DEVELOPMENT OF WEB-BASED LIFE-CYCLE COST ANALYSIS FOR GREEN BUILDING INDEX ENERGY EFFICIENCY EVALUATION

ROSLI BIN AHMAD

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

AUGUST 2019

ACKNOWLEDGEMENT

First and foremost, all thanks to Allah (S.W.T) for the blessing and opportunity in helping me to get to this stage of this academic journey. Without His help I would not have achieved anything. I praise Him for all the supply He granted me in all areas that enabled me to successfully execute this research.

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Associate Professor Dr. Rozana Zakaria, for her encouragement, guidance, critics and friendship. I also wish to express my gratitude to Dr Khairulzan Yahya for his encouragement and guidance. Without their continued support and interest, this thesis would not have been the same as presented here.

ABSTRACT

In order to maximize the potentials of green buildings which focuses on increasing the efficiency of resource use of energy, water, and materials while reducing building impact on human health and environment during the building's life cycle, green building rating tools need to be maximized with the inclusion of Life-Cycle Costing (LCC). However, Green Building Index (GBI) Malaysia is a rating tool that does not maximize the application of Life Cycle Costing Analysis (LCCA) which would have been embedded in the rating system and during the rating process when it is traditionally carried out. Therefore, the construction industry needs the integration of software as a smart solution that response within immediate time, investment within budget, organized project management, efficient construction, and profitable. The aim of the study is to develop a web-based GBI rating system for Energy Efficiency (EE) evaluation that incorporates LCC analysis. The objectives of the study were to identify the criteria of established GBI rating tools, to identify the cost element of life-cycle cost, to develop a framework for EE criteria of GBI and LCC interface and lastly, to develop the web-based interface GBI-LCC that evaluates Energy Efficiency. A questionnaire survey was conducted through Focus Group Discussion (FGD) that consists of various qualified professional of the green building assessment tool in order to identify the life cycle cost association of EE criteria. The result was analysed using SPSS to perform the Mean Index, Factor Score, and Weightage Factor. It revealed that renewable energy is the most important criteria with the Factor Score of 7 and Weightage Factor of 0.27, followed by minimum energy performance criteria, lighting zoning, electrical sub-metering and advanced EE performance. The results also showed that management cost is the most influence LCC elements for EE criteria under GBI followed by operation costs, construction and installation cost, maintenance cost, development and replacements cost and lastly is contingencies/risk cost. Through the results obtained, a framework of EE and LCC was established. Then, a web-based automation interface GBI-LCC was developed using PHP programming for Green Building Index Integrated with Life Cycle Costing, called GBI-LCC. The web-based GBI-LCC is a dynamic invention which helps to calculate the cost analysis of green technology and to achieve energy efficiency points based on EE criteria. It is a better option that would assist construction industry stakeholders in making the decision on cost-effective of investment towards offering the best value of the project.

