation guidelines for tenants • Appropriate training for security and public relations personnel	

	Occupier satisfaction and productivity	• Quality of communal service area e.g. toilets, kitchen facilities • Complementary usage of building • Occupant productivity in terms of satisfaction and physical wellbeing • Wheelchair access	
Demolition	Health and safety	• The health of staff on site and people nearby (depend on the demolition methods, techniques and equipment employed) • Health and safety risk assessment	
	Local impacts	• The views, appearance of local communities via the demolition process. • Availability and efficiency of public transport - whether occupying public road and facilities	

Appendix H: Weighting calculation for indicators

Weighting calculation for indicators at different stages of a project for the three pillars

Weighting for economic indicators in inception and design stage					
	Land cost	Professional fee	Other costs & charges	W	C.R.
Land cost	1.0000	4.0953	5.9328	0.6934	0.048 <0.1
Professional fee	0.2442	1.0000	2.9302	0.2141	
Other costs & charges	0.1686	0.3413	1.0000	0.0924	

Weighting for social indicators in inception and design stage						
	Impact on community	Urban integration	Proximity to facilities	Cultural issue	W	C.R.
Impact on community	1.0000	2.9302	5.0363	6.7317	0.5560	0.042 <0.1
Urban integration	0.3413	1.0000	3.7764	5.5467	0.2856	
Proximity to facilities	0.1986	0.2648	1.0000	2.2206	0.1008	
Cultural issue	0.1486	0.1803	0.4503	1.0000	0.0576	

Weighting for environmental indicators in construction stage								
	Energy	Water	Resources	Waste	Noise	Emissions	W	C.R.
Energy	1.0000	4.5359	2.2206	2.5468	7.3841	3.0863	0.3825	0.059 <0.1
Water	0.2205	1.0000	0.7579	1.9473	6.6022	2.8619	0.1742	
Resources	0.4503	1.3195	1.0000	1.6438	7.1895	2.0965	0.1916	
Waste	0.3927	0.5135	0.6084	1.0000	7.2823	3.0467	0.1499	
Noise	0.1354	0.1515	0.1391	0.1373	1.0000	0.7177	0.0326	
Emissions	0.3240	0.3494	0.4770	0.3282	1.3933	1.0000	0.0691	

Weighting for economic indicators in construction stage					
	Construction cost	Professional fee	Other costs & charges	W	C.R.
Construction cost	1.0000	3.6801	6.7875	0.6678	0.07 <0.1
Professional fee	0.2717	1.0000	5.7239	0.2647	
Other costs & charges	0.1473	0.1747	1.0000	0.0675	

Weighting for social indicators in construction stage				
	Impact on community	Health & safety of work environment	W	C.R.
Impact on community	1.0000	3.0314	0.7519	0<0.1
Health & safety of work environment	0.3299	1.0000	0.2481	

Weighting for environmental indicators in operation stage						
	Energy	Water	Resources	Emissions	W	C.R.
Energy	1.0000	2.6390	2.0000	3.3798	0.4410	0.065 <0.1
Water	0.3789	1.0000	1.7411	2.4082	0.2444	
Resources	0.5000	0.5743	1.0000	3.7920	0.2230	
Emissions	0.2959	0.4152	0.2637	1.0000	0.0916	

Weighting for economic indicators in operation stage				
	Operating cost	Occupancy cost	W	C.R.
Operating cost	1.0000	3.6768	0.7862	0 <0.1
Occupancy cost	0.2720	1.0000	0.2138	

Weighting for social indicators in operation stage					
	Occupants health and comfort	Stakeholder relations	Occupier satisfaction & productivity	W	C.R.
Occupants' health and comfort	1.000	3.1037	2.8619	0.5980	0.009 <0.1
Stakeholder relations	0.3222	1.0000	1.2457	0.2130	
Occupier satisfaction & productivity	0.3494	0.8027	1.0000	0.1890	

Weighting for environmental indicators in demolition stage					
	Waste	Noise	Emission	W	C.R.
Waste	1.0000	3.1037	3.4822	0.6203	0.0025 <0.1
Noise	0.3222	1.0000	1.3195	0.2110	
Emission	0.2872	0.7579	1.0000	0.1688	

Weighting for economic indicators in demolition stage					
	Demolition cost	Salvage value	Other costs & charges	W	C.R.
Demolition cost	1.0000	3.3227	6.1879	0.6697	0.025 <0.1
Salvage value	0.3010	1.0000	3.1037	0.2390	
Other costs & charges	0.1616	0.3222	1.0000	0.0913	

Weighting for social indicators in demolition stage				
	Health and safety	Local impacts	W	C.R.
Health and safety	1.0000	3.6502	0.7850	0 <0.1
Local impacts	0.2740	1.0000	0.2150	

Appendix I: Calculation details for Case Study No 1

Table I1 - Economic assessment

					Discount rate =			5%									
					Construction	Opeartion											
								Replace & Repair						Special cleaning		Polishing and waxing	
Code	Element	Unit	Quantities	Rate (RMB)	Capital Cost	Life expectancy	Repair	10	20	30	40	50	Total	Price ($/m2)	Total	Price ($/m2)	Total
1.00	**Substructure**																
1.01	Raft foundation (C30 concrete)	m^3	172.85	473.30	81,809.91	50							0.00				
1.02	Other substurcture (C30 concrete)	m^3	1,145.46	521.60	597,474.02	50							0.00				
1.03	Steel for raft foundation	m^3	172.85	501.38	86,663.53	50							0.00				
1.04	Steel for other substracture	m^3	1,145.46	247.92	283,983.43	50							0.00				
2.00	**Columns**																
2.01	Concrete for rectangular columns from top of foundation to 1st floor (C40)	m^3	64.46	564.71	36,400.08	50							0.00				
2.02	Concrete for circular columns from top of foundation to 1st floor (C40)	m^3	69.95	573.59	40,120.33	50							0.00				
2.03	Concrete for rectangular columns from 2nd floor to roof (C30)	m^3	69.30	505.39	35,024.03	50							0.00				
2.04	Concrete for circular columns from 2nd floor to roof (C30)	m^3	75.26	514.26	38,702.18	50							0.00				
2.05	Steel for rectangular columns from top of foundation to 1st floor	m^3	64.46	1,104.36	71,184.84	50							0.00				
2.06	Steel for circular columns from top of foundation to 1st floor	m^3	69.95	930.02	65,051.18	50							0.00				
2.07	Steel for rectangular columns from 2nd floor to	m^3	69.30	1,104.36	76,533.25	50							0.00				
2.08	Steel for circular columns from 2nd floor to roof	m^3	75.26	930.02	69,991.45	50							0.00				
3.00	**Beams**																
3.01	Concrete for rectangular beam	m^3	1,186.28	466.02	552,827.88	50							0.00				
3.02	Concrete for slab with beam	m^3	1,153.87	466.56	538,349.59	50							0.00				
3.03	Steel for rectangular beam	m^3	1,186.28	841.06	997,728.45	50							0.00				
3.04	Steel for slab with beam	m^3	1,153.87	832.35	960,432.69	50							0.00				
3.05	Others	m^3	34.50	507.33	17,502.98	50							0.00				
4.00	**Staircases**																
4.01	Concrete for staircases	m^2	193.42	166.76	32,255.39	50							0.00				
4.02	Steel for staircases	m^2	193.42	79.80	15,435.24	50							0.00				
5.00	**Others**																
5.01	Other materials	t	176.97	6,623.25	1,172,116.64	50							0.00				
6.00	**Roof**																
6.01	Insulated waterproof roof	m^2	2,656.62	316.43	840,634.90	50								3.00	611,088.57		
6.02	Non-insulated waterproof roof	m^2	69.70	230.30	16,050.76	50								3.00	16,031.57		
6.03	Glass canopy	m^2	1,043.28	826.56	862,330.21	15	10 (20%)	105,879.19	65,000.64	199,523.76	24,498.06	172,466.04	567,367.69	3.00	239,979.21		
6.04	Steel frame for canopy	m^2	35.93	49.60	1,782.99	50							-				
6.05	Metal handrail	m	159.39	568.03	90,535.46	25				26,735.37			26,735.37				

