IMPACT OF SUSTAINABLE FEATURES ON LIFE CYCLE COST (LCC) OF GREEN BUILDINGS IN SRI LANKA

Achini Shanika Weerasinghe

(168010B)

Degree of Master of Science by Research

Department of Building Economics

University of Moratuwa

Sri Lanka

June 2018

IMPACT OF SUSTAINABLE FEATURES ON LIFE CYCLE COST (LCC) OF GREEN BUILDINGS IN SRI LANKA

Achini Shanika Weerasinghe

(168010B)

Thesis submitted in partial fulfilment of the requirement for the degree of Master of Science by Research

Department of Building Economics

University of Moratuwa

Sri Lanka

June 2018

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

The above candidate has carried out research for the MSc Dissertation under my supervision.

Signature of the supervisor: Date:

DEDICATION

To My Beloved Parents…………

ACKNOWLEDGEMENT

This research study embraces much commitment and guidance received from many individuals and organisations without whom, the completion of this piece of work would not have been possible. I would like to take this opportunity to express my gratitude to each and every one of them.

First and foremost, I am grateful to my research supervisor, Dr. (Mrs.) Thanuja Ramachandra for patiently providing me thoughtful guidance and encouragement along with constructive criticisms, which were immeasurably helpful in completion of this study.

I extend my sincere gratitude to Dr. (Mrs.) Yasangika Sandanayake, Head of the Department, Department of Building Economics, University of Moratuwa, for her dependable assistance and guidance throughout the course of this research.

I am also thankful to my research advisors, Dr. Rangika Halwatura, Dr. (Mrs.) Thilini Jayawickrama and Dr. (Ms.) Sachie Gunathilake for their reviews and comments which were invaluable in directing this research towards success.

I gratefully acknowledge the funding received towards my MSc from the SRC (Senate Research Committee) Grant, University of Moratuwa.

A special thanking thought is conveyed to the construction industry experts and the workforce who gave me an immense support to successfully complete the empirical study of this research by kindly cooperating throughout the knowledge generating interviews and data collection process.

Last, but not least, I express my heartfelt gratitude to my family and friends, my colleagues, and many unnamed others, who willingly gave me their utmost support, assistance and inspiration to carry out the work successfully.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

JOURNAL PAPERS

- Weerasinghe, A.S. and Ramachandra, T., Economic sustainability of green buildings: life cycle cost analysis, BEPAM Special Issue on "Built Environment Sustainability: What's New and what's Next?" (Accepted with minor comments)

CONFERENCE PAPERS

- Weerasinghe, A.S., Ramachandra, T. and Thurairajah, N. (2017) Life cycle cost analysis: green vs. conventional buildings in Sri Lanka. *In*: Chan, P. W. and Neilson, C. J. (Eds.) *Proceeding of the 33rd Annual ARCOM Conference*, 4-6 September 2017, Cambridge, UK, Association of Researchers in Construction Management, 309-318.

- Weerasinghe, A.S., and Ramachandra, T. (2017) Are green buildings economically sustainable: a LCC approach. *In*: Sandanayake, Y.G., Ramachandra, T. and Gunatilake S. (Eds.) *Proceedings of the 6th World Construction Symposium 2017: What's New and What's Next in the Built Environment Sustainability Agenda?* 30 June—02 July 2016, Colombo, Sri Lanka, ISSN: 2362-0919.

ABSTRACT

Recently, the focus to green buildings has fore-fronted in countries like Sri Lanka. However, in the context of Sri Lanka, the number of green certified buildings is still at a minimal level and the reason could be attributed to green investors who continue to perceive that green buildings are costly with a 20 to 25% of green premium. They fail to appreciate the benefits that could be absorbed in the long run in terms of operation and maintenance costs. Further, in the global context, there are contradictory views with regards to green cost premium. However, in both context, only a little information is available on the status of operation and maintenance costs reduction. Further, quantitative evidence of running cost reduction in green buildings compared to conventional buildings, would enable green investors in their decision making. Therefore, this study establishes the economic sustainability of green buildings followed by a comparison of life cycle cost of green certified and that of conventional industrial manufacturing buildings in Sri Lanka and an assessment of the impact of each sustainable feature on life cycle cost of green buildings.

First, a preliminary study was conducted using the already published data on LEED certified buildings in Sri Lanka to identify the level of sustainability achievement in terms of variable sustainable features and the reasons for the level of achievement of those sustainable features. Afterwards, two green buildings and a conventional building with similar physical and performance characteristics were selected with due considerations to year of construction, Net Internal Area, and occupancy rate. The quantitative data on construction, operation, maintenance and end of life cycle costs of the selected green and conventional buildings were collected referring to green building construction budget, operation and maintenance expenditure budget records and analysed using Net Present Value and sensitivity analysis.

The analysis shows that the construction cost of green building is 37% higher than that of a conventional building while the green building offers a saving of 28%, 22% and 11% in terms of operation, maintenance and end of life cycle costs respectively. Overall the green buildings offer an economic sustainability of 21% over its life time. According to the sensitivity analysis, the changes in variables do not affect the economic sustainability of green buildings, still the life cycle cost of green building is less than that of a conventional building. Further, the sustainable features: Energy and Atmosphere and Indoor Environmental Quality contribute more to life cycle cost of green buildings due to the implementation of energy metering and sub metering, Building Management System, CO_2 and airflow measurement equipment, high-performance glazing, building commissioning and 3D energy modelling.

Therefore, the study recommends the green building investors to select suitable green strategies and technologies to reduce the life cycle cost of green industrial manufacturing buildings.

Keywords: Green Buildings, Green Rating Systems, LCC, Sustainable Features, Sri Lanka.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Green building is a part of the larger concept of sustainable development (Paul & Taylor, 2008). The global implication on how heavily the built environment contributes to the natural environment had led to the evolution of green buildings over conventional buildings (Means, 2011). U.S. Environmental Protection Agency (2016) defined green buildings as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle”. For example, United Nations Environment Program [UNEP] (2012) indicated that conventional buildings use about 40% of global energy, 40% of other resources, 25% of global water, and emit approximately 1/3rd of Green House Gas (GHG) emissions while green buildings save 19% of aggregate operational costs, 25% of energy, and 36% of CO_2 emissions (U.S. General Services Administration [USGSA], 2011).

Further, green buildings are said to be high performance buildings, focused to enhance the environment, social and economic sustainability pillars (Smith, Fischlein, Suh & Huelman, 2006). Green buildings reduce the environmental impacts significantly while using energy, water, and other resources efficiently by adopting various sustainable features such as sustainable sites, management, energy and atmosphere, water efficiency, materials and resources, indoor environmental quality, health and wellbeing etc. (U.S. Green Building Council [USGBC], 2009).

As per Dodge Data & Analytics (2016), the number of green buildings continues to double every three years and is responsible for 24% of the total construction activities. However, there exists some barriers in deciding whether to execute a green building project. Perceived higher construction cost is one such barrier amongst many barriers (Dwaikat & Ali, 2016; Fowler & Rauch, 2006). Further, Wilson and Tagaza (2006) identified, perception on higher capital cost, investment on short term paybacks rather than life cycle costing and lack of tenant demand contribute to financial barriers. Similarly, Durmus-Pedini and Ashuri (2010) pointed out that the return on investment needs more of a historical perspective to become more predictable. Company budgets are not usually structured to track the life cycle cost (LCC) for a project making longer term gain. The construction cost, cost of use and disposal cost should be considered at the beginning of a construction project to identify the most economically viable project (Akadiri, Chinyio, & Olomolaiye, 2012). Hence, there is a need to compare the LCC of green buildings with conventional buildings to address the issue of economic sustainability of green buildings.

Cole (2000) highlighted the fact that there is a widespread belief that the green buildings cost much more to build than traditional buildings. On a similar view, Kansal and Kadambari (2010) added that the initial cost of a green building is more compared to that of a conventional building while the operation cost of green building is less. A study conducted by reviewing 30 number of green schools across U.S. by Kats (2006), showed that construction cost of green schools cost than conventional schools by 2% and provide benefits over 20 times within 20-year period. Another study that analysed 150 recently constructed conventional and green office and school buildings in 33 states of 11 different countries, found that green buildings cost up to 4% more than conventional buildings, while majority ranges from 1 to 2% more than the similar conventional buildings. The study further indicated that green buildings reduce energy use by an average of 33%, which outweighed the initial cost premium (additional cost incurred to construct a green building) paid constructing these buildings within a 20-year study period (Kats, James, Apfelbaum, Darden, Farr & Fox, 2008).

Further, Kats (2010) also indicated the premium of cost of green school building ranges between 0 to 18%. However, more than 75% of the green buildings in Kats's sample had 0 to 4% premium higher than traditional building. However, the above findings were derived through a questionnaire survey with a single question responsible for quantifying cost premium. The participants of the survey were principal architects of the LEED-certified green buildings. Therefore, the reliability of the findings became questionable due to biasness of participants and the method employed. Moreover, most of the studies used cost estimation methods such as comparing actual cost of green buildings against modelled cost of conventional buildings and comparing modelled cost of green buildings and conventional buildings, while a very few were able to compare the actual cost of green buildings with that of conventional buildings (Dwaikat & Ali, 2016).

Moreover, previous authors have reported that higher levels of sustainability are usually linked to higher cost premium. Foregoing review further indicates that the cost premium of green buildings varies within the type of buildings. For example, Bartlett and Simpson (1998) compared the estimated capital cost for energy efficient and environmentally friendly buildings and concluded that industrial green buildings incur a higher capital cost than that of commercial buildings and houses. However, Dwaikat and Ali (2016) found that amongst the office, hospital, library, school, laboratory, house and apartment buildings, the highest green premium (21%) is from the office buildings. Whereas, the industrial manufacturing category was rarely considered in the previous studies.

With the growing global interest on sustainability, the concept of green building construction has come to the forefront of the construction industry in Sri Lanka (Abidin, 2010). However, as studies highlighted, there are some challenges for a developing country like Sri Lanka when leading towards the sustainable construction. For example, Bombugala and Atputharajah (2010) concluded that the construction cost of green buildings is about 20 to 25% higher than that of traditional buildings. Further, Waidyasekara and Fernando (2012) indicated that the green building investors primarily focus on minimising construction cost and failing to consider the life cycle economic performances. Therefore, investors completely ignore the other benefits which can be achieved through green buildings such as lower energy cost, lower annual electricity cost, reduced annual water cost and wastewater cost, lower annual fuel cost, and lower cost for waste disposal (Waidyasekara & Fernando, 2012). Lately, in the context of Sri Lanka, there have been a growing interest of manufacturing organisations to attract the international customers in order to market the products by producing them as carbon neutral.

Since cost is one of the most crucial concerns in promoting green buildings there is a need to provide robust evidence to counter the high initial cost barrier. The foregoing background review indicates that cost commitments of green buildings is the prime concern and has contradictory views with respect to different contexts, types of building, weather conditions, site conditions etc. Furthermore, the previous studies have no indication on running costs of green buildings compared to conventional buildings. The availability of quantitative evidence of running cost reduction in green buildings would enhance the investment on green buildings.

Therefore, there exists a significant gap in the quantified cost premiums and it is still questioned whether the green buildings cost more than its conventional counterparts. Yet, there is no conclusive answer to the question: are green buildings economically sustainable? Hence, a comparative analysis of LCC of green buildings and conventional buildings in Sri Lanka would provide a clear understanding of the cost impact and thereby enable potential green investors to take informed decisions about their green investments. The current study therefore, analyses the LCC of green vs. traditional industrial manufacturing buildings which have received the highest number of LEED certifications in Sri Lanka.

1.2 Problem Statement

Given social, environmental and economic benefits, there exist some economic barriers which decide whether to execute a green building project or not. Morris and Langdon (2007) indicated that most of the buildings require a little or no additional cost to incorporate a reasonable level of sustainable design. However, Kats (2003), Stegall (2004), Nilson (2005) and Fowler and Rauch (2006) are of the view that the construction cost of a green building is higher than conventional building while there is a less operation cost. The authors further stated that usually higher premiums result in higher level of sustainability. Packard Foundation (2002) estimated that a premium of 0.9%, 1.3%, 1.5% and 2.1% of total hard costs which include excavation, foundation works, concrete flatwork, etc., is required to achieve LEED Certified, Silver, Gold, and Platinum for an office building, respectively.

In the Sri Lankan context, it was identified that the construction cost of green buildings is 20-25% higher than conventional buildings while the advantage gained is 10 times as much over the entire life of the building (Bombugala & Atputharajah, 2010). Further, Waidyasekara and Fernando (2012) stated that still fewer buildings have implemented the green concept in Sri Lanka due to lack of understanding among professionals about the period of achievement of economic savings of green buildings.

Therefore, the extra investment cost of green buildings is happend to be the primary barrier which restricts the implementation of green buildings in Sri Lanka. Green building investments are unattractive to those who expect fast investment returns. A visible limitation of the past studies is that the researchers were unable to quantify the running cost saving of the green buildings over its high construction cost. The contradictory nature of the previous studies in terms of construction cost premium of green buildings drove to current study. The current study therefore compares the LCC of industrial manufacturing building and thereby establishes whether green buildings are economically sustainable. Further, the study analyses the LCC contributing through each sustainable feature to establish the resaerch question “are green buildings economically sustainable?”.

1.3 Aim and Objectives

The principal focus of this study is to establish the economic sustainability of green buildings. The following outlines the research objectives pursued throughout the study:

- Review the features and criteria of sustainability rating systems which are practiced in Sri Lanka and potential green building strategies and technologies which are related to each criterion and their cost impact
- Identify the level of achievement of available sustainable features as per green rating systems and the reasons for the level of achievement in green industrial manufacturing buildings in Sri Lanka
- Compare the LCC of green Vs. conventional industrial manufacturing buildings in Sri Lanka

- Assess the impact of sustainable features which cause the difference in LCC of green industrial manufacturing buildings in Sri Lanka

1.4 Research Methodology

A comparative analysis between a green building and a conventional building was adopted for this study. Prior to this, a preliminary analysis was carried out into green certified buildings to identify the most significant green space type, and the level of sustainability achievement in terms of main sustainable features within it. This analysis enabled to identify the relationship between sustainable features and its impact on initial cost as well as LCC. The preliminary analysis was performed on the secondary data collected from 38 of LEED Green certified buildings in Sri Lanka. Amongst eight (08) green industrial manufacturing cases which were certified under LEED BD+C: New Construction & Major Renovations (V.3 - 2009) rating system were screened for further study. The eight (08) industrial manufacturing cases included Garment (04), Printing and Packaging (03) and Cleaning Products (01) buildings. The age, Net Internal Area (NIA), and occupancy rates differ for each case. However, the building height is mostly limited to 01 or 02 floors. Subsequently, a comparative analysis was performed by selecting two (02) green buildings and a conventional building with similar physical and performance characteristics. When selecting these two cases, the age, NIA, and occupancy rate factors were considered. The conventional case was identified easily, then careful selection of two (02) green cases with similar characteristics was carried out by eliminating the cases which have considerable differences in physical characteristics.

Relevant real-life cost data: construction, annualised and periodic operation and maintenance (O&M), and end of life cycle costs data were collected through document analysis according to the standard cost categories suggested by Building Cost Information Service (BCIS). The documents relevant to the initial green building construction budget, and O&M expenditure budget records were used to collect the cost data. Simultaneously, physical and performance data such as the year of construction, the number of floors, NIA, life cycle, the height of the building, and the number of occupants were collected from the selected green and conventional buildings. Statistical analysis techniques: NPV and sensitivity analysis were used to measure the LCC of green buildings. All the costs were escalated at assumed inflation rate and then discounted for the base year. The analysis was carried out for 50 years and the discount rate (4.26%) was obtained from the Central Bank of Sri Lanka.

1.5 Research Scope

The current study aims to asses the impact of various sustainable features on the LCC of green buildings and thereby to, promote the implementation of green buildings or transformation of existing buildings into green through achieving sustainable features over their associated higher initial cost. The current study is limited to green buildings certified under the LEED BD+C: New Construction v3 (2009) rating system in Sri Lanka. The LEED BD+C: New Construction v3 (2009) rating system is the mostly used certification system in the context in Sri Lanka. Amongst, the types of green spaces certified in Sri Lanka, Industrial Manufacturing has reached the top place. Thus, the study was limited to Industrial Manufacturing facilities. Lately, there has been a growing global interest on sustainable manufacturing in Sri Lanka to attract the international customers and thereby contribute to the national economy. Therefore, this study focuses on sustainable features based on its implementation on Sri Lankan buildings, its contribution to LCC of green buildings and how the cost contribution can be impacted the LCC of green buildings than that of conventional buildings.

1.6 Chapter Breakdown

Chapter One - Chapter one introduces the research project and provides background information on the magnitude of the research problem. It goes on to justify the need for the study with a commentary on previous studies around the problem area. The research objectives are presented which address the research question.

Chapter Two - This chapter presents the literature review connected with definitions of green building, green buildings development through the global perception of green buildings, their benefits, economic barriers for green buildings, LCC of green buildings and conventional buildings, cost efficiency of green buildings, sustainability domains and criteria which makes buildings green and the significant sustainability domain and criteria in the context of Sri Lanka. The chapter provides the conceptual framework to the study's approach to green buildings.

Chapter Three - Chapter three describes the research methodology. Accordingly, the adopted research paradigm, strategy, and methods were discussed in Chapter 3.

Chapter Four - Chapter four presents the analysis and findings of the survey and the research verification using LEED accredited professionals. The analyses of the data obtained is presented and discussed within the context of the research objectives.

Chapter Five - This chapter presents a synthesis of the research findings by comparing the outputs of literature review with the survey findings and the opinion held by LEED accredited professionals. The chapter sieves through the key findings of the research and paves way for the recommendations in chapter six.

Chapter Six - Chapter six concludes the study by integrating all the parts of the thesis into a meaningful conclusion. The chapter provides a list of recommendations for the improvement of green buildings in Sri Lanka.

CHAPTER TWO

2.0 LITERARTURE REVIEW

2.1 Introduction

This chapter aims to synthesize the current knowledge level regarding the research area and thereby refine the research problem. This chapter presents an overview of economic sustainability of green buildings in five major sections. The first section is about the concept of sustainable development, followed by literature on green buildings in second section including definition of green buildings, their benefits, and the economic barriers for green buildings. The third section discusses sustainable features, criteria, strategies and technologies which make buildings green. The fourth section focuses on the cost of green building vs. conventional buildings and also brings the relationship between sustainable features and the cost of green buildings. . The fifth section is about factors influencing LCC of buildings. Finally, the chapter presents the summary literature findings and establishes the knowledge gap.

2.2 Sustainable Development (SD) and Green Buildings

In recent years, the term sustainability has been identified as the ability to maintain and it is dependent upon the object being described (Bhamra & Lofthouse, 2007; Laloe, 2007; Lutzkendorf & Lorenz, 2007). Accordingly, Venkatesh (2015) stated that SD is a process which ensures that the end goals of sustainability are achieved. The three pillars of the SD: social, environmental and economic or the triple bottom line approach was first suggested by the Economist Ed Barbier in 1987 (Du Plessis, 2007). Later, John Elkington introduced the 3Ps: people, planet and profit in achieving SD in 1994 (Venkatesh, 2015). Venkatesh (2015) further stated that term holistically SD is used where all these aspects: social, environment and economic sustainability are factored in (Venkatesh, 2015).

Several authors attempted to prioritise the three pillars (Hopwood et al., 2005; Kates et al., 2008; Lehtonen, 2004). Among them, Lehtonen (2004) introduced the hierarchy of the three elements as environment, social and economy. However, he further observed that the hierarchy could be changed in different circumstances considering the relevant situation, time, and where the operation of society and economy does not undermine the environment. Similarly, Venkatesh (2010) found that environment comes first by mapping individual sustainability to global sustainability. Accordingly, the physical development of individual contributes to the global economic sustainability, mental, emotional and psychological components of individual development contribute to the social sustainability and the spiritual growth of the individual contributes to the environmental sustainability (Venkatesh, 2010). Therefore, the three pillars could be prioritized as follows: environment comes first, then the social and lastly the economy.

Construction industry is considered as a key sector for achieving SD goals. Sustainable construction (SC) has been increasingly acknowledged during the past few decades, due to the global implication on how heavily the construction sector contributes to the global resources. For instance, UNEP (2012) found that the construction sector uses about 40% of global energy, 40% of other resources, 25% of global water, and emits approximately 1/3rd of Green House Gas (GHG) emissions. As of today, green buildings and sustainable buildings are important concepts which minimise the global resource consumption. Sustainable building focuses specifically on the state: environmental and functional quality and the functional value of the end product: building during its whole life cycle (Anink et al., 1996; John et al., 2005; Rohracher, 2001), whereas green concept focuses more on the environmental issues. Kibert (2008) stated that green building is a sub-set of sustainable building. Accordingly, USEPA (2016), green building is defined as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle”. Further, as noted by Kibert (2008), a sustainable building is more towards the quality and characteristics of the actual structure created using the principles and methodologies of SC, than the process of achieving the product. Therefore, Kibert (2008) further noticed that, even though the SC addresses total sustainability, the green buildings become the flagship of achieving SC as it is impractical to reach total sustainability.

2.3 Green Buildings

Green buildings are something more than assembling environmental friendly elements to a building or retrofitting of existing buildings (Karolides, 2002). It also provides a healthy work environment for the building occupants and makes profit to the organization (Dow Corning, 2005) through the savings of energy and other resources (World Green Building Council [WGBC], 2013). The Green Building Council of Australia (GBCA, 2012) specified that, green building concept should be involved in all the stages of a building from designing, constructing, operating, maintaining to demolishing of a building. Thereby, green building positively impacts and enhances the convenience of both occupants and natural environment.

Various definitions provided by different authors and reputed organizations about green buildings are summarised in Table 2.1.

Table 2.1: Definitions of Green Buildings

Year	Source	Green Building Definition
n.d.	Otogawa Anschel	A system with efficient usage of energy and water, indoor environment quality and managing the site which represents the best practices
2003	Smith	The designing, constructing and operation are focusing the high performance of the building with the enhancement of health of the occupants, environment as well as the economy
2008	Local Initiatives Support Corporation	Bunch of sectors maximizing the economic efficiency, health efficiency and enhancing the life span of the building by adopting environmental friendly practices to the life cycle phases of the building
2014	Green Building Council of USA	A combination of well recognized practices in planning, designing, construction, operation of the building with proper energy management procedures, water management, waste disposal, indoor environment comfortability, material usages and the effects on the site
2017	Environmental Protection Agency	The practice of creating structures and using processes that is environmentally responsible and resource-efficient throughout a building’s life-cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction.

Consequently, the green building is defined as “a building focusing on the environmental sustainability as well as the sustainable social and economic practices throughout its lifecycle,” for this study.

According to WGBC (2013), there are seventy-four (74) Green Building Councils established all over the world by today which also shows the encouragement to being involved in the green building development. The green building is a widely practiced concept in globally and the construction professionals are trying to implement green thereby enhance the sustainability of the building (WGBC, 2013). Nowadays, the building owners have the opportunity of converting an existing building into green with the aid of technological development (Kavani & Pathak, 2014). Further, Samer (2013) indicated that the advantages of green buildings have reflected in immense increased of recent trend in green buildings.

Waidyasekara and Fernando (2013) stated that there is a great requirement to promote the construction of green buildings in Sri Lanka with the rapid growth of the construction industry. However, many professionals have less adequate knowledge about the economic, social and environmental benefits that a green building could bring and a less number of buildings in Sri Lanka have been implemented with green concerns.

Green Building Council Sri Lanka (GBCSL) was launched in 2009 and is a non-profit organization which is devoted to encourage the adoption of green building practices thereby develop a sustainable building industry in Sri Lanka and also has introduced a green rating system. GBCSL came into existence because of an emerging trend towards applying greener concepts for the built environment. Thus, the green building concept is new to the Sri Lankan context and it is introduced to many industries as they are searching for more energy efficient buildings for their usage (GBCSL, 2010). Green buildings represent the next phase of buildings, however, the reality is that most of the buildings in Sri Lanka are not green. These traditional buildings will avoid the green building benefits explained in next section.

2.3.1 Benefits of Green Buildings

The benefits of green buildings may be ten times more than in its construction cost (Bombugala & Atputharajah, 2010). Heerwagen (2000) identified the following benefits of green buildings.

- Optimum usage of resources at construction stage and after occupying the building
- Increase the usage of renewable resources like solar power, wind etc.
- Waste management
- Maintain good and healthier landscaping practices
- Integrate natural environment and built environment
- Reduce the CO_2 emission through regional priority of resources

Subsequently, Kats et al. (2008), indicated that green buildings offer following economic, environmental and social benefits.

- Energy efficiency and conservation through building orientation, natural daylight and ventilation
- Use of natural insulation such as roof gardens
- Use of renewable energy sources such as solar, wind, geothermal, biomass, hydro power, biogas
- Material selection based on their life-cycle environmental impacts
- Reduce, reuse, and recycle of materials throughout building construction and demolition
- Reduce harmful waste products during construction
- Reduce or eliminate toxic and harmful materials
- Sustainable maintenance and operational practices which reduce or eliminate harmful effects on people and the natural environment
- Personal and local control over temperature, air flow, and lighting

The green building benefits ensure the well-being of the environment and humans (Kats, Alevantis, Berman, Mills & Perlman, 2003). Green buildings have been widely accepted as one of main practices to constrain resource diminution. Globally, much emphasis has been placed on optimizing energy and resource efficiency to meet building performance objectives and achieve economic benefits through green buildings (Brown, 2009). Similarly, USGSA (2011) found out that, green buildings have a 19% lower aggregate on operational costs, 25% of less energy, and 36% of fewer CO_2 emissions. Similarly, Bombugala and Atputharajah (2010) concluded that the construction cost of green buildings is 20-25% higher than that of traditional buildings, however, green buildings reduce carbon emissions by 35%, water usage by 40%, energy usage by 50%, and solid waste by 70%.

Although green buildings are beneficial in many ways, there are certain barriers to green buildings. The background study indicates different arguments on the LCC of green buildings amongst high cost for green technologies has become one of the top barriers in the implementation of green buildings. The next section of literature therefore focuses onto economic barriers of green buildings and thereby to identify the most prevalent barriers which restrain the growth of green buildings.

2.3.2 Economic Barriers and Drivers of Green Buildings

According to recent surveys, the first costs remains as the primary barrier to green building. In fact, over 700 construction professionals responded to the Global Green Building Trends survey, released in 2008, indicated that higher first costs is an obstacle to implementation of green building (Kats, 2010). It is therefore more important to understand how the excessive cost of green technologies can become the major obstacle.

The misperception towards the capital costs of green buildings and the inadequacy of green building market value are the primary barriers which prevalent the development of green buildings (Bon & Hutchinson; 2000, Hydes & Creech; 2000 and Zhou & Lowe; 2003). In fact, the cost consultants have overestimated the capital costs and underestimated the potential cost savings of green buildings (Bartlett & Howard, 2000). Similarly, Hydes and Creech (2000) highlighted that higher costs of green buildings come due to increases in the consultancy fees and unfamiliarity of the design team and contractors towards green building strategies and technologies. Recent studies by Sayce et al. (2007) and Sodagar and Fieldson (2008) emphasised, additional construction cost is one of major obstacles exists for the wide uptake of green buildings. The authors further suggested that financial incentives and innovative fiscal arrangements should be available to overcome the high cost barrier. Thereby, the extra costs can be recovered through increased rentals later.

The clients who willing to invest on green buildings, should rely on the green buildings' positive effect on market and use values of buildings. The increased market value for green buildings is difficult to achieve due to the lack of direct visibility of energy and environmental impacts. In fact, Ala-Juusela, Short, and Shvadron (2014) stated that, major cost savings of energy-efficient buildings during operation stage are not adequately communicated to a wide audience. The authors further demonstrated that significant improvements in energy performance need a very little additional cost using real cost data of energy efficient technologies and design solutions. These findings contradict the assumption of high costs required for energy-efficiency. Contradictory, Waddel (2008) stated that those who rate social and environmental impacts as important such as banks and other financial institutions have less attractiveness and lower market value on green buildings due to the realisation of improved energy efficiency and corresponding lower operational costs rather than environmental and social aspects.

In a different point of view, Bordass (2000) stated that consideration on life cycle cost of green buildings is often ignored due to those who construct the building and pay the upfront costs are not the building occupiers and do not receive the benefits. Adding to that, Heerwagen (2000) highlighted that the barriers for green buildings remain because of the lack of quantitative documentation of LCC benefits of green building features. Addressing the importance of applying LCC methods in green projects, Cole and Sterner (2000) and Sterner (2000) showed that lack of motivation, reliable data and methods are the reasons for insignificant use of LCC. According to Gluch and Baumann (2004), the application of LCC on green projects has been questioned due to the omission of the cost impacts on natural environment. The background study indicated different arguments on the cost of green buildings and higher initial cost for green technologies has become one of the top most barriers for the implementation of green buildings.

2.4 Sustainable Features of Green Buildings

This section primarily reviews the principal sustainable features incorporated in green buildings and their impact on the LCC of green buildings. In doing that, the study first presents the green building rating systems available in global context including Sri Lanka and the sustainability features and criteria available within those rating systems. Secondly, the study analyses the LCC impact of sustainable features through the degree of impact on construction cost and LCC impact element.

Worldwide there are several building evaluation tools which focus on different areas of sustainable development and are designed for different types of projects. By March 2010, there were 382 registered building software tools for evaluating energy and atmosphere, renewable energy, and buildings' sustainability (Nguyen, 2011). Nowadays, most of the countries have established a body of environmental certification and developed national assessment systems for sustainability (Smith et al., 2006). However, only a few systems are widely acknowledged and of recognizable standard for sustainable development. Additionally, GREENSL rating system holds the credit for national assessment system in Sri Lanka. Table 2.3 is an extract from Table 2.2 in Annexure 1 highlights the summary of key rating systems along with their common sustainability features considered and building types applied to. As per, Table 2.3, sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality features are common features. These rating systems identified can be applied to variety of buildings types such as office, industrial, retail, school, homes, residential, healthcare, educational facilities and institutional buildings whether new construction or existing buildings.

Accordingly, the next section considers a comparison of point allocation among the common sustainability features available under LEED and GREENSL® ratings.