ABSTRAK

Demi memaksimumkan potensi bangunan hijau yang memberi fokus kepada peningkatan kecekapan penggunaan sumber tenaga, air, dan bahan-bahan di samping mengurangkan kesan bangunan ke atas kesihatan manusia dan alam sekitar semasa kitaran hayat bangunan, alat penarafan hijau bangunan perlu dimaksimumkan dengan memasukkan Kos Kitaran Hayat (LCC). Walau bagaimanapun, Indeks Bangunan Hijau (GBI) Malaysia adalah alat penarafan yang tidak memaksimumkan penggunaan Analisis Kos Kitaran Hayat (LCCA) yang mungkin perlu diterapkan didalam sistem penarafan dan semasa proses penarafan apabila ia dijalankan secara tradisi. Oleh itu, industri pembinaan memerlukan integrasi perisian sebagai penyelesaian pintar yang boleh bertindak balas dalam masa yang cepat, pelaburan dalam belanjawan, pengurusan projek yang teratur, pembinaan cekap, dan menguntungkan. Tujuan kajian ini adalah untuk membangunkan sistem penarafan GBI berasaskan web untuk penilaian kecekapan tenaga yang menggabungkan analisis LCC. Objektif kajian ini adalah untuk mengenal pasti kriteria dari alat penarafan GBI yang telah tersedia, untuk mengenal pasti elemen kos di dalam Kos Kitaran Hayat, untuk membangunkan satu rangka kerja untuk kriteria Kecekapan Tenaga (EE) GBI dan antara muka LCC dan akhir sekali untuk membangunkan antara muka berasaskan web GBI-LCC yang menilai Kecekapan Tenaga. Tinjauan soal selidik telah dijalankan melalui Perbincangan Fokus Berkumpulan (FGD) yang terdiri daripada pelbagai profesional yang berkelayakan di dalam alat penarafan bangunan hijau untuk mengenal pasti perhubungan LCC pada kriteria kecekapan tenaga. Keputusan yang diperoleh dianalisis menggunakan SPSS untuk mendapatkan *Indeks Min, Skor Faktor* dan *Faktor Pemberat*. Ia mendedahkan bahawa tenaga yang boleh diperbaharui adalah kriteria yang paling penting dengan Skor Faktor 7 dan Faktor Pemberat 0.27, diikuti oleh kriteria prestasi tenaga minimum, zon pencahayaan, elektrik sub-meter dan prestasi EE yang termaju. Keputusan juga menunjukkan bahawa kos pengurusan adalah elemen LCC yang paling berpengaruh untuk kriteria EE di bawah GBI diikuti dengan kos operasi, kos pembinaan dan pemasangan, kos penyelenggaraan, kos pembangunan dan penggantian dan akhir sekali adalah kos kontingensi/risiko. Melalui keputusan yang diperolehi, satu rangka kerja EE dan LCC telah ditubuhkan. Kemudian, antara muka automasi berasaskan web GBI-LCC telah dibangunkan menggunakan pengaturcaraan PHP untuk integrasi GBI dengan LCC yang dipanggil sebagai GBI-LCC. GBI-LCC berasaskan web adalah ciptaan dinamik yang membantu untuk mengira kos analisis teknologi hijau dan untuk mencapai mata kecekapan tenaga berdasarkan kriteria EE. Ia adalah pilihan yang lebih baik yang akan membantu mereka yang berkepentingan di dalam industri pembinaan dalam membuat keputusan ke arah pelaburan yang kos efektif bagi menawarkan nilai terbaik kepada projek.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
BCA	-	Benefit Cost Analysis
BIM	-	Building Information Modelling
BIPV	-	Building-integrated photovoltaic
BREEAM	-	Building Research Establishment Environmental Assessment Method
CFL	-	Compact Fluorescent Light
DSS	-	Decision Support System
EE	-	Energy Efficiency
EMS	-	Energy Management System
FGD	-	Focused Group Discussion
GBCA		Green Building Council of Australia
GBI	-	Green Building Index
GBI- (EE)	-	Green Building Index (Energy Efficiency)
GBI-LCC		Green Building Index-Life Cycle Costing
GBRT	-	Green Building Rating Tools
GEO	-	Green Energy Office
GLS	-	General Lighting Source
GRIHA		Green Rating for Integrated Habitat Assessment
HK BEAM	-	Hong Kong Building Environmental Assessment Method
HVAC	-	Heating, Ventilating and Air Conditioning
IDA ICE	-	Indoor Climate and Energy
IEQ	-	Indoor Environmental Quality
IIT	-	Indian Institute of Technology
IR	-	Infrared
LED	-	Light Emitting Diodes
LCC	-	Life Cycle Costing
LCCA	-	Life Cycle Cost Analysis
LEEDS	-	Leadership in Energy and Environmental Design

NPV	-	Net Present Value
OTTV	-	Overall Thermal Transfer Value
PH JKR	-	Penarafan Hijau Jabatan Kerja Raya
PTM	-	Pusat Tenaga Malaysia
PV	-	Present Value
QP'S	-	Qualified Professionals
RTTV	-	Roof Thermal Transfer Value
SCADA	-	Supervisory Control and Data Acquisition
SPSS	-	Statistical Package for Social Science
TDD	-	Tubular Daylighting Design
UTM	-	Universiti Teknologi Malaysia
UV	-	Ultraviolet
WHRU	-	Waste Heat Recovery Unit
ZEO	-	Zero Energy Office

LIST OF SYMBOLS

CO_2	-	Carbon Dioxide
CO2-eq	-	Carbon Dioxide Equivalent
W	-	Watt
°C	-	Degree Celcius
%	-	Percentage

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The so-called ‘sustainable or green building’ is the practice of designing, constructing, operating, maintaining, and removing buildings in ways that conserve natural resources and reduce their impact on climate change. By implementing sustainable practices in the facilities own, government, organizations and other building owners reduce energy consumption, conserve financial and environmental resources, and also reduce greenhouse gas emissions. A green building focuses on increasing the efficiency of resource use of energy, water, and materials while reducing building impact on human health and the environment during the building’s life cycle, through better sitting, design, construction, operation, maintenance, and removal. Green buildings should be designed and operated to reduce the overall impact of the built environment on their surroundings. In recent years, building owners and designers, researchers and others have begun performing studies related to the costs and benefits of sustainable design. Among the studies available, this research will choose, focus, and elaborate more on Life Cycle Costing Analysis (LCCA) in evaluating the potential performance of Energy Efficiency (EE) to be achieved in green buildings.