7.00	**External Walls**																
7.01	Terracotta louver	m^2	2,463.08	1,469.58	3,619,696.78									3.00	566,569.83	10.00	79,228.97
	200 mm brick wall					50							-				
	20mm cement					50							-				
	7mm aggregate cement mortar					50							-				
	50*150 Prefabricated terracotta louver					20			389,890.23		146,945.53		536,835.76				
7.02	Laminated glass curtain wall	m^2	1,436.18	1,143.03	1,641,595.68	20	10(10%)	100,779.73	618,700.15	37,982.82	233,181.58	14,315.33	1,004,959.61	3.00	330,356.59		
7.03	Low-E glass curtain wall	m^2	573.92	1,417.22	813,372.32	20			306,551.47		115,536.03		115,536.03	3.00	132,015.98		
7.04	Vertical terracotta louver	m^2	800.73	490.55	392,796.63	20			148,040.92		55,795.07		-	3.00	184,186.96	10.00	25,756.65
7.05	Decorative aluminum panel tp wall	m^2	307.04	1,287.82	395,409.68	20			149,025.75		56,166.24		205,191.99	3.00	70,626.31		
8.00	**Windows**																
8.01	Aluminum windows	No	2.00	810.93	1,621.86	20			611.26		230.38			25.00	3,833.74		
8.02	Metal shutters	m^2	729.28	160.93	117,363.03	20			44,232.89		16,670.91		60,903.80	2.00	111,834.92		
8.03	Aluminum sliding windows	m^2	800.73	490.55	392,796.63	20			148,040.92		55,795.07		203,835.98	2.00	122,791.30		
8.04	Low-E glass windows	m^2	746.21	1,293.17	964,978.84	20	10 (10%)	59,241.33	363,690.38	22,327.43	3,171.52	1,947.04	448,430.66	2.00	114,431.44		
9.00	**External Doors**																
9.01	Steel fire-rated door	No	19.00	3,055.80	58,060.20	20			3,055.80		58,060.20		61,116.00				
9.02	Fire resistant rolling shutter door	m^2	237.70	500.00	118,850.00	20			500.00		118,850.00		119,350.00				
10.00	**Internal Walls**																
10.01	Aerated concrete block wall	m^3	1,584.05	376.59	596,537.39	50							-				
10.02	RC basement wall	m^3	298.69	466.42	139,313.12	50							-				
11.00	**Internal Doors**																
11.10	Timber fire-rated door	No	18.00	401.61	7,228.98	20			2,724.53		7,228.98		9,953.51				
11.20	Timber door	m^2	459.28	700.00	321,496.00	20			121,168.46		321,496.00		442,664.46				
12.00	**Wall Finishes**																
12.10	12mm Cement and sand (1:3) render for painting	m^2	7,880.84	18.21	143,510.10	50							0.00				
12.20	12mm Cement and sand (1:3) render and plaster for painting	m^2	8,053.38	25.57	205,924.93	50							0.00				
12.30	Cement & sand backing for cermic tile to wall	m^2	1,600.94	147.10	235,498.27	50							0.00				
12.40	Cement & sand backing for marble to wall	m^2	702.00	287.06	201,516.12	50							0.00				
12.50	2 coats of Gross latex to rendered wall	m^2	7,880.84	14.60	115,060.26	15			55,345.95	26,622.35	12,805.81		94,774.11				
12.60	Sound absorption wall	m^2	375.15	92.77	34,615.09	15			16,650.45	8,009.15	3,852.54		28,512.14				
	- 60 x 60 x 120mm timber @ 600 centres																
	- 40mm insulation batt																
	- 150 x 50 x 1.5mm thick aluminum strip																
12.70	Ceramic tile to wall	m^2	1,600.94	88.34	141,427.04	15			68,028.82	32,723.03	15,740.34		116,492.19	2.00	245,503.79		
12.80	Glazed tile to wall	m^2	1,945.27	400.00	778,108.00	15			374,283.25	180,036.64	86,600.70		640,920.60	2.00	298,306.71		
12.90	Marble to wall	m^2	702.00	360.72	253,225.44	15			121,805.77	180,036.64	28,183.11		330,025.52	4.00	215,303.08	65.00	146,776.14
13.00	**Floor Finishes**																
13.01	Cement mortar to floor	m^2	519.98	91.58	47,619.76	50							0.00				
13.02	Fine aggregate concrete floor	m^2	220.12	237.20	52,212.46	50							0.00				
13.03	Tiles floor base	m^2	304.63	61.60	18,765.21	50							0.00				

13.04	Stone floor base	m^2	4,468.89	15.44	68,999.66	50							0.00				
13.05	Non-slip tile to floor	m^2	308.40	428.00	131,995.20	50							0.00	2.00	47,293.07		
13.06	Tiles floor	m^2	153.72	72.52	11,147.77	20			4,201.48		1,583.49		5,784.97	2.00	23,572.93		
13.07	Stone floor (Entrance, lobby, hallway)	m^2	4,210.49	292.53	1,231,694.64	35					223,294.27		223,294.27	4.00	1291355.38	65.00	880,341.10
13.08	Stone floor (staircase)	m^2	258.40	476.34	123,086.26	30				28,479.38			28,479.38	4.00	79,251.16	65.00	54,027.00
13.09	Non-slip tiles floor	m^2	308.04	109.88	33,847.44	20			12,756.74		4,807.88		17,564.63	2.00	47,237.86		
13.10	Painting to RC column	m^2	56.80	18.00	1,022.40	10		627.66	385.33	236.56	145.23	89.16	1,483.94				
13.11	External timber floor	m^2	195.70	300.00	58,710.00	10		36,042.85	22,127.18	13,584.17	8,339.50	5,119.73	85,213.43	2.00	30,010.55		
13.12	Timber floor backing	m^2	195.70	12.68	2,070.14	50							-				
13.13	Timber staircase	m^2	305.50	550.00	168,025.00	15			80,822.90	38,877.20		18,700.60	138,400.69	2.00	46,848.36	4.00	3,930.76
14.00	**Ceiling Finishes**																
14.01	8mm Cement and sand (1:3) render to ceiling of offices	m^2	5,564.30	18.06	100,491.33	20			100,491.33		100,491.33		200,982.66				
14.02	2 Coats of plaster and 2 coats of paint to basement ceiling	m^2	824.76	7.37	6,078.48	20			6,078.48		6,078.48		12,156.96				
14.03	3 Coats of plaster and 2 coats of paint to ceiling of offices	m^2	4,739.54	14.60	69,197.34	20			69,197.34		69,197.34		138,394.68				
14.04	Aluminum suspended ceiling to bathroom	m^2	308.04	184.04	56,691.68	15			56,691.68	13,117.18		56,691.68	126,500.54				
15.00	**Other detailed finishes**	**m^2**	**10,009.60**	**20.00**	**200,192.00**	**50**							**0.00**				
TOTAL					**21,652,770.57**			**302,570.77**	**3,350,100.10**	**808,291.70**	**1,774,745.56**	**269,329.57**	**5,991,861.56**		**4,828,429.33**		**1,190,060.62**