Table 2.3: Green Building Rating Systems and Sustainability Features

Source	Rating System	Established Year	Country	Common Sustainability Features	Applied Building Types	Applied Building Phases
Fowler and Rauch (2006); Say and Wood (2008); Nguyen (2011)	Building Research Establishment Environmental Assessment Method (BREEAM)	1990	United Kingdom	Sustainable sites Water efficiency Energy & atmosphere Materials & resources Indoor environmental quality	Homes Industrial Multi-residential Offices Retail Schools Healthcare facilities Education facilities Institutional buildings	New Construction Existing buildings
	Leadership in Energy and Environmental Design (LEED)	1998	United States			
	Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)	2001	Japan			
Nguyen (2011)	Hong Kong Building Environmental Assessment Method (HK-BEAM)	1996	Hong Kong			
Fowler and Rauch (2006)	GBTool	1998	Canada			
Say and Wood (2008); Nguyen (2011b)	Green Star	2003	Australia			
Fowler and Rauch (2006); Say and Wood (2008)	Green Globes	2005	Canada			
Green Building Council of Sri Lanka (2015)	GREEN SL® Rating System	2010	Sri Lanka			

2.4.1 Significant Sustainable Features of Green Buildings in Sri Lanka

LEED has been active in Sri Lanka, even before the GREEN$^{SL®}$ rating was introduced by the GBCSL in 2010. For example, the first LEED certification in Sri Lanka was issued in 2008 (Bombugala & Atputharajah, 2010). Fowler and Rauch (2006) highlighted LEED® is the dominant and most widely used rating system around the world. To date, LEED encompasses more than 72,500 LEED building projects over 150 countries and territories. Moreover, GREEN$^{SL®}$ rated building has an equivalent efficiency as a LEED rated building (GBCSL, 2015). Table 2.6 is an extract from Table 2.4 and Table 2.5 in annexure 2 provides the summary of point allocation of LEED BD+C NC (V3) and GREEN$^{SL®}$ for the sustainable features.

Table 2.6: Summary of Point Allocation of LEED NC Version 3.0 and GREEN$^{SL®}$

	Sustainability Feature	**Possible Points**	
		LEED BD+C NC v3 (2009)	GREENSL®
Most Significant	Energy and Atmosphere	35	21
	Sustainable Sites	26	25
	Indoor Environmental Quality	15	21
	Materials and Resources	14	21
	Water Efficiency	10	14
Less Significant	Innovation and Design	6	4
	Regional Priority	4	-
	Management	-	4
	Social and Cultural Awareness	-	3
	Total	110	113

As shown in Table 2.6, energy and atmosphere is top ranked in LEED BD+C NC (v3) rating system and sustainable sites feature is close second, whereas, the sustainable site is identified as the most important sustainable feature in the Sri Lankan context (energy and atmosphere, material & resources and indoor environmental quality are close second) and associated with higher points in GREEN$^{SL®}$ rating system. Management and social and cultural awareness are specific sustainable features to the GREEN$^{SL®}$ rating system while regional priority feature is excluded from GREEN$^{SL®}$ rating system. However, the sustainability criteria in each common sustainable feature seems to be similar between the two rating systems.

The common sustainable features; sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality are further identified as the most significant sustainable features of the green buildings in Sri Lanka, as 10 or more than 10 points were allocated for those features in both rating systems. Next section identifies the sustainability criteria with their green building strategies and the technologies that belong to each sustainable feature derived from LEED and GREEN$^{SL®}$ rating systems.

- **Sustainable sites (SS)**

Sustainable sites feature emphasizes about the integration of building location with the sustainable aspects in order to reduce the negative impacts of buildings on local ecosystems (Kibert, 2008). Thereby, encourages the green building d decision makers to preserve or restore the natural ecosystems.

- **Water efficiency (WE)**

This category deals with adoption of water conservation strategies such as reducing or eliminating the use of potable water for landscaping, incorporating innovative technologies for storing or reusing water, reducing wastewater generation and maximizing water efficiency in buildings by adopting high efficiency fixtures (Kibert, 2008).

- **Energy and atmosphere (EA)**

Energy and atmosphere category focuses on optimizing the energy performance of the projects to reduce operation costs and adopting measures like renewable energy that can help in reducing the energy consumption (Lavy & Fernandez-Solis, 2009).

- **Materials and resources (MR)**

This feature takes account of support reusing the existing building materials, minimising waste generation, usage of recycled and locally available materials, along with certified wood to reduce the environmental impact (Kibert, 2008).

- **Indoor environmental quality (IEQ)**

This category emphasizes various measures for the health of building occupants such as lighting, ventilation, thermal comfort, indoor air quality. Further, the usage of low emitting materials has been considered to reduce the impacts of volatile organic compounds on comfort and well-being of occupants (Lavy & Fernandez-Solis, 2009).

As the study focuses on LCC of the green buildings, next section discusses the LCC cost impact of identified sustainability criteria compared to conventional counterparts.

2.5 Cost of Green Buildings vs. Conventional Buildings

Above literature revealed that there is a visible encouragement to being involved in the green building concept, while considering the economic efficiency of life cycle phases in green buildings. As an example, the definitions introduced by Smith (2003), Local Initiatives Support Corporation (2008) and Environmental Protection Agency (2017) specifically use the word “economic”. However, the literature also revealed that there exist some economic barriers when executing green buildings. Among them perception of high risk and higher investment costs (Hydes & Creech, 2000; Larsson & Clark, 2000; Nelms, Russel, & Lence, 2005), inadequate communication to the wider audience about major cost savings during operation (Ala-Juusela et al., 2014), misperception of incurring higher capital costs (Hydes & Creech, 2000; Zhou & Lowe, 2003), overestimating the initial cost and underestimating the potential cost savings of energy efficient measures (Bartlett & Howard, 2000) and the inadequate market value (Kohler, 2008) remain as the main hindrances to the uptake of green buildings.

Empirical studies which have compared the green buildings with similar natured conventional buildings have contributed to raise the awareness among investors and developers on the cost benefits and feasibility of implementing green buildings. The comprehensive review of empirical findings indicates that the construction cost premium of green building differs in terms of building type, certification level, cost estimation methods and sample size, etc. An in-depth analysis conducted by Kats (2003), revealed that investors should spend higher capital cost on LEED-NC certified high performance sustainable buildings and the cost is likely to be increased with respect to the level of certification (Kats, 2003).

As estimated by Nilson (2005), 0.82% of total construction costs should be incurred to achieve the LEED Gold certification for an office building. Moreover, a premium of 1-3% is estimated for a residential building which is enough to achieve LEED Silver certification (Stegall, 2004). In another situation, Kats (2006) performed an analysis on 30 green school buildings that were built in 10 different states during 5 years' time. According to results of the study, it was found that green school design involved 1-2% additional cost when compared with a conventional design. Author further explained that green buildings offer benefits that were 20 times as large over a 20-year period. Savings in health and productivity costs due to increased earnings, reduction in respiratory diseases, and higher employee retention made up 85% of total whole life cost savings, with savings in energy, water and waste contributing to the remaining 15%.

Another study that analysed 150 recently completed green and conventional buildings in 11 countries, estimated that green buildings' cost is above 4% than conventional buildings, however, most buildings cost up to 2% than conventional buildings (Kats et al., 2008). Authors further found that, energy used in green buildings was reduced by 33% on average, and that energy cost savings alone over a 20-year study period outweighed the construction cost premium of these buildings (Kats et al., 2008).

In this sense, this section analyses the empirical findings of previous studies in terms of type of building, methodology adopted, sample size used, and certification level and the outcome. Table 2.7 presents the summary of findings of Twenty-Five (25) previous studies.

As seen from Table 2.7, studies have focused on various types of buildings such as residential - high-rise apartments, office, education, and hotel buildings, etc. while the industrial manufacturing category was rarely considered. Further, the focus on running cost and LCC of green buildings is also lacking in the previous studies. In addition to that, the construction cost premium of green buildings varies largely from -15% to 20% than the construction cost of conventional buildings.

Table 2.7: Summary of Previous Studies on Green Cost Premium

Type of Building	Cost Premium Range	Methodology Adopted	Source
Office	-0.3 to 1.3%	Cost analysis of re-designing 03 existing buildings to green	Xenergy and Sera Architects (2000)
Office	LEED Certified: 0.9% Silver: 13.1% Gold: 15.5% Platinum: 21%	Single case study: comparative cost analysis of modelled cost of green building against market baseline	Packard foundation (2002)
Office, School	Average:1.84% LEED Certified: 0.66% Silver: 2.11% Gold: 1.82% Platinum - 6.5%	Cost comparative analysis - actual cost of 33 green buildings against conventional design estimated through participants' perception	Kats, Alevantis, Berman, Mills and Perlman (2003)
Office	Soft costs: -1.5 to 3.1% Hard costs: 3 to 8%	Meta-analysis of secondary research and unspecified analysis of actual cost of green	Northbridge Environmental Management Consultants (2003)
Office and Courthouse	-0.4% to 8.1%	Cost comparative analysis - modelled costs of 02 green buildings against conventional	Steven Winter Associates (2004)
Office	0.82%	Single case study: cost comparative analysis	Nilson (2005)
Office	No statistically significant cost difference	Unpaired t-test of actual green fit-out costs of 12 green buildings against 13 non-green fit-out costs	Davis Langdon (2007)
Office	4 Star: 3 to 7% 5 Star: 7 to 15%	Cost comparative analysis - modelled costs of 20 green building against conventional	Fullbrook (2007)
Office	4 Star: 1.25% 5 Star: 4.37% 6 Star: 6.23% Unrated: 2.91%	Single case study – Cost comparative analysis	Fullbrook and Woods (2009)
Office	No statistically significant cost difference	Cost comparative analysis - actual cost of 17 green buildings against modelled cost of conventional	Rehm and Ade (2013)
Office	1.5 to 6.5%	Single case study – cost comparative analysis	Fullbrook, Jackson and Finlay (2005)
Office	LEED Certified: 1.2% Silver: 2.25% Gold: 3.37% Platinum: 7.66%	Participants' Perception	Kats, Braman and James (2010)
Academic	No statistically significant cost difference	Unpaired t-test - actual costs of 22 green building against non-green buildings	Matthiessen and Morris (2007)
Academic	-15%	Single case study – cost comparative analysis	Fullbrook, Jackson and Finlay (2005)
Academic	LEED Certified: 1.65% Silver: 1.8% Gold: 1.93% Platinum: 2.53%	Participants' Perception	Kats, Braman and James (2010)
Academic, Laboratory and Library	No statistically significant cost difference Majority: no additional cost	Unpaired t-test - actual cost of 45 LEED seeking buildings against 93 non-LEED seeking buildings	Matthiessen and Morris (2004)
Library	4.90%	Single case study – cost comparative analysis	Fullbrook, Jackson and Finlay (2005)

Higher education	3 to 5%	Participants' Perception	Building Design and Construction (2007)
School	11 to 15%	Participants' Perception	Building Design and Construction (2007)
Schools	LEED Certified: 0.35% Silver: 1% Gold: 1.3% Platinum: 9.6%	Participants' Perception	Kats, Braman and James (2010)
School	Average: 1.7%	Cost comparative analysis - 30 green buildings against conventional	Kats (2006)
School	46%, Mean construction cost per square foot is significantly higher	Cost comparative analysis - 30 green buildings against 30 conventional	Shrestha and Pushpala (2012)
School	5.70%	Single case study – cost comparative analysis	Fullbrook, Jackson and Finlay (2005)
House	LEED Silver: 17%	Single case study: itemized cost impact analysis	NAHB Research Centre (2009)
Residential	Cost per square foot - no statistically significant cost difference	Cost comparative analysis – 15 green projects against 22 conventional	USGBC (2009)
Residential	10.77%	Single case study: cost comparative analysis	Kim, Greene and Kim (2014)
Residential	6 to 10%	Participants' Perception	Building Design and Construction (2007)
Healthcare	0% to 5%	Cost comparative analysis - cost of 13 green and buildings against conventional	Houghton, Vittori and Guenther (2009)
Healthcare	1.50%	Single case study – cost comparative analysis	Fullbrook, Jackson and Finlay (2005)
Healthcare	3 to 5%	Participants' Perception	Building Design and Construction (2007)
Hotel	3 to 5%	Participants' Perception	Building Design and Construction (2007)
Restaurant	3 to 5%	Participants' Perception	Building Design and Construction (2007)
Bank	No statistically significant cost difference	Cost comparative analysis - 02 green and conventional	Mapp, Nobe and Dunbar (2011)
Commercial	Cost per square foot - no statistically significant cost difference	Cost comparative analysis - 12 green commercial interior projects and 13 conventional	USGBC (2009)
General	-5 to 10% Majority: 5 to 10%	Participants' Perception	Ahn and Pearce (2007)
General	1 to 15% Majority: 6 to 10%	Participants' Perception	Building Design and Construction (2007)
General	1 to 10% Majority: 5 to 10%	Participants' Perception	Park, Nagarajan and Lockwood (2008)
General	0 to 18% Majority: 0 to 4%	Participants' Perception	Kats (2010)

Considering the methods followed by the previous cost studies specified in the Table 2.7, this ranges from studying single case studies to larger sample sizes. Various cost estimation methods have been used to find out the cost premium of green buildings. Amongst, estimation of green cost through the survey respondents is the least applied method and Rehm and Ade (2013) pointed out that this method is less reliable, and the findings are biased from the selected respondents. Comparing actual cost of green buildings with actual or modelled cost of conventional buildings and comparing modelled cost of green buildings with the modelled cost of conventional buildings are other methods which were employed in the empirical investigations to estimate the cost premium of green buildings.

Most of the empirical studies were conducted by trade organizations where the methods used to model the cost of the buildings are unclear. Due, to the lack of indexed papers in the focus area, there is a need for conducting detailed research which provides measurable definitions for the green building and to define the green cost premium and its measurement methods (Rehm & Ade, 2013).

Further, the cost premium for these buildings were based on different green certification levels in BREEM, Green Star and LEED rating systems. The cost premium increases with the certification level. The buildings with higher level of green often require increased green cost premium than those lower of certification level. Amongst the selected buildings for the previous studies, most of the studies were conducted on office buildings and reported the highest green premium (21%).

Table 2.8 presents a further scrutiny of the findings shown in Table 2.7, according to the cost premium of different types of buildings. Here, the different types of buildings were further divided into four main categories as social, commercial, residential and unclassified considering the main purpose which those buildings serve for.

Table 2.8: Summary of Cost Premium for Green Buildings

Type of Building	**Number of Studies (Cost Premium %)**						**Total (No.)**
	Less than 0%	0%	0 - 5%	0 - 10%	0 - 20%	Higher than 20%	
Social							**18**
Schools/ Higher Education	1	2	3	3	1	1	11
Healthcare			3				3
Library		1	1				2
Laboratories		1					1
Courthouse	1						1
Commercial							**15**
Office	2	2	1	5	1	1	12
Bank		1					1
Hotel/ Restaurant			1				1
Commercial		1					1
Residential/House		1		1	2		**4**
Unclassified	1			1	2		**4**

As shown in Table 2.8, most of the previous studies have focused on the buildings which are used for social purposes such as, school/higher education, healthcare, libraries, laboratories and courthouse. The number of studies done for this type of building equals to 18. Amongst, the highest number of studies have focused on the construction cost premium of school/higher education buildings which ranges between less than 0% to above 20% of total construction cost of traditional buildings. Whereas, healthcare and library buildings were selected for 3 and 2 studies respectively, and laboratories and courthouse have been selected for only one study. Second largest category of building type is buildings constructed for commercial purposes and consists with 15 studies focused on office, bank, hotel/restaurant and commercial buildings. Amongst, most (12) studies have focused on office buildings and construction cost premium ranges between less than 0% to above 20% of total construction cost of traditional buildings. Rest of the studies under this category contributes one study per each type of building. The studies conducted for residential and unclassified purposes equally contributed by 04 number of studies.

Although the estimated cost premium percentages were different, many studies have concluded that green certification is likely to result in a higher premium. Also, the green cost premium is expected to change according to the type of green certification, the desired level of green rating, the impact of sustainable features incorporated, and the nature of the buildings. The previous studies on green building costs were limited to the initial cost of green buildings, while completely ignoring the LCC of green buildings compared to conventional buildings. However, some of the previous authors also have indicated that there are green building benefits which can be obtained in a life cycle perspective.

The reasons identified in the global context couldn’t generalise into Sri Lankan context. These variations in green cost premiums among different types of buildings and inadequacy in methods adopted to assess the green cost premium have driven the current study to compare the LCC of a conventional industrial building with a similar type of green building and confirm whether green buildings are economically sustainable. The green space for industrial manufacturing buildings has received the top most position with 18 out of 38 LEED certified green buildings in Sri Lanka to date while in the global context the industrial manufacturing category was rarely considered for the cost studies. Therefore, the above review confirms the need of LCC analysis of green industrial manufacturing buildings in Sri Lanka.

2.5.1 Cost Impact of Sustainable Features

As discussed previously, the high initial cost of green building is attributed due to applications of sustainable features. This is further supported by Fowler and Rauch (2006) and Nguyen (2011) that green buildings promote sustainability through principal areas like sustainable sites, management, energy and atmosphere, water efficiency, materials and resources, indoor environmental quality, health and wellbeing etc. This section therefore reviews the impact of those sustainable features on LCC.

Table 2.10 is an extract from Table 2.9 in Annexure 3 summarises the literature findings on sustainable features and its cost impact. The cost impact of sustainable features was assessed on the four-point qualitative scale of Minimal (M), Low (L), Significant (S) and Minimal to Significant (M to S). Further, BMCIS standard cost classification system was used in relating the sustainable features to respective LCC (main) element(s).

As observed from Table 2.10, many of the sustainable elements of sustainable sites have very low initial cost impact (Davis Langdon, 2007). And those can be readily achievable at a little cost. 10 out of 14 applicable criteria in the sustainable site category contribute to the LCC of the green building through fuel oil, electricity, service attendants, internal/ external surface and window cleaning, gardening, repairs and decoration, roads pavement, external glazing (shading), fuel, loose appliances, lamp replacement (BMCIS, 1984).

The applicable criteria of water efficiency also have a low initial cost impact, excluding the instances where the project involves high-end technologies like innovative waste water technologies (Davis Langdon, 2007). The LCC of the green building is affected by all three applicable criteria in the water efficiency category, through water charges, service attendants, repairs and decoration, cold-water services, sanitary fittings, water meter readings, and built in fittings (BMCIS, 1984).

Energy applicable criteria require a high degree of focus and can be challenging for many projects (Davis Langdon, 2007). In fact, those have very high initial cost with most readily calculated LCC such as electricity, air conditioning & ventilation, gas meter readings, electricity meter readings, refrigerant equipment, loose appliances, repairs and decoration, and built in fittings (BMCIS, 1984).

Almost all the applicable criteria associated with material and resources have both minimal and significant cost impacts considering the compliance or other physical conditions (Davis Langdon, 2007). Considering the LCC impact of material and resources, almost all the applicable criteria contribute to the cost of waste disposal and fabric maintenance (BMCIS, 1984). Due to the existing building elements with major renovations they can be less durable and costly to maintain than the newly constructed elements. For example, Stas (2007) assumed that the operating expense ratio of the adaptive reuse (maintaining the existing building structure for 100% is 12% of the operating income and 10% for the new constructions. However, building and material reuse greatly reduce the construction and demolition waste.

The applicable criteria in IEQ are readily achievable with low costs (Davis Langdon, 2007) and contribute to the LCC through glazing and windows, built in furniture, ceiling, wall and floor finishes, air conditioning and ventilation, meter readings, lighting, lamp replacement, built in fittings, internal/ external surface and window cleaning, electricity, gas and service attendants (BMCIS, 1984).

The points allocated for sustainable features; innovation in design and regional priority are either achieved with a minimal cost impact or the application of these two features is covered by other sustainable features which were discussed earlier (Davis Langdon, 2007).

However, in return sustainable applicable criteria can bring benefits like conserving natural resources, enhancing occupant comfort and health, reducing operating costs, creating value within the compatible market, a positive impact on the construction industry etc. (Durmus-Pedini & Ashuri, 2010).

2.10: Summary of LCC Impact of Sustainable Features

Feature	Criteria	Degree of Impact on Construction Cost	LCC Impact Element
SS	Construction activity pollution prevention	M	Utilities Administrative works Fabric Services Cleaning External works
	Alternative transportation—Public transportation access	M	
	Alternative Transportation—Bicycle Storage and Changing Rooms	M	
	Alternative Transportation—Low–Emitting and Fuel–efficient Vehicles	M	
	Alternative Transportation—Parking Capacity	M	
	Light pollution reduction	M	
	Stormwater design—Quality control	S	
	Development density & community connectivity	S	
	Brownfield redevelopment	S	
	Heat island Effect—Roof	S	
	Site selection	M - S	
	Site Development—Protect or restore Habitat	M - S	
	Site Development—Maximize open space	M - S	
	Stormwater design—Quantity control	M - S	
	Heat island effect non-roof	M - S	
WE	Water use reduction	L	Utilities Administrative works Services External works
	Innovative wastewater technologies	S	
	Water efficient landscaping	M - S	
EE	Fundamental refrigerant management	M	Utilities Services External works
	Enhanced refrigerant management	L	
	Fundamental commissioning of building energy systems	S	
	Minimum energy performance	S	
	Optimize energy performance	S	
	Onsite renewable energy	S	
	Enhanced commissioning	S	
	Measurement and verification	S	
	Green Power	S	
MR	Storage and collection of recyclables	M	Administrative works Fabric External works
	Regional materials	M	
	Building Reuse	M - S	
	Construction waste management	M - S	
	Materials reuse	M -S	
	Recycled content	M - S	
	Rapidly renewable materials	M -S	
	Certified wood	M - S	
IEQ	Minimum IAQ performance	M	Utilities Administrative works Fabric Services Cleaning External works
	Outdoor air delivery monitoring	M	
	Construction IAQ management plan—before occupancy	M	
	Low-emitting materials—adhesives and sealants	M	
	Low-emitting materials—paints and coatings	M	
	Low-emitting materials—flooring systems	M	
	Thermal comfort—design	M	
	Increased ventilation	L	
	Indoor chemical and pollutant source control	L	
	Controllability of systems—thermal comfort	L	
	Thermal comfort—verification	L	
	Environmental Tobacco Smoke control	M - S	
	Construction IAQ management plan—during construction	M - S	
	Low-emitting materials—composite wood and agrifiber products	M - S	
	Controllability of systems—lighting	M - S	
	Daylight and views—daylight	M - S	
	Daylight and views—views	M - S	

Adapted from: BMCIS (1984); Kats (2006); Kats (2010); Davis Langdon (2007); USGBC (2009)

According to Hwang and Tan (2012) energy and atmosphere applicable criteria bring incremental economic benefits and environmental benefits. Preservation of water resources for future generations and lower potable water resources are benefits of water efficiency applicable criteria on green buildings (Waidyasekara & Fernando, 2013). For example, Kats (2006) analysed the cost benefits of green buildings and highlighted the benefits such as, 13%saving of maintenance cost, 19% of lower aggregate operational cost, 22% reduce of water cost, 25% reduction of Cooling cost, 36% of fewer CO_2 emissions, 30% of energy cost reduction 50 to 75% of solid waste management and cost reduction of productivity and health is 70%. Table 1 divides those benefits to the identified categories of sustainable features.

As identified in the literature, the impact of sustainable features on the LCC of green buildings is represented by the number of costs elements in the O&M stage. Therefore, it is difficult to measure the impact of sustainable features on a single entity of costs elements and the best way to reflect this impact is to calculate the LCC of green building using NPV method. Therefore, a LCC comparison between green buildings and similar natured conventional buildings should be carried out.

In the previous attempts to find out the green building cost premium compared to that of conventional buildings, the authors have been careful about selecting similar buildings for the cost comparison between green and conventional buildings. Therefore, next section considers the factors influencing LCC of buildings.

2.6 Factors Influencing LCC of Green Buildings

2.6.1 Factors Affecting Construction Cost of Buildings

Numerous studies were conducted to analyse the cost difference between green and conventional buildings. Thereby previous authors have documented the costs and benefits of green practices for capital projects and those studies were reviewed in the section 2.4.1. As identified, the studies showed different views on the cost of green buildings and the respective authors have identified the factors that caused the difference. In the study of Kats (2003) the average cost premium of 33 green buildings across the U.S. was compared to that of conventional buildings and identified the increased architectural and engineering design time, modelling costs and time necessary to integrate green building into projects that increase the cost premium. Moreover, Fullbrook and Woods (2009), Kats (2003) and Packard foundation (2002) have found a series of results ranging from the lowest levels of certification to the highest levels of certification and identified that achieving high certification levels cost more than getting lower sustainability levels. Similarly, Kim, Greene and Kim (2014) found that the upgrades to adhering to green building codes directly affect the bid amount presented to the client and construction schedule. Due to increased project duration, the longer the contractor is on a project site, greater will be the capital expenditure required by the project.

Based on the cost comparative analysis of actual cost of 17 green buildings against modelled cost of conventional buildings, Rehm and Ade (2013) concluded that, green buildings are expensive due to their provision of sustainable features such as green materials, high-performance cladding systems, rainwater harvesting and energy-efficient mechanical equipment. Moreover, the authors found that substantial costs were associated with applying for Green Star certification and integrating high-quality design features. Similarly, Syphers and Darren (2001) discovered that project location impacts the LEED projects costs. A study done by Davis Langdon (2007) indicated that the total construction cost increases are due to material cost, with little or no change in labor and equipment.

Previous studies, (Ashworth, 2004; Belniak & Zima, 2013; Cunningham, 2013; Ferry & Brandon, 1991; Ibrahim, 2007; Seeley, 1996; Tan, 1999; Zima & Plebankiewicz, 2012) have identified the factors which influence the construction cost of buildings. As Cunningham (2013) suggests the plan shape, size of the building, storey height, total height of the building, grouping buildings, wall to floor ratio, and degree of circulation space are the principle factors which influence the cost of building work. For an example, more complex the shape, higher will be the overall cost of the structure. Design variables of a building have been defined as the parameters that describe a building and define its cost (Ibrahim, 2007). Kouskoulas and Koehn (1974) argued that the cost of a building is a function of many design variables including building locality, price index, building type, building height, building quality, and building technology.

Brandon (1978), Ferry and Brandon (1991) and Seeley (1996) have contended the inclusion of plan shape as a design variable while Ibrahim (2007) argued that building size is also an important variable that defines a building cost. It is common to find buildings that have been designed to meet the same or similar needs costing different amounts because of differences in some of the design variables. Belniak and Zima (2013) argued that one of the basic elements to be considered when estimating investment costs is the shape of the building.

The above studies identified the factors affecting the construction cost of buildings irrespective of the nature of the building, whether it's a green or conventional building. Similarly, when considering the cost comparative studies done on the green verses conventional buildings, some studies have considered location, building type, building age, building size (net lettable area) and building tenancy type (Packard Foundation, 2002; Kats et al., 2003; Matthiessen & Morris, 2004; Davis Langdon, 2007; Fullbrook & Woods, 2009).

Out of them, Matthiessen and Morris (2004) highlighted that the cost of the green is influenced by the demographic location: rural or urban, bidding climate and culture, local and regional design stages including codes and initiatives, intent and values of the project, climate, and the timing of implementation, size of building and point synergies. Similarly, in an urban site the cost associated with storm water management, attempting to build green in an area where sustainable design is not a familiar concept, and contractors' unwillingness to bid are some other factors which could significantly impact the cost of the green project. It is likely to impact the cost of building, if the building owner and the design team are unwilling to invest time and cooperation that may be needed to reach the desired certification level.

Further, Kim, Greene, and Kim (2014); Mapp, et al. (2011); Shrestha and Pushpala (2012) explained that building size, type, function, location, climate and type of certification as the factors affecting the green buildings.

2.6.2 Factors Affecting O&M Costs of Buildings

Building investors focus on reduced O&M expenses of buildings. Yet the construction of buildings for the cheapest initial costs could lead to expensive O&M costs (Kehily, 2010). BSI (2008) reports that operation costs include rent, taxes and rates, insurances, energy and environmental regulatory charges which are incurred in running and managing buildings, while maintenance costs are responsible for retaining a building or its parts in a state which enables the constructed asset to serve its intended purposes. The costs include those for implementing maintenance strategies and their associated management, cleaning, servicing, repainting, repairing and replacing parts.

As Omari (2015) suggests the running costs of a building is influenced by various factors such as managerial, social, environmental, financial and technical. Management is a crucial aspect in O&M work. Organizing, controlling, planning and staffing of O&M activities are significant when carrying out the specific works and as a result affect the running costs of the building (Omari, 2015). Social factors involve the end-users including user awareness, delays in reporting problems, accessibility to the property, early response to the building O&M activities etc. (Saghatforoush, Trigunarsyah, & Too, 2012). The environmental factors are the factors that enable O&M activities to be carried out with ease by creating a conducive working environment and also include external factors (Herbert, 2010). According to Omari (2015), environmental factors include new maintenance techniques, unqualified and unavailable maintenance contractors, inadequate standards and specification, and harsh climatic conditions. The building owners should prepare the annual budgets including enough financial allocation for O&M work (Ofori, Duodu, & Bonney, 2015). An unavoidable cost burden for projects occurs in the absence of financial support for specific activities and leads to over budget issues during the running stage of buildings (Lai, 2010). Technical factors are important critical sources and expensive rework during the O&M phase of a building (Al-Khatam, 2003). Technical factors include design problems, design complexity, faulty design, design variables, building materials used, and building age and therefore could impact planning, design, construction or even during the O&M phases of building (Saghatforoush, Trigunarsyah, & Too, 2012).

Amongst other factors which affect the running cost of buildings, design problems are momentous as the decisions and actions performed during early stages cannot be reformed or difficult to reform during the building running stage. Defects on buildings during construction stage cause O&M expenditure to rise (Lai, Yik, & Jones, 2008).