1.2 Background of Study

LCCA is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a building or building system. LCCA is useful especially when the project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes the net

savings (Sieglinde, 2010). LCCA is a method of determining the entire cost of a structure, product, or component over its expected useful life (Kathleen, 2008)

Further, Kathleen (2008) defined that the importance of LCCA in building construction stems from the actual distribution of costs incurred over the life span of a construction project. Buildings are typically long-term investments of significant magnitude, and valuation models must account for all costs and benefits throughout the length of ownership.

On the other hand, buildings are consuming 40% of the energy throughout the world and it has significant chances to increase to 50% by 2030 (Hassan *et al.*, 2014). Although buildings play an impactful role from cradle to grave, throughout their life cycle, it is immensely been observed that buildings account for CO_2 gases production. The contribution was estimated 30% of total greenhouse gas emissions and 80-90% of the CO_2 emissions is from operation phase (Zaid & Kiani, 2016).

Building intensifies CO_2 emission specifically in operation due to the occupants demand on its users, especially for cooling and lighting (Ghaffarianhoseini *et al.*, 2013). As many occupants use energy in all the elements of building and end users are the occupants of the building for the rest of life and uses energy frequently. The energy has been a crucial problem all around the world; everyone is chasing to find a better, long-lasting and essentially a proactive solution for energy savings. The fundamental needs of the society have been increased dramatically and it has urged humans to be efficient in resources usage and its long-term availability for future generations. The need of the time has begun to start the research about the resource efficient houses since many decades and it has come to the level of integrated sustainability and green buildings have been initiated. Many people around the world have started their journey towards the green building and paved the way towards the need of the social, economic, and environmental development (Huo *et al.*, 2017).

The formation of the green building development and its rationale has been made on various efforts resulted from the environmental degradation and requirements on speedy natural resources consumptions. Green building would have fostered the same old conventional building approach if the green building has not been assessed

through the green building rating assessment. Huo *et al.* (2017) speculated that the green building rating assessment tool is one the major assessing tool that assesses the performance of the green building from cradle to grave on its life cycle.

1.2 Statement of the Problem

The basis of the green building being evaluated is commonly from the rating tools. Green building rating tools are able to act in assessing and evaluating the performance of the green building based on the life cycle (Illankoon *et al.*, 2016). The active approaches of the green buildings and the rating assessment tools are fundamentally increasing the essence of the construction industry and interest of the building owners, developers, and investors. The green building rating assessment tools have traditionally gripped over the past decade on the construction industry to fetch the new and innovative approach towards the development of green buildings.

The green building rating systems have offered a lot of new approaches varying from country to country from formation to usage. Many countries have developed their own tools for the green building assessment such as LEEDS by United States of America (USGBC, 2017), BREEAM by United Kingdom (BRE, 2017), GBCA by Australia (GBCA, 2018), HK BEAM by Hong Kong (HKGBC, 2017), and Green Building Index (GBI) by Malaysia (GBI-Malaysia, 2009). These rating tools play an important role in assessing green buildings even though all the tools vary by their local nature in detail. However, the existing green building rating assessment tool in all over the world still lacks the life cycle elements in depth and it should become the initial stage in the decision of green building implementation

According to Illankoon *et al.*, 2016, even though the green building rating tool has now been widely practiced and recognized, there is still lack of LCC identification which makes the green building implementation in construction industry experiencing a dwarf growth. It is because the term ‘cost’ itself is an important issue discussed when dealing with the green building project. Furthermore, society has a perceived idea that the cost of green buildings is always higher in compared to conventional buildings

caused by disregard of LCC. In addition, many have focused only on initial cost when they discuss green building as a topic and thus consideration of LCC is needed to provide a better view and valuable approach to spent on green buildings

Khan *et al*., (2018) also added that there are many researchers that conducted an extensive study on green building and green building rating tools, which covers from various developed and developing countries. However, the focuses towards the incorporation of green building rating tools with LCC is still lacking, hence the integration plays an important part to be discovered in this research as an effort to improve and enhance the current practice.