Table I2 - The calculation of salary in operation stage

Type	Number	Salary	Total
General manager	4	20,000	80,000
Vice president	1	15,000	15,000
Secretary of Chairman	2	10,000	20,000
Senior manager	3	15,000	45,000
Director of marketing	3	10,000	30,000
Department manager	44	8,000	352,000
Department head	30	7,000	210,000
Director of sales	8	8,000	64,000
General staff	228	3,000	684,000
Office staff	13	3,000	39,000
Sales	30	4,000	120,000
Lawyer and consultants	11	6,000	66,000
Per year			1,725,000
For 50 years			396,792,540

Table I3 - The calculation of energy bill in operation stage

Equipment	Power (kw)	Number	Total (kwh/h)
HVAC	1.5	1	1.5
	1.1	1	1.1
	5.5	4	22
	4	2	8
	4	2	8
	1.1	1	1.1
	5.5	1	5.5
	1.1	1	1.1
	0.75	1	0.75
	0.55	1	0.55
	0.55	1	0.55
	1.1	1	1.1
	0.75	1	0.75
	0.085	6	0.51
	0.12	6	0.72
	0.0155	4	0.062
	127	2	254
	5.5	2	11
	15	2	30
	15	2	30
	75	2	150
	1.1	2	2.2
	37	1	37
	15	1	15
	13	1	13
	3	3	9
	3	3	9
	0.55	4	2.2
	1.5	6	9
	0.55	5	2.75
	3.2	1	3.2
			630
Strong electricity			
Transformer 1TM		kw/h	470
Transformer 2TM		kw/h	254
		kw/h	724
Electricity price		yuan/kwh	0.78
Total energy cost for 50 year life cycle		Yuan	40,508,139

Table I4 - The calculation of water bill in operation stage

Type	Unit	Daily usage
Office	m^3/d	20
Green		8
Cleaning		36
sum		64
unexpected usage (15% of sum)		9.6
Total		73.6
Price	Yuan/m^3	1.9
Water bill	Yuan	670,138.51

Table I5 - Other costs in operation stage

Security cost		
Security	number	salary
	10	3,000
	6,900,739.82	Yuan
Cleaning cost		
According to the price catalog of local cleaning company the price for contract cleaning for office building is 0.68/m2/month		
General cleaning cost =	1,709,478.87	Yuan
Suppose the office building hire cleaning company to do the cleanup quarterly		
the special cleaning cost =	4,828,429.3	Yuan

Table I6 - The Coefficient For demolition (%) (Cost manual for construction project, China Water Power Press, May 2005 1st Edition)

Structure type	Function	Coefficient of demolition (%)
Brick	construction cost * coefficient	10
Mixed		20
Reinforcement concrete		
(1) can be blasted		20
(2) cannot be blasted		30~50
Temporary		8
Steel		
(1) can be reused after demolition		55
(2) cannot be reused after demolition		38

Demolition costs
According to the coefficient below
Demolition cost = 4,330,554.11 Yuan

Table I7 - Environmental assessment of Case Study No 1

					Construction						Operation			
Code	**Element**	**Unit**	**Quantities**	**Life expectancy**	**Energy coefficient**	**Embodied energy (MJ)**	**CO2 coefficient**	**CO2 emission (kg CO2)**	**Embodied water**	**Materials**	**Recurrent EE (incl replace & repair)**	**CO2**	**Emb water**	**Materials**
1.00	Substructure													
1.01	Raft foundation (C30 concrete)	m^3	172.85	50.00										
	water	kg	30,283.32		0.720	21,803.99	0.0010	30.28	30283.32					
	cement	kg	79,649.28		10.200	812,422.66	0.7300	58,143.97		79649.28				
	sand	kg	88,360.92		0.081	7,157.23	0.0048	424.13		88360.92				
	aggregrate	kg	216,546.48		0.083	17,973.36	0.0048	1,039.42		216546.48				
1.02	Other substurcture (C30 concrete)	m^3	1,145.46	50.00										
	water	kg	200,684.59		0.720	144,492.90	0.0010	200.68	200684.59					
	cement	kg	527,827.97		10.200	5,383,845.27	0.7300	385,314.42		527827.97				
	sand	kg	585,559.15		0.081	47,430.29	0.0048	2,810.68		585559.15				
	aggregrate	kg	1,435,032.29		0.083	119,107.68	0.0048	6,888.15		1435032.29				
1.03	Steel	kg	182,627.70	50.00	35.400	6,465,020.58	2.7100	494,921.07		182627.70				
2.00	Columns													
2.01	Concrete for rectangular columns from top of foundation to 1st floor (C40 concrete)	m^3	64.46	50.00										
	water	kg	11,763.95		0.720	8,470.04	0.0010	11.76	11763.95					
	cement	kg	29,168.15		10.200	297,515.13	0.7300	21,292.75		29168.15				
	sand	kg	34,808.40		0.081	2,819.48	0.0048	167.08		34808.40				
	aggregrate	kg	85,409.50		0.083	7,088.99	0.0730	6,234.89		85409.50				
2.02	Concrete for circular columns from top of foundation to 1st floor (C40 concrete)	m^3	69.95	50.00										
	water	kg	12,765.88		0.720	9,191.43	0.0010	12.77	12765.88					
	cement	kg	31,652.38		10.200	322,854.28	0.7300	23,106.24		31652.38				
	sand	kg	37,773.00		0.081	3,059.61	0.0048	181.31		37773.00				
	aggregrate	kg	92,683.75		0.083	7,692.75	0.0048	444.88		92683.75				
2.03	Concrete for rectangular columns from 2nd floor to roof (C30 concrete)	m^3	69.30	50.00										
	water	kg	12,141.36		0.720	8,741.78	0.0010	12.14	12141.36					
	cement	kg	31,933.44		10.200	325,721.09	0.7300	23,311.41		31933.44				
	sand	kg	35,426.16		0.081	2,869.52	0.0048	170.05		35426.16				
	aggregrate	kg	86,819.04		0.083	7,205.98	0.0048	416.73		86819.04				
2.04	Concrete for circular columns from 2nd floor to roof (C30 concrete)	m^3	75.26	50.00										
	water	kg	13,185.55		0.720	9,493.60	0.0010	13.19	13185.55					
	cement	kg	34,679.81		10.200	353,734.06	0.7300	25,316.26		34679.81				
	sand	kg	38,472.91		0.081	3,116.31	0.0048	184.67		38472.91				
	aggregrate	kg	94,285.73		0.083	7,825.72	0.0048	452.57		94285.73				
2.05	Steel	kg	117,488.40	50.00	35.400	4,159,089.36	2.7100	318,393.56		117488.40				
3.00	Beams													
3.01	Concrete for rectangular beam (C30 concrete)	m^3	1,186.28	50.00										
	water	kg	207,836.26		0.720	149,642.11	0.0010	207.84	207836.26					
	cement	kg	546,637.82		10.200	5,575,705.76	0.7300	399,045.61		546637.82				
	sand	kg	606,426.34		0.081	49,120.53	0.0048	2,910.85		606426.34				
	aggregrate	kg	1,486,171.58		0.083	123,352.24	0.0048	7,133.62		1486171.58				
3.02	Concrete for slab with beam (C30 concrete)	m^3	1,153.87	50.00										
	water	kg	202,158.02		0.720	145,553.77	0.0010	202.16	202158.02					
	cement	kg	531,703.30		10.200	5,423,373.66	0.7300	388,143.41		531703.30				
	sand	kg	589,858.34		0.081	47,778.53	0.0048	2,831.32		589858.34				
	aggregrate	kg	1,445,568.34		0.083	119,982.17	0.0048	6,938.73		1445568.34				