Previous studies have examined the principal design variables which influence construction costs of buildings (Ashworth & Perera, 2015; Belniak & Zima, 2013; Cartlidge, 2013; Cunningham, 2013; Ibrahim, 2007; Kirkham, 2014; Seeley, 1996; Tan, 1999; Zima & Plebankiewicz, 2012). As Cunningham (2013) suggests the plan shape, size of buildings, storey height, total height of the building, grouping buildings, wall to floor ratio, and degree of circulation space are the principal design variables which influence the costs of building work. Ibrahim (2007) is of the view that design variables also include optimum envelope area, roofing, open space and voids factors. For example, the more complex the shape, the higher will be the overall costs of the structure. Although, studies have focused on design variables that affect the running costs, their main concern was into energy consumption of buildings (Catalina, Virgone, & Iordache, 2011; Choi, Cho, & Kim, 2012; Depecker, Menezo, Virgone, & Lepers, 2001; Krem, 2012; Krem, Hoque, & Arwade, 2013). For example, Krem (2012) investigated the effect of design variables on energy and structural performances over climate changes in high-rise office buildings. However only the shape of the building footprint and the placement of the structural cores were considered as the design variables. Krem (2012) concluded that the energy performance of a high-rise office building is highly influenced by its morphology

The studies also indicate the possibilities where the running cost can be affected through the building morphology, but, the main concern of the studies is to relate the building morphology into the energy consumption of buildings (Catalina, Virgone, & Iordache, 2011; Choi, Cho, & Kim, 2012; Depecker, Menezo, Virgone, & Lepers, 2001; Krem, 2012; Krem, Hoque, & Arwade, 2013). Energy cost is only a part of the running cost. For example, Krem (2012) investigated the effect of high-rise office building morphology on energy and structural performances for the major climates. Only the shape of the building footprint and the placement of the structural cores were considered as the morphology factors for this study. The study concluded that the energy performance of a high-rise office building is highly impacted by its morphology and proved that the building configuration significantly influences the overall energy performance.

These varying factors which affect the running costs of green buildings are classified as major and sub-factors and given in Table 2.11.

Table 2.11: Factors affecting the Running Costs of green buildings

Main Factor	Sub Factor	Source
Managerial	• Materials selection does not comply with client sub-factors • Usage of cheaper/sub-standard materials • Usage of new materials with little behaviourent sub factors • Lack of skilled and uneducated labours • Poor management by maintenance personnel • Lack of building maintenance manuals • Poor communication between maintenance parties • Failure to execute maintenance at the right time • Interdepartmental boundaries • Accelerated maintenance work due to poor fiscal control • Unqualified maintenance contractors	El-Haram and Horner (2002); Matthiessen and Morris (2004); Omari (2015)
Social	• User does not understand importance of O&M work • End users' behaviours • Cultural practices • High expectation of tenants • Improper use of the property • Vandalism by the tenant • Delay in reporting failures	El-Haram and Horner (2002); Al-Khatam (2003); Omari (2015)
Environmental	• Demographic location • Physical site conditions • Climate • Environmental considerations	Kim, et al. (2011); Mapp, et al. (2011); Shrestha and Pushpala (2012)
Financial	• Inadequate finance • Poor financial control on site and when executing maintenance work • Market conditions • Poor financial support for maintenance work	Lai, Yik and Jones (2008); Omari (2015)
Technical	• Design complexity • Faulty design • Faulty maintenance • Low concern to future maintenance • Failure to identify the true cause of defects	El-Haram and Horner (2002); Al-Khatam (2003); Saghatforoush, Trigunarsyah, and Too (2012);

	• Selection of sub-optimal maintenance strategy • Unfamiliarity with maintenance methods • Type of structure • Availability of services • Resource availability • Aging of building	Omari (2015)
Morphology	• Plan shape • Size of building • Wall to floor ratio • Degree of circulation space • Storey height • Total height of the building • Grouping of buildings	Belniak and Zima (2013); Cunningham (2013); Ashworth and Perera (2015)
Other	• Bidding climate and culture • Local and regional design standards: codes and initiatives • Intent and values of the project • Timing of implementation • Point synergies • Legislative constraints • Method of construction • Political factors • Method of procurement	El-Haram and Horner (2002); Al-Khatam (2003); Matthiessen and Morris (2004); Omari (2015)

2.7 Knowledge Gap

In line with the first objective of the current study, this chapter first reviewed the concept of sustainable development and green buildings, including the definitions, development, benefits and economic barriers of green buildings. Literature reveals that there is a visible encouragement towards the use of the green building concept. As identified in the literature review, higher levels of sustainability are usually linked to higher green premiums. Further, cost commitment of green buildings is of contradictory views with respect to different contexts; type of building, climate condition, site conditions, etc. Previous studies have focused on various types of buildings such as residential - high-rise apartments, office, education, and hotel buildings, etc. while the industrial manufacturing category was rarely considered. Despite, economic barriers for green buildings are still prevalent due to the lack of quantitative documentation of LCC benefits of green buildings according to the different green criteria and green elements or strategies. The LCC is an important tool for achieving cost efficiency in green building construction projects. Hence, there is a need for comparing the LCC of green building elements with conventional counterparts. According to the previous studies, green design cost is largely dependent on several factors, including building type, project location, local climate, site conditions, and the familiarity of the project team with green design. Other factors include architectural and engineering (A&E) design time, modelling costs and time necessary to integrate sustainable building practices into projects. Hence, the question about the cost of green is highly subjective. Moreover, the cost premium of green buildings is also subjected to the green building certification level, and would likely to increase with higher levels of certification. The previous studies on green building costs were limited to the initial cost of acquiring the sustainability features. Therefore, the impact of those sustainability features to the LCC of the green buildings is still in question in the context of Sri Lanka.

2.8 Chapter Summary

In this chapter, already available subject area is harmonized to justify the research problem. Hence, this chapter identified the green building concept, life cycle costing concept, the sustainability features of green buildings and their impact to LCC of green buildings. Moreover, the limitations which were encountered by previous studies were also identified to justify the problem statement. Next chapter of the study provides the methodology which is most suitable to find the solutions for above question.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the procedural plan adopted to find the answers for the formulated research problem and mainly consists of a detailed explanation of the research process adopted for this research. The research process consists of the research approach, the research strategy, and the research techniques such as data collection methods and data analysis methods which were used to achieve the formulated research objectives.

3.2 Research Design

The research design considers two main aspects such as what research questions the research study wants to find answers to and how to find the answers to the research questions. The path to find the answers to the research questions constitutes research methodology (Kumar, 2011). The researcher should select the appropriate research philosophy, research approach, research strategy and research techniques which help to achieve the research objectives at an optimum level (Kumar, 2011). Research 'onion' introduced by Saunders, Lewis and Thornhill (2008) explicates the research design in six layers, this is illustrated in Figure 3.1 below. The six layers are as philosophies, approaches, strategies, choices, time horizons, and techniques and procedures.

The research process for the study was developed using the research 'onion' concept and illustrated in Figure 3.2.

Initially a background study was carried out to familiarize with the identified research area which mainly focused on the Green Buildings development in international and national contexts, benefits and barriers, and the cost of Green Buildings. The background study was done by referring journal articles, books, and unpublished researches. The background study helped to identify the research gap, define the research problem, research aim, objectives, research scope and limitations.

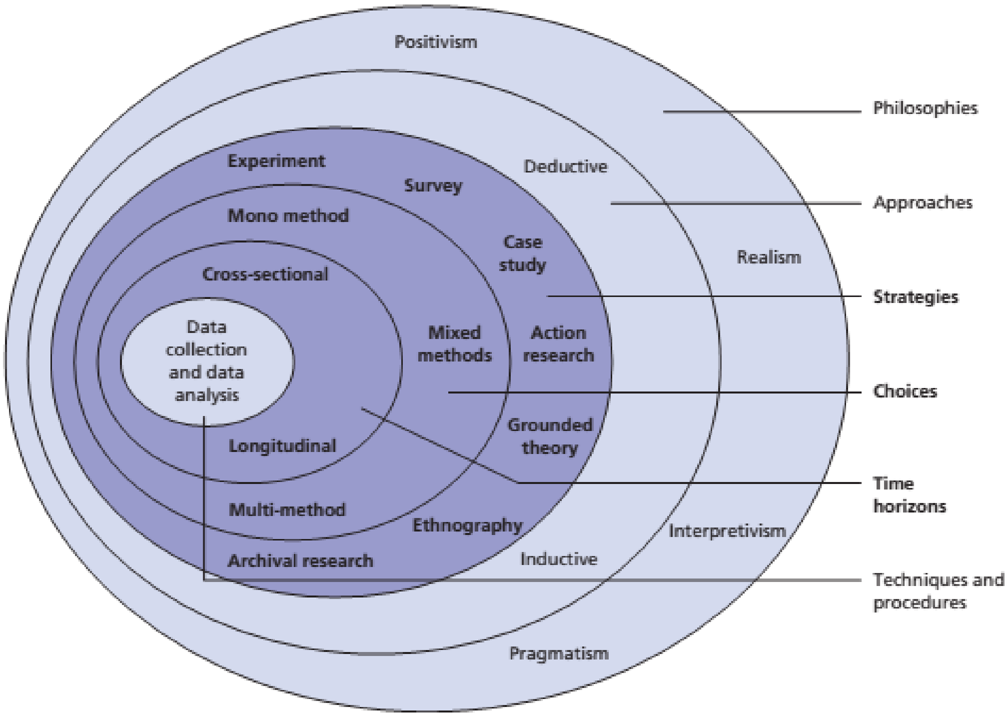


Figure 3.1: Research 'Onion'

Source: (Saunders et al., 2008)

After initiating the research problem, the aim and objectives of the research, next, a comprehensive literature review was developed in chapter two of this research by going through journal articles, books, conference proceedings, unpublished dissertations, newspaper articles and standards to identify the economic barriers for Green Buildings, cost efficiency of Green Buildings compared to that of conventional buildings, sustainability domains and criteria considered in Green Buildings and their cost impact and the application of Green Buildings in the context of Sri Lanka. The literature review emphasizes the research gap and draws attention to the research problem in advance.

3.2.1 Research Philosophy

A research philosophy is certainly the way in which data about a phenomenon should be collected, analyzed and used. The most commonly used research philosophies or paradigms are the positivism, realism, interpretivism and pragmatism. Those four paradigms were imagined to be based on three distinct ways, such as ontology, epistemology, and axiology (Saunders et al., 2009). Ontology is concerned with the nature of reality. This raises questions related to the assumptions researchers have about the way the world operates and the commitment held to views. Epistemology concerns what constitutes as acceptable knowledge in a field of study. This raises the question whether the reality represented by objects that are ‘real’ or by feelings and attitudes, as social phenomena which have no external reality and which cannot be seen, measured and modified. Axiology is a branch of philosophy that studies the judgments about value. Although this may include values we possess in the fields of aesthetics and ethics, it is the process of social enquiry with which we are concerned here (Heron, 1996).

Pragmatism argues that the most important determinant of the epistemology, ontology and axiology is the research question – one may be more appropriate than the other for answering questions. Moreover, if the research question does not suggest unambiguously that either a positivist or interpretivist philosophy is adopted, this confirms the pragmatist’s view that it is perfectly possible to work with variations in epistemology, ontology and axiology (Tashakkori & Teddlie, 1998).

The aim of the current study is to establish the economic sustainability of green buildings compare to conventional buildings. Thereby, the target group of the research would be able to have a broad view on the economic sustainability of green buildings compared to conventional buildings. Hence, the researcher’s view of the nature of reality is both independent of social actors and is socially constructed. The researcher’s view regarding what constitutes acceptable knowledge can be both observable phenomena and subjective meanings. The researcher’s view of the role of values in research maintains both value free and value laden stance. Both quantitative and qualitative data were collected by the researcher to compare the LCC of green and similar natured conventional buildings, thereby assess the impact of sustainable features on LCC of green buildings. Therefore, the current study follows a pragmatism philosophy.

3.2.2 Research Approach

Research approach can be classified under two broad generic categories as qualitative and quantitative researches. Study designs in qualitative research are more appropriate for exploring the variation and diversity in any aspect of social life and involve qualitative data, whereas quantitative researches are more suited to finding out the extent of this variation and diversity, and involve quantitative data (Kumar, 2011). Although qualitative and quantitative approaches are grounded in different paradigms, it is possible to combine them into one study. The mixed approach is expanding as a viable methodology in the social and human sciences (Roberts, 2010). Mixed approach involves collecting and integrating both qualitative and quantitative data. This type of approach assumes that the combination of qualitative and quantitative approaches provides a more complete understanding of a research problem than the qualitative or quantitative approach alone (Creswell, 2014).

The aim of this research is to establish the economic sustainability of Green Buildings in Sri Lanka. The research requires dealing with the more detailed quantitative data such as the cost information with the actual values to achieve the research aim and qualitative data: reasons for the level of achievement of sustainability of sustainable features as well. Thus, the mixed method approach is selected as the appropriate approach for this study to collect the data on life the cycle cost of green buildings and conventional buildings in Sri Lanka via documentation analysis and semi-structured interviews.

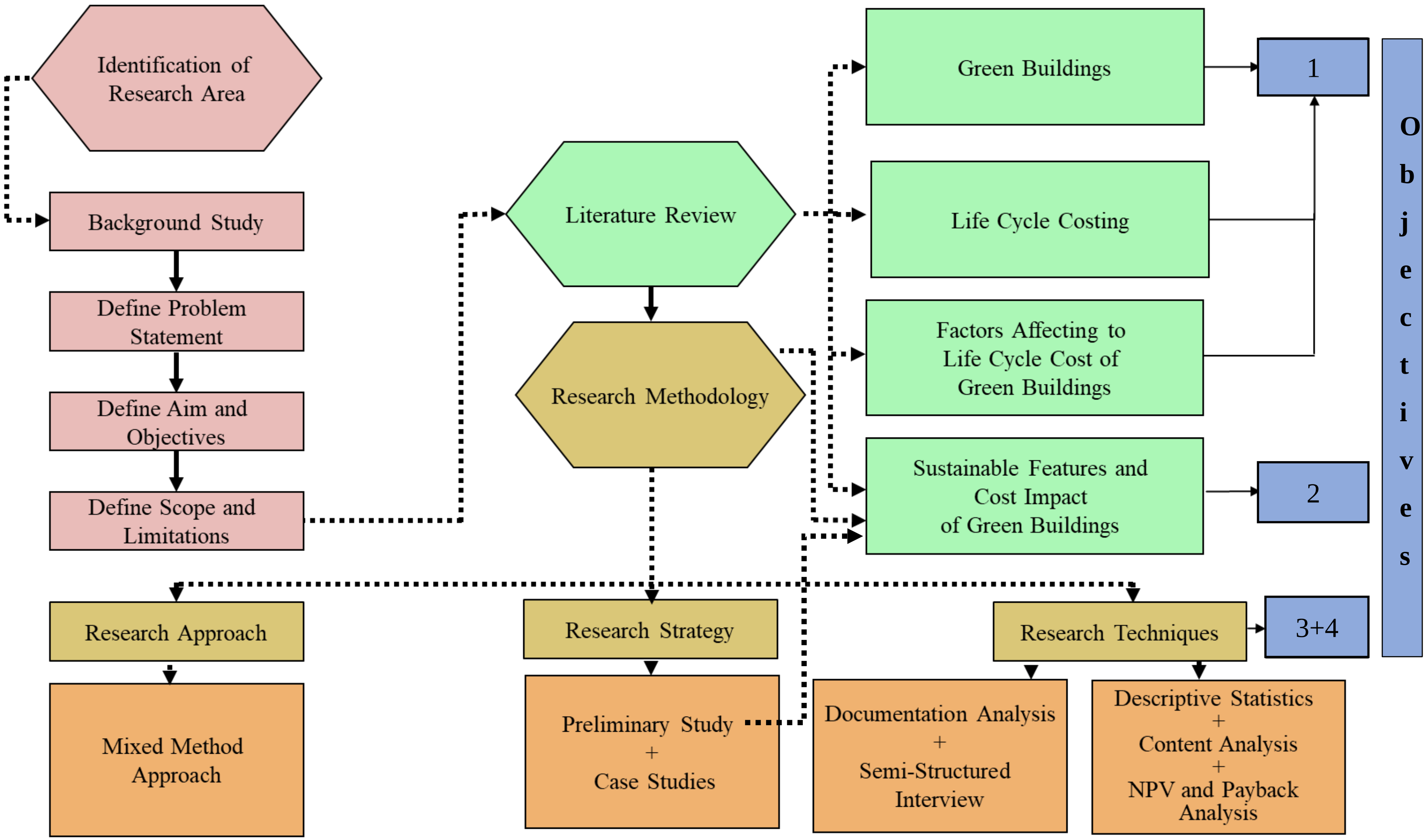


Figure 3.2: Research Process

3.2.3 Research Strategy

As mentioned in Saunders et al. (2009) six different types of research approaches can be adapted to a research such as experiment, ethnography, survey, case study, grounded theory and action research. In a case study, the selected case becomes the basis of a thorough, holistic and in-depth exploration of the aspects that the researcher wants to find about. It is an approach in which an instance or a few carefully selected cases are studied intensively (Yin, 2009). It is a very useful design when exploring an area where little is known and provides an overview understanding of a case within a unit of study, but cannot claim to any generalizations to a population beyond cases similar to the one studied (Yin, 2009).

3.2.3.1 Preliminary Study

A preliminary study was conducted to identify the green building profile of Sri Lanka, their sustainability level with the achievement of sustainability features and the reasons for the level of achievement of sustainability features. This preliminary study provides the groundwork for the research by further identifying the specific research problem in the Sri Lankan context.

3.2.3.2 Case Study

According to Kumar (2011), the case study method is more feasible where, it is necessary to study the phenomenon in its natural settings. Further, the case study method is not just a form of qualitative research even though it may be recognized among the array of qualitative research choices (Creswell, 2014). Some case study research goes beyond being a type of qualitative research, by using a mix of quantitative and qualitative evidence. Also, the case studies need not always include the direct and detailed observational evidence marked by other forms of qualitative research (Yin, 2009). Hence, the case study approach is selected to conduct an in depth analysis of the research problem.

a) Case study design

Case study can be either single or use of multiple cases. In determining the choice between single verses multiple case studies creates the 2x2 matrix for the basic types of case study designs (Yin, 2009). A multiple case study enables the researcher to explore differences within and between cases. The goal is to replicate findings across cases. Because comparisons will be drawn, it is imperative that the cases are chosen carefully so that the researcher can predict comparable results across cases, or predict contrasting results based on a theory (Yin, 2009).

If being either a critical, unique, representative, revelatory or longitudinal case provides the rationale to select the single case method over multiple cases (Keraminiyage, Amarathunga, & Haigh, 2005).But, the current study is focused on exploring and finding out the extent of the LCC variation across green and conventional buildings. Thus, the multiple case design is preferred for this study. In the multiple case study design, there are three aspects to consider as the unit of analysis, number of cases and selection of the cases (Yin, 2009).

b) The unit of analysis

The unit of analysis can be referred as the "case" and connected with the research problem (Yin, 2009). The unit of analysis of the research is the industrial manufacturing buildings in Sri Lanka. Further, the unit of analysis of the study is broadly divided into two distinct categories such as green and conventional industrial manufacturing buildings in Sri Lanka with similar characteristics.

c) Number of cases

After identifying the unit of analysis of the case study design, the next step is to define the number of cases which are undertaken to explore the research phenomenon. According to Yin (2009), the possible number of cases in a specific research may fall between the minimum of two to four and maximum of ten to fifteen. The number of cases selected for this research is three.

d) Criteria for case selection

According to Yin (2009), the criteria for selecting cases are a matter of discretion, judgment, convenience and accessibility which are subjective for the research. A conventional case constructed in similar location and climatic condition, with similar tenure, i.e. management style and quality of the selected green cases was chosen. In addition, physical and performance characteristics such as the year of construction, number of floors, shape, NIA, designed life cycle, building height and number of occupants were matched among the cases.

3.2.4 Research Techniques

Research techniques comprise of data collection methods and data analysis methods. Research methods are concerned with the techniques which are available and those which are employed in research project (Fellows and Liu, 2003).

3.2.4.1 Data Collection Techniques

A variety of data collection methods can be used in researches. Such as interviews, questionnaires, document surveys, observations, participation and simulation (Kumar, 2011). It is important to identify the appropriateness of the selected techniques to the research design. The data collection techniques which were used for this research are discussed below with the justification for the selection.

a) Documentation Analysis - Preliminary

The main objective of the preliminary study is to identify the green building profile of Sri Lanka, their sustainability level with the achievement of sustainability features and the reasons for the level of achievement of sustainability features. The preliminary study collected the information on green certified buildings in Sri Lanka from USGBC Directory and GBIG databases. More importantly, the number of LEED certified buildings and their different certification types: LEED BD+C: New Construction, LEED O+M: Existing Buildings, LEED ID+C: Commercial Interiors and LEED BD+C: Core and Shell were identified through the study and analysed by dividing into different green space categories: industrial manufacturing, lodging, office, retail, warehouse and distribution, laboratory and higher education. Thereby the best sample was identified to conduct the questionnaire survey.

a) Semi-structured interviews - Preliminary

Interviews can be classified into structured, semi-structured or unstructured interviews. This research considers the semi-structured interview method as ideal because it elicits more elaborate and purposeful answers from the responds to the research questions (Yin, 2009). Moreover, semi-structured interviews allow the researcher to ask additional questions to follow up on any interesting or unexpected answers (Keraminiyage et al., 2005). Semi-structured interviews were used to identify the reasons for the level of achievement of sustainable features of LEED BD+C New Construction buildings. Facilities management and engineering professionals who have been engaged since the green building initiation project to current O&M activities of the selected green buildings were interviewed

b) Documentation Analysis –Case Study

Relevant real-life cost data: construction, annualised and periodic O&M, and simulated end of life cycle cost data were collected through document analysis according to the standard cost categories suggested by Building Cost Information Service (BCIS). Table 3.1 in Annexure 4 provides the developed framework referring to standard cost classifications which used to collect the cost data. The documents relevant to the initial green building construction budget, and records of O&M expenditure budget records were used to collect the cost data. Simultaneously, physical and performance data such as the constructed year, number of floors, NIA, life cycle, building height and number of occupants were collected from the selected green and conventional buildings.

3.2.4.2 Data Analysis Techniques

This research follows descriptive statistics analysis, content analysis and NPV calculations to analyse the collected data from documentation analysis and semi-structured interviews.

a) Descriptive Statistics Analysis

Descriptive statistics summarizes the information contained in a sample. This summary may be achieved by condensing the information and presenting it in a tabular form (Nolan & Heinzen, 2008). Frequency distributions and graphical methods of summarizing data, such as histograms, pie charts, bar charts, and scatter plots were used. Data also can be summarized by numerical values such as, the centre of a data set, the mean or median, the variance, standard deviation, or interquartile range might be used to describe variability. Each of the numerical values is a single number computed from the data that describe a certain characteristic of a sample. Secondary data obtained by the selected cases may be analysed by using descriptive statistics analysis (Nolan & Heinzen, 2008). Microsoft excel computer software was used to do the descriptive analysis.

b) Content Analysis

Content analysis is a technique for data analysis which involves codifying qualitative information into pre-defined categories to derive patterns in the presentation and reporting of information (Kumar, 2011). This process involves many steps, such as, identifying the main themes, assigning code to the main theme, classifying responses under the main themes, and integrating themes and responses into the text of the report. Manual content analysis was used in this research to capture the interviews' findings on the reasons for the level of achievement of sustainability.

c) NPV Technique

NPV is the sum between the present value of cash inflows and the present value of cash outflows, which is used for the LCC appraisal (BSI, 2008). Following equation was used to determine the NPV.

$$\boxed{NPV = \sum_{i=0}^{n} FV \frac{(1+i)^n - 1}{i(1+i)^n}}$$

r is the nominal interest rate of interest per annum

n is the number of years between the base date and the occurrence of the cost

i is the expected real interest rate per annum which is adjusted for inflation.

d) Non-Discounted Payback Method

The period takes to recover initial investment costs is being measured through PB which is also a useful basis for evaluating alternative investment options. There are ways of calculating PB such as, non-discounted and discounted PB. This method ignores costs and savings after the payback point, therefore it is possible that an investment with a longer payback is a better option than with a shorter PB, over the entire period of analysis. It enables users to weigh the additional capital costs against the time it takes for these costs to be recouped through savings or income during the operational period.

$$\boxed{Payback\ Period = \frac{Capital\ cost\ of\ the\ Project}{Cash\ inflow}}$$

e) Annual Equivalent Value

The AC or AEV is a uniform annual amount that, when totalled over the period of analysis, equals the total net cost of the project considering the time value of money over the period. It is used to compare investment options where the natural replacement cycle cannot easily be directly related to the period of analysis. The lowest AEV indicates the lowest cost option.

$$\boxed{AEV = \frac{i(NPV)}{1-(1+i)^{-n}}}$$

3.3 Summary

This chapter explained the research process and methodological framework used to get the answers to the research problem. Research process consisted with the research approach and the research techniques which addressed within this chapter. The selected approach was mixed method approach with case studies and the techniques consist with the documentation analysis and semi-structured interviews for the data collection and descriptive, content and NPV analysis for the data analysis.

CHAPTER FOUR

4.0 DATA ANALYSIS AND FINDINGS

4.1 Introduction

This chapter explicates research findings of preliminary analysis and the case study analysis. The preliminary analysis consists of identification of the LEED certified green buildings in Sri Lanka, level of achievement of sustainable features and the reasons which contributed to the achievement level and thereby justify the cost impact of sustainable features in the case study stage. Data collection techniques used for the preliminary stage were documentation analysis and expert interviews. Next stage of the data collection consists of a case study. Documentation analysis and semi-structured interviews were conducted to collect the data in the case study analysis. The data related to LCC and cost savings were collected through the documents, such as budget and expenses records. The semi-structured interviews were used to identify the sustainable features of green buildings and to obtain the costs data which were not possible to be collected through the document analysis. Data analysis techniques such as content analysis, descriptive statistics, NPV and sensitivity analysis were used to analyse the collected data in two stages.

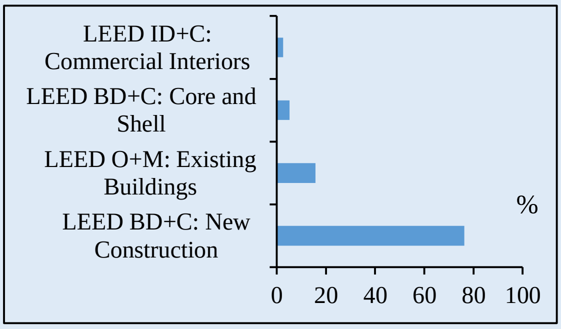
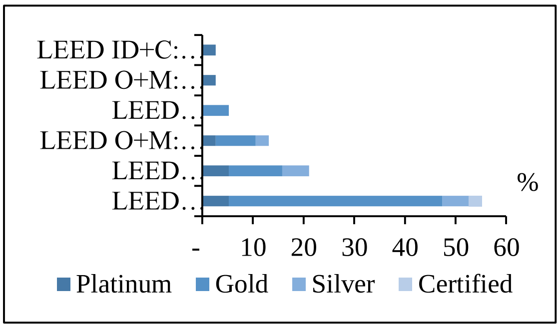
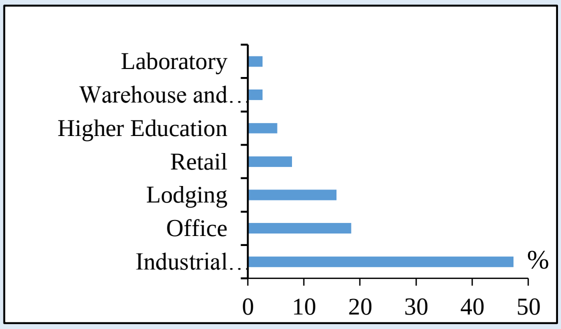
4.2 Preliminary Study Analysis and Findings

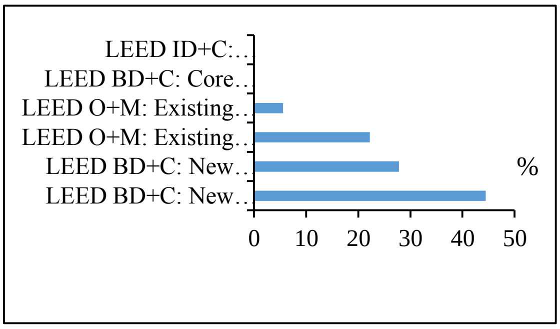
Purpose of the preliminary survey is to identify the profile of the green certified buildings in Sri Lanka, their level of sustainability achievement in terms of variable sustainability features and the reasons for the level of achievement of those sustainability features. This preliminary study provides the groundwork for the research by further identifying the specific research problem in the Sri Lankan context. The preliminary study was conducted using the secondary data already published on USGBC and GBGI databases under the category of green certified buildings in Sri Lanka. The following presents the preliminary study analysis and findings. The first two sections analyse the green certified building profile of Sri Lanka and level of sustainability achievement using simple descriptive analysis. The third section analyses the reasons for the level of achievement of sustainability under two sub themes.

4.2.1 Profile of LEED Certified Green Buildings in Sri Lanka

Based on the information which appeared under the category of LEED registered green buildings in Sri Lanka, 74 buildings have been registered under USGBC LEED certification to date. Only 38 buildings have received the certification. This indicates that almost an equal percentage of buildings are certified and not certified with green certification. Table 4.1 presents the profile of LEED certified green buildings which include green space type, and certification type.

Table 4.1: Demographic Profile of the LEED Certified Green Buildings in Sri Lanka

Demographic information		Number	Percentage
Green Certifications Categories of the Buildings	LEED ID+C: CI	1	
	LEED BD+C: CS	2	
	LEED O+M: EB	6	
	LEED BD+C: NC	29	
	Total	38	
Certification Levels	Certified	1	
	Silver	5	
	Platinum	7	
	Gold	25	
	Total	38	
Green Space Types	Laboratory	1	
	Warehouse and Distribution	1	
	Higher Education	2	
	Retail	3	
	Lodging	6	
	Office	7	
	Industrial Manufacturing	18	
	Total	38	

Green Industrial Manufacturing Buildings	LEED ID+C: CI(v3)	0	
	LEED BD+C: C&S (v3)	0	
	LEED O+M: EB (v2)	1	
	LEED O+M: EB (v3)	4	
	LEED BD+C: NC (v2)	5	
	LEED BD+C: NC (v3)	8	
	Total	18	

Source: (GBGI, 2016; USGBC, 2016)

As observed from Table 4.1, different green certifications such as LEED BD+C NC, LEED O+M EB, LEED BD+C C&S and LEED ID+C CI are exercised in Sri Lanka. Amongst them, over 75% of green spaces have been certified under the category of LEED BD+C NC, while buildings certified with LEED O+M EB, LEED BD+C C&S and LEED ID+C CI represents 16%, 5% and 3%. In Sri Lanka, LEED certified green buildings emerged in 2009. Therefore, a majority of newly constructed buildings were certified with LEED built design and construction after 2009. This version of LEED continues to date in Sri Lanka.

As shown in Table 4.1, the total of 38 buildings certified to date have different certification levels. Most of the buildings (66%) received the Gold level while, only 18% received the Platinum level: the highest level of sustainability, out of the remaining green buildings: 13% and 3% have obtained Silver and Certified certification levels respectively. Therefore, majority of buildings share the Gold certification level. This could be due to the intents and values of the parties engaged in the green project or the feasibility of achieving between 60 to 79 points from the allocated points for the Gold certification level.