In Malaysian, the first green building rating tools commonly used is known as GBI, which established in 2009. It can incorporate with LCC through the establishment of LCC elements at each of the criteria available in rating tools that comprise of management cost, operation cost, maintenance cost, replacement cots, construction and installation cost, development cost, and contingencies/risk cost. This incorporation helps investors, owners, developers, and all other stakeholders to find the life cycle of the green buildings when dealing with GBI. It also helps to plan for the building service life to deliver the best for the project whole life value. It has a relevant influence on the project such as the period recommends for replacement frequency and applicability to use the building. Therefore, this research develops the GBI-LCC Energy Efficiency (EE) framework and proposed developing web-based automation for the GBI-LCC (EE) prototype PHP program. This GBI-LCC (EE) program will assist stakeholder to evaluate the points in quick, easy and real-time to the green technology chosen in EE criteria for green buildings.

Therefore, the arising questions that initiate the research problems are, what are the GBI assessment criteria to be incorporated with LCC; what are the LCC elements that can be used with the GBI rating tools; how GBI rating tool can be integrated with LCC elements.

1.3 Aim of the Research

This research aims to develop a web-based Green Building Index (GBI) rating system for Energy Efficiency evaluation that incorporates LCC analysis

1.4 Objectives of the Research

a) To identify the criteria from established GBI rating tools.
b) To identify the cost element of the life cycle cost.
c) To develop a framework for EE criteria of GBI and LCC interface.
d) To develop the web-based interface GBI-LCC that evaluates Energy Efficiency.

1.5 Research Scope

The LCC has been a crucial element in the waves of the buildings for many decades. From the time when green building rating assessment tool has been initiated, the prime focus has been to drag the buildings' concepts towards the green building development. The development cannot be witnessed as a green building development until it is not assessed as a green building. The procedure of evaluation brings up the essence of green building and certifies as a green building with the concept and idea that the building is resource efficient and more economical in life after completion.

However, such argument gets to be nowhere if the element of the life cycle is not included during the assessment of the building to become a green building. Therefore, this research entails and conducts the research to incorporate essential elements of GBI and LCC. The scope of the research is limited to EE criteria taken as a prototype; thus it can be extended for future research. Then, it continues with the development of a framework to incorporate selected EE criteria of GBI and LCC. The research also develops a web-based interface of the GBI-LCC (EE) for the better and

easier way of finding the worth of the investment. This research also endeavours to focus on LCC of some office building designed with GBI and is located in Malaysia.

1.6 Significance of the Research

Interestingly, energy has been a crucial point to be discussed all over the world. Significantly, the construction industry contributes a lot towards the usage of energy from design, construction and more specifically in operation and maintenance phase. From cradle to grave, energy is one of the most used elements in every stage of building. Researchers outlined that from the development of every material to its demolition, energy is being used and that energy is somehow directly or indirectly depleting our natural resources (Vamosi, 2010). The depletion of natural resources has come into focus after the WCED conference, which has significantly emphasized the turmoil of development that impacts inevitably to the natural resources ((The Brundtland Report) WCED, 1987).

Green building development has been a critical factor in a recent development, where it entails higher cost at the earlier stage and investors find this inefficient investment at the initial stages (Tan *et al.*, 2011). Therefore, the lack of interest in investment to green building and green elements is deemed in the construction industry. However, if the investors are showing result of worth on investment on certain green technology and most importantly, the LCC of green building, thus a better decision can be made for a suitable or better way to invest. This research explores the GBI elements of EE along with the LCC to finds out the worth on investment of green building element in a better easy and quick way through web-based interface development.

1.7 Research Gap

Over a period of two decades, much emphasis on green buildings were concentrated on optimizing energy, but less on Indoor Environmental Quality (IEQ)

which will impact more on occupants' comfort, productivity, and health which would result in financial gain through cost of construction and operation (Nurul Mohd Annuar *et al*., 2014). Though the researcher has also emphasized on the well-being of the occupants by providing many features in construction projects. There is more of importance to consider worth, need and future benefits of the building in this modern era rather than just a shelter to live. Much research has been conducted to develop green building framework, line of action for green building, green building rating assessment tool but less effort has been put to form the green building rating assessment tools integrated with some other major project management tools such as LCC etc.

In Malaysia, green building assessment tool initially was developed in 2009, and with the passage of time, it has been evolving and turning towards better and more efficient tool and finally, green building rating index came into formation. Green building rating index has been thoroughly discussed and many researchers have conducted their research on the GBI, but very few have focused on integrating other tools into GBI and get fringe benefits out of it. Though, none has taken interest in the LCC tool to be incorporated in GBI to get the better idea and better results of investing in green buildings by just one element as a prototype. Thus, this research seeks an optimistic approach towards the development of the integrated framework and web-based interface for the GBI-LCC (EE) criteria.