3.03	Ohers (C30 concrete)	m^3	34.50	50.00										
	water	kg	6,044.40		0.720	4,351.97	0.0010	6.04	6044.40					
	cement	kg	15,897.60		10.200	162,155.52	0.7300	11,605.25		15897.60				
	sand	kg	17,636.40		0.081	1,428.55	0.0048	84.65		17636.40				
	aggregrate	kg	43,221.60		0.083	3,587.39	0.0048	207.46		43221.60				
3.04	Steel	kg	255,451.20	50.00	35.400	9,042,972.48	2.7100	692,272.75		255451.20				
4.00	Staircases													
4.01	Concrete for staircases (C30 concrete)	m^2	193.42	50.00										
	assume the hight of the stair step is 160mm	m^3	30.95											
	water	kg	5,422.44		0.720	3,904.16	0.0010	5.42	5422.44					
	cement	kg	14,261.76		10.200	145,469.95	0.7300	10,411.08		14261.76				
	sand	kg	15,821.64		0.081	1,281.55	0.0048	75.94		15821.64				
	aggregrate	kg	38,774.16		0.083	3,218.26	0.0048	186.12		38774.16				
4.02	Steel	kg	30,367.57	50.00	35.400	1,075,011.98	2.7100	82,296.11		30367.57				
5.00	Roof													
5.01	Insulated waterproof roof	m^2	2,656.62	50.00										
	30mm cement ceramisite (1:8)	m^3	79.70	50.00										
	cement	kg	11,423.47		10.200	116,519.44	0.7300	8,339.14		11423.47				
	ceramisite	kg	49,590.28		10.000	495,902.77	0.6600	32,729.58		49590.28				
	20mm cement mortar (1:3:0.6)	m^3	53.13	50.00										
	cement	kg	14,900.18		10.200	151,981.88	0.7300	10,877.13		14900.18				
	sand	kg	55,511.85		0.081	4,496.46	0.0050	277.56		55511.85				
	water	kg	6,930.32		0.720	4,989.83	0.0010	6.93	6930.32					
	2mm Polymer waterproofing membrane			50.00										
	15mm cement mortar (1:3:0.6)	m^3	39.85	50.00										
	cement	kg	11,175.14		10.200	113,986.41	0.7300	8,157.85		11175.14				
	sand	kg	41,633.89		0.081	3,372.34	0.0050	208.17		41633.89				
	water	kg	5,197.74		0.720	3,742.37	0.0010	5.20	5197.74					
5.02	Non-insulated waterproof roof	m^2	69.70	50.00										
	30mm cement ceramisite (1:8)	m^3	2.09											
	cement	kg	299.69		10.200	3,056.82	0.7300	218.77		299.69				
	ceramisite	kg	1,300.97		10.000	13,009.73	0.6600	858.64		1300.97				
	35mm cement mortar (1:3:0.6)	m^3	2.44	50.00										
	cement	kg	684.07		10.200	6,977.53	0.7300	499.37		684.07				
	sand	kg	2,548.56		0.081	206.43	0.0050	12.74		2548.56				
	water	kg	318.17		0.720	229.08	0.0010	0.32	318.17					
	40 mm C20 (0.51:1:1.81:3.68)	m^3	2.79	50.00										
	water	kg	487.47		0.720	350.98	0.0010	0.49	487.47					
	cement	kg	955.82		10.200	9,749.33	0.7300	697.75		955.82				
	sand	kg	1,730.03		0.081	140.13	0.0048	8.30		1730.03				
	aggregrate	kg	3,517.41		0.083	291.94	0.0048	16.88		3517.41				
5.03	Glass canopy	m^2	1,043.28	15.00										
	Aluminum frame	kg	456.43		155.000	70,747.15	8.2400	3,761.01		456.43	212241.46	11283.03		1369.30
	Glass	kg	40,359.28		15.000	605,389.20	0.8600	34,708.98		40359.28	2300478.96	104126.94		121077.84
5.04	Handrail	m	159.39	25.00										
	height: 1.35m, glass balusters, thickness 12mm	kg	6,659.28		15.000	99,889.20	0.8600	5,726.98		6659.28	99889.20	5726.98		6659.28
5.05	Steel	kg	10,779.82	50.00	35.400	381,605.63	2.7100	29,213.31		10779.82				
6.00	External Walls													
6.01	Terracotta louver	m^2	2,463.08											
	200 mm brick wall	kg	946,809.11	50.00	3.000	2,840,427.32	0.2300	217,766.09		946809.11	0.00			
	20mm cement	kg	63,547.54	50.00	10.200	648,184.92	0.7300	46,389.71		63547.54	0.00			