According to Table 4.1, over 40% (8 out of 18) of the industrial manufacturing facilities are certified under the LEED BD+C: NC (v3 -2009) rating system. The remaining green industrial manufacturing spaces in Sri Lanka certified under LEED BD+C: NC (v2.2), LEED O+M EB (V3) and LEED BD+C C&S by 25%, 20% and 5%. Therefore, the green industrial manufacturing buildings certified under LEED

BD+C: NC (v3 -2009) and achieved a Gold certification level and represent the major share of green spaces available in Sri Lanka.

The above analysis of the total population of LEED certified green buildings in Sri Lanka indicates that the green industrial manufacturing buildings under the LEED BD+C: NC (v3 -2009) rating system represent the largest sample (08 out of 38 buildings) of green space type under the same level of sustainability. The sustainability level of above sample should be analysed to understand in which proportions those buildings had achieved each sustainable feature. Further, the most suitable samples to collect the data for the current study was selected considering the above sample in a later stage of the study.

4.2.2 Level of Achievement of Sustainable Features

Having analysed the green certified building profile of Sri Lanka, this section first considers all the LEED certified green industrial manufacturing buildings (08 out of 38 buildings) to identify the sustainability level of each feature. Level of achievement of each sustainable feature was identified with reference to the points allocated and achieved to obtain the green certification. Accordingly, the points achieved for sustainable features and which scored less about 50% level will be considered as features with lower sustainability levels. Table 4.2 presents the sustainability level achievement of each feature under LEED BD+C NC certification categories. The table includes the % of possible points allocated for each sustainable feature, average achieved points and the percentage of achieved points from the possible points of each feature.

As shown in Table 4.2, the average points achievement of the total population (08 buildings) of green certified industrial manufacturing buildings in Sri Lanka under the LEED BD+C NC (V3) category, indicate that WE and RP features have achieved 100% of the possible points. SS feature shows an 80% achievement of sustainability level, whereas the sustainability level of ID feature equals to 67%. Accordingly, those four features show a higher level of sustainability. The remaining features: IEQ, EA and MR have achieved a sustainability level of 47%, 46% and 36% respectively and have a lower level of sustainability considering the 50% cut-off level. Considering the achieved points of each feature, the points achievement of one or few criteria in a particular feature varies among the 08-green certified industrial manufacturing buildings. However, most of the criteria under all the features have achieved similar number of points for the LEED certification.

Table 4.2: Sustainability Level Achievement

Feature	Sustainability Criteria	Points Allocated	Points Achieved	Achievement Level (%)
SS		26	21	80
	Alternative transportation – public transportation access	6	6	
	Development density and community connectivity	5	5	
	Alternative transportation – low-emitting and fuel-efficient vehicles	3	3	
	Alternative transportation – parking capacity	2	2	
	Other criteria: *Site selection, Alternative transportation – public transportation access, Alternative transportation – bicycle storage and changing rooms, Site development – maximize open space, Site development – protect or restore habitat, Stormwater design – quality control, Stormwater design – quantity control, Heat island effect – nonroof, Heat island effect – roof, Light pollution reduction,*	10	Varies	
WE		10	10	100
	Water efficient landscaping	4	4	
	Water use reduction	4	4	
	Innovative wastewater technologies	2	2	
EA		35	16	46
	Optimize energy performance	19	Varies	
	Enhanced commissioning	2	2	
	Enhanced refrigerant management	2	2	
	Measurement and verification	3	3	
	On-site renewable	7	0	
	Green power	2	0	
MR		14	5	36
	Construction waste management	2	2	
	Regional materials	2	2	
	Recycled content	2	2	
	Building reuse, maintain existing walls, floors and roof	3	Varies	
	Materials reuse	2	Varies	
	Building reuse, Maintain interior non-structural elements, Rapidly renewable materials, Certified wood	3	0	
IEQ		15	7	47
	Low-emitting materials, adhesives and sealants, paints and coatings, flooring systems, composite wood and agrifiber products	4	Varies	
	Controllability of systems, lighting, thermal comfort	2	2	
	Thermal comfort, design, verification	2	Varies	
	Daylight and views, daylight, views	2	2	
	Construction IAQ management plan, during construction, before occupancy	2	Varies	
	Outdoor air delivery monitoring	1	1	
	Increased ventilation	1	1	
	Indoor chemical and pollutant source control	1	1	
ID		6	4	67
	Innovation in design	5	Varies	
	LEED Accredited Professional	1	1	
RP		4	4	100

Figure 4.1 illustrates points allocated for each sustainable feature and the achieved points from the allocated points for each feature of industrial manufacturing buildings certified under LEED BD+C: NC (v3 -2009). Following figure is a further scrutiny of Table 4.2 above and illustrates the points achievement of most significant feature to less significant features.

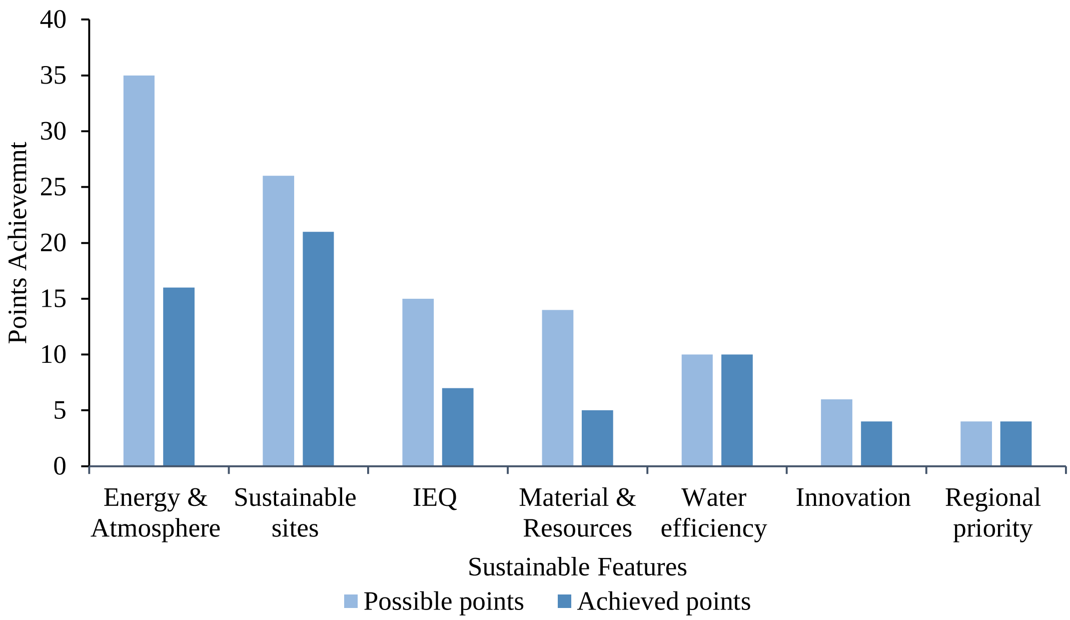


Figure 4.1: Level of Achievement of Sustainable Features

As shown in Figure 4.1, the significant features: WE and SS have achieved a sustainability level of equals or greater than 80%, whereas, other significant features: EA, MR and IEQ have achieved a sustainability level of less than 50%. Considering the less significant features: RP has a sustainability level of greater than 80%, while, ID has achieved a sustainability level between 50 to 80%. These variations in sustainability achievement could be due to the high cost of features, design and construction complexities of the features, clients' intents and values or due to any other reason. These reasons could affect the LCC of green buildings through the sustainable features. Therefore, next section analyses the reasons for the various sustainable levels of the features.

4.2.3 Reasons of Level of Achievement of Sustainable Features

Following the above preliminary analysis, two (02) out of eight (08) certified green industrial manufacturing buildings and similar conventional building were selected for the further analysis of the LCC comparison. Prior to detailed analysis, professionals who engaged in O&M activities of the selected cases were interviewed, in order to confirm the reasons of level of achievement of sustainable features. Table 4.3 presents a brief summary of profile of participants who were interviewed.

Table 4.3: Profile of Participants

Building	Interviewees	Position	Profession	Work Experience (Years)	Involvement at the Project
Green 1 (GB1)	I01	Maintenance Engineer	Mechanical Engineering	1-10	Construction, O&M
Green 2 (GB2)	I02	Manager Maintenance	Mechanical Engineering	1-10	Construction, O&M
Conventional (CB)	I03	O&M Manager	Mechanical Engineering	11-20	O&M

The interviewees were presented with the findings of comparative analysis of points allocated and achieved and asked to comment on the reasons for the level of achievement of sustainability in terms of each sustainability feature.

Reasons for the achievement level of each sustainable feature were sought and analysed separately under each feature and then a summary of all the reasons are presented. The reasons for level of achievement of each sustainable feature are explained below.

- ***Water Efficiency***

As discussed previously in the preliminary analysis, the certified buildings have achieved 100% of sustainability level in terms of water efficiency. The interviewees were asked to comment on the 100% achievement of the water efficiency feature. Water efficiency consists of three criteria as water efficient landscaping, innovative waste water technologies and water use reduction. Both the interviewees (I01 and I02) agreed that organisations are willing to invest on water efficiency since the building owners are required to pay for utility costs over the life cycle of the building. According to interviewees, high efficiency irrigation using reclaimed water (water supplied to the site by the local water district) can be designed at minimal cost. Adding to that, Interviewee (I02) stated that the native plants which are suited to the local rainwater levels reduce the additional water consumption. On a similar note, Interviewee (I01) explained that "natural drainage such as grass paving and planted storm water retention areas were used to reduce storm water run-off from the site at a less cost".

Considering the innovative waste water technologies, interviewees stated that sewage treatment plants (STPs) are available in both green building sites. Interviewee (I01) indicated that they used the treated water for gardening and flushing purposes, while

Interviewee (I02) stated that the treated water discharged to a water way in an environmentally friendly manner. Although, implementing a STP incurs considerable cost, both the interviewees agreed that the building owners often invest on STPs due to the familiarity with the technology engaged with STP.

The last criterion of water use reduction, is acquired by installing water-efficient plumbing fixtures. The Interviewee (I01) stated that when achieving the points for water use reduction, feasibility in implementation is the main concern rather than the cost. He further noticed that "our building has installed low flow fixtures for toilets and urinals, and dual plumbing which serve the recycled water from STP for flushing purposes". In a similar point of view the Interviewee (I02) explained that "the waterless urinals are engaged with a technology that is unfamiliar to the technical staff; however, there is no cost impact". Therefore, it is obvious that the green industrial buildings achieve 100% sustainability in water efficiency through low cost, feasible and familiar (no modern technology) alternatives of water efficiency strategies and technologies.

- ***Sustainable Sites***

According to the preliminary analysis, on average the percentage achievement of sustainability level is 80% in terms of sustainable site. According to interviewees (I01 and I02), more than 50% of the points can be achieved by fulfilling the requirements of development density and community connectivity, and alternative transportation since, this feature allocates more points for those criteria. The Interviewee (I02) explained that, "providing provision for bike racks and changing rooms are inexpensive to achieve with low design impact therefore we have targeted this point from the start". Similarly, Interviewee (I01) stated that "low emitting and fuel-efficient vehicles with electric refuelling stations can be added almost any time during design and construction". Therefore, both interviewees (I01 and I02) have agreed that over 50% of sustainability level can easily be added to the building by making minimal design changes which require low cost and design impact.

Interviewee (I02) further added that they have achieved the points for site development – protecting or restoring habitat by planting native species and heat island effect was achieved by changing the colour of concrete paving and adding shade elements at a relatively low cost. According to interviewee (I01), other points which can be achieved with a low cost and design impact are maximising the open space and designing and construction of the building in a location near wetlands or natural ponds. Consequently, most of the LEED certified green industrial buildings can reach a higher sustainability level in terms of sustainable sites.

- ***Innovation in Design***

The innovation in design feature in LEED BD+C NC certification is designed to allow projects to earn points for items that may not fall into any other designated point. According to the interviewees (I01 and I02), most of the projects have achieved 50 to 80% of points allocated for this feature by pursuing one of low-cost innovation points and hiring a LEED accredited professional into the green industrial manufacturing project.

- ***Indoor Environmental Quality***

As identified previously, IEQ feature includes 15 single points. According to the interviewees (I01 and I02), the first point: outdoor air delivery monitoring, usually achieved by installing CO_2 and airflow measurement equipment and feeding the information to the heating, ventilating and air conditioning (HVAC) system and building automation system (BAS). Knowledge on modern technologies and incorporating these strategies to the building is the key requirement to achieve this point. Further, the Interviewee (I01) stated that *"it is all about sensing, monitoring and controlling the outdoor air intake flow"*.

Similarly, both interviewees (I01 and I02) agreed that modern technology as well as the strong commitment of the members of the green project is necessary to achieve the second point: which is increased ventilation. Next two points are construction indoor air quality (IAQ) management plan during construction and before occupancy. As the Interviewee (I02) opined, IAQ management plan during construction is relatively difficult to achieve because this point requires significant coordination and management on the contractor's part. He further stated, "The cost to achieve this point is low, however the contractor's bid can be very significant. Due to the reason that the construction must be planned and scheduled with well-trained members, it is ensured that all the criteria are met".

Considering the IAQ plan before occupancy, the interviewee (I01) opined that achieving this point depends on the climate condition. In dry areas, a two-week flush-out with outdoor air is quite feasible, while in wet climate where there is high humidity, the mould could grow on the interior of the building.

Both interviewees agreed that it is easy to achieve low emitting materials points where local or regional regulations already established the use of low emitting materials. Similarly, the next points: indoor chemical and pollutant source control can often be met with low cost and controllability of the system. Lighting could be achieved by integrating occupant controls for lighting and task lighting at a low cost. The controllability of the system: which is the thermal comfort often achieved by incorporating operable windows with a low direct cost premium. However, there is a significant added cost when combined with a traditional air conditioning system with extra controls, zones and ductwork. According to the interviewees (I01 and I02), achieving this point with operable windows may also be impractical due to the concern over the security of raw materials for the garment and the climate may not lend itself to operable windows for much of the year.

Under the thermal comfort design and verification, the building envelope and systems should be designed with the capability to meet the comfort criteria under expected environmental and use conditions and should be able to permanently monitor building performance: air temperature, radiant temperature, air speed and relative humidity levels. According to the interviewees (I01 and I02), these points are feasible to achieve with the strong commitment of the parties engaged with the green building project. Both the interviewees (I01 and I02) opined that many projects attempted to achieve day lighting and views due to benefits of day lighting and views became more desired over the time.

Most of the IEQ points need to have the commitment of construction owners and teams. However, not all the parties are willing to maintain the level of management needed to ensure the performance necessary to meet these points successfully. These points may seem easy to achieve, but often turn out far more complicated, and thus less feasible, than anticipated. Therefore, most of the green industrial manufacturing buildings in Sri Lanka have achieved less than 50% points for the IEQ feature over the allocated 15 points.

- ***Energy and Atmosphere***

As discussed previously, the energy and atmosphere feature consists of optimize energy performance, enhanced commissioning, enhanced refrigerant management, measurement and verification, on-site renewable and green power criteria. Amongst, LEED has allocated more points for optimize energy performance and site renewable energy. The certified buildings have scored less than 50% (16 out of 35 points) in terms of energy and atmosphere, while the feature has been assigned highest number of points in the rating system.

According to the Interviewee (I02), the points for the optimize energy performance were awarded considering the percentage of energy cost savings. Therefore, to achieve more points the investor should prove that the building is responsible for the threshold points which incurs a high initial cost to achieve that level. Similarly, the Interviewee (I01) stated that “it is difficult to reach the higher percentages, because these require innovative technology. Further, reaching these higher levels added significant costs and they specially need an early design commitment”.

Considering the building commissioning, measurement and verification, both interviewees (I01 and I02) agreed that these represent a significant added cost. However, feasible to achieve with early commitment. Further, Interviewee (I02) opined that, measurement and verification require a complex monitoring system which ultimately benefits the users. In terms of refrigerant management, both the interviewees agreed that, nowadays more energy efficient air conditioning alternatives are available which use environmentally friendly refrigerant. Therefore, it is only a matter of selecting a system which environmentally and economically benefited in the long run.

However, considering renewable energy and green power, these have a substantial construction cost impact and provide a long-term cost savings. The Interviewee (I02) explained,

> Assume that to initiate an investment on photovoltaic system, there should be financially backup for the investors. Currently, few organisations provide Energy Service Contracts (ESCO) model for those kinds of investments. However, the location and climate conditions should also consider achieving uninterrupted solar energy supply.

Therefore, these green certified industrial buildings were able to achieve a less than 50% of allocated points with an early commitment and integrated design process.

- ***Material and Resources***

Those certified industrial green buildings (08 out of 18) in Sri Lanka have achieved a level of less than 50% in terms of material and resources. This feature is classified into two distinct categories: A) most projects pursuing the credits related to construction waste management, local content and recycled content, and B) very few pursuing the other points like building reuse, renewable materials, material reuse and certified wood. Therefore, the interviewees were asked to comment on reasons for this achievement level.

Building reuse as the first point, Interviewee (I01) stated that "it is difficult to reuse existing building structural and non-structural elements due to its impact on the cost of achieving energy and atmosphere points". Similarly, the Interviewee (I02) added, that this point is uncommon in most projects due to the additional work and substantial cost associated with the building. Most projects achieving material and resources must sacrifice the energy and atmosphere of the building. However, achieving energy and atmosphere is more economical considering the long term economic benefits.

The interviewees (I01 and I02) opined that, most projects are unable to incorporate rapidly renewable materials and reused materials into their design because these materials tend to be costly. Further, both interviewees agreed that certified wood costs more than the non-certified wood. Without a clear understanding on cost fluctuations the investors were unable to establish the cost impact.

Construction waste management is the highly achieved point in almost every green project. The interviewees (I01 and I02) explained that, the cost to achieve this point is highly dependent on the contractor's commitment. If the contractor is familiar with the construction waste recycling programs and practices this can be achieved with a minimum cost. However, the cost is also dependent on the project location, usually in urban projects the cost is less.

Both interviewees (I01 and I02) agreed that, use of recycled content and regional materials usually incur minimal costs. Therefore, the investors go for the projects in the category A since the achievement of those features requires less cost compared to projects in the category B and can maintain a sustainability level of less than 50%.

The following Table 4.4 summarises the reasons identified through the content analysis under each sustainable feature.

Table 4.4: Reasons for the Level of Achievement of Sustainability

Sustainable Features	Level of Achievement	Reasons
Sustainable Sites	≥ 80	Minimal design changes which require low cost and design impact
Water Efficiency		Feasible and familiar (no modern technology) alternatives
Innovation in Design	$50 < \% \leq 80$	Low-cost innovation strategies
Energy and Atmosphere	≤ 50	High initial cost of implementation Early commitment and integrated design process
Material and Resources		Additional works and substantial cost Contractor's commitment and familiarity
IEQ		Commitment of the project owners and construction team

This preliminary study was carried out on green certified buildings to identify the most significant green space type, and the level of sustainability achievement in terms of main sustainable features within it. Thereby, it was enabled to identify the relationship between sustainable features and its impact on the initial cost. However, this alone cannot attract the potential green building investors because making sense of running cost is essential to highlighting the future costs. Therefore, the next section analyses the LCC of a green industrial manufacturing building compared to that of a conventional building in a detailed perspective.

4.3 Comparative analysis of Green vs. Conventional Buildings

As identified in the preliminary analysis, majority of the green certified industrial manufacturing buildings in Sri Lanka were certified under LEED BD+C NC (V3) category. Table 4.5 illustrates the profile of above buildings including the nature of business, certification level and commencement year.

Table 4.5: Profile of Industrial Manufacturing Buildings Certified under LEED BD+C New Construction (V3)

Type of Business	Certification Level	Commencement of Operation/ Green Certified
Cleaning products	Certified	2010
Printing and Packaging	Gold	2012
Printing and Packaging	Gold	2015
Printing and Packaging	Gold	2016
Garment	Gold	2010
Garment	Gold	2013
Garment	Gold	2013
Garment	Gold	2015

As shown in Table 4.5, the majority (4 out of 8) of buildings are used for garment products, while remaining 3 and 1 buildings are used for printing and packaging and cleaning products respectively. Therefore, the current study selected the two garment manufacturing buildings certified with LEED BD+C New Construction (V3) category buildings constructed in the same year, due to similar characteristics. The next section describes the profile of the selected garment buildings and the profile of participants who interviewed.

4.3.1 Profile of Cases

The two types of buildings: the conventional and similar type of green buildings were carefully selected by considering the important features such as location, climate condition, tenure, i.e. management style and quality of the selected green building were chosen. In addition, physical and performance characteristics such as the year of construction, number of floors, shape, NIA, designed life cycle, building height and the number of occupants were matched among three cases. Table 4.6 presents the profile of the three selected buildings.

Table 4.6: Profile of the buildings

Building	**GB 1**	**GB 2**	**CB**
Year of Construction	2013	2013	2013
No. of Floors	1	1	2
Shape	Rectangular	Rectangular	Rectangular
NIA (m2)	3,809	3,567	4,032
Life Cycle	50	50	50
Building height(m)	3.8	4	7.8
No. of Occupants	1,400	1310	1,340
Type of Function	Garment	Garment	Garment
Type of Structure	Steel	Steel	Concrete
Roof Structure	Flat roof	Flat roof	Pitched roof
Roof Material	Concrete	Concrete	Fibre cement sheet
Orientation	East-west	East-west	East-west
Glazing Orientation	South facing	South facing	South facing
Location	✓	✓	✓
Climate condition	✓	✓	✓
Tenure	✓	✓	✓
Glazing Type	×	×	×
End users behaviours	×	×	×

As observed from table 4.6, The LEED BD+C: NC (V3) rating system is designed to rate both new buildings and major renovations of existing buildings: significant envelope modifications, HVAC renovation and interior rehabilitation. Both certified green buildings belong to newly designed and constructed category of the LEED. The year of commencements, shape of the building and designed life cycle was made equal for the selected three cases. However, in terms of the size of buildings the conventional building is slightly larger than the green buildings as it consists of a mezzanine floor. In terms of the structure of buildings two green buildings which were selected consist of a steel frame structure and flat roof, while, conventional building has a concrete frame structure and roof with a fibre cement sheet.

In terms of structure of buildings, the selected green buildings consist of a steel frame and flat roof, while conventional building is of concrete frame and pitch roof with fibre cement sheet. Therefore, it could be considered that the structural difference could affect the LCC of the two structures by ways of embodied energy consumption and

CO_2 emissions. However, there are evidence to suggest that there are no significant differences in carbon emission between the two structures, particularly during operational phase of the buildings which often absorbs substantial share of the total life cycle cost of the buildings (Wen, Qi and Jrade, 2016). Further, embodied carbon and energy both are exclusive stages in life cycle cost consideration of buildings. Therefore, current study has not considered the cost of embodied carbon and energy in the construction phase of the buildings. However, in the demolition phase, the carbon emissions of concrete structures are again high due to low recovery rate of materials and carbon emissions is very less in steel structures due to recyclability of steel. Above difference was treated by considering 2% and 3% of capital cost as the end life costs of green and conventional buildings respectively.

The number of occupants in the organizations are closely related, but, the end user behaviours were unable to match among three cases which is a highly influential factor on the cost of buildings. Considering the orientation of the selected buildings, the rectangular floor plans were elongated on an east-west direction and a larger portion of the glazing was included in the south-facing wall, however, the glazing types of the buildings were different.

4.3.2 LCC Comparison: Green vs. Conventional Buildings

A cross case analysis of LCC of green and conventional buildings was performed in order to compare the LCC difference between green and that of similar conventional buildings. First, real life cost data of the selected buildings were collected, thereafter, estimated the discount rate, service life of the building, and maintenance periods of the systems. Afterwards, all the costs were discounted to the base year 2016 and the present values were summed up to produce the LCC estimate.

This section of the study presents the complete LCC analysis including six sub sections: LCC profile of cases, assumptions and limitations of the LCC analysis, LCC comparison of green and conventional buildings, PB and AEV, sensitivity analysis and the impact of sustainable features.

4.3.2.1 LCC Profile of Cases

LCC data of the selected building: cost of construction, annualized and periodic O&M, and end of life cycle cost data were collected referring to the documents relevant to the initial green building construction budget, and O&M expenditure budget records, according to the standard cost categories suggested by RICS new rules of measurement: NRM and BCIS systems. Accordingly, the cost profiles of the selected buildings are as follows:

- **Construction Cost**

According to NRM 1: Order of cost estimating and cost planning for capital building work, the construction cost of buildings consists of facilitating work, building work (substructure, superstructure, internal finishes, fittings, furnishing and equipment, services, prefabricated buildings and building units, work to existing buildings, external work), main contractor's preliminaries, main contractor's overheads and profit, project/design team fees, other development/project costs, client's contingencies, taxes.

However, the current study considers the facilitating work, building work, cost of LEED certification and other costs (main contractor's preliminaries, main contractor's overheads and profit, project/design team fees, other development/project costs, client's contingencies, taxes) as the main categories of costs incurred in the construction stage. Accordingly, the construction cost data was collected as real costs to the year 2013. The collected data was first normalised using the elemental cost per m^2 of net lettable area of the respective building (i.e by dividing each elemental cost of a building by the net lettable area of the respective building). Table 4.7 shows the contribution of each elemental cost of the selected three buildings to the total construction cost of the respective buildings and the difference of cost per m^2 of each cost component of green and conventional buildings.

As shown in Table 4.7, the average % contributions of building work, facilitating work and other costs of green buildings are higher than those of conventional buildings by 22% and 1% respectively. The cost difference of building work is mainly contributed by cost of superstructure, internal finishes and substructure. Further, an additional cost of 14% are incurred to obtain the LEED certification, which includes registration cost, LEED consultancy, hiring LEED APs etc. Therefore, overall the construction cost of green building is higher than that of a conventional building by 37%.

- **O&M Cost**

O&M costs of buildings consist of arrange of cost elements such as rent, insurance, utility, administrative costs, taxes, decoration, cleaning, maintenance of building services and repairs and replacement of minor systems and components etc. Accordingly, the study developed a cost template using costs classifications introduced by BS ISO 15686-5:2008 standard, NRM and BCIS and collected the data through interviewing professionals who engaged in O&M activities and employed in selected buildings as well as referring to the relevant documents available with respective organisations.

As per the template operational cost elements include rent, insurance, utility, administrative costs and taxes. Rent costs of selected buildings were not considered in the study as both buildings are owned and operated by the client. The insurance cost is usually determined on a package based deal depending on reinstatement value of property, plant and machinery. The utility cost of selected buildings covers costs of electricity, water, and fuel. These costs are recorded and maintained separately. The administrative costs of the buildings mainly consist of service attendants, waste disposal, and security costs. Especially in green buildings, the operational cost also includes consultancy, audit, testing and monitoring costs for energy, environmental and social projects. The renewal of the LEED certification usually conducted only for the buildings certified under LEED O+M: existing Building category. Therefore, LEED renewal cost is not considered in the current analysis as buildings in concern here are certified as per LEED BD+C New Building category. Apart from above cost items, the selected buildings are charged National Building Tax (NBT), income taxes, Value Added Tax (VAT) etc.

As per the template, following costs: decoration, building services, fabric, external work, cleaning and repairs and replacement of minor systems and components contribute to the maintenance costs of the selected buildings. All together sixty-five (65) O&M costs elements were identified and fifty-nine (59) of them were considered for the analysis due to the lack of running costs data on industrial buildings in Sri Lanka. Table in Annexure 5 indicates the developed cost template and the selected elemental costs under the study.

The cumulative (January to December 2016) annual cost for the year 2016) for all identified O&M cost elements were collected referring to relevant documents. As in the previous case of construction costs, these O&M costs were normalised and cost per m^2 of GIFA of each O&M element was obtained. Table 4.8 indicates the contribution of main elemental costs to the total annual O&M cost of the selected buildings.

As shown in Table 4.8, according to the average annual running costs of the selected green and conventional buildings, total O&M cost of green buildings is less than that of similar conventional building by 28%. Considerable contributions to the above cost difference can be seen from the utilities cost in the operation costs category, whereas only few elements: such as fabric, external works and services in the maintenance cost category also show considerable contributions. Therefore, above four cost elements are significant elemental costs which determine the reduce cost of O&M of green buildings.

Further, the contribution of O&M cost to total running cost of green buildings are equal to 75% and 25% respectively, while same in conventional building is 70% and 30% respectively. This indicates that O&M contributions to running cost are in similar range in both green and conventional buildings. However, operation cost contributes than maintenance cost to the total running cost in industrial buildings in Sri Lanka through utilities, administrative and insurance cost elements. On the other hand, the second highest contributor of operational costs, administrative cost is due to higher proportion of staff cost than other costs such as security and waste disposal costs.

The identification of significant O&M elemental costs would be helpful to validate the LCC analysis in a later stage. Therefore, next section identifies the significant O&M elemental costs of selected three buildings.

- **Significant O&M Elemental Costs**

Significant O&M elemental costs were identified using Pareto's 80/20 rule. When identifying the significant elemental cost items, initially the annualised elemental costs of the three cases were normalised using the elemental cost per m^2 of net lettable area of the respective buildings. Accordingly, the percentage contribution of each elemental cost to the total running costs of three buildings was computed and established the significant cost elements incompliance with Pareto rule was established. Table 4.9 presents the significant elemental costs according to the Pareto's 80/20 rule.

Table 4.7: Significant O&M Costs Elements

	Green 01	**Green 02**	**Conventional**
Electricity	✷	✷	✷
Service attendants	✷	✷	✷
Insurance	✷	✷	✷
Water rates	✷	✷	✷
Cleaning	✷	✷	✷
Air Conditioning	✷	✷	
Taxes	✷		✷
External works			✷
External Wall			✷
Effluent and drainage charges			✷
Key issues			✷
Repairs and replacement of components			✷
Number of Cost Items	7	6	11
Cost Items (%)	17%	15%	25%
Cumulative Cost Contribution (%)	82%	81%	81%

According to Table 4.9, a deviation to Pareto's 80/20 rule where the top most 17%, 15% and 25% of costs elements which respectively contribute to 82%, 81% and 81% of total running costs were considered in determining significant costs elements of Green 01, Green 02 and conventional cases respectively. Moreover, as seen from the table the significant elemental costs: such as electricity, service attendants, insurance, water rates and cleaning are common to all three cases, while air conditioning was highlighted as significant in the two green cases and taxes for Green 01 and conventional buildings. Apart from those, taxes, external works, external wall, effluent and drainage charges, key issues and repairs and replacement of components were highlighted as significant elemental cost only for the conventional building.