1.8 Original Contribution to The Body of Knowledge

The study focused on the development of computer programming through an integrated web-based interface GBI-LCC (EE) to evaluate the green buildings. GBI (EE) criteria have been used to classify its categories and principles. Also, the LCC tool with its classification and principles of elements have been taken into account. The GBI (EE) classifies green technology to be used in evaluating the green building, thus this emphasises to understand the LCC of the green technology that is pivotal in any green building project in order to know the worth.

Thereafter, a framework is developed by an integrated approach of GBI-LCC. This framework has significantly contributed to GBI-LCC computer programming model which is easy, quick, and efficient with a time-saving approach for users within the construction industry. This research will also add on to fetch more investors and developers towards the green building development.

The GBI-LCC will make the index more user-friendly and stakeholders or users can explore and pre-evaluate their project investment worth. In line with the introduction of the computer-based assessment tools to the industry, the e-performance evaluation can be executed and communication between all the parties will be more efficient. There is also the potential of extension to blend to other criteria of GBI. Thus, it is a milestone to form a comprehensive or integrated decision support tool of GBI and LCC development in Malaysia.

Furthermore, the computer-based GBI-LCC has been developed specifically for the unique Malaysian tropical weather, environment, cultural, and social needs. Thus, this research is a very significant contributing to the benefits of the nation.

1.9 Outline of the Thesis

This thesis consists of six Chapters. A brief summary of each Chapter is outlined below:

Chapter 1 comprises the introductory section which illustrates the reason for the direction of the research. It also states the research background, research problems, research objectives, methodology, scope and original contribution to the Body of Knowledge.

Chapter 2 comprises the literature on green building, GBI and LCC its variables and factors, Decision Support Systems (DSS) for green buildings, cost and financial benefits, measuring performance.

Chapter 3 summarises the literature on derived layers of GBI and comprehensive energy-efficient technology. It also presents the LCC elements, along with the GBI-LCC scorecard.

Chapter 4 presents the research design and methodology, including the research design, the participants involved, reliability and validity of the data, the methods of data analysis to be employed and development of computer-based assessment tool.

Chapter 5 presents the results of comparative review from the literature review, the data collection from survey questionnaires, refinement and validation through expert discussions. Furthermore, this chapter also shows the steps in achieving the objectives. This chapter also proposes a framework and approaches to develop a computer-based GBI-LCC PHP program.

Chapter 6 presents the conclusions, recommendations for future research, and closing remark of this research.

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Appendix A Sample of Questionnaire Survey

THE AUTOMATION OF LIFE CYCLE COST ANALYSIS IN EVALUATING GREEN BUILDING INDEX ENERGY EFFICIENCY CRITERIA

FACULTY OF CIVIL ENGINEERING (FKA)
UNIVERSITI TEKNOLOGI MALAYSIA
SKUDAI, JOHOR

QUESTIONNAIRE FORM

THE AUTOMATION OF LIFE CYCLE COST ANALYSIS IN EVALUATING GREEN BUILDING INDEX ENERGY EFFICIENCY CRITERIA

Dear respondent,

We are pleased to have your expert review for a PhD research on the above topic; your prior expertises and specialization is warmly welcome to provide contribution to the outcome of this research.

This questionnaire contains of **TWO (2)** sections and will take **15 minutes** (approx) of your precious time.

Thank you so much for your kind consideration and sparing time, your contribution and participation is highly appreciated.

All responses will be kept **strictly confidential** and exclusively for **academic purposes.**

Thank you

Prepared By: Rosli Bin Ahmad (PhD Student)

Supervised By: Assoc. Prof. Dr. Rozana Zakaria
Faculty of Civil Engineering, Universiti Teknologi Malaysia
81300 Skudai, Johor Bahru,
Contact No: 0163088671
Email: rosli.ahmad858@yahoo.com.my

SECTION A: Demographic Information

Please tick (√) where appropriate corresponding to your choice.

Name:

Please state your gender

a. Male b. Female

Organisation:

Position:

Please state your Highest Level of Academic Qualification

a) Certificate
b) Diploma
c) Bachelor Degree
d) Master Degree
e) Doctorate/ PhD
f) Others please specify: ……..

Qualified Professional (QP):

(Please mention such as GBI, MYCREST, LEED, BREEAM etc)

Experience dealing with Green Projects:

Guidelines for the Expert Reviews

This section is to obtain feedback from the respondents on the association of Life Cycle Cost (LCC) with Energy Efficiency (EE) criteria . From the Elements of EE1 to EE5, please tick (√) where appropriate corresponding to your choice. Give the rate of association towards each EE criteria according to the scale given

SCALE	LABEL