	7mm aggregate cement mortar			50.00							0.00			
	water	kg	3,026.12		0.720	2,178.81	0.0010	3.03	3026.12					
	cement	kg	5,933.57		10.200	60,522.38	0.7300	4,331.50		5933.57				
	sand	kg	10,739.76		0.081	869.92	0.0048	51.55		10739.76				
	aggregrate	kg	21,835.53		0.083	1,812.35	0.0048	104.81		21835.53				
	50*150 Prefabricated terracotta louver	kg	328,411.07	20.00	12.000	3,940,932.80	0.7400	243,024.19		328411.07	7881865.60	486048.38		656822.13
6.02	Laminated glass curtain wall	m^2	1,436.18	20.00										
	glass	kg	18,519.53		15.000	277,792.92	0.8600	15,926.79		18519.53	555585.85	31853.59		37039.06
	steel frame	kg	11,489.43		20.100	230,937.58	1.3700	15,740.52		11489.43	461875.17	31481.04		22978.86
6.03	Low-E glass curtain wall	m^2	573.92	20.00										
	50*120 Aluminum frame	kg	160,144.92		155.000	24,822,462.00	8.2400	1,319,594.11		160144.92	49644923.99	2639188.22		320289.83
	glass	kg	17,761.71		15.000	266,425.61	0.8600	15,275.07		17761.71	532851.21	30550.14		35523.41
6.04	Vertical terracotta louver	m^2	800.73	20.00										
	750*120 Prefabricated terracotta louver	kg	44,484.83		12.000	533,818.00	0.7400	32,918.78		44484.83	1067636.00	65837.55		88969.67
	80*120 steel frame	kg	3,352.38		20.100	67,382.78	1.3700	4,592.76		3352.38	134765.56	9185.51		6704.75
6.05	Decorative aluminum panel tp wall	m^2	307.04	20.00										
	steel frame	kg	1,570.00		20.100	31,557.00	1.3700	2,150.90		1570.00	63114.00	4301.80		3140.00
	2mm thickness aluminum	kg	934.62		155.000	144,866.67	8.2400	7,701.30		934.62	289733.34	15402.60		1869.25
7.00	Windows													
7.01	Aluminum windows	No	2.00	20.00										
	aluminum window frame	kg	15.00		155.000	2,325.00	8.2400	123.60		15.00	4650.00	247.20		30.00
	glass	kg	145.00		15.000	2,175.00	0.8600	124.70		145.00	4350.00	249.40		290.00
7.02	Metal shutters	m^2	729.28	15.00										
	1.8mm thickness	kg	1,997.94		155.000	309,680.00	8.2400	16,462.99		1997.94	929040.00	49388.97		5993.81
7.03	Aluminum sliding windows	m^2	800.73	20.00										
	aluminum window frame	kg	36.57		155.000	5,668.35	8.2400	301.34		36.57	11336.70	602.67		73.14
	glass (thickness 8mm)	kg	16,520.60		15.000	247,808.99	0.8600	14,207.72		16520.60	495617.98	28415.43		33041.20
7.04	Low-E glass windows	m^2	746.21	20.00										
	50*120 Aluminum frame	kg	47.53		155.000	7,367.15	8.2400	391.65		47.53	14734.30	783.29		95.06
	glass	kg	9,622.40		15.000	144,336.06	0.8600	8,275.27		9622.40	288672.11	16550.53		19244.81
8.00	External Doors													
8.01	Steel fire-rated door	No	19.00											
	assume 40kg per door	kg	760.00	20.00	18.800	14,288.00	1.3000	988.00		760.00	28576.00	1976.00		1520.00
8.02	Fire resistant rolling shutter door	m^2	237.70											
	16kg/sq.m	kg	3,803.20	20.00	18.800	71,500.16	1.3000	4,944.16		3803.20	143000.32	9888.32		7606.40
9.00	Internal Walls													
9.01	Aerated concrete block wall	m^3	1,584.05											
	2403kg/cu.m	kg	3,806,472.15	50.00	0.750	2,854,854.11	0.1000	380,647.22		3806472.15	0.00			
9.02	RC basement wall C40 (0.4:1:1.19:2.92)	m^3	298.69	50.00							0.00			
	water	kg	52,234.81		0.720	37,609.07	0.0010	52.23	52234.81					
	cement	kg	130,587.04		10.200	1,331,987.78	0.7300	95,328.54		130587.04				
	sand	kg	155,398.57		0.081	12,587.28	0.0048	745.91		155398.57				
	aggregrate	kg	381,314.15		0.083	31,649.07	0.0048	1,830.31		381314.15				
10.00	Internal Doors													
10.01	Timber fire-rated door	No	18.00											
	assmue the size of doors 2000mm*800mm*40mm	kg	6,336.00	25.00	15.000	95,040.00	0.4200	2,661.12			190080.00	5322.24		
10.02	Timber door	m^2	459.28											
	assume the thickness of the door is 40mm	kg	10,103.50	25.00	15.000	151,552.50	0.4200	4,243.47			303105.00	8486.94		
11.00	Wall Finishes													
11.01	12mm Cement and sand (1:3) render for painting	m^2	7,880.84	50.00							0.00			
	Cement	kg	30,498.85		10.200	311,088.28	0.7300	22,264.16		30498.85				
	Sand	kg	113,625.95		0.081	9,203.70	0.0050	568.13		113625.95				
11.02	12mm Cement and sand (1:3) render and plaster for painting	m^2	8,053.38	50.00							0.00			

	Cement	kg	31,166.58		10.200	317,899.12	0.7300	22,751.60		31166.58				
	Sand	kg	3,872,459.72		0.081	313,669.24	0.0050	19,362.30		3872459.72				
	plaster	kg	13,674.64		1.800	24,614.35	0.1200	1,640.96		13674.64				
11.03	Cermic tile to wall include cement & sand backing	m^2	1,600.94	50.00							0.00			
	22mm cement mortar (1:3)	kg	84,635.29		1.330	112,564.94	0.2080	17,604.14		84635.29				
	1mm waterproof	m^2	1,600.94		59.000	94,455.46	2.1200	3,393.99						
11.04	Marble to wall including cement & sand backing	m^2	702.00	50.00										
	20mm cement mortar (1:3)	kg	33,738.12		1.330	44,871.70	0.2080	7,017.53		33738.12	0.00			
	7mm Polymer cement mortar	kg	11,808.34		10.400	122,806.76	1.0900	12,871.09		11808.34				
	1mm waterproof	m^2	702.00		59.000	41,418.00	2.1200	1,488.24						
11.05	2 coats of Gross latex to rendered wall	m^2	7,880.84	15.00	21.000	165,497.64	0.7300	5,753.01			496492.92	17259.04		
11.06	Sound absorption wall	m^2	375.15	15.00										
	- 60 x 60 x 120mm timber @ 600 centres	kg	234.09		10.000	2,340.94	0.7100	166.21		234.09	4681.87	332.41		468.19
	- 150 x 50 x 1.5mm thick aluminum strip	kg	4,109.40		155.000	636,957.00	8.2400	33,861.46		4109.40	1910871.00	101584.37		12328.20
11.07	Ceramic tile to wall	m^2	1,600.94											
	5mm tiles	kg	19,235.29	15.00	15.000	288,529.41	0.8600	16,542.35		19235.29	865588.23	49627.06		57705.88
11.08	Glazed tile to wall	m^2	1,945.27											
	5mm tiles	kg	25,084.26	15.00	15.000	376,263.85	0.8600	21,572.46		25084.26	1128791.55	64717.38		75252.77
11.09	Marble to wall	m^2	702.00											
	25mm Marble	kg	1,300.00	15.00	3.330	4,329.00	0.1160	150.80		1300.00	8658.00	301.60		2600.00
12.00	Floor Finishes													
12.01	Cement mortar to floor	m^2	519.98											
	40-60 mm aggregate	kg	41,650.40	50.00	1.260	52,479.50	0.0730	3,040.48		41650.40	0.00			
	20mm cement mortar (1:3)	kg	24,990.24	50.00	1.330	33,237.02	0.2080	5,197.97		24990.24	0.00			
12.02	Fine aggregate concrete floor	m^2	220.12											
	20mm cement mortar (1:3)	kg	10,578.97	50.00	1.330	14,070.03	0.2080	2,200.43		10578.97	0.00			
	40mm C20 fine aggregate concrete			50.00							0.00			
	water	kg	1,539.58		0.720	1,108.50	0.0010	1.54	1539.58					
	cement	kg	3,018.79		10.200	30,791.64	0.7300	2,203.72		3018.79				
	sand	kg	5,464.01		0.081	442.58	0.0048	26.23		5464.01				
	aggregate	kg	11,109.14		0.083	922.06	0.0048	53.32		11109.14				
12.03	Tiles floor base	m^2	304.63											
	20mm cement mortar (1:4)	kg	14,640.52	50.00	1.110	16,250.97	0.1710	2,503.53		14640.52	0.00			
12.04	Stoon floor base	m^2	4,468.89											
	30mm cement mortar (1:4)	kg	322,162.28	50.00	1.110	357,600.13	0.1710	55,089.75		322162.28	0.00			
12.05	Non-slip tiles floor base	m^2	308.40	50.00										
	30mm cement mortar (1:3)	kg	22,232.56		1.330	29,569.30	0.2080	4,624.37		22232.56	0.00			
	2mm Polymer waterproof coating	m^2	308.40		59.000	18,195.60	2.1200	653.81						
	10mm Polymer cement mortar	kg	7,410.85		10.400	77,072.86	1.0900	8,077.83		7410.85				
12.06	Tiles floor	m^2	153.72											
	8-10mm tiles	kg	33,245.02	20.00	12.000	398,940.29	0.7400	24,601.32		33245.02	797880.59	49202.64		66490.05
12.07	Stone floor (Entrance, lobby, hallway)	m^2	4,210.49											
	20mm marble tile	kg	215,829.72	35.00	3.330	718,712.96	0.1920	41,439.31		215829.72	1437425.92	82878.61		431659.43
12.08	Stone floor (staircase)	m^2	258.40											
	20mm marble tile	kg	13,245.58	30.00	3.330	44,107.79	0.1920	2,543.15		13245.58	132323.38	5086.30		26491.17
12.09	Non-slip tiles floor	m^2	308.04											
	8-10mm tiles	kg	6,661.98	20.00	12.000	79,943.77	0.7400	4,929.87		6661.98	159887.55	9859.73		13323.96
12.10	Painting to RC column	m^2	56.80	15.00	10.500	596.40	0.3600	20.45			1789.20	61.34		
12.11	External timber floor	m^2	195.70	10.00										
	10mm timber	kg	1,017.64		10.000	10,176.40	0.7100	722.52		1017.64	40705.60	2890.10		4070.56
12.12	Timber floor backing	m^2	195.70	25.00										