As summarized in Table 4.9, only 5 out of 55 costs elements contribute significantly to the O&M cost of the selected three cases. Amongst, most of the significant costs elements (4 out of 5) are from the operation category while only 1 element is from the maintenance costs category.

- **End of Life Cycle Costs**

The end of life cycle cost of buildings consists of disposal inspection, disposal and demolition, reinstatement to meet contractual requirements, taxes and other costs. However, interviewees were unable to provide data on disposal and demolition plans of the selected buildings as there was no forecast available in this regard. Therefore, the demolition and disposal cost were assumed that the building will be let on suitable demolition contract at the end of 50 years assigned to a suitable demolishing contractor at the end of 50 years and considering the residual value after the depreciation over its service life. The condition of the asset at its end life will often influence the disposal value.

However, the environmental pollution is less in respect of demolition and disposal of green buildings. According to the “polluter pays” principle, the demolition and disposal cost should be less in a green building where environmental friendly material is being used. It may therefore be necessary to make assumptions about future costs which are dependent on the use and the level of pollution likely to cause due to demolition.

Therefore, it was assumed that at the end of life cycle green buildings have more residual value than conventional buildings and disposal and demolition cost of green buildings is also less than that of conventional buildings. Therefore, the current study assumed that end of life cycle costs of green and conventional buildings is 2% and 3% from the capital value of the selected buildings respectively. As in the case of construction cost and O&M costs, the cost per m^2 is calculated for end of life cycle cost. This generic comparison shows from which elements the green buildings make O&M costs savings. However, the cost impacts due to the different maintenance frequencies of the building components of green and conventional buildings are not visible in the analysis. Therefore, the following sections of the chapter present the information on the complete LCC analysis of the current study.

Table 4.8: Distribution of Construction Cost: Green vs. Conventional Buildings

Elemental Cost	GB1 (3809 m2)			GB2 (3567 m^2)			GB Avg.	Conventional (CB)			Difference %
	Cost LKR	LKR/m^2	%	Cost (LKR)	LKR/m^2	%		Cost (LKR)	LKR/m^2	%	
Facilitating works	**18,245,900**	**4,790**	**5.96**	**17,100,000**	**4,794**	**5.91**	**5.94**	**17,833,860**	**4,423**	**7.53**	**18,245,900**
Building works	**225,731,628**	**59,263**	**73.80**	**217,118,354**	**60,870**	**75.07**	**74.44**	**189,757,908**	**47,063**	**80.17**	**225,731,628**
Substructure	20,987,565	5,510	6.86	20,915,210	5,864	7.23	7.05	16,578,187	4,112	7.00	20,987,565
Superstructure	80,000,000	21,003	26.15	80,663,489	22,614	27.89	27.03	62,044,525	15,388	26.21	80,000,000
Internal finishes	35,824,674	9,405	11.71	30,780,000	8,629	10.64	11.17	20,217,999	5,014	8.54	35,824,674
Fittings, furnishing and equipment	3,129,521	822	1.02	8,039,605	2,254	2.78	1.91	7,962,806	1,975	3.36	3,129,521
Services	34,342,133	9,016	11.23	30,300,000	8,495	10.48	10.85	32,229,422	7,993	13.61	34,342,133
Prefabricated buildings and building units	11,907,147	3,126	3.89	15,000,000	4,205	5.19	4.54	13,933,010	3,456	5.88	11,907,147
Work to existing buildings	36,969,638	9,706	12.09	28,000,000	7,850	9.68	10.88	33,436,976	8,293	14.12	36,969,638
External works	2,570,950	675	0.84	3,420,050	959	1.18	1.01	3,354,983	832	1.41	2,570,950
LEED certification	**35,427,500**	**9,301**	**11.58**	**25,000,000**	**7,009**	**8.64**	**10.11**	**-**	**-**	**0**	**35,427,500**
Other costs	**26,482,530**	**6,953**	**8.66**	**30,000,000**	**8,410**	**10.37**	**9.52**	**29,083,986**	**7,213**	**12.28**	**26,482,530**
Total construction cost	**305,887,557**	**80,307**	**100.00**	**289,218,354**	**81,082**	**100.00**	**100.00**	**236,675,754**	**58,699**	**100.00**	**305,887,557**

Table 4.9: Distribution of O&M Cost: Green vs. Conventional Buildings

Elemental Cost	GB 1 (3809 m^2)			GB 2 (3567 m^2)			GB Avg. %	Conventional (CB) (4032 m^2)			Difference %
	Cost (LKR)	LKR/m^2	%	Cost (LKR)	LKR/ m^2	%		Cost (LKR)	LKR/m^2	%	
Operation	**68,296,211**	**17,930**	**76.07**	**59,702,243**	**16,737**	**73.85**	**74.99**	**90,102,144**	**22,347**	**70.02**	**-16**
Utilities	27,916,211	7,329	31.10	22,744,031	6,376	28.14	29.64	43,485,000	10,785	33.79	-12
Administrative Cost	19,630,000	5,154	21.87	20,322,748	5,697	25.14	23.47	24,833,694	6,159	19.30	-2
Insurance	12,000,000	3,150	13.37	15,035,464	4,215	18.60	15.93	17,000,000	4,216	13.21	-2
Taxes	8,750,000	2,297	9.75	1,600,000	449	1.98	5.94	4,783,450	1,186	3.72	1
LEED certification maintenance	1,200,000	315	1.34	1,080,000	303	1.34	1.34	-	-	**-**	1
Maintenance	**21,478,156**	**5,639**	**23.93**	**21,914,747**	**6,144**	**27.11**	**25.49**	**38,575,213**	**9,567**	**29.98**	**-12**
Fabric	5,803,000	1,523	6.46	4,139,217	1,160	5.12	5.80	11,030,000	2,736	8.57	-4
Services	5,756,156	1,511	6.41	6,882,964	1,930	8.52	7.44	10,615,000	2,633	8.25	-3
Cleaning	7,575,000	1,989	8.44	8,083,583	2,266	10.00	9.20	7,440,213	1845	6	1
External works	464,000	122	0.52	432,984	121	0.53	0.53	5,250,000	1302	4	-4
Repairs and replacement	700,000	184	0.78	550,000	154	0.68	0.73	2,550,000	632	2	-1
Decoration	1,040,000	273	1.16	1,576,000	442	1.95	1.55	1,635,000	406	1	-0.15
Maintenance Management	140,000	37	0.16	250,000	70	0.31	0.23	55,000	14	0.04	0.12
Total (O&M)	**89, 774,367**	**23,569**	**100.00**	**80,835,827**	**22,662**	**100.00**	**100.00**	**128,677,357**	**31914**	**100**	**-28**

4.3.2.2 Assumptions and Limitations

The following assumptions were taken in the LCC analysis. However, these assumptions were reviewed while performing sensitivity analysis in order to confirm the acceptability of the calculated LCC.

- Inflation rate (e) is considered as 5.5 % year on year basis (at December 2016), according to Central Bank reports of Sri Lanka

- Further, Central Bank reports of Sri Lanka highlight that the inflation Rate in Sri Lanka averaged 9.63% from 1986 until 2017, reaching an all-time high of 28.30% in June of 2008 and a record low of -0.90% in March of 1995. Interest Rate in Sri Lanka averaged 7.86% from 2003 until 2017, reaching an all-time high of 10.50% in February of 2007 and a record low of 6% in April of 2015.

- The market interest rate (r) is recorded as 10% (Nominal interest rate of the Treasury bond for the last few years)

- Discount of all feature costs to a base year using escalation and discount rates is required in order to calculate LCC. Accordingly, discount rate (i) to be applied in the LCC calculation was calculated by using the following formula

$$i = \frac{1+r}{1+e} - 1$$

- According to the previous studies, the life cycle of building ranges from 20 to 100 years (Goh & Sun, 2015), whereas, Gurung and Mahendran (2002) assumed the life cycle of industrial building as 50 years. As suggested by Davis Langdon (2006), buildings costs are difficult to predict for longer period the LCC analysis period was limited to 50

- As discussed under section 4.3.2.1, the end life cycle cost of green and conventional buildings is assumed 2% and 3% respectively.

- All selected buildings were constructed in 2013, therefore construction cost of those buildings were converted to 2016 prices using the appropriate tender price indices, as year 2016 was considered for the base year for the LCC

- On average the selected building has taken two years of construction period. Therefore, total construction cost was distributed among two years equally
- It was assumed that the real costs which occur annually and periodically remain constant throughout the analysis period
- All collected cost data were discounted to year 2016 by using Single Present Value (SPV) and Uniform Present Value (UPV) formulas

4.3.2.3 LCC Comparison: Green vs. Conventional Buildings

Relevant cost data were collected as per the standard cost categories of BMCIS and LCC analysis of the three cases was performed using the life time of 50 years and the discount rate of 4.26%. Table 4.10 illustrates the comparison of LCC of green buildings and that of similar conventional building.

Table 4.10: LCC: Green Buildings vs. Conventional Building

LCC Elements	**Cost per Unit Area (LKR/m^2)**						**Difference** $\frac{\textbf{Green} - \textbf{Conventional}}{\textbf{Conventional}} \times \textbf{100\%}$		
	Green 1	**%**	**Green 2**	**%**	**Conventional**	**%**	**Green 1**	**Green 2**	**Avg.**
Construction	80,306.53	16	81,081.68	17	58,699.34	10	37%	38%	37%
Operation	347,042.41	70	333,689.04	69	469,918.75	76	-26%	-29%	-28%
Maintenance	69,408.48	14	67,278.20	14	87,763.17	14	-21%	-23%	-22%
End of life cycle	180.88	0.04	162.60	0.03	192.04	0.03	-6%	-15%	-11%
NPV (LCC)	**496,938.29**	**100**	**482,299.95**	**100**	**616,573.31**	**100**	**-19%**	**-22%**	**-21%**

As observed from Table 4.10, on average the construction cost of the green building is 37% higher than the construction cost of the conventional building. However, in terms of other costs such as operation, maintenance and end of life cycle costs green buildings offer a substantial saving of 61% over conventional building. This results in overall saving of 21% over the whole life of green industrial manufacturing buildings in Sri Lanka. The main contributor for this saving is operational cost as it contributes over 70% of LCC.

On closer scrutiny of Figure 4.2, depicts the cumulative cost effect of LCC for the 50-years analysis period of the selected green and conventional buildings.

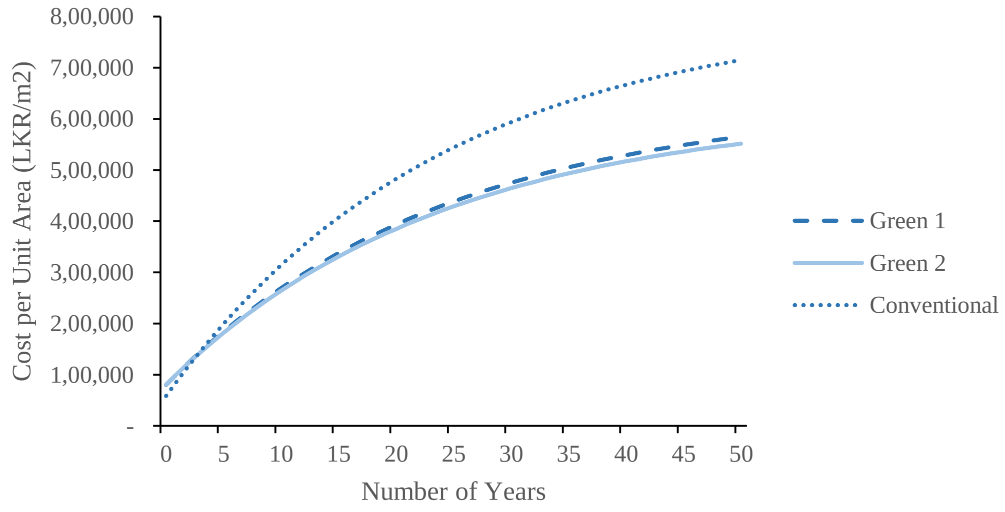


Figure 4.2: LCC Comparison: Green vs. Conventional Buildings

As shown in Figure 4.2, each line represents an upward trend of the PV of the selected two green buildings and the conventional buildings. In the 3rd year, the present value of three buildings intersects and the PV of the conventional building rising higher than that of the green buildings while the PV of green buildings reduced due to the O&M savings.

Apart from LCC, PB and AEV are another two techniques which used for the economic evaluation of buildings. Next section therefore compares the PB of the two green buildings and AEV of all three cases.

4.3.2.4 PB and AEV

Payback period for green buildings was calculated using the non-discounted method and using the annual savings of electricity and water costs by 26% and 31% respectively. Along with the electricity and water cost savings, the green buildings can recover the capital costs of buildings within 14 years approx. Figure 4.3 in the following shows the payback over the life cycle of the selected green buildings.

As shown in Figure 4.3, the cost savings of the selected green buildings show a straight line over the life cycle. This could be due to the consideration of non-discounted payback.

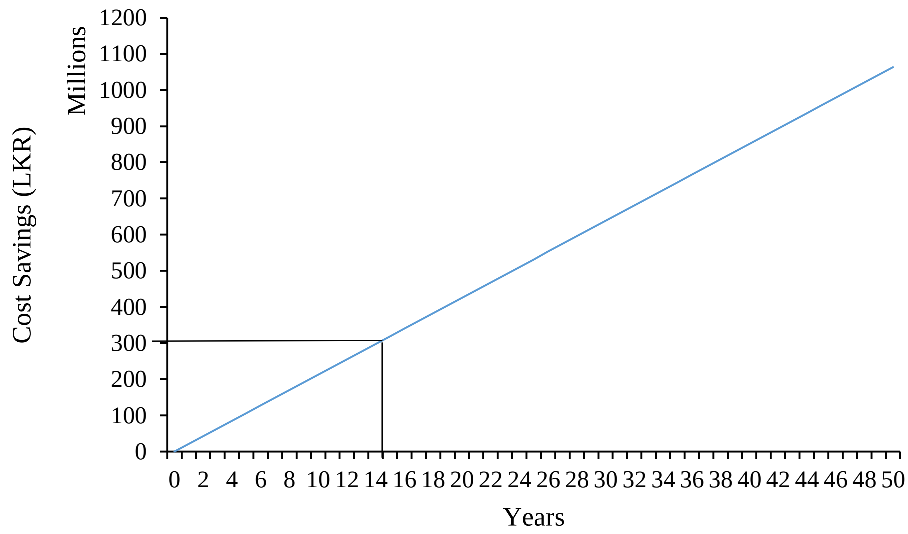


Figure 4.3: Payback over the Life Cycle of the Selected Green Buildings

Further, the annual equivalent value of green buildings equals 0.2, whereas for the conventional buildings it equals 0.4. Therefore, considering the payback period and annual equivalent value of the green buildings, the green buildings are economically sustainable than conventional buildings.

However, above LCC results are vulnerable to change due to the risk and uncertainty associated with the predicted and assumed costs and other data. At this point, sensitivity analysis is an important guide which enables to assess the impact on LCC due to changes in sensible variables. Key assumptions which will have the biggest effects on the uncertainties typically are discount rates, the period of analysis, unreliable maintenance and repair and replacement cycles or costs data based on assumptions. Therefore, the next section presents the results of sensitivity analysis performed.

4.3.2.5 Sensitivity Analysis of LCC

Sensitivity analysis involves iterating the sensitivity analysis calculation with a range of values for the variable data. The insignificant effect on recommendations by the alternative variables reflects an unaffected decision. If, recommended option is varied by different discount rates, service lives and costs etc. being applied, it may indicate that further analysis is required and that the decision is based upon factors other than LCC.

Initially, the life cycle analysis was performed based on the assumptions of discount rate of 4.26%, the life cycle of 50 years, residual value is 3% and 2% of capital cost of buildings for green and conventional respectively, and the annual real costs which remain constant for the entire analysis period. Therefore, a sensitivity analysis has been undertaken to examine how changes to these assumed values will influence the LCC results. The following presents the LCC analyses performed for varying values assumed variables.

Table 4.11 shows the comparison of LCC analysis of green and conventional buildings for the discount rates of 1%, 3%, 5%, 7% and 9%.

Table 4.11: LCC Analysis for Alternative Discount Rates

Buildings	**LCC (*Cost per m²*)**					
	1%	**3%**	**4.26%**	**5%**	**7%**	**9%**
GB 1	890,369	611,842	496,938	457,348	365,294	306,650
GB 2	860,976	592,836	482,300	444,098	355,471	299,008
GB Avg.	875,672	602,339	489,176	450,723	360,382	302,829
CB	1,143,262	770,413	616,573	563,577	440,323	361,797
Difference (%)	-23%	-22%	-21%	-20%	-18%	-16%

As observed from Table 4.11, with increased discount rates the LCC of both GBs and CB are reduced. Accordingly, the minimum difference in LCC of 16% is achieved at the predicted interest rate of 9%.

Further scrutiny of above, Figure 4.4 shows that this reduction in LCC difference is at an increasing rate. However, this graph could lead to a question whether the LCC of GB and CB can be equal at any discount rate. As the literature identified, the highest possible discount rate of 7% is possible at the lowest inflation rate of -0.09% and interest rate of 6% in Sri Lanka, above sensitivity analysis indicates that the LCC of GB is less than the CB even in the worse scenario of the discount rates. Therefore, there is rare possibility of getting equal.

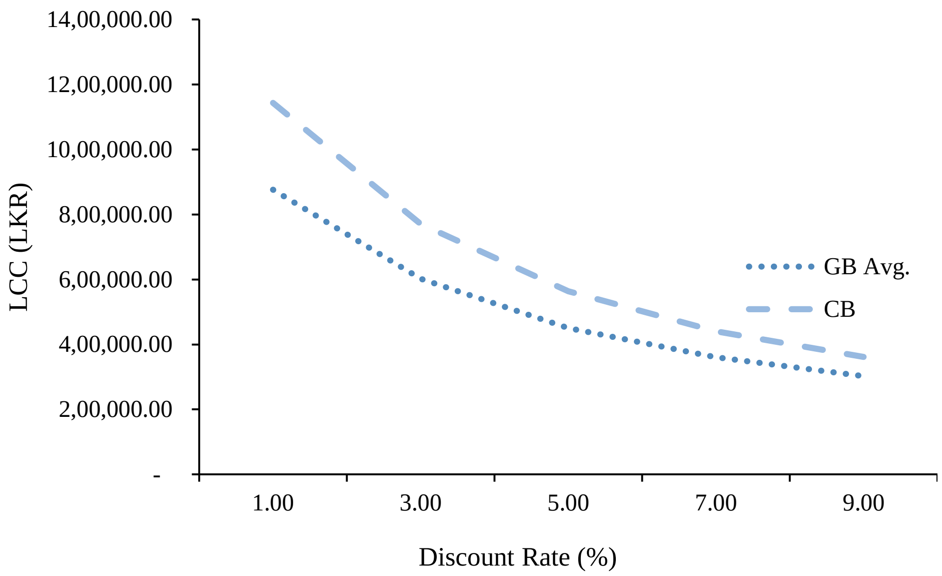


Figure 4.4: LCC at Alternative Discount Rates

Similarly, a LCC comparison was performed for varying analysis period of 40 and 60 years. Table 4.12 presents the results of the analysis.

Table 4.12: LCC Analysis for Alternative Analysis Periods

Buildings	**LCC (*Cost per m²*)**		
	40	**50**	**60**
GB 1	473,863	496,938	525,420
GB 2	459,991	482,300	509,639
GB Avg.	466,393	489,176	517,298
CB	585,656	616,573	654,735
Difference (%)	-20%	-21%	-21%

As shown in Table 4.12, when the analysis was repeated with possible variation in life cycle of the selected buildings, it was observed a slight variation in the difference of LCC of GBs and CB for the possible life cycle of 40 years and there is no variation of the LCC difference at the possible life cycle of 60 years, shows the same difference in LCC of 21%. As a detailed scrutiny, Figure 4.5 illustrates the variation of LCC of GBs and CB for five different life cycles.

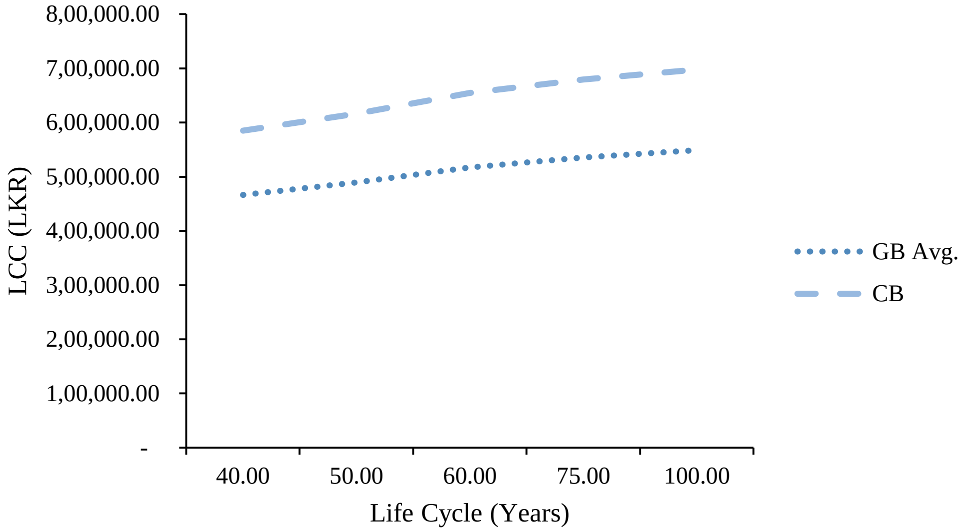


Figure 4.5: LCC at Alternative Life Cycles

As shown in Figure 4.5, the LCC of GBs and CB increases at a decreasing rate and maintains a constant difference between GB and CB. However, compared to the sensitivity showed by LCC in terms of the variable: discount rate, the sensitivity of LCC to the life cycle is less and the decision is unaffected.

Afterwards, the actual cost of significant O&M elements which were identified previously were varied by ±10 and ±20% and the sensitivity of those elemental costs were checked. Table 4.13 illustrates the sensitivity analysis of the insurance cost.

Table 4.13: LCC Analysis for Alternative Insurance Cost

Buildings	**LCC** (*Cost per m²*)				
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	484,030	490,507	496,938	503,461	509,938
GB 2	464,946	473,612	482,300	490,943	499,609
GB Avg.	470,151	479,891	489,176	499,371	509,110
CB	598,879	607,548	616,573	624,884	633,552
Difference (%)	-21%	-21%	-21%	-20%	-20%

As seen in Table 4.13, the sensitivity analysis indicates a slight variation between LCC of GBs and CB and the LCC difference is slightly decreases when insurance cost increases. The sensitivity analysis also indicates that the variation is a slightly downward when the insurance cost increase.

Table 4.14 illustrates the sensitivity analysis of the electricity cost.

Table 4.14: LCC Analysis for Alternative Electricity Cost

Buildings	LCC (*Cost per m²*)				
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	479,210	488,097	496,938	505,871	514,757
GB 2	461,092	471,685	482,300	492,870	503,463
GB Avg.	470,151	479,891	489,176	499,371	509,110
CB	592,251	604,233	616,573	628,198	640,181
Difference (%)	-21%	-21%	-21%	-21%	-20%

According to Table 4.14, the LCC difference of GBs and CB indicates a slight reduction of the LCC difference with respect to the increase in electricity cost. However, electricity as the element with highest contribution to the total O&M cost, could significantly affect to the LCC of buildings with the increase of electricity tariff and inflation rates. Similarly, a LCC comparison was performed for varying water rates and Table 4.15 indicates the results of the analysis.

Table 4.15: LCC Analysis for Alternative Water Costs

Buildings	LCC (*Cost per m²*)				
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	486,296	491,640	496,938	502,328	507,672
GB 2	479,267	480,772	482,300	483,783	485,288
GB Avg.	482,781	486,206	489,176	493,056	496,480
CB	601,735	608,975	616,573	623,456	630,697
Difference (%)	-20%	-20%	-21%	-21%	-21%

As shown in Table 4.15, there is a slight variation of the difference of LCC between GBs and CB. Unlike, insurance and electricity costs, the LCC difference of GBs and CB increases with the increases of the cost of water rates.

Table 4.16 shows the sensitivity analysis of the cost of service attendants. The results indicate a slightly downward variation of LCC difference between GBs and CB and the LCC of both buildings increase with the increase of the cost of service attendants.

Similarly, Table 4.17 illustrates the results of sensitivity analysis in terms of the significant element: cleaning.

Table 4.16: LCC Analysis for Alternative Cost of Service Attendants

Buildings			LCC (*Cost per m²*)		
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	480,166	488,575	496,938	505,393	513,802
GB 2	461,240	471,759	482,300	492,797	503,316
GB Avg.	470,703	480,167	489,176	499,095	508,559
CB	595,735	605,975	616,573	626,456	636,697
Difference (%)	-21%	-21%	-21%	-20%	-20%

According to the table, the LCC difference at various cleaning costs indicates a slight change at a decreasing rate and also the LCC of GBs and CB is an upward trend.

Table 4.17: LCC Analysis for Alternative Cost of Cleaning

Buildings			LCC (*Cost per m²*)		
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	488,807	492,895	496,938	501,072	505,161
GB 2	472,959	477,619	482,300	486,937	491,596
GB Avg.	480,883	485,257	489,176	494,005	498,378
CB	608,628	612,422	616,573	620,009	623,803
Difference (%)	-21%	-21%	-21%	-20%	-20%

Next, the sensitivity analysis was performed by varying end of life cycle cost of the selected three buildings. Table 4.18 indicates the results of sensitivity analysis.

Table 4.18: LCC Analysis for Alternative End of Life Cycle Cost

Buildings			LCC (*Cost per m²*)		
	-20%	**-10%**	**0**	**10%**	**20%**
GB 1	496,902	496,920	496,938	496,956	496,974
GB 2	482,179	482,195	482,300	482,228	482,244
GB Avg.	489,541	489,558	489,176	489,592	489,609
CB	616,535	616,554	616,573	616,593	616,612
Difference (%)	-21%	-21%	-21%	-21%	-21%

According to Table 4.18, the sensitivity analysis indicates no variations with respect to the changes of end life cycle cost of GBs and CB.

Having considered the above sensible variables, it is evident that the degree of influence of these individual variables on LCC is different. According to above analysis, amongst the variable considered, discount rate tends to have top most influence on difference in LCC between GB and CB. The next section analyses the impact of sustainable features through the associated cost and benefits of sustainable features.

4.4 Impact of Sustainable Features on LCC

Foregoing analysis on LCC indicates that initial cost of GBs are higher than CBs, while in terms of running cost CBs are more expensive. However, in terms of overall LCC, GBs are more economical than CBs. These variations in cost are attributed to implementing and maintaining sustainable features and the economic benefits of green buildings. As per the points assigned for various sustainable features and achieved by the LEED certification, the impact of sustainable features on LCC elemental cost vary. Figure 4.6 illustrates the sustainable features implemented and points achieved for those features in green certification of the selected two green buildings.

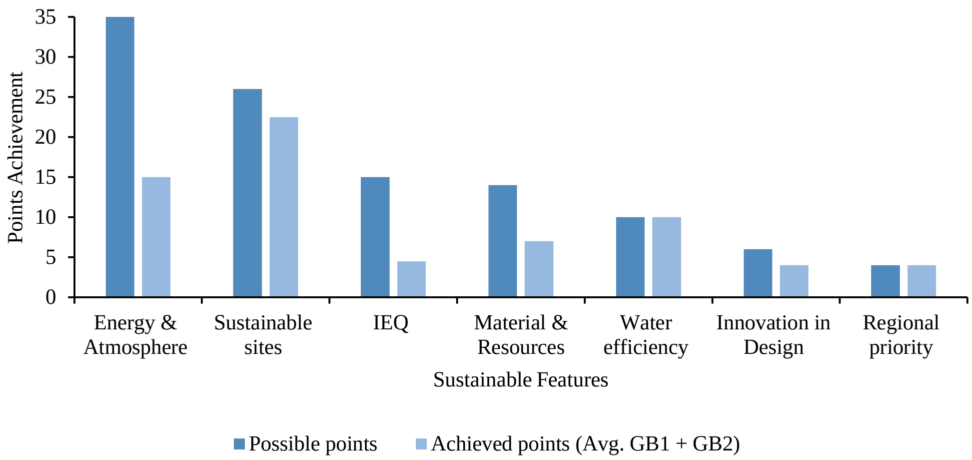


Figure 4.6: Level of Achievement of Sustainable Features of Green Buildings

As shown in Figure 4.6, in terms of energy and atmosphere feature which has the highest possible points, the green buildings have achieved 15 points (out of 35). For the feature: sustainable sites, the green buildings have achieved 23 points (out of 26). Moreover, IEQ feature has achieved 5 points (out of 15) and material and resources feature has achieved 7 (out of 14) points. Considering the sustainable feature; water efficiency, green buildings has achieved total possible points (out of 10). The features: innovation in design and regional priority have achieved 4 points.

First, considers the construction cost of the green buildings and the interviewees were asked to provide the data related to additional cost premium of implementing and maintaining sustainable features. Table 4.19 summarizes the cost premium of two green buildings and the contribution of sustainable features to the construction cost.

According to Table 4.19, the construction premium of green building is due to the integration of sustainable features to the green buildings and the supporting cost for achieving LEED certification. As shown in Table 4.18, the contribution of LEED certification is 10%, whereas the implementation of sustainable features contributes 18% which is highly impacted to the construction cost to increase. When considering the significant sustainable features contribute towards the construction cost of green buildings, the highest contribution is from energy and atmosphere; 7%, whereas IEQ contributes around 6% which is also very close to the highest contribution. The highest contribution of these two features are due to the implementation of energy metering and sub metering, building management system, CO_2 and airflow measurement equipment, high-performance glazing, building commissioning and 3d energy modeling. Incorporation of salvaged materials into structural elements and furnishers and use of steel result to contribute 3% from material and resources. Sustainable sites and water efficiency equally contribute by 1%. Building in an urban location, constructed wetlands, rainwater harvesting and implementation of sewage treatment plant coursed to the cost impact of sustainable sites and water efficiency features. Identification of the green building strategies and technologies with their cost impact would be helpful to the green building investors when they selecting the right strategies and technologies at a right cost. Thereby, The LCC of green buildings could be further reduced by selecting most of the low cost alternative sustainable strategies and technologies of the green buildings.