12.13	Timber staircase	m^2	305.50	10.00										
	8mm timber	kg	1,270.88		10.000	12,708.80	0.7100	902.32		1270.88	50835.20	3609.30		5083.52
13.00	Ceiling Finishes													
13.01	8mm Cement and sand (1:3) render to ceiling of offices	m^2	5,564.30											
	Cement & sand mortar (1:3)	kg	44.51	20.00	1.330	59.20	0.2080	9.26		44.51	118.41	18.52		89.03
13.02	2 Coats of plaster and 2 coats of paint to basement ceiling	m^2	824.76	20.00										
	Plaster	kg	1,400.44		1.800	2,520.80	0.1200	168.05		1400.44	5041.59	336.11		2800.88
	Coat	m^2	824.76		21.000	17,319.96	0.7300	602.07			17319.96	602.07		0.00
13.03	3 Coats of plaster and 2 coats of paint to ceiling of offices	m^2	4,739.54	20.00										
	Plaster	kg	12,071.62		1.800	21,728.91	0.1200	1,448.59		12071.62	43457.83	2897.19		24143.24
	Coat	m^2	4,739.54		21.000	99,530.42	0.7300	3,459.87			199060.85	6919.73		
13.04	Aluminum suspended ceiling to bathroom	m^2	308.04	15.00										
	Aluminum frame and aluminum broad	kg	2,813.02		155.000	436,018.30	8.2400	23,179.30		2813.02	1308054.90	46358.59		5626.04
14.00	Other detailed finishes	m^2	10,009.60											
	TOTAL					87,251,481.53		5,941,991.38	772019.986	20892211.12	74267107.29	4001438.88		2098470.728

Table I8 - The energy consumption in construction stage

Equipment	Power (KW)	Amount	TOTAL
Crane	35	2	70
Concrete mixer	15	2	30
Steel cutting machine	2	3	6
Steel bending machine	2	3	6
Hoist	6	1	6
AC welder	12.5	1	12.5
Woodworking circular saw	3	1	3
Plug-shaker	1.1	2	2.2
Electro slag welding	35	1	35
Lighting	/	/	15
Life on site	/	/	12
Total			197.7
Energy consumed on site = 197.7*8*180=284688KWh=1024876.8MJ			

Table I9 - The energy consumption in operation stage

Equipment	Power (kw)	Number	Total
HVAC machine	1.5	1	1.5
	1.1	1	1.1
	5.5	4	22
	4	2	8
	4	2	8
	1.1	1	1.1
	5.5	1	5.5
	1.1	1	1.1
	0.75	1	0.75
	0.55	1	0.55
	0.55	1	0.55
	1.1	1	1.1
	0.75	1	0.75
	0.085	6	0.51
	0.12	6	0.72
	0.0155	4	0.062
	127	2	254
	5.5	2	11
	15	2	30
	15	2	30
	75	2	150
	1.1	2	2.2
	37	1	37
	15	1	15
	13	1	13
	3	3	9
	3	3	9
	0.55	4	2.2
	1.5	6	9
	0.55	5	2.75
	3.2	1	3.2
			630.642KW
Strong electricity			
Transformer 1TM			470 KW
Transformer 2TM			254 KW
			724 KW
Energy =(630.642 + 724)×8×250×50 = 135,464,200 KWh =487,671,120.00 MJ			

Table I10 - Solid waste in construction stage

Construction waste		J=Q×C
	Q - gloss floor area	
	C - waste per m2	
	assume that 2t waste is produced by 100 m2 construction area	
	J = 2 × 10929/100 =218.58 t	
Garbage on site		Ws =Ps×Cs
	Ps - the number of workers on site	
	Cs - the garbage produced by workers	
	assume that 1kg waste is produced per person per day	
	Ws = 1×700×180/1000=126 t	
Waste	218.58+126= 344.58 t	=344,580 kg

Table I11 - Social assessments for Case Study No 1

Stages	Indicators	Expert No.1	Expert No.2	Expert No.3	Expert No.4	Expert No.5	Ave score
Inception & design	Impact on community	4	3	5	3	4	3.8
	Urban integration	3	4	3.5	2	3	3.1
	Proximity to facility	4	3	5	3	5	4
	Cultural issue	3	4	4	2	4	3.4
Construction	Impact on community	5	4	5	4	5	4.6
	Health & safety of work environment	3	3	4	3	3.5	3.3
Operation	Occupants' health and comfort	4	5	5	4.5	4	4.5
	Stakeholder relations	5	4	4	3	4	4
	Occupier satisfaction and productivity	4	3	4	4	2	3.4
Demolition	Health and safety	3	5	4	2	4	3.6
	Local impacts	4	3	2	3.5	3	3.1

Appendix J: Assessing the cases in LEED and ESGB

Table J1 - Assessing the sustainable performance of the three case studies using LEED-NC

Indicators		Case Study No 1	Case Study No 2	Case Study No 3
Sustainable sites (Total 26)				
Prereq 1	Construction Activity Pollution	Y	Y	Y
Credit 1	Site Selection	1	1	1
		No prime farmland, no habitat for any species, no public parkland, etc.	No prime farmland, no habitat for any species, no public parkland, etc.	No prime farmland, no habitat for any species, no public parkland, etc.
Credit 2	Development Density and Community Connectivity	1	5	3
		Has pedestrian access between the building and the services	located on a highly developed area	on a previously developed site , within 1/2 mile of at least 10 basic services
Credit 3	Brownfield Redevelopment	0	1	0
		Greenfield	Brownfield	Greenfield
Credit 4.1	Alternative Transportation - Public Transportation Access	6	6	6
		Bus Stop Proximity– have bus stops within 400 meters	Bus Stop Proximity– have bus stops within 400 meters	Bus Stop Proximity– 2 bas stop within 400 meters
Credit 4.2	Alternative Transportation - Bicycle Storage and Changing Rooms	0	0	0
Credit 4.3	Alternative Transportation - Low-Emitting and Fuel-Efficient Vehicles	0	0	0

Credit 4.4 Alternative Transportation - Parking capacity	2	2	2
	Size parking capacity to meet but not exceed minimum local zoning requirements	Provide no new parking	Size parking capacity to meet but not exceed minimum local zoning requirements
Credit 5.1 Site Development - Protect or Restore Habitat	1	1	1
	Limit the disturbance to12 meters beyond the building perimeter and parking garages, and etc.	Restore or protect a minimum of20% of the total site area	Limit all site disturbance to the existing natural areas
Credit 5.2 Site Development - Maximize Open Space	1	0	1
	Provide vegetated open space equal to 20% of the project site area		vegetated roof
Credit 6.1 Stormwater Design - Quantity Control	1	0	1
	Green area for outdoor rainwater harvesting		Installed rainwater harvesting and recycling system
Credit 6.2 Stormwater Design - Quality Control	0	0	1
			Installed rainwater harvesting and recycling system
Credit 7.1 Heat Island Effect - Non-roof	1	0	1
	Provide shade from the existing tree canopy		Provide shade from structures covered by solar panels
Credit 7.2 Heat Island Effect - Roof	0	0	1

			Install a vegetated roof that covers at least 50% of the roof
Credit 8 Light Pollution Reduction	1	1	1
	After-hours override may be provided by a manual device provided the override last no more than 30 minutes	After-hours override may be provided by a manual device provided the override last no more than 30 minutes	After-hours override may be provided by occupant-sensing device provided the override last no more than 30 minutes
Water efficiency(Total 10)			
Prereq 1 Water Use Reduction - 20% Reduction	Y	Y	Y
Credit 1 Water Efficient Landscaping	0	0	2
			Installed water-saving irrigation system , water consumption for irrigation Reduce by 50%
Credit 2 Innovative Wastewater Technologies	0	0	2
			Installed reclaimed water system
Credit 3 Water Use Reduction	0	0	2
			Select high performance water pump system, and selecting water-saving appliances
Energy and Atmosphere (Total 35)			
Prereq 1 Fundamental Commissioning of Building Energy Systems	Y	Y	Y

Prereq 2	Minimum Energy Performance	Y	Y	Y
Prereq 3	Fundamental Refrigerant Management	Y	Y	Y
Credit 1	Optimize Energy Performance	/	/	9
				51.3%
Credit 2	On-site Renewable Energy	/	/	5
				Solar energy 8%
Credit 3	Enhanced Commissioning	0	0	0
Credit 4	Enhanced Refrigerant Management	0	0	0
Credit 5	Measurement and Verification	0	0	0
Credit 6	Green Power	0	0	2
				solar photovoltaic systems
Material and Resources (Total 14)				
Prereq 1	Storage and Collection of Recyclables	Y	Y	Y
Credit 1.1	Building Reuse - Maintain Existing Walls, Floors, and Roof	/	/	/
Credit 1.2	Building Reuse - Maintain 50% of Interior Non-Structure Elements	0	0	0
Credit 2	Construction Waste Management	0	0	1
				50%
Credit 3	Materials Reuse	/	/	/
Credit 4	Recycled Content	0	0	1
				10.3%
Credit 5	Regional Materials	/	/	/
Credit 6	Rapidly Renewable Materials	0	0	0

Credit 7	Certified Wood	0	0	0
Indoor Environmental Quality (Total 15)				
Prereq 1	Minimum Indoor Air Quality	Y	Y	Y
Prereq 2	Environmental Tobacco Smoke (ETS)	Y	Y	Y
Credit 1	Outdoor Air Delivery Monitoring	0	0	1
Credit 2	Increased Ventilation	0	0	1
Credit 3.1	Construction IAQ Management Plan - During Construction	0	0	0
Credit 3.2	Construction IAQ Management Plan - Before Occupancy	0	0	0
Credit 4.1	Low-Emitting Materials - Adhesives and Sealants	0	0	0
Credit 4.2	Low-Emitting Materials - Paints and Coatings	0	0	0
Credit 4.3	Low-Emitting Materials - Flooring	0	0	0
Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Product	0	0	0
Credit 5	Indoor Chemical and Pollutant Source	1	1	1
Credit 6.1	Controllability of Systems - Lighting	1	1	1
		Provide individual lighting controls for ≥90% of the building occupants to enable adjustments to suit individual task needs and preferences		
Credit 6.2	Controllability of Systems - Thermal Comfort	1	1	1
		Provide individual comfort controls for≥50% of the building occupants to enable adjustments to meet individual needs and preferences		

Credit 7.1 Thermal Comfort - Design	1	1	1
Credit 7.2 Thermal Comfort - Verification	0	0	0
Credit 8.1 Daylight and Views - Daylight	1	1	1
Credit 8.2 Daylight and Views - Views	1	0	1
Innovation and Design Process (Total 6)			
Credit 1.1 Innovation in Design: Specific Title	0	0	0
Credit 1.2 Innovation in Design: Specific Title	0	0	0
Credit 1.3 Innovation in Design: Specific Title	0	0	0
Credit 1.4 Innovation in Design: Specific Title	0	0	0
Credit 1.5 Innovation in Design: Specific Title	0	0	0
Credit 2 LEED Accredited Professional			
Regional Priority Credits (Total 4)			
Credit 1.1 Regional Priority: Specific Credit	0	0	0
Credit 1.1 Regional Priority: Specific Credit	0	0	0
Credit 1.1 Regional Priority: Specific Credit	0	0	0
Credit 1.1 Regional Priority: Specific Credit	0	0	0

Table J2 - Assessing the sustainable performance of the three case studies using ESGB

Groups	Categories	Criteria	Case Study No 1	Case Study No 2	Case Study No 3
Land saving & outdoor environment	Controlling items	In the process of building, the original terrain of land shall be maintained, as well as valuable trees, pools, water systems and inherit historical of region	☑	☑	☑
		The site selection should avoid natural disaster, like flood, mud-rock flow, and avoid the polluting sources, like electromagnetic wave radiation	☑	☑	☑
		not to generate influence to the surrounding od the project	☑	☑	☑
		Near the land of a construction project, there should be no pollution sources exceed the standards.	☑	☑	☑
		During the construction process, there should be technical treatment and procedures to control the dust and other pollution	☑	☑	☑
	General items	The noise generate by the construction process meet the requirement of 'surrounding noise standard for urban area' (GB 3096)	☑	☑	☑
		The speed of wind in the walking area near buildings above the ground 1.5m <5m/s, provide good air flow and ventilation	☒	☒	☑
		Encourage green coverage on roof and walls	☒	☒	☒
		In setting up plants, chose the local plants adaptable to the local climate and soil condition	☑	☒	☑
		Convenient access to the public transportation (<500 m)	☑	☒	☑
		Develop and utilize the underground area	☑	☒	☑
	Prior items	Develop and utilize the brown filed	☒	☑	☑
		Fully utilize the old buildings	-*	-	-
		The area of water penetration land equal or exceed 40%	☒	☒	☒