When considering the maintenance cost of green buildings, they are divided into two major components as maintenance of sustainable features and other maintenance. Table 4.20 summarises the contribution of each element to the total maintenance cost.

Table 4.19: Impact of Sustainable Features on Construction Cost

Elements of Cost Premium	Contribution to premium (LKR/m2)					Green Strategies and Technologies Adopted
	GB1	%	GB2	%	Avg.	
Total Construction	80,306.53	100	81,081.68	100	80,694.11	
Building Cost	58,959.55	73	58,667.47	72	72	
Sustainable Features	12,045.98	15	15,405.52	19	18	
Sustainable sites	950.83	1	1,278.39	2	1	• The location has excellent public transport accessibility • Installation of bicycle racks, changing rooms and showers • Cycling facilities are provided for 5% of staff as well as the visitors • Designated car parking spots for low emitting and fuel efficient • Landscape consists of native indigenous plants • No irrigation is needed after the initial establishment • Rooftop rainwater is collected and harvested in the garden • Light-colored roofing material are provided
Water efficiency	578.86	1	1,201.06	1	1	• Grey water collect to a storage tank and supply for the landscaping and toilet cisterns • Sewage treatment plant install for irrigation purposes and toilets. • Low-water use plumbing fittings: dual-flush, 3/6*l* toilet cisterns, flow restrictors, automatic shut off
Energy and atmosphere	4,818.39	6	5,675.72	7	7	• 3D Energy modelling • The building optimised orientation for passive solar design with north and south facing glazing • Utilise free cooling low-energy T5 light fittings on shared ballasts linked to daylight sensors • Double glazing and insulation • Building Management System monitors and controls HVAC system in the building • Partially exposed structure to provide passive cooling effect • Efficient T5 lighting with dimmable ballasts provided with occupancy and daylight control
Material and resources	1,606.13	2	2,432.45	3	3	• Renovation of an abandoned building • Site specific waste management plan was adopted and monitored during the construction • Construction waste management requirements were specified in the scope of the general contractor • Incorporate salvaged materials into structural elements and furnishers • Use of steel • Most materials required in the project were produced and procured within 500 miles of the project site
IEQ	4,091.77	5	4,817.90	6	6	• Additional ventilation of the building before occupancy to remove harmful chemicals from construction • Stored on-site and insulated absorptive materials from moisture damage and control pollutants • Use of zero VOC paints • CO2 and airflow measurement equipment integrated with building management system • Over 75% of space has external view, with higher level of daylight to over 90% of the space
LEED certification	9,301.00	12	7,008.69	9	10	

Table 4.20: Impact of Sustainable Features on Maintenance Cost

Cost	Contribution to Maintenance Cost per Unit Area (LKR/m2)					Respective Maintenance Cost Element
	GB1	%	GB2	%	Avg.	
Total maintenance cost	69,408.48	100	67,278.20	100	100	
Maintenance of	46,423.58	67	51,126.44	76	72	
Sustainable sites	4,109.35	6	3,848.27	6	6	• Landscaping
Water efficiency	461.09	1	431.79	1	1	• Sewage water treatment
Energy and atmosphere	18,584.71	25	17,403.95	28	26	• T5 bulb replacement • BMS maintenance • HVAC maintenance
Material and resources	6,123.82	6	4,280.15	9	8	• Cyclical maintenance of finishes • Waste management procedures
IEQ	21,847.48	29	20,459.42	32	31	• Sensors and controllers • Shading devices and glazing • Cost of air quality testing • Cost of building painting • Replacing coir mat etc.
Other Building Maintenance	22,984.90	33	16,151.76	24	28	

According to Table 4.20, 72% of total maintenance cost is dedicated to maintaining the sustainable features. Among those features, IEQ involves the highest maintenance cost of 31%, while another 26% is due to maintaining energy and atmosphere technologies. The features of material and resources, sustainable sites and water efficiency are responsible for remaining 15% of the total maintenance cost.

Cost savings are observed in terms of operational costs: electricity, water, waste disposal and carbon emission compared to that of conventional buildings. Average electricity saving of the two green buildings were compared with a benchmark value and illustrated in Figure 4.7. Monthly electricity consumption per production (total kWh divided by number of production unites) was extracted for twelve months.

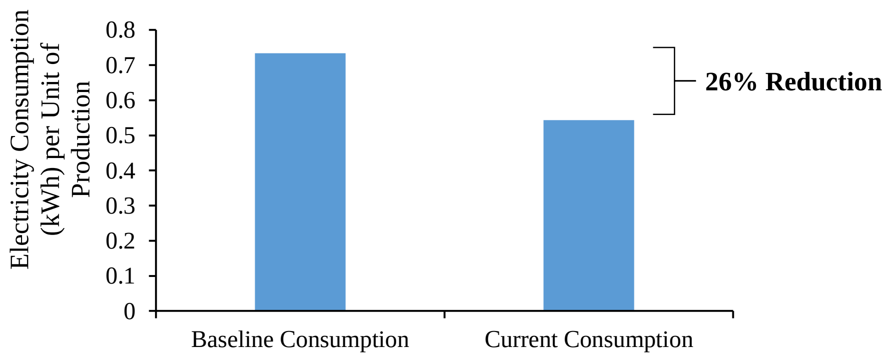


Figure 4.7: Electricity Consumption of Green Buildings

According to Figure, a 26% reduction in electricity consumption is achieved by green buildings.

Similarly, water consumption of green buildings was compared with the benchmark level as indicated in Figure 4.8. Accordingly, 31% of saving in water consumption was achieved in green buildings. This is due to water efficiency strategies and technologies adopted in green buildings.

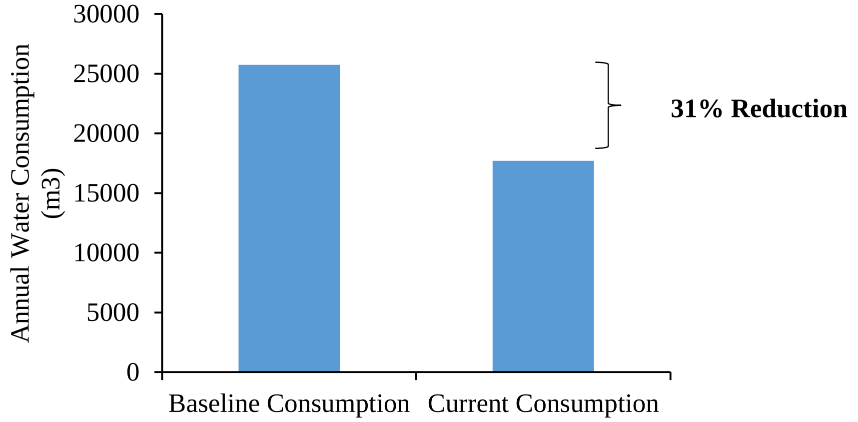


Figure 4.8: Water Consumption of Green Buildings

Table 4.21 summarizes the electricity and water cost savings per m^2 of green buildings. According to Table 4.21, the electricity and water consumption of green buildings together save 35% of the total operation cost of green buildings. Therefore, the major contribution of operation cost saving is from electricity and water saving, while remaining savings are due to other operational cost elements.

Table 4.21: Electricity and Water Cost Saving of Green Buildings

Cost	GB Cost per Unit Area (LKR/m2)		Average
	GB1	GB2	
Total Operation Cost	347,042	333,689	340,366
Electricity + Water Cost Saving	114,814	122,603	118,708
% saving	33%	37%	35%

Average waste disposal to the landfill and recycled waste within the site of the two green buildings were compared with that of conventional building and illustrated in Figure 4.9. According to the figure, only a 20% of the total disposal and demolition waste divert from landfill and use for the recycling in a conventional building.

Whereas, 99% of the total waste from a green building divert from landfill and contributes to the environmental sustainability.

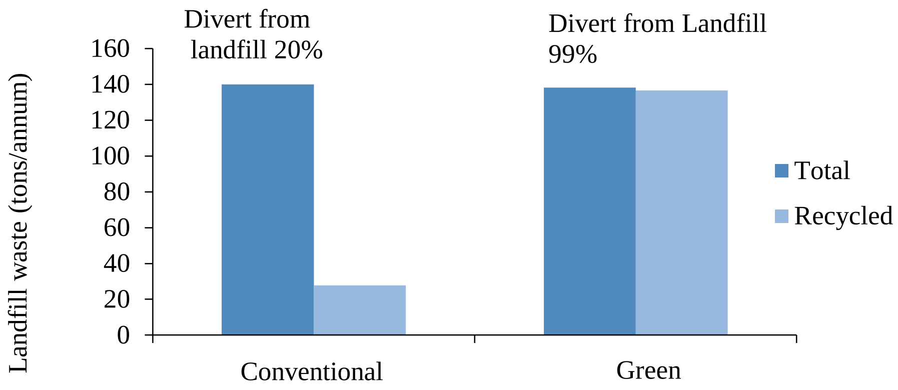


Figure 4.9: Landfill Waste Diversion in Green and Conventional Buildings

Similarly, the average CO_2 emission reduction of green building was compared with that of conventional building.

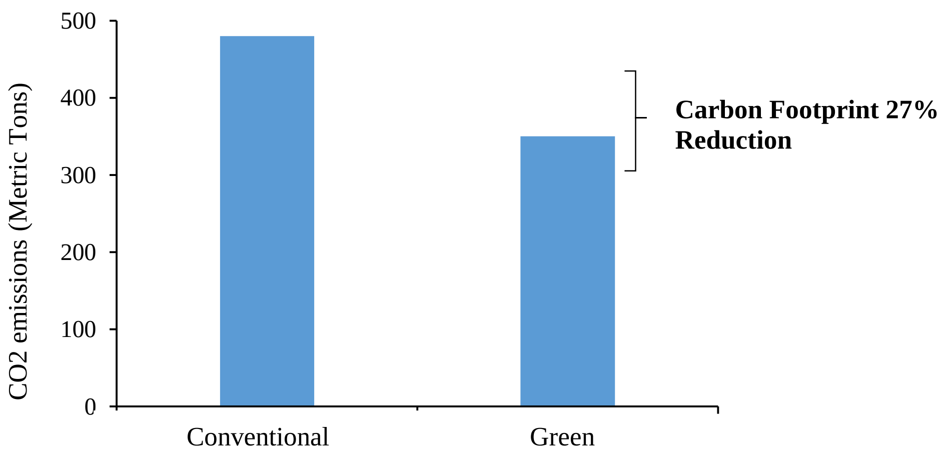


Figure 4.10: Carbon Footprint Reduction of Green Buildings

As shown in Figure 4.10, the green buildings reduce 27% of the Carbon footprint when compared to conventional building. Therefore, these savings together contribute to the end of life cycle cost saving of green buildings.

4.5 Summary

This chapter discussed the findings of the data analysis. The preliminary study identified that high initial cost, design complexities, design time and unfamiliarity of the project team of certain sustainable features prevent green buildings from achieving better sustainability levels. On the other hand, minimal design changes with low cost and design impact, feasible and familiar alternatives, early commitment and use of integrated design processes optimize the sustainability level. Hence, sustainable features; energy and atmosphere, material and resources and indoor environmental quality are incorporated less in the green buildings in Sri Lanka. In addition, the LCC comparison indicated that the green industrial manufacturing buildings are economically sustainable compared to conventional industrial manufacturing buildings in Sri Lanka. The construction cost premium of green building is higher than that of conventional buildings due to the incorporation of LEED professional fees, constructed wetlands, rainwater harvesting, sewage treatment plant, building commissioning, energy metering and sub metering, 3D energy modelling, building management system, incorporate salvaged materials into structural elements and furnishers, use of steel, CO_2 and airflow measurement equipment, high-performance glazing. The study also identified that 72% of total maintenance cost of green buildings is due to maintenance cost of sustainable features while the rest is from other building maintenance activities.

CHAPTER FIVE

5.0 DISCUSSION ON FINDINGS

5.1 Introduction

This chapter discusses the literate findings and synthesis on research findings in three main sections to draw conclusions and recommendations. The first section presents the status of green buildings in Sri Lanka. This is followed by a discussion on LCC analysis of green buildings in the second section, while third section of the chapter discusses the cost impact of sustainable features.

5.2 Status of Green Buildings in Sri Lanka

This section presents the findings on preliminary analysis on the profile of green certified buildings in Sri Lanka as per the LEED BD+C NC, LEED O+M EB, LEED BD+C C&S and LEED ID+C CI categories. Accordingly, altogether 38 buildings out of 74 buildings registered under USGBC LEED certification include: industrial manufacturing office, lodging, retail, higher education, warehouse and laboratories. This concluded that currently nearly 50% of registered buildings have achieved green certification in Sri Lanka and the reason is attributed due to the higher initial cost of green buildings as suggested by Bombugala and Atputharajah (2010). Amongst certified buildings, industrial buildings received the first place. Further, the review of literature indicated that studies (Dwaikat & Ali, 2016; Rehm & Ade, 2013) have focused on various types of green certified buildings such as residential, high-rise apartments, office, education, and hotel buildings and its implications on construction cost leaving the room for focusing LCC of industrial manufacturing category. The next stage of the study therefore involved a comparative study of LCC analysis of green and conventional industrial manufacturing buildings in order to establish the cost implications due to application of green features.

5.3 LCC of Green Buildings

The review of literature identified that the upfront cost concern is one of the main barriers in deciding whether to execute a green building project (Hydes & Creech, 2000; Nelms, Russel & Lence, 2005). Kansal and Kadambari (2010) indicated that initial cost of a green building is more compared to that of a conventional building while the operation cost of green building is less. Whereas, several authors (Ahn & Pearce 2007; Building Design and Construction, 2007; Fullbrook, 2007; Kim, Greene & Kim, 2014; Packard foundation, 2002; Shrestha & Pushpala, 2012) were of the view that the initial cost of green buildings is substantially higher than conventional buildings.

Another set of authors (Davis Langdon, 2007; Morris & Langdon, 2007; Rehm & Ade, 2013) indicated that green buildings require no additional cost and the green building require less cost than conventional buildings (Fullbrook, Jackson & Finlay, 2005) to incorporate a reasonable level of sustainable design.

In line with those studies, in the current study, the analysis of initial cost indicates that green industrial manufacturing buildings are 37% higher in total construction cost compared to conventional buildings. This is partially due to cost involved in implementing sustainable features which is responsible for 18% of the total construction cost. The LEED certification cost is another contributor with 10% contribution. However, when the LCC is considered the costs of implementing sustainable features and LEED certification are responsible for only 3% and 2% respectively as the total construction contributes 20% to the LCC.

However, in terms of operation, maintenance and end life costs, green buildings are comparatively less costly than the conventional building, respectively by 28%, 22% and 11%. This results in a 21% reduction in total LCC of green buildings over conventional buildings for the given discount rate of 4.26% and 50 years of life time period. The study further found that green buildings contribute significantly to the energy and water consumption reduction where the annual saving of electricity and water costs by 26% and 31% over a 14-year study period outweigh the initial green cost premium of the selected buildings. Considering the end life cost of green buildings, green buildings save 10% of the LCC than that of a conventional building. This is due to the, 99% of the total disposal and demolition waste are divert from landfill and CO_2 emission is reduced by 27% than a conventional project.

Subsequently, a sensitivity analysis was performed, in order to verify these costs differences between green and conventional buildings, due to changes in significant

O&M costs elements, discount rate, and life time. Significant cost elements were identified using cost significance analysis using Pareto’s 80/20 rule where the topmost 20% of costs elements contributes to 80% of total running costs. Accordingly, for all possible alternative values of above variables, the LCC of green buildings remains cheaper by 21% on average.

5.4 Cost Impact of Sustainable Features

The review of literature identified that applicable criteria of water efficiency have a low initial cost impact, excluding the instances where the project involves high-end technologies like innovative waste water technologies (Davis Langdon, 2007). Many of the elements of sustainable sites have very low initial cost impact (Davis Langdon, 2007) and can be readily achievable with little cost. Energy applicable criteria require a high degree of focus and can be challenging for many projects (Davis Langdon, 2007). Almost all the applicable criteria associated with material and resources have both minimal and significant cost impacts considering the compliance or other physical conditions (Davis Langdon, 2007) and the applicable criteria in IEQ are readily achievable with low costs (Davis Langdon, 2007).

In line with above findings, according to preliminary analysis carried out in to green certified industrial manufacturing buildings in Sri Lanka, the buildings have achieved 100% sustainability in terms of water efficiency feature through low cost, feasible and familiar alternatives of water efficiency technologies and strategies which save utility costs over the life cycle of the building. As per the score achieved by sustainable sites feature, the industrial manufacturing buildings in Sri Lanka have achieved a higher sustainability level. This is due to over 50% of the sustainability level being easily added to the building by making minimal design changes which require low cost and design impact. Usually, a higher initial cost, an early commitment and integrated design process are required to achieve energy and atmosphere features which provide a long-term cost savings. Therefore, most of the time, the buildings have managed to achieve less than 50% of the sustainability.

Most of the features in material and resources category of green certification are uncommon in most projects due to the additional work and substantial cost associated with incorporating features. And projects achieving material and resources must sacrifice the energy and atmosphere of the building. However, achieving energy and atmosphere is more economical considering the long term economic benefits. Therefore, the industrial manufacturing buildings in Sri Lanka have achieved a sustainability level of less than 50% of the material and resources feature. Most of the IEQ criteria need to have the commitment of the project owners and construction team. However, all clients are not willing to maintain the level of management needed to ensure the performance necessary to meet these points successfully. These points may seem easy to achieve, but often turn out far more complicated, and thus less feasible, than anticipated. Therefore, most of the green industrial manufacturing buildings in Sri Lanka have scored less than 50% points for the IEQ feature.

Further, the findings of the study indicate that construction cost premium of green buildings is contributed 10% due to administration cost of the LEED certification while another 18% is due to the integration of sustainable features. The impact of sustainable features on the construction cost includes energy and Atmosphere; 7%, IEQ; 6%, material and resources; 3%, sustainable sites and water efficiency; respectively 1%. The implementation of energy metering and sub metering, building management system, CO_2 and airflow measurement equipment, high-performance glazing, building commissioning and 3d energy modelling have contributed much in the selected buildings. Further, the incorporation of salvaged materials into structural elements and furnishers, use of steel, building in an urban location, constructed wetlands, rainwater harvesting and implementation of sewage treatment plant also contributed to increase construction cost of green buildings than that of conventional buildings. However, only few of these high cost integrations have contributed to maintenance cost, such as shading devices and glazing, cyclical maintenance of building finishes and sewage water treatment. Other than those, activities like maintenance of sensors and controllers, conducting air quality test, building painting, replacing coir mat, T5 bulb replacement, BMS maintenance, HVAC maintenance, waste management procedures and landscaping also contribute for high maintenance cost.

The sustainable features contribute about 72% to the total maintenance cost where in turn results in 28% saving over conventional buildings as adequate measures are taken in designing of key building elements to provide dedicated and generous space for regular cleaning, maintenance, and repair to the central or major elements of the HVAC system and choosing materials that require little maintenance; such as painting, retreatment and waterproofing. The highest impact (31%) of sustainable features to the maintenance cost is from the IEQ feature, while energy and atmosphere feature contribute 26%. Material and resources, sustainable sites and water efficiency contribute 8%, 6% and 1% respectively.

Discussion on literature findings and synthesis on research findings indicate that IEQ and energy and atmosphere have the highest cost impact compared to other sustainable features in green industrial manufacturing buildings in Sri Lanka.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Although it is widely discussed the social, environmental and economic benefits of green buildings, the uptake of green buildings is still at minimum level in countries including Sri Lanka. Past studies have focused on impact of green buildings on construction costs where contradictory views of green cost implications are presented. Further, green building investors rely on decisions which based the initial cost but not the life cycle green benefits and costs. Therefore, the current study compares the life cycle costs of green and conventional buildings and thereby assesses the impact of sustainable features on the LCC of green buildings in Sri Lanka through a step by step achievement of four objectives.

Accordingly, the first chapter of the thesis provided the background information and highlighted the research gap reviewing the empirical studies. The key research gap identified in the background study is the lack of quantified LCC and running costs of green buildings compared to the conventional buildings. Accordingly, the research question: are green buildings economically sustainable compared to conventional buildings? was identified under the problem statement. Next, the chapter formulated the aim and four objectives to address the research gap.

The second chapter presented the comprehensive review of the concepts of sustainable development and green buildings, the features and criteria of sustainability rating systems which are practiced in Sri Lanka, potential green building strategies, technologies which are related to each criterion and their cost impact. Accordingly, sustainable sites, water efficiency, energy and atmosphere, materials and resources, and IEQ are commonly available sustainable features in the green rating systems used in Sri Lanka. The review further indicated that amongst the applicable criteria, water efficiency, sustainable sites and IEQ can readily be incorporated with low costs, while energy and atmosphere, material and resources require a high degree of focus and involve very high initial cost.

The third chapter of the study provided the appropriate methodology adopted for the study. The selected approach was mixed method approach with case studies and the techniques consist with the documentation analysis and semi-structured interviews for the data collection and descriptive, content and NPV analysis for the data analysis.

The fourth chapter presents the analysis and findings of preliminary study and case study. A preliminary study in to document analysis was conducted to identify the profile of LEED certified green buildings in Sri Lanka and expert interviews to identify the reasons for the level of achievement of sustainability. Accordingly, the water efficiency feature has achieved 100% sustainability level through low cost, feasible and familiar alternatives of water efficiency technologies and strategies, whereas over 50% of sustainability level has achieved through making minimal design changes to the building which require low cost and design impact in terms of sustainable sites feature. However, in terms of energy and atmosphere, the certified buildings have achieved only 50% of allocated points as it required alternatives with higher initial cost, early commitment and integrated design process. Similarly, in terms of IEQ features, the industrial buildings have earned less than 50% of the sustainability level since most of the IEQ points which seem easy to achieve, but often turn out to be far more complicated, and thus less feasible, than anticipated. The certified industrial manufacturing buildings have achieved less than 50% sustainability in terms of material and resources because most of the points are uncommon in most projects due to the additional work and the substantial cost associated with the building.

Subsequently, a comparison of the LCC of green vs. that of conventional buildings in Sri Lanka was conducted via case study. Two green buildings and a conventional building of similar characteristics were selected. Afterwards, the cost profiles of the three buildings were identified as per BMCIS standard framework and analysed in order to assess the cost differences between green and conventional buildings considering their annual costs. Accordingly, higher cost was indicated in the construction cost of superstructure and internal finishes of green buildings. Further, the construction cost of the green building is 37% higher than that of the conventional building considering the all costs differences of construction costs elements. In the O&M stage of the selected buildings, cost of utilities: electricity and water costs in green buildings indicates a substantial saving, whereas maintenance cost of fabric, services and external works also indicate significant savings. Considering the operation cost, the total utility cost saving through energy and water contributes 35% which repay the initial construction cost within 14 years.

In line with above findings, outcome of the LCC analysis between green and conventional buildings indicates that operation, maintenance and end life costs of the green building are comparably less than those of the conventional building, respectively by 28%, 22% and 11%. Therefore, green industrial manufacturing buildings are more economically sustainable than that of conventional buildings. LCC analysis involves conducting a sensitivity analysis on the key assumptions made and the significant running costs elements of green and conventional buildings in Sri Lanka. The sensitivity analysis indicated that there is a small effect on the green building life cycle impact at various discount rates, life cycles and significant running cost elements.

Ultimately, assessed the impact of sustainable features on the LCC elements: construction cost, operation, maintenance cost and end life cost of Green Buildings in Sri Lanka. Costs spent to achieve each sustainable feature: sustainable sites, water efficiency, energy and atmosphere, material and resources and IEQ were assessed for the construction and maintenance costs, whereas for the operation and end life costs, actual savings from the green buildings were compared with that of conventional design. Accordingly, the implementation of sustainable features contributes 18% to the total construction cost of green buildings with a major contribution of energy and Atmosphere and IEQ features. Further, those contributions are mainly due to the implementation of energy metering and sub metering, building management system, CO_2 and airflow measurement equipment, high-performance glazing, building commissioning and 3d energy modelling.

The sustainable features contribute about 72% to the total maintenance cost, while in turn results in 28% of saving compared to the cost of maintenance in conventional buildings. Maintenance cost is mainly involved with cost of maintaining shading devices and glazing, cyclical maintenance of building finishes, sewage water treatment plants and sensors and controllers, conducting air quality test, building painting, replacing coir mat, T5 bulb replacement, BMS maintenance, HVAC maintenance, waste management procedures and landscaping. Further, the operation cost involves with savings of energy and water by 26% and 31% respectively, whereas in the building disposal stage, disposal and demolition waste and CO_2 emission reduction contribute by 99% and 27% than a conventional project.

This fifth chapter brought clarity to the gap between the theory findings and research analysis and findings. Accordingly, the research findings show that in the global context, approximately 50,000 buildings have achieved the LEED certification, whereas in Sri Lanka only 38 buildings have achieved green to date. Lately, there has been a growing global interest towards sustainable manufacturing buildings to attract more global customers. In order to market their products, industrial manufacturers need to assure they produce carbon neutral products. Therefore, the use of green building concept has for fronted in industrial manufacturing buildings in Sri Lanka.

The implementation of green buildings in Sri Lanka is lacking due to the increased costs due to increased architectural and engineering design time, modelling costs and time necessary to integrate sustainable building practices into projects, specific enhancements, such as photovoltaic systems and redundant mechanical systems and lack of experience of project team assigned for green design and construction. Even the green buildings which achieved the LEED certification are incorporated less energy and atmosphere, material and resources and indoor environmental quality criteria due to the above identified reasons.

On that note, a case study approach was adopted where the LCC of two green buildings and a similar natured conventional industrial building was compared. According to comparison, the construction cost of green building is 37% higher than that of a conventional building while the green building offers a saving of 28%, 22% and 11% in terms of operation, maintenance and end life cycle costs respectively. A sensitivity analysis performed subsequently concluded that the green industrial buildings are economically sustainable with the overall saving of 21% achievable over its possible life time at the possible discount rates. Therefore, the findings of this study enable green investors to take informed decision upfront and thereby promote higher level of sustainability at large.

6.2 Recommendations to the Green Building Investors

Based on the findings and conclusions, the current study recommends the following to be practiced by green building investors.

- Green building investors should consider about the LCC benefits of green buildings rather than going for conventional solutions with lower construction costs.
- The green buildings need more preparation and better implementation demanding a steady assurance of altering the following: how building schemes are planned, built, operated and sustained to attain a lower total LCC.
- Adding low cost green strategies and technologies; locating the building where there is an excellent public transport accessibility, installation of bicycle racks, changing rooms and showers, provision of designated car parking spots for low emitting and fuel efficient vehicles, landscaping with native indigenous plants, keeping irrigation to a minimum, providing light-coloured roofing material, collection and supplying of grey water for the landscaping and toilet cisterns, installing low-water use plumbing fittings such as dual-flush, 3/6 litre toilet cisterns, low-flow shower heads, taps with flow restrictors, and automatic shut off, optimised orientation for passive solar design, double glazing and insulation, measurement and verification plan, renovation of an abandoned building, waste management plan, use of materials produced and procured within 500 miles of the project site, additional ventilation before occupancy, storage on-site and insulation of absorptive materials from moisture damage and control pollutants, use of zero VOC paints, application of both natural and mechanical ventilation to the building.

6.3 Limitation of the Study

There are certain limitations to the current study. Initially, this research has investigated the reasons for the level of achievement of sustainability from the perspectives of expert professionals in green industrial manufacturing buildings certified under LEED BD+C New Construction category. Recognising the importance of external stakeholders to the study, the research had attempted to collect the views of green building consultants but was not successful due to practical difficulties in contacting and getting response from consultants.

Secondly, this study is limited to three cases due to the lack of green industrial manufacturing buildings in Sri Lanka with similar characteristics and the accessibility constraints of the cost data of industrial manufacturing buildings. The cost data for the study was collected through a developed framework and only 55 O&M costs elements out of 71 costs elements were used to calculate the LCC and the cost data was collected only for one year, due to limited access of data from organisational level and the absence of a national level database on the running cost of industrial manufacturing buildings in Sri Lanka.

Subsequently, it is believed that other factors such as end user behaviours, glazing type, managerial, social, environmental, and financial could also affect the green building cost. However, the study only considers few factors like location, climatic condition, management style and quality, year of construction, number of floors, shape, NIA, designed life cycle, building height and number of occupants.

6.4 Recommendations for Further Research

Different avenues for further research are identified and discussed to enable researchers to explore the study area.

a) The current study can be extended with rest of the sample green certified industrial manufacturing buildings. This would strength the accuracy of the findings and thereby increase the green investors' confidence.

b) The current study can be repeated to other categories of green certified buildings as per LEED.

c) The current study focused on impacts of sustainable features on construction cost as a single item. However, construction cost comprises of several elemental costs which can be influenced by sustainable features by varying degree. Therefore, it is recommended to study the significant building elements and their impacts on sustainable features.

d) The current study is limited to comparing LCC of buildings in similar physical and performance characteristics. Therefore, it is recommended the future studies to consider other factors such as managerial, social, environmental, and financial and identify their impact on LCC of green buildings to facilitate green building investors to take better decisions of their green investments.

REFERENCES

Abidin, N. Z. (2010). Investigating the awareness and application of sustainable construction concept by Malaysian developers. Habitat international, 34(4), 421-426.

Ahn, Y., & Pearce, A. (2007). Green construction: contractor experiences, expectations, and perceptions. Journal of Green Building, 2(3), 1–17.

Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector. Buildings, 2, 126-152. doi:10.3390/buildings2020126

Ala-Juusela, M., Short, M., & Shvadron, U. (2014). Tools to support sustainable entrepreneurship in energy positive neighbourhoods. Entrepreneurship and sustainability Issues, 2(2), 49-59.

Al-Hajj, A., & Horner, M. W. (1998). Modelling the running costs of buildings. Construction Management and Economics, 16(4), 459-470. doi:10.1080/014461998372231

Ali, H. H., & Al Nsairat, S. F. (2009). Developing a green building assessment tool for developing countries: case of Jordan. Building and Environment, 44, 1053-1064.

Al-Khatam, J. A. (2003). Buildings Maintenance Cost. Dhahran: King Fahd University of Petroleum & Minerals.

Anink, D., Boonstra, C., & Mak, J. (1996). Handbook of sustainable building: an environmental preference method for selection of materials for use in construction and refurbishment. London: Earthscan Publications.

Arditi, D., & Nawakorawit, M. (1999). Issues in building maintenance: property managers' perspective. Journal of Architectural Engineering, 5(4), 117-132. doi:10.1061/(ASCE)1076-0431(1999)5:4(117)

Arpke, A., & Strong, K. (2006). A comparison of life cycle cost analyses for a typical college using subsidized versus full-cost pricing of water. Ecological Economics, 58, 66–78.