Energy saving & energy utilization	Controlling items	Thermal of the fencing structure should meet the national and regional standard	☑	☑	☑
		Energy consumption of air conditioners should meet the national standard, i.e. GB19576 of energy efficiency of air conditioners	☑	☑	☑
		Avoid using heat-accumulation electric boiler and other electric-heat equipment as directly heat source.	☑	☑	☑
		The illumination of rooms and other space should not exceed the current value in the GB 50034 of Building Illumination Design Standard	☑	☑	☑
		The energy consumption should analyses independently in HVAC, lighting and other systems.	☒	☒	☑
	General items	The design of building can improve the natural ventilation in summer and make sufficient sunlight in winter	☑	☒	☑
		The area of openable windows should ≥30% of the entire window area, and there need to be openable area or ventilation equipment in curtain walls	☒	☒	☑
		The airproof function of outside windows need to meet the Class 4 requirement of GB 7107 of Classification and Testing Methods of Airproof Function of Outside Window for buildings	☑	☑	☑
		Rational use the heat and cold accumulation technology	☒	☒	☒
		Recycling the energy from air-conditioner exhaust	☒	☒	☑
		In air-conditioning system design, not only construction situation, but the operation mode for the whole year shall be considered	☒	☒	☑
		HVAC System design should ensure when the building is partly in use, the energy supply as actually need	☑	☑	☑
		Use energy-saving equipment and systems, meet the requirement of GB 50189-2005 of Energy Saving Standard for Public Buildings	☑	☑	☑

		Encourage using residual heat from HVAC system, heat pump, and others to provide heat for daily life	☒	☒	☑
		Independent measurement of energy consumption for each part of building	☒	☒	☑
	Prior items	The energy consumption of building < 80% of the energy consumption in national standard	☒	☒	☑
		Using distributional heat-electricity-coldness co-generation system	☒	☒	☑
		Proper utilization of renewable energy and new energy technology	☒	☒	☒
		The illumination of rooms and other space should not exceed the target value in the GB 50034 of Building Illumination Design Standard	☒	☒	☑
Water saving & water utilization	Controlling items	Planning proposal on water system, consider not only indoor water resources, water supply, but also the drainage of outdoor rainwater and sewage, utilization of non-traditional water resources, green coverage and other issues.	☑	☑	☑
		Planning water drainage and supply system	☑	☑	☑
		In the planning and design stage, when selecting the water supply facilities, like pipe and pipeline accessories, it should not generate second pollution to the water resources.	☑	☑	☑
		Chose water-saving equipment, follow the requirement in CJ 146 of Water Saving Equipment and GB/T 18870 of Technical Conditions and General Management Rules on Water-saving Products.	☑	☑	☑
		When using the non-traditional water resources, the safety and quality need to be guaranteed	☑	☑	☑
	General items	Choosing the suitable route for the water system based on the technical and economic rationality	☑	☑	☑
		Using non-traditional water resources for green, scenery, car washing and others	☒	☒	☑
		Using water-saving irritation	☑	-	☑

		Consider using sewage water after treatment	☒	☒	☑
		Set up water meters according to the usage and purpose of use	☑	☑	☑
		The usage of non-traditional water resources for office and mall should ≥20%, and for hotel should≥15%	☒	☒	☒
	Prior items	The usage of non-traditional water resources for office and mall ≥40%, and for hotel ≥25%	☒	☒	☒
Material saving & material utilization	Controlling items	The amount of harmful substance in construction material should not exceed the GB 18580~18588	☑	☑	☑
		Simply style, avoid numerous decoration components without function value	☑	☑	☑
	General items	Using local produced material, the amount of construction material produced within 500m of the project should ≥60% of the total amount	☒	☒	☑
		Using pre-mixed concrete	☑	☑	☑
		Using high-performance concrete and steel	☒	☒	☒
		Making full use of the demolition waste of the old buildings	☑	☑	☑
		Consider using the recycle materials, the recycle material should ≥10% of the total amount of material when the safety and quality not affected	☒	☒	☑
		Integrated the construction and decoration process, avoid repeated construction	☑	☑	☑
		Using more flexible separation structure in the interior of office and other commercial buildings, avoid the waste generated by the space layout	☒	☒	☑
		The weight of construction material produced by the waste should ≥30%, when the quality and safety is guaranteed	☒	☒	☑
	Prior items	Choosing the building structure with low energy consumption and good environmental performance	☒	☒	☒
		The weight of reused material should≥ 5%	–	–	–

Indoor environmental quality	Controlling items	Thermal comfort. Room temperature, humidity and air flow meet GB50189	☑	☑	☑
		Avoid dew congealing on the surface of building outside and interior	☑	☑	☑
		The minimum amount of fresh air of public building should meet the requirement of GB 50189	☑	☑	☑
		Indoor pollutant density should be strictly controlled to ensure people's health, based on the GB 50325 of Regulation on Control over Indoor Pollution for Civil Building	☑	☑	☑
		Indoor background noise level should be in line with the GBJ 118 of Sound-proof Design Regulation for Civil Building	☑	☑	☑
		Indoor illumination quality shall satisfy the regulations in section 5.2 of GB 50034 of Building Illumination Design Standard	☑	☑	☑
	General items	Building design and structure design can improve natural ventilation	☒	☒	☑
		Using customize air-conditional terminal, users can satisfy their demand by self-adjustment or auto-adjustment	☑	☑	☑
		As for hotel type building, the sound proof function for fencing structure should meet the requirement of section 6.2.1 and 6.2.2 in GBJ 118-88 of Sound-proof Design Regulation for Civil Building	☒	☒	☒
		Indoor noise level shall be controlled according to related hygiene standard	☒	☒	☑
		For office and hotel building, the natural light for 75% of the function area should meet the 3.2.2~3.2.7 in GB/T 50033 of Building Daylight Design Standard	☒	☒	☑
		Encourage to set non-obstacle facilities in major movement space, like building entrance, life etc.	☑	☑	☑

	Prior items	Using sunlight-shield measures, improve indoor thermal comfort	☒	☒	☒
		Setting indoor air quality monitor system	☒	☒	☒
		Improving the effect of natural day lighting	☒	☒	☑
Operation management	Controlling items	Property management company should submit the management proposal about the energy saving, water saving and green management	☑	☑	☑
		During the operation stage of building, the waste gas and waste water should meet the standard before emission or discharge	☑	☑	☑
		The operation garbage should be sorted by source, and not cause second pollution during the process	☑	☑	☑
	General items	The land, road and other facilities in construction process should treat properly in order to use again in operation stage	☒	☒	☒
		Property management company should meet the ISO 14001	☒	☒	☑
		The equipment and pipeline should be set to be convenient for future repair and replacement	☑	☑	☑
		The air supply system of air conditioner should be regularly check according to the GB17093	☑	☑	☑
		Proper and complete building network system should be set up according to GB/T 50314 of Intelligence Building Design Standard	☑	☑	☑
		Effective monitoring shall be conducted on HVAC system	☑	☑	☑
		Analyze the amount of energy consumption in different part of buildings	☒	☒	☒
	Prior items	Connect the management incentives with energy and resource saving and	☒	☒	☒
Note: *this indicators do not exist in this project					

Table J3 - Item requirement for grade classification of public buildings in ESGB

Grade	General items (Total: 43 items)						Prior items (Total: 14 items)
	Land saving & outdoor environment (Total: 6 items)	Energy saving & utilization (Total: 10 items)	Water saving & Water resource utilization (Total: 6 items)	Materials saving & material resources utilization (Total: 8 items)	Indoor environmental quality (Total: 6 items)	Operation management (Total: 7 items)	
★	3	4	3	5	3	4	-
★★	4	6	4	6	4	5	6
★★★	5	8	5	7	5	6	10