Ashworth, A. (2004). Cost studies of buildings (4th ed.). London: Trans-Atlantic Pubns.

Ashworth, A., & Perera, S. (2015). Cost Studies of Buildings (6th ed.). New York: Routledge. Retrieved November 17, 2016, from https://books.google.lk/books?hl=en&lr=&id=8_YsCgAAQBAJ&oi=fnd&pg=PP1&dq=cost+studies+of+buildings&ots=aU0cryt-HM&sig=M1uq4ZSm-rS10ISr_2ASbK0aph0&redir_esc=y#v=onepage&q=cost%20studies%20of%20buildings&f=false

Australian Bureau of Statistics. (2000). Water Account for Australia. AustStats.

Aziz, A. A., & Adnan, Y. M. (2007). Incorporation of innovative passive architectural features in office building design towards achieving operational cost saving-the move to enhance sustainable development. 1-11.

Bartlett, E., & Howard, N. (2000). Informing the decision makers on the cost and value of green building. Building Research & Information, 28(5-6), 315-324.

Bartlett, E., & Simpson, S. (1998). Durability and reliability, alternative approaches to assessment of component performance over time. CIB Congress.

Belniak, S., & Zima, K. (2013). The influence of the building shape on the costs of its construction. Journal of Financial Management of Property and Construction, 18(1), 90-102. doi:10.1108/13664381311305096

Bhamra, T. & Lofthouse, V. (2007). Design for sustainability: A practical approach. Hampshire: Gower Publishing.

Bhaskar, R. (1989). Reclaiming Reality: A Critical Introduction to Contemporary Philosophy. London: Verso.

Bombugala, B. A., & Atputharajah, A. (2010). Sustainable development through Green Building Concept in Sri Lanka. International Conference on Sustainable Built Environment. Kandy.

Bon, R., & Hutchinson, K. (2000). Sustainable construction: some economic challenges. Building Research & Information, 28(5), 310-314.

Bond, S. (2011). Barriers and drivers to green buildings in Australia and New Zealand. Journal of Property Investment & Finance, 29(4/5), 494 - 509. doi:10.1108/14635781111150367

Brandon, P. S. (1978). A framework for cost exploration and strategic cost planning in design. Chartered Surveyor Building and Quantity Surveying Quarterly, 5(4), 60-63.

British Standard Institution. (1984). British standard glossary of maintenance management terms in terotechnology. London.

British Standard Institution. (2008). Buildings and constructed assets-Service life planning-Part 5: life cycle costing, BS ISO 15686-5:2008. London.

Brown, C. (1984). Residential Water Conservation Projects: Summary Report; Report HUD-PDR-903; Prepared for U.S. Department of Housing and Urban Development. Washington, DC, USA: Office of Policy Development and Research.

Brown, Z. B. (2009). Occupant comfort and engagement in green buildings: Examining the effects of knowledge, feedback and workplace culture. Vancouver: The University of British Columbia.

Building Design and Construction. (2007). Green buildings research white paper. Retrieved from http://www.bdcnetwork.com/bdcs-2007-green-buildings-researchwhite-paper-where-building-owners-end-users-and-aecprofessionals

Catalina, T., Virgone, J., & Iordache, V. (2011). Study on the Impact of the Building Form on the Energy Consumption. 12th Conference of International Building Performance Simulation Association. Sydney.

Chandratilake, S. R., & Dias, W. P. (2013). Sustainabili ty ratin g systems for bu ildings: Comp arisons and correlations. Energy, 22-28. Retrieved from http://dx.doi.org/10.1016/j.energy.2013.07.026

Chatterjee, S., & Hadi, A. S. (2012). Regression analysis by example (5th ed.). New Jersey: John Wiley and Sons.

Choi, I. Y., Cho, S. H., & Kim, J. T. (2012). Energy consumption characteristics of high-rise apartment buildings according to building shape and mixed-use development. Energy and Buildings, 46, 123–131.

Cole , R. J., & Sterner, E. (2000). Reconciling theory and practice of life-cycle costing. Building Research & Information, 28(5/6), 368-375. doi:10.1080/096132100418519

Cole, R. J. (2000). Editorial: Cost and Value In Building Green. Building Research & Information, 28(5-6), 304-309.

Creswell, J. W. (2014). Research design : qualitative, quantitative, and mixed methods approaches (4th ed.). California: SAGE Publications Ltd.

Cunningham, T. (2013). Factors Affcting The Cost of Building Work - An Overview. Dublin Institute of Technology.

Davis Langdon. (2007). Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption. Davis Langdon.

Dell'Isola, A. J., & Kirk, S. J. (2003). Life cycle costing for facilities. Kingston: Construction Publishers & Consultants.

Depecker, P., Menezo, C., Virgone, J., & Lepers, S. (2001). Design of buildings shape and energetic consumption. Building and Environment, 36, 627–635.

Dodge Data & Analytics. (2016). World Green Building Trends 2016. Bedford: Dodge Data & Analytics.

Du Plessis, C. (2007). A strategic framework for sustainable construction developing different approaches. *Sustainable Development*, 13 (1), 38-52.

Durmus-Pedini, A., & Ashuri, B. (2010). An Overview of the Benefits and Risk Factors of Going Green in Existing Buildings. International Journal of Facility Management, 1(1), 1-15.

Dwaikat, L. N., & Ali, K. N. (2016). Green buildings cost premium: A review of empirical evidence. Energy and Buildings, 110, 396–403.

El- Haram, M. A., & Horner, M. W. (2002). Factors affecting housing maintenance cost. Journal of Quality in Maintenance Engineering, 8(2), 115-123. doi:10.1108/13552510210430008

Environmental Protection Agency. (2017, June 12). Basic Information: Green Building. Retrieved from https://archive.epa.gov/greenbuilding/web/html/about.html

Ferry, D. J., & Brandon, P. S. (1991). Cost planning of buildings (6th ed.). London: Blackwell Scientific Publications Ltd.

Fowler, K. M., & Rauch, E. M. (2006). Sustainable Building Rating Systems Summary. Battelle: U.S. Department of Energy.

Fullbrook, D. (2007). Value cases for achieving Green Star NZ 4 Star and 5 Star environmental ratings in commercial office buildings. Wellington: Ministry for the Environment.

Fullbrook, D., & Woods, J. (2009). Value case for Green Star-rated fitting out of central government office accommodation (ME 934). Wellington: Ministry for the Environment.

Fullbrook, D., Jackson, Q., & Finlay, G. (2005). Value case for sustainable building in New Zealand (ME 705). Wellington: Ministry for the Environment.

Gluch, P., & Baumann, H. (2004). The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. Building and Environment, 39, 571-580.

Green Building Council of Australia. (2012). The Value of Green Star: a Decade of Environmental Benefits. Sydney: Green Building Council of Australia.

Green Building Council Sri Lanka. (2010). Green rating system for built environment. Colombo: Green Building Council Sri Lanka.

Heerwagen, J. H. (2000). Green Buildings, Organizational Success, and Occupant Productivity. Building Research & Information, 28(5), 353-367.

Heron, J. (1996). Co-operative Inquiry: Research into the Human Condition. London: Sage.

Hopwood, B., Mellor, M., & O'Brien, G. (2005). *Sustainable development: mapping environmental preference method for selection of materials for use in construction and refurbishment*. London: Earthscan Publications.

Houghton, A., Vittori, G., & Guenther, R. (2009). Demystifying first-cost green building premiums in healthcare. Journal of Health Environment Research and Design, 2, 10–45.

Hydes, K., & Creech, L. (2000). Reducing mechanical equipment cost: the economics of green design. Building Research & Information,, 28(5/6), 403–407.

Ibrahim, A. D. (2007). Effect of changes in layout shape on unit construction cost of residential buildings. Samaru Journal of Information Studies, 7(1), 24-31.

John, G., Clements-Croome, D., & Jeronimidis, G. (2005). Sustainable building solutions: a review of lessons from the natural world. *Building and Environment*, 40 (3), 319-328.

Kansal, R., & Kadambari, G. (2010). Green Buildings: An Assessment of Life Cycle Cost.

Kats, G. (2003). Green Building Costs and Financial Benefits. Westborough, MA: USA for Massachusetts Technology Collaborative.

Kats, G. (2006). Greening America's schools: Costs and benefits, A capital E report. Retrieved May 25, 2016, from U.S. Green Building Council: http://www.usgbc.org/Docs/Archive/General/Docs2908.pdf

Kats, G. (2010, September 24). Costs and Benefits of Green Buildings.

Kats, G., Alevantis, L., Berman, A., Mills, E., & Perlman, J. (2003). The costs and financial benefits of green buildings. Capital E.

Kats, G., James, M., Apfelbaum, S., Darden, T., Farr, D., & Fox, R. (2008). Greening buildings and communities: costs and benefits. Capital E.

Kehily, D. (2010). Guide to life cycle costing. Society of chartered surveyors Ireland. Retrieved from http://www.scsi.ie

Keraminiyage, K. P., Amarathunga, R. D., & Haigh, R. P. (2005). A capability maturity approach for construction process improvement: Use of case studies approach. Salford: University of Salford.

Kibert, C. J. (2008). Sustainable Construction: Green building Design and Delivery (2nd ed.). New York: John Wiley & Sons, Inc.

Kibert, C. J. (2008). *Sustainable Construction: Green building Design and Delivery* (2nd ed.). New York: John Wiley & Sons, Inc.

Kim, J., Greene, M., & Kim, S. (2014). Cost comparative analysis of a new green building code for residential project development. Journal of Construction Engineering and Management, 140, 1-10.

Kouskoulas, V., & Koehn , E. (1974). Predesign cost-estimation function for buildings. Journal of the Construction Division, 100(CO4), 589–604.

Krem, M. (2012). Effct of Building Morphology on Energy and Structural Performance of High-Rise Office Buildings. Amherst: University of Massachusetts.

Krem, M., Hoque, S. T., Arwade, S. R., & Breña, S. F. (2013). Structural Configuration and Building Energy Performance. Journal of Architectural Engineering, 19(1), 29-40. doi:10.1061/(ASCE)AE.1943-5568.0000103

Kumar, R. (2011). Research methodology (3rd ed.). London: SAGE Publications Ltd.

Lai, J., Yik, F., & Jones, P. (2008). Expenditure on operation and maintenance service and rental income of commercial buildings. Facilities, 26(5/6), 242 - 265. doi:10.1108/02632770810865014

Laloe, F. (2007). Modelling sustainability: from applied to involved modelling. *Social science information*, 46 (1), 87-107.

Langston, C. A. (2011). Life-cost approach to building evaluation. New York: Routledge.

Lehtonen, M. (2004). The environmental-social interface of sustainable development: capabilities, social capital, institutions. *Ecological Economics*, 49 (2). pp. 199-214. ISSN 0921-8009

Lutzkendorf, T., & Lorenz, D. (2007). Integrating sustainability into property risk assessments for market transformation. *Building Research and Information*, 35 (6), 644661.

Mapp, C., Nobe, M., & Dunbar, B. (2011). The cost of LEED—an analysis of the construction of LEED and non-LEED banks. Journal of Sustainability and Real Estate, 3(2011), 254–273.

Matthiessen, L., & Morris, P. (2004). Costing green: A comprehensive cost database and budgeting methodology. Retrieved from http://www.davislangdon.com/USA/Research/ResearchFinder/2004-Costing-Green-A-Comprehensive-Cost-Database-and-Budgeting-M

Matthiessen, L., & Morris, P. (2007). Cost of green revisited. Retrieved from http://www.davislangdon.com/USA/Research/ResearchFinder/2007-The-Cost-ofGreen-Revisited

Means, R. S. (2011). Green Building: Project Planning & Cost Estimating (3rd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Morris, P., & Langdon, D. (2007). What Does Green Really Cost? The Green Issue Feature, PREA Quarterly(Summer), 55-60.

NAHB Research Centre. (2009). The added cost of greening a new home. Retrieved from http://www.toolbase.org/PDF/CaseStudies/LCCTC_AddedCostGreeninNewHome.pdf_

Nelms, C., Russel, A. D., & Lence, B. J. (2005). Assessing the performance of sustainable technologies for building projects. Canadian Journal for Civil Engineering, 32, 114-128.

Nilson, M. L. (2005). Quantifying the cost impacts of LEED-NC Gold construction in New York city. Senior Honors Thesis, Lafayette College, Easton, PA.

Nolan, S. A., & Heinzen, T. E. (2008). Statistics for the behavioral sciences. New York: Worth Publishers.

Northbridge Environmental Management Consultants. (2003). Analyzing the cost of obtaining LEED certification. Retrieved from http://www.cleanair--coolplanet.org/for_communities/LEED_links/AnalyzingtheCostofLEED

Omari, D. O. (2015). An Investigation into Factors Affecting the Maintenance Cost of Commercial Buildings in Nairobi, Kenya. School of the Built Environment.

Packard Foundation. (2002). Building for sustainability report. Los Altos, CA: The David and Lucile Packard Foundation.

Park, C., Nagarajan, S., & Lockwood, C. (2008). The dollars and sense of green retrofits. Retrieved from http://www.deloitte.com/assets/DcomUnitedStates/Local%20Assets/Documents/us_re_Dollars_Sense_Retrofits_190608_pdf

Paul, W. L., & Taylor, P. A. (2008). A comparison of occupant comfort and satisfaction between a green building and a conventional building. Building and Environment, 43, 1858–1870.

Rehm, M., & Ade, R. (2013). Construction costs comparison between “green” and Conventional office buildings. Building Research and Information, 41(2013), 198–208.

Remenyi, D., Williams, B., Money, A., & Swartz, E. (1998). Doing Research in Business and Management: An Introduction to Process and Method. London: Sage.

Roberts, C. M. (2010). The dissertation journey: a practical and comprehensive guide to planning, writing, and defending your dissertation. California: Corwin A SAGE Company.

Rohracher, H. (2001). Managing the Technological Transition to Sustainable solutions: a review of lessons from the natural world. *Building and Environment*, 40 (3), 319-328.

Royal Institution of Chartered Surveyors. (1986). A guide to life cycle costing for construction. London: Surveyors Publications.

Saghatforoush, E., Trigunarsyah, B., & Too, E. G. (2012). Assessment of Operability and Maintainability Success Factors in Provision of Extended Constructability Principles. 9th International Congress on Civil Engineering, 8-10 May 2012. Isfahan-Iran: Isfahan University of Technology.

Saunders, M., Lewis, P., & Thornhill, A. (2009). Research Methods for Business Students (5th ed.). Harlow: Pearson Education Limited.

Say, C., & Wood, A. (2008). Sustainable Rating Systems around the World. CTBUH Journal, 18-29.

Sayce, S., Ellison, L., & Parnell, P. (2007). Understanding investment drivers for UK sustainable property. Building Research & Information, 35(6), 629-643.

Seeley, I. H. (1996). Building Economics: Appraisal and control of building design cost and efficiency (4th ed.). London: MACMILLAN PRESS LTD.

Shrestha, P. P., & Pushpala, N. (2012). Green empirical and non-green school buildings: a comparison of construction cost and schedule. Construction Research Congress (pp. 1820–1829). ASCE.

Smith, T. M., Fischlein, M., Suh, S., & Huelman, P. (2006). Green building rating systems: A comparison of the LEED and green globes systems in the US. St. Paul: University of Minnesota.

Stas, N. (2007). The Economics of Adaptive Reuse of Old Buildings A Financial Feasibility and Analysis. Ontario: University of Waterloo.

Stegall, N. (2004). Cost implications of LEED Silver certification for new house residence hall at Carnegie Mellon University. Senior Honors Research Project, Carnegie Mellon University, Pittsburgh, PA.

Sterner, E. (2000). Life-cycle costing and its use in the Swedish building sector. Building Research & Information, 28(5-6), 387-396. doi:10.1080/096132100418537

Steven Winter Associates. (2004). GSA LEED cost study. Retrieved from http://www.wbdg.org/ccb/GSAMAN/gsaleed.pdf

Syphers, G., & Darren, B. (2001). Capital Cost Analysis for Building Two Green Libraries in San José. San José, CA.

Tan, W. (1999). Construction cost and building height. Construction Management and Economics, 17(2), 129-132. doi:10.1080/014461999371628

Tashakkori, A., & Teddlie, C. (1998). Mixed Methodology: Combining Qualitative and Quantitative Approaches. Thousand Oaks, CA: Sage.

U.S. EPA Region 5. (2008). Removing Market Barriers to Green Development.

U.S. General Services Administration. (2011). Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Washington, dc 20405: GSA Public buildings service.

United Nations Environment Programme. (2012). SBCI Sustainable Building and Climate Initiative. Vision for Sustainability on Building and Construction. Retrieved from UNEP: http://www.unep.org/sbci/AboutSBCI/Background.asp

Urban Development Authority. (2008). City of Colombo development plan (Amendment) – 2008.

USGBC. (2009). Green Building Facts. Retrieved from USGBC: http://www.usgbc.org/

USGBC. (2016, February 23). Green Building Facts. Retrieved from USGBC: http://www.usgbc.org/

Venkatesh, G. (2010). Triple bottom line approach to individual and global sustainability. *Problems of sustainable development*, 5(2), 29-37.

Venkatesh, G. (2015). *ABC of Sustainable Development*, bookboon.com

Waidyasekara, K. G., & Fernando, W. N. (2013). Benefits of Adopting Green Concept for Construction of Buildings in Sri Lanka.

Wen, R., Qi, S. and Jrade, A., 2016. Simulation and Assessment of Whole Life-Cycle Carbon Emission Flows from Different Residential Structures, *Sustainability*, 8, 807-821.

Wilson, J. L., & Tagaza, E. (2006). Green Buildings in Australia: Drivers and Barriers. Australian Journal of Structural Engineering, 7(1), 57-63. doi:10.1080/13287982.2006.11464964

Woodward, D. G. (1997). Life cycle costing- theory, information acquisition and application. Internattonal Journal of Project Management, 15(6), 335-344.

Xenergy and Sera Architects. (2000). Green city buildings: Applying the LEED rating system. Portland, Oregon: Portland Energy Office. Retrieved from http://neea.org/docs/reports/casestudyongreencitybuildingsmarketresearchrep or

Yin, R. K. (2009). Case Study Reserch: Design and Methods (4th ed.). London: Sage Publications.

Zahirah, N. M., & Abidin, Z. N. (2012). Main Elements of Soft Cost in Green Buildings. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, 6(12), 3601-3607.

Zima, K., & Plebankiewicz, E. (2012). Analysis of the building shape erected in Krakow and its impact on construction cost. Organization, Technology and Management in Construction, 4(1), 411-419. doi:10.5592/otmcj.2012.1.6

ANNEXURES

Annexure 1: Green Building Rating Systems

Table 2.2: Green Building Rating Systems

Source	Rating System	Established Year	Country	Sustainability Domains	Building Types Covered
Fowler and Rauch (2006); Say and Wood (2008); Nguyen (2011b)	BREEAM (Building Research Establishment Environmental Assessment Method)	1990	United Kingdom	• Management (commissioning, monitoring, waste recycling, pollution minimization, materials minimization) • Health & Wellbeing (adequate ventilation, humidification, lighting, thermal comfort) • Energy (sub-metering, efficiency and CO2 impact of systems) • Transport (emissions, alternate transport facilities) • Water (consumption reduction, metering, leak detection) • Materials (asbestos mitigation, recycling facilities, reuse of structures, facade or materials, use of crushed aggregate and sustainable timber) • Land Use (previously used land, use of remediated contaminated land) • Ecology (land with low ecological value or minimal change in value, maintaining major ecological systems on the land, minimization of biodiversity impacts) • Pollution (leak detection systems, on-site treatment, local or renewable energy sources, light pollution design, avoid use of ozone depleting and global warming substances)	• Courts • Homes • Industrial • Multi-residential • Prison • Offices • Retail • Schools
	LEED (Leadership in Energy and	1998	United States	• Sustainable Sites (construction related pollution prevention, site development	• Homes

	Environmental Design)			impacts, transportation alternatives, stormwater management, heat island effect, and light pollution) • Water Efficiency (landscaping water use reduction, indoor water use reduction, and wastewater strategies) • Energy and Atmosphere (commissioning, whole building energy performance optimization, refrigerant management, renewable energy use, and measurement and verification) • Materials and Resources (recycling collection locations, building reuse, construction waste management, and the purchase of regionally manufactured materials, materials with recycled content, rapidly renewable materials, salvaged materials, and sustainably forested wood products) • Indoor Environmental Quality (environmental tobacco smoke control, outdoor air delivery monitoring, increased ventilation, construction indoor air quality, low emitting materials use, source control, and controllability of thermal and lighting systems) • Innovation and Design Process (LEED® accredited professional, and innovative strategies for sustainable design)	• New commercial construction and major renovations • Existing building • Commercial interiors • Core and shell development • Neighbourhood development • Schools • Retail • Health care units
	CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)	2001	Japan	• Indoor environment (noise and acoustics, thermal comfort, lighting and illumination, and air quality) • Quality of services (functionality and usability, amenities, durability and reliability, flexibility and adaptability)	• Pre-design • New Construction • Existing buildings • Renovation

				• Outdoor environment on site (preservation and creation of biotope, townscape and landscape, and outdoor amenities) • Energy (thermal load, use of natural energy, efficiency of systems, and efficient operations) • Resources and materials (water conservation, recycled materials, sustainably harvested timber, materials with low health risks, • Reuse and reusability, and avoidance of CFCs and halons) • Off-site environment (air pollution, noise and vibration, odor, sunlight, obstruction, light pollution, heat island effect, and local on local infrastructure)	
Nguyen (2011b)	HK-BEAM (Hong Kong Building Environmental Assessment Method)	1996	Hong Kong	• Site aspects (land use, site design appraisal, pollution during construction) • Materials aspects (building reuse, rapidly renewable materials, demolition waste) • Energy use (annual building energy use, embodied energy in building structural elements, air conditioning, appliances and lighting, testing and commissioning) • Water use (annual water use and monitoring effluent • Indoor environmental quality (safety and security, indoor air quality and ventilation, thermal comfort, lighting, acoustics and noise, building amenities) • Innovation and performance enhancements, innovative techniques, performance enhancements)	• New Construction • Existing buildings
Fowler and Rauch (2006)	GBTool	1998	Canada	• Energy consumption is assessed through total use of non-renewable energy (embodied and operational), electrical peak demand for operations, use of renewable energy, and commissioning.	• Tenant build out • Operations and maintenance applications

				• Resource consumption is assessed through materials use (salvaged, recycled, bio-based and sustainably harvested, locally produced, designed for disassembly, re-use, or recycling) and water use for irrigation, building systems, and occupant use. • Environmental loadings include greenhouse gas emissions, other atmospheric emissions, solid wastes, stormwater, wastewater, site impacts, and other local and regional impacts. • Indoor environmental quality is assessed through indoor air quality, ventilation, temperature and relative humidity, daylight and illumination, and noise and acoustics. • Other criteria include selection of appropriate site (in terms of land use, brownfields, access to transportation and amenities), project planning, urban design (density, mixed uses, compatibility, native plantings, and wildlife corridors), building controls, flexibility and adaptability, maintenance of operating performance, and a few social and economic measures.	
Say and Wood (2008); Nguyen (2011b)	Green Star	2003	Australia	• Management (green star accredited professional, commissioning and tuning, adaptation and resilience, building information, commitment to performance, metering and monitoring, construction environmental management, operational waste) • Indoor Environment Quality (indoor air quality, acoustic comfort, lighting comfort, visual comfort, indoor pollutants, thermal comfort)	• Commercial office design and construction • Shopping centers • Healthcare facilities • Education facilities • Mixed use/multi-unit residential • Industrial • Public buildings

				• Energy (greenhouse gas emissions, peak electricity demand reduction) • Transport (sustainable transport) • Water (potable water) • Materials (life cycle impacts, responsible building materials, sustainable products, construction and demolition waste) • Land Use & Ecology (ecological value, sustainable sites, heat island effect) • Emissions (stormwater, light pollution, microbial control, refrigerant impacts) • Innovation	
Fowler and Rauch (2006); Say and Wood (2008)	Green Globes	2005	Canada	• Project Management (integrated design, environmental purchasing, commissioning, emergency response plan) • Site (site development area, reduce ecological impacts, enhancement of watershed features, site ecology improvement) • Energy (energy consumption, energy demand minimization, "right sized" energy-efficient systems, renewable sources of energy, energy-efficient transportation) • Water (flow and flush fixtures, water-conserving features, reduce off-site treatment of water) • Indoor Environment (effective ventilation systems, source control of indoor pollutants, lighting design and integration of lighting systems, thermal comfort, acoustic comfort) • Resource, Building Materials and Solid Waste (materials with low environmental impact, minimized consumption and depletion of material resources, re-use of existing structures, building durability, adaptability	• New commercial building • Existing commercial buildings • Homes

				and disassembly, and reduction, re-use and recycling of waste)	
Green Building Council of Sri Lanka (2015)	GREEN SL® Rating System	2010	Sri Lanka	• Management (green building accredited professional, commissioning clauses, building tuning, optimizing occupant comfort and energy efficiency, building user's guide, building user's guide, environmental management, environmental management plan, environment management system (complying with ISO 14001) • Sustainable sites (erosion and sedimentation control, site selection, development density and community connectivity, brownfield redevelopment, alternative transportation, public transportation access, parking capacity, reduced site disturbances, protect or restore habitat, development footprint, stormwater design-quantity control, stormwater design-quantity control, heat island effect, non – roof, heat island effect, roof, light pollution reduction) • Water efficiency (water efficient landscaping, reduce potable water consumption, eliminate potable water consumption, water efficiency in air-conditioning system, innovative wastewater technologies, reduce potable water use or treat waste water, harvested rainwater, water use reductions) • Energy and atmosphere (fundamental building systems commissioning, minimum energy performance, CFC reduction in HVAC&R equipment, optimize energy performance, renewable energy, additional commissioning, ozone depletion, measurement & verifications, green power)	• Commercial, • Institutional buildings • High-rise residential buildings

		• Materials and resources (storage & collection of recyclables, building reuse: maintaining 50% of existing building structure and shell, maintaining 75% of existing building structure and shell, maintaining 75% of existing building structure and shell and 25% of non-shell areas, construction waste management: for 50% recycling, for 75% recycling, resource reuse: for at least 5% of the building, for at least 10% of the building, recycled content: for at least 10% of total value of materials, for at least 20% of total value of materials, local / regional materials: for a minimum of 20% usage, for a minimum of 50% usage, rapidly renewable materials, certified wood • Indoor environmental quality (minimum IAQ performance, smoke (ETS) control, outdoor air delivery monitoring, increased ventilation, construction IAQ management plan before and after construction, low - emitting materials, paints and coatings, carpet systems, composite wood and agrifiber products, indoor chemical & pollutant source control, controllability of systems, lighting controls, comfort controls, thermal comfort: design, thermal comfort: verification, daylight & views) • Innovation and design process (innovation in design, exemplary performance) • Social and cultural awareness (archaeological sites & heritage buildings, social wellbeing, public health & safety, cultural identities)	

Annexure 2: Green Building Rating Systems used in Sri Lanka

Table 2.4: LEED-BD+C: NC version 3.0 (2009)

Sustainable Sites		**26 Possible Points**
Prereq 1	Construction Activity Pollution Prevention	Required
Credit 1	Site Selection	1
Credit 2	Development Density & Community Connectivity	5
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation, Public Transportation Access	6
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
Credit 4.3	Alternative Transportation, Low Emitting & Fuel-Efficient Vehicles	3
Credit 4.4	Alternative Transportation, Parking Capacity	2
Credit 5.1	Site Development, Protect or Restore Habitat	1
Credit 5.2	Site Development, Maximize Open Space	1
Credit 6.1	Stormwater Design, Quantity Control	1
Credit 6.2	Stormwater Design, Quality Control	1
Credit 7.1	Heat Island Effect, Non-Roof	1
Credit 7.2	Heat Island Effect, Roof	1
Credit 8	Light Pollution Reduction	1
Water Efficiency		**10 Possible Points**
Prereq 1	Water Use Reduction	Required
Credit 1	Water Efficient Landscaping	2-4
Credit 2	Innovative Wastewater Technologies	2
Credit 3	Water Use Reduction	2-4
Energy & Atmosphere		**35 Possible Points**
Prereq 1	Fundamental Commissioning of Building Energy Systems	Required
Prereq 2	Minimum Energy Performance	Required
Prereq 3	Fundamental Refrigerant Management	Required
Credit 1	Optimize Energy Performance	1-19
Credit 2	On-Site Renewable Energy	1-7
Credit 3	Enhanced Commissioning	2
Credit 4	Enhanced Refrigerant Management	2
Credit 5	Measurement & Verification	3
Credit 6	Green Power	2
Materials & Resources		**14 Possible Points**
Prereq 1	Storage & Collection of Recyclables	Required
Credit 1.1	Building Reuse, Maintain Existing Walls, Floors & Roof	1-3
Credit 1.2	Building Reuse, Maintain Interior Non-Structural Elements	1
Credit 2	Construction Waste Management	1-2
Credit 3	Materials Reuse	1-2
Credit 4	Recycled Content	1-2
Credit 5	Regional Materials	1-2
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1

Indoor Environmental Quality		15 Possible Points
Prereq 1	Minimum IAQ Performance	Required
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
Credit 4.2	Low-Emitting Materials, Paints & Coatings	1
Credit 4.3	Low-Emitting Materials, Flooring Systems	1
Credit 4.4	Low-Emitting Materials, Composite Wood & Agrifiber Products	1
Credit 5	Indoor Chemical & Pollutant Source Control	1
Credit 6.1	Controllability of Systems, Lighting	1
Credit 6.2	Controllability of Systems, Thermal Comfort	1
Credit 7.1	Thermal Comfort, Design	1
Credit 7.2	Thermal Comfort, Verification	1
Credit 8.1	Daylight & Views, Daylight	1
Credit 8.2	Daylight & Views, Views	1
Innovation in Design		**6 Possible Points**
Credit 1	Innovation in Design	1-5
Credit 2	LEED Accredited Professional	1
Regional Priority		**4 Possible Points**
Credit 1	Regional Priority	1-4

Source: (USGBC, 2009)

Project Totals 110 Possible Points

- Certified 40–49 points
- Silver 50–59 points
- Gold 60–79 points
- Platinum 80 points and above

Table 2.5: GREENSL® Rating System

Management		4 Possible Points
Prerequisite 1	Green Building Accredited Professional	Required
Prerequisite 2	Commissioning Clauses	Required
Credit 1.1	Building Tuning	
Credit 1.1.1	Optimizing occupant comfort and energy efficiency	1
Credit 1.2	Building User’s Guide	
Credit 1.2.1	Building User’s Guide	1
Credit 1.3	Environmental Management	
Credit 1.3.1	Environmental Management Plan	1
Credit 1.3.2	Environment Management System (Complying with ISO 14001)	1

Sustainable Sites		**25 Possible Points**
Prerequisite 1	Erosion and Sedimentation Control	Required
Credit 2.1	Site Selection	5
Credit 2.2	Development Density and Community Connectivity	4
Credit 2.3	Brownfield Redevelopment	1
Credit 2.4	Alternative Transportation	
Credit 2.4.1	Public Transportation Access	2
Credit 2.4.2	Parking Capacity	1
Credit 2.5	Reduced Site Disturbances	
Credit 2.5.1	Protect or Restore Habitat	2
Credit 2.5.2	Development Footprint	2
Credit 2.6	Stormwater Design, Quantity Control - I	3
Credit 2.7	Stormwater Design, Quantity Control - II	2
Credit 2.8	Heat Island Effect, Non – Roof	1
Credit 2.9	Heat Island Effect, Roof	1
Credit 2.10	Light Pollution Reduction	1
Water Efficiency		**14 Possible Points**
Credit 3.1	Water Efficient Landscaping	
Credit 3.1.1	Reduce Potable Water Consumption	2
Credit 3.1.2	Eliminate Potable Water Consumption	2
Credit 3.2	Water Efficiency in Air-conditioning System	1
Credit 3.3	Innovative Wastewater Technologies	
Credit 3.3.1	Reduce Potable Water Use or Treat Waste water	2
Credit 3.3.2	Harvested Rainwater	3
Credit 3.4	Water Use Reductions	1-4
Energy & Atmosphere		**21 Possible Points**
Prerequisite 1	Fundamental Building Systems Commissioning	Required
Prerequisite 2	Minimum Energy Performance	Required
Prerequisite 3	CFC Reduction in HVAC&R Equipment	Required
Credit 4.1	Optimize Energy Performance	1-10
Credit 4.2	Renewable Energy	7
Credit 4.3	Additional Commissioning	1
Credit 4.4	Ozone Depletion	1
Credit 4.5	Measurement & Verifications	1
Credit 4.6	Green Power	1
Materials & Resources		**21 Possible Points**
Prerequisite 1	Storage & Collection of Recyclables	Required
Credit 5.1	Building Reuse	
Credit 5.1.1	Maintaining 50% of Existing Building Structure and Shell	1
Credit 5.1.2	Maintaining 75% of Existing Building Structure and Shell	2
Credit 5.1.3	Maintaining 75% of Existing Building Structure and Shell and 25% of Non-shell Areas	3
Credit 5.2	Construction Waste Management	
Credit 5.2.1	For 50% Recycling	1
Credit 5.2.2	For 75% Recycling	2
Credit 5.3	Resource Reuse	
Credit 5.3.1	For at least 5% of the Building	1
Credit 5.3.2	For at least 10% of the Building	2
Credit 5.4	Recycled Content	

Credit 5.4.1	For at least 10% of Total Value of Materials	1
Credit 5.4.2	For at least 20% of Total Value of Materials	1
Credit 5.5	Local / Regional Materials	
Credit 5.5.1	For a Minimum of 20% Usage	1
Credit 5.5.2	For a Minimum of 50% Usage	3
Credit 5.6	Rapidly Renewable Materials	1
Credit 5.7	Certified Wood	1
Indoor Environmental Quality		**21 Possible Points**
Prerequisite 1	Minimum IAQ Performance	Required
Prerequisite 2	Smoke (ETS) Control	Required
Credit 6.1	Outdoor Air Delivery Monitoring	1
Credit 6.2	Increased Ventilation	1
Credit 6.3	Construction IAQ Management Plan	
Credit 6.3.1	Construction IAQ Management Plan Before and After Construction	1
Credit 6.4	Low - Emitting Materials	
Credit 6.4.1	Paints and Coatings	1
Credit 6.4.2	Carpet Systems	1
Credit 6.4.3	Composite Wood and Agrifiber Products	1
Credit 6.5	Indoor Chemical & Pollutant Source Control	1
Credit 6.6	Controllability of Systems	
Credit 6.6.1	Lighting Controls	1
Credit 6.6.2	Comfort Controls	1
Credit 6.7	Thermal Comfort, Design	1
Credit 6.8	Thermal Comfort, Verification	1
Credit 6.9	Daylight & Views	
Credit 6.9.1	Daylight	1
Credit 6.9.2	Views	1
Innovation & Design Process		**4 Possible Points**
Credit 7.1	Innovation in Design	
Credit 7.1.1	Innovation in Design	1-2
Credit 7.1.2	Exemplary Performance	1-2
Social & Cultural Awareness		**3 Possible Points**
Prerequisite 1	Archaeological Sites & Heritage Buildings	Required
Credit 8.1	Social Wellbeing, Public Health & Safety	1-2
Credit 8.2	Cultural Identities	1-2

Source: (GBCSL, 2015)

- Certified 40–49 points
- Silver 50–59 points
- Gold 60–69 points
- Platinum 70 points and above

Annexure 3: Sustainability Domains and Criteria, Green Building Strategies and Technologies and Construction Cost Impact

Table 2.9: Sustainability Domains and Criteria, Green Building Strategies and Technologies and Construction Cost Impact

Domain	Criteria	Green Building Strategies and Technologies	Construction Cost Comparing to Conventional Counterparts	LCC Impact (Yes/No)	LCC Elements	Factors Influencing
Sustainable Sites	Construction activity pollution prevention	Erosion and sedimentation control plan (strategies)	No construction or soft cost impact or minimal added cost	No Only construction	A very small reduction from overall construction cost by reducing clean-up and corrective action	
	Site selection	Avoiding non-compliant sites	No construction or soft costs Possible costs, where appropriate sites are available at an added cost	No Only construction	Choice of location can affect feasibility and cost of sustainable design measures. Overall project cost	
	Development density & community connectivity	Construct or renovate a building in a previously developed site with pedestrian access between the building and services	Significant cost impact[1] when increasing density by development of multi-story buildings and structured parking in urban sites	No	Tax incentives and property cost savings at construction	Rural or suburban buildings
			Significant cost impact to smaller rural or suburban buildings (single story buildings with surface parking) to increase the density of the project	No		

	Brownfield redevelopment	Hazardous materials removal or encapsulation during demolition or renovation	Significant cost impact	No	Additional soft cost for design, testing and monitoring	
		Encapsulation of contaminated soils or remediation of contaminated soils using chemical additives	Significant cost impact	No		
	Alternative transportation— Public transportation access	Bring bus lines to the site	No construction or soft costs	No	Reduced parking and reducing cost	
		Shuttle buses to transport staff and patients from the project site to bus or train stops		Yes	Fuel	
	Alternative Transportation— Bicycle Storage and Changing Rooms	Installation of adequate bicycle racks and shower/changing facilities	Minimal construction or soft cost	Yes	Cleaning, utilities, services and fabric maintenance, sign and demarcation Reduced parking	
	Alternative Transportation— Low–Emitting and Fuel–efficient Vehicles	Parking for low-emitting and fuel-efficient vehicles	Minimal construction cost impact	Yes	Cleaning, sign and demarcation, fabric maintenance	
		Refuelling stations or electric refuelling stations	Minimal construction and soft cost	Yes	Cleaning, sign and demarcation, maintenance of equipment	
		Low-emitting and fuel-efficient vehicles	Low cost impact	Yes	Fuel, emission test	
		Low-emitting or fuel-efficient vehicle-sharing program	No cost impact	No		
	Alternative Transportation— Parking Capacity	Sharing parking facilities with adjacent buildings minimize parking lot/garage size	Minimal construction cc	Yes	Cleaning, sign and demarcation, fabric maintenance	
	Site Development— Protect or restore Habitat	Minimize disruption to existing ecosystems and design the building to minimize its footprint Stacking the building programme tuck under parking and sharing parking facilities native or adopted plants	Significant or prohibitive cost, where parking is underground or in a structure to provide space for natural habitat Relatively small soft cost	Yes	Cleaning Native or adopted plants require minimal or no irrigation do not require active maintenance such as mowing or chemical inputs and fertilizers	Parking is underground or in a structure to provide space for
		Landscape	Low cost impact			
		Parking spaces with green roof				

	Site Development—Maximize open space	Pedestrian oriented hardscape and limited hardscape, vegetated roof areas, wetlands or naturally designed ponds, tuck-under parking and sharing parking facilities with neighbours	Minimal to significant cost impact for urban sites, green roofs Rural zero to minimal cost	Yes	Cleaning, landscaping	
	Stormwater design—Quantity control	Detention through swales	Minimal cost impact	No		
		Infiltration of stormwater via vegetated roofs, and paving Reuse stormwater for non-portable uses such as landscape irrigation toilet and urinal flushing and custodial use	Significant cost impact	Yes	Landscaping	
		Detention and retention through ponds, surge chambers or tanks	Significant cost impact	Yes	Cleaning	
		Rainwater harvesting	Significant cost impact	Yes	Cleaning, repairs and replacements	
	Stormwater design—Quality control	Constructed wetlands, vegetated filters and open channels to treat stormwater runoff, and reuse the water for irrigation, toilet and urinal flushing	Significant cost impact	Yes	Water quality testing, cleaning, Services maintenance	
	Heat island effect non-roof	Shade from native or adapted trees and large shrubs, vegetated trellises	Minimal cost impact	No		
		Shade from structures covered by solar panels	Significant cost impact	Yes	Maintenance of the solar panels	
		White asphalt or by providing open grid paving or gravel at parking stalls, leaving only the aisles asphalt Light coloured surface	Minimal or no cost impact	No		High end technologies
		Changing the colour of concrete paving	Low cost impact			
		Shade from architectural devices or structures that reflect solar (photovoltaic cells)	Low cost impact	Yes	Repairs and replacements, cleaning	
		Vegetated roof previous pavement, grid pavers, rains gardens, vegetated swales, rainwater recycling, infiltration				
	Heat island Effect—Roof	High emissivity roof	Low cost impact[3]	Yes	Repairs and replacement	Roofing material with solar reflectance index

		Green roof	Significant cost impact	Yes	Landscaping	
	Light pollution reduction	Full cut-off luminaires, low-reflectance surfaces and low-angle spotlights Manual or occupant sensing device	Minimal cost impact	Yes	Maintenance cost of lighting, electricity cost	Vegetated roofs high albedo roofs
Water Efficiency	Water efficient landscaping	Native, drought tolerant plants	Minimal cost impact	No		
		Drip irrigation or automated controls with moisture sensors and municipally provided reclaimed water for irrigation	Minimal cost impact	Yes	Repairs and replacements	
		Rainwater harvesting	Significant cost impact	Yes	Cleaning, repairs and replacements	
		HVAC condensate or cooling tower waste water for irrigation (non-chemical cooling tower systems)	Minimal cost impact	Yes	Cleaning, treating and minor repairs and replacements	
	Innovative wastewater technologies	Low-flow and waterless flush fixtures	Low cost impact	Yes	Repairs and replacements	
		Gray water treatment	Significant cost impact	Yes	Repairs and replacements	
		Sewage water treatment	Significant cost impact	Yes	Repairs and replacements	
	Water use reduction	Low flow fixtures for lavatories and showers, motion sensor operated devices, reduced flush or dual flush toilets, and waterless or reduced flush urinals	Low cost impact	Yes	Repairs and replacements	
Energy and atmosphere	Fundamental commissioning of building energy systems	Engage a Commissioning Authority and adopt a commissioning plan	Significant cost impact	No		
	Minimum energy performance	Whole building energy simulation, prescriptive compliance path: ASHRAE advanced energy design guide, prescriptive compliance path: advanced buildings™ core performance™ guide	If energy effciency is not addressed early the costs can become significant	Yes	Energy cost	
	Fundamental refrigerant management	Zero use of chlorofluorocarbon (CFC)-based refrigerants	No cost impact	Yes	Replacement cost	
	Optimize energy performance	Whole building energy simulation, prescriptive compliance path: ASHRAE	Significant cost impact	Yes	Energy cost	

		advanced energy design guide, prescriptive compliance path: advanced buildings™ core performance™ guide				
	Onsite renewable energy	Solar, wind, geothermal, biomass, large hydro power, low–impact hydro, biogas and municipal solid waste	Significant cost impact	Yes	Maintenance, repair and replacement	
	Enhanced commissioning	Engage a Commissioning Authority and adopt a commissioning plan early in project design phase	Significant cost impact	No		
	Enhanced refrigerant management	Select HVAC & R equipment with reduced refrigerant charge and increased equipment life	Low cost impact	Yes		
		Maintain equipment to prevent leakage of refrigerant to the atmosphere	Low cost impact	Yes		
		Utilize fire suppression systems that do not contain HCFCs or Halons	Low cost impact	Yes		
	Measurement and verification	Energy metering and sub metering	Significant cost impact	Yes		
	Green Power	Solar, wind, geothermal, biomass, biogas and low impact hydropower	Significant cost impact	Yes		
Material and Resources	Storage and collection of recyclables	Designate an area for recyclable collection and storage that is appropriately sized and located in a convenient area	Minimal or no cost impact	No		
	Building Reuse	Reusing existing, previously–occupied building structures, envelopes and elements	Do not necessarily add cost to a project, it is the impact of the cost of achieving other necessary points	Yes		
		Reusing existing building structures, envelopes and interior non–structural elements		Yes		
	Construction waste management	Designate a specific area on the construction site for segregated or comingled collection of recyclable materials to divert from disposal in landfills and incineration facilities	Minimal cost impact: in areas where construction waste management is widely used Significant cost impact: in areas with contractors unfamiliar with construction waste management	Yes		Contractors unfamiliar with construction waste management

	Materials reuse	Incorporate salvaged materials into such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick, and decorative items	Minimal or no construction cost impact Significant cost impact for compliance	Yes		Compliance
	Recycled content	Use recycled content materials	Minimal or no construction cost impact Significant cost impact for compliance	Yes		
	Regional materials	Use locally sourced materials	Difficult to assess what the cost implications might be	Yes		
	Rapidly renewable materials	Use rapidly renewable materials such as bamboo, wool, cotton insulation, agrifiber, linoleum, wheat board, strawboard and cork	Minimal or no construction cost impact Significant cost impact for compliance	Yes		
	Certified wood	Install FSC–certified wood products	Minimal cost impact for buildings using certified wood only in finished carpentry Significant cost impact for buildings requiring large quantities of dimensional softwood or sheet goods	Yes		
Indoor Environmental Quality (IEQ)	Minimum IAQ performance	Design mechanical or natural ventilation systems to meet or exceed the minimum outdoor air ventilation rates as described in the ASHRAE standard	No cost impact	Yes	HVAC	
	Environmental Tobacco Smoke control	Prohibit smoking in buildings	No cost impact	No		
		Locate any exterior designated smoking areas or effectively control the ventilation air in smoking rooms	Significant cost impact			

	Outdoor air delivery monitoring	Install CO_2 and airflow measurement equipment and feed the information to the HVAC system to trigger alarms	Minimal cost impact	Yes	CO_2 air flow measurement equipment Gas meter readings	
	Increased ventilation	For mechanically ventilated spaces: use heat recovery	Low cost impact			
		For naturally ventilated spaces: design airflow paths, estimate external driving pressures and select types of ventilation devices				
	Construction IAQ management plan—during construction	Control pollutant sources and interrupt contamination pathways, sequence the installation of materials to avoid contamination of absorptive materials, such as insulation, carpeting, ceiling tile and gypsum wallboard and avoid using permanently installed air handlers for temporary heating/cooling during construction	Minimal cost impact, in areas where construction IAQ management is widely used Significant cost impact, in areas with contractors unfamiliar with construction IAQ management	No		
	Construction IAQ management plan—before occupancy	Perform a building flush-out or test the air contaminant levels in the building prior to occupancy	Minimal cost impact	No		
	Low-emitting materials—adhesives and sealants	Use low-VOC materials for adhesives and sealants	Minimal cost impact	Yes		
	Low-emitting materials—paints and coatings	Use low-VOC paints and coatings	Minimal cost impact	Yes		
	Low-emitting materials—flooring systems	Select products that are either certified under the Green Label Plus program or for which testing has been done by qualified independent laboratories	Minimal cost impact	Yes		
	Low-emitting materials—composite wood and agrifiber products	Specify wood and agrifiber products that contain no added urea-formaldehyde resins and laminating adhesives for field and shop-applied assemblies that contain no added urea-formaldehyde resins	Cost can be vary widely depending on the product selected and market conditions	Yes		Market conditions

	Indoor chemical and pollutant source control	Design facility cleaning and maintenance areas with isolated exhaust systems for contaminants, install permanent architectural entryway systems and high-level filtration systems in air handling units	Low cost impact, unless the building has multiple entries	Yes		
	Controllability of systems—lighting	Design the building with occupant controls for lighting	Costs can range from minimal to significant	Yes		
	Controllability of systems—thermal comfort	Design the building and systems with comfort controls to allow adjustments to suit occupancy rate using operable windows and mechanical systems	Low cost impact, unless areas are under the control of the single occupants	Yes		
	Thermal comfort—design	Establish comfort criteria according to ASHRAE 55-2004 that support the desired quality and occupant satisfaction with building performance	No cost impact	No		
	Thermal comfort—verification	Design monitoring and corrective action systems	Moderate cost impact	Yes		
	Daylight and views—daylight	Maximize interior day lighting using building orientation, shallow floor plates, increased building perimeter, exterior and interior permanent shading devices, high-performance, glazing, and high-ceiling reflectance values, automatic photocell-based controls	Costs can range from minimal to significant	Yes		High end technologies
	Daylight and views—views	Maximize day lighting and view using lower partitions, interior shading devices, interior glazing and automatic photocell-based controls	Costs are minimal to moderate	Yes		

Source: (Kats, 2010; Langdon, 2007; Matthiessen & Morris, 2007)

Annexure 4: Breakdown of Running Cost Elements

Table 3.1: Breakdown of Running Cost Elements

		Running costs Elements	Definition
Running costs			
Operation			
	Utilities		
		Electricity	Electricity consumption
		Water rates	Water consumption
		Fuel oil	Fuel charges
		Effluent & drainage charges	Effluent and drainage removal by authorities
	Administrative costs		
		Security	Technicians, housekeeping personnel, in house and outsource O&M staff
		Service attendants	Property management contract
		Waste disposal	Security personnel
		Property management	Waste disposal to the responsible authorities
		Sundries	
	Taxes		Tax and other overheads
	Insurance		Property insurance
Maintenance			
	Services		
	Heating & Ventilation		
		Air conditioning &Ventilation	Chillers, AHU, FCU, VRV, VAV, cooling towers, valves, pumps, emission units, thermal insulation, controllers, grills, fans, and filters, diffusers, ductwork, pipework, air curtains, air extract systems, fume extracts, dust collection units, rotating ventilators, roof-mounted ventilation units
	Lifts & Escalators		Lifts, firefighting lifts, escalators,

	Electric power &lighting		
		Lighting	Light fittings, conduits and cable trunking, lighting switches, lighting control equipment
		HV Generation, transmission & distribution	HV transformer, HV switchgear, HV cables and wiring, bus bar trunking, standby generator,
		Lightning conductors	Earthling and bonding cables, components, surge protection
		Lamp Replacement	Internal, external lamps/luminaires replacement
		Power	General LV power, Extra LV power supply, DC installations, LV switchgear, UPS, cables and wirings
	Telecommunication & data		PA, PABX systems, computer networking, wiring, modems, routers, radio system
	Plumbing & internal drainage		
		Cold water Service	CW distribution pipe lines, valves, water saving devices, taps, pumps, expansion vessels, water storage tanks and cisterns,
		Sanitary fittings	Tap and outlet, WCs, shower basins, urinals, cisterns, sinks, bidets, shower unit, towel trails, hand dryers, paper towel dispensers
	Fire detection & protection system		Fire hose reels, dry and wet risers, pipework, thermal insulation, fire and smoke detectors, fire extinguishers
	Other M&E Services		
		Refrigeration equipment	Refrigeration plant and equipment
		Fire alarms	Manual and automatic fire alarms
		Emergency lighting	Emergency lamps and battery replacement
		Built in fittings	Mirrors, curtains, wall hangings, storage racks, shelves, blinds, shutters,
		CCTV Camera	Camera, recorders, monitors, controllers
		Loose appliances	Damaged mechanical and electrical appliances such as computers, laptops, processors, printers, scanners etc.
	Decoration		
		Internal Decoration	Paintings and decorating internal elements
		External Decoration	Paintings and decorating external elements
	Fabric		
	External Wall		
		Walls	External enclosing walls
		Windows	Windows and openings in external walls for ventilation and light

	Glazing	Glazing in external enclosing walls; façade,
	Doors	Doors and openings in external enclosing walls; entrance doors, door frames, door linings, door sets
Internal Finishes		
	Floor Finishes	Non-structural screeds, in-situ floor finishes, tiled floor finishes, woodblock
	Wall finishes	In-situ coatings applied to walls, sprayed monolithic coatings to columns and walls, plasterboard, ceramic wall tiling,
	Ceilings	Linings, plaster in-situ, sprayed coatings
Roof Structures		
	Covering Flats	Roof cladding, roof ventilation tiles, photovoltaic devices, thermal insulation, surface treatments to roof coverings, paving tiles, paving slabs
	Covering Pitched	Roof decks and slabs, trusses, purlins, rafters, binders, hangers, hip and valley rafters, ridge boards, wall plates,
	Gutters and rain water pipes	Gutters, including fittings, gutter outlets, balloons and gratings, roof drainage pipe work, rainwater heads, painting and anti-corrosion treatments to gutters
Other structural Items		
	Floors staircase & Steps	Floor steps, handrails, springer board, repair of worn or damaged nosing
	Internal walls & Partitions	Internal walls and fixed partitions: walls from cubicles
	Internal glazing & windows	Internal glass work, window frames
	Internal Doors	Doors, hatches, shutters and grills and other openings in internal walls and partitions
Fitting & Fixtures		
	Vandalism	Deliberate destruction or damage to the fitting and fixtures
	Built in furniture	Counters, desks, benches, worktops, chairs, bathroom furniture
	Key issues	Access controls, magnetic locks, electrified locksets, standalone locksets, electric strikes, key and exit switches, exit devices
	Ironmongery	Ironmongery to fittings, doors, windows, cubical,
	Signs	Directional signboards, notice boards, sign writing, nameplates
Cleaning		
	Internal / External Surface	Regular cleaning of the building
	Windows cleaning	Removing stains and deposits from windows

	External works		
		Roads pavement	Replacement and refurbishment of paving, paths
		Repairs and decoration	Minor building external works
		Landscaping	Seeding, turfing, planting, and irrigation
		Grounds maintenance	Trimming, blowing, spreading manure, compost and fertiliser
		Pest control services	Spraying and fogging
		Drains	Outlets, gutters, pipes, down pipes
	Repairs and replacement of minor components/ small areas		Reactive maintenance activities of minor components
	Maintenance management		Planned, reactive, proactive maintenance management, maintenance contractor's

Annexure 5: Interview Guidelines

Impact of Sustainability Criteria on the LCC of Green Buildings in Sri Lanka

Dear Sir/ Madam,

Interview Guideline for Dissertation – MSc by Research Degree

I am A.S. Weerasinghe a postgraduate student of Faculty of Graduate Studies, University of Moratuwa following MSc by Research Degree. In fulfilment of this degree, the students are required to study as a full-time research student and produce a report on their interesting area of knowledge. The focus of my research is to assess the impact of sustainable features on the LCC of green buildings in Sri Lanka. Specifically, the research intends to identify and analyze the LCC and economic benefits contributing through the sustainable features; sustainable sites, water efficiency, energy and atmosphere, material and resources and indoor environmental quality of green buildings.

This interview guideline will be distributed to the professionals of the organization such as Facilities Managers and Engineers who are engaged with the initial green building project or currently engage with the green building activities. The confidentiality of the organization as well as the participants will be maintained throughout the research and the identities of the participants will not be revealed in this report or in any other document or event relating to this study. I hereby certify that the information collected from this interview will be used only for fulfilling the research aim. I would be grateful if you could participate in this interview.

Thank you.

Section 1- Background Information

The information relates to the organization and respondents (Please write the answer on the given space or tick the relevant category)

1. Please specify the type(s) of industrial manufacturing which your organization involved in

I.	Apparel Industry	☐
II.	Chemical and allied Industry	☐
III.	Electronic and Electrical Equipment Industry	☐
IV.	Metal Industry	☐
V.	Food and Kindred Industry	☐
VI.	Furniture and Fixtures Industry	☐
VII.	Industry and Commercial Machinery Industry	☐
VIII.	Pharmaceuticals	☐
IX.	Leather Industry	☐
X.	Lumber and Wood Industry	☐
XI.	Paper and Allied Industry	☐
XII.	Petroleum Refining and Related Industry	☐
XIII.	Printing, Packaging, and Allied Industry	☐
XIV.	Rubber and Miscellaneous Plastic Industry	☐
XV.	Stone, Clay, Glass, and Concrete Industry	☐
XVI.	Tobacco Industry	☐
XVII.	Transportation Equipment Industry	☐

2. Designation of the Respondent………………………………………………….
3. Years of Experience

   1-10 ☐ 11-20 ☐ 21-30 ☐ More than 30 ☐

4. Did you involve at the construction stage of this project?

   Yes ☐ No ☐

Section 2 – Reasons of Level of Achievement of Sustainable Features

This section collects the data on reasons of level of sustainability achievement of green building projects in Sri Lanka. A graph which illustrates the level of achievement of *each sustainable feature according to LEED BD+C: New Construction (v3 -2009) was developed and given in the below. The participants have freedom to explain the reasons referring to the below graph.*

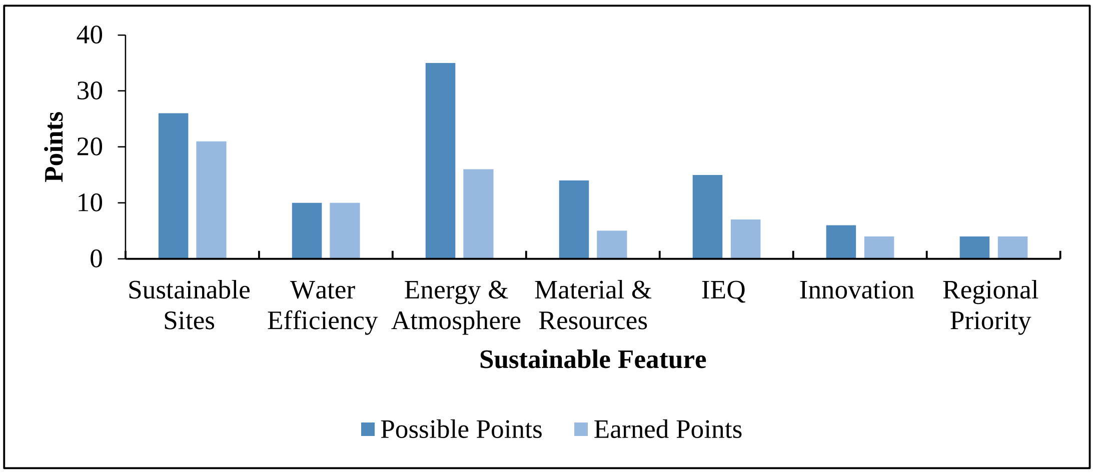


Figure 1: Level of Achievement of Sustainable Features: LEED BD+C: New Construction (v3 - 2009)

5. What are the sustainable criteria that could be easily achieved under each sustainability feature?
6. In your opinion, the level of achievement for above criteria is high or low?
7. Please explain the reasons for the higher achievement of sustainability criteria mentioned in the question 05.
8. What are the sustainable criteria that could be difficult or very difficult to achieve under each sustainability feature?
9. In your opinion, the level of achievement for above criteria is high or low?
10. Please explain the reasons for the lack of achievement of sustainability criteria mentioned in the question 07.
11. In your opinion, would it be possible to achieve the identified number of points for each sustainable feature using the criteria mentioned in the question 05?
12. If not, what kind of strategies we should take to increase the level of achievement of sustainable features of green buildings?

THANK YOU!!!!

Feature	Sustainable Criteria (SC)	Initial Cost of SC > Initial Cost of Conventional Counterparts (Yes/No)	Increase Cost of Construction (LKR)	LCC Impact (Yes/No)	O&M Cost Elements	O&M Cost (LKR)
SS	☑ Construction activity pollution prevention					
	Site selection					
	Development density & community connectivity					
	Brownfield redevelopment					
	Alternative transportation—Public transportation access					
	Alternative Transportation—Bicycle Storage and Changing Rooms					
	Alternative Transportation—Low–Emitting and Fuel–efficient Vehicles					
	Alternative Transportation—Parking Capacity					
	Site Development—Protect or restore Habitat					
	Site Development—Maximize open space					
	Storm water design–Quantity control					
	Storm water design–Quality control					
	Heat island Effect—Non–Roof					
	Heat island Effect—Roof					
	Light pollution reduction					
WE	☑ Water use reduction					
	Water efficient landscaping					
	Innovative wastewater technologies					

	Water use reduction					
EA	☑ Fundamental commissioning of building energy systems					
	☑ Minimum energy performance					
	☑ Fundamental refrigerant management					
	Optimize energy performance					
	Onsite renewable energy					
	Enhanced commissioning					
	Enhanced refrigerant management					
	Measurement and verification					
	Green Power					
MR	☑ Storage and collection of recyclables					
	Building reuse–Maintain existing walls, floors and roof					
	Building reuse–Maintain existing interior non-structural elements					
	Construction waste management					
	Materials reuse					
	Recycled content					
	Regional materials					
	Rapidly renewable materials					
	Certified wood					
IEQ	☑ Minimum IAQ performance					
	☑ Environmental Tobacco Smoke control					
	Outdoor air delivery monitoring					
	Increased ventilation					
	Construction IAQ management plan—during construction					
	Construction IAQ management plan—before occupancy					

	Low-emitting materials—adhesives and sealants					
	Low-emitting materials—paints and coatings					
	Low-emitting materials—flooring systems					
	Low-emitting materials—composite wood and agrifiber products					
	Indoor chemical and pollutant source control					
	Controllability of systems—lighting					
	Controllability of systems—thermal comfort					
	Thermal comfort—design					
	Thermal comfort—verification					
	Daylight and views—daylight					
	Daylight and views—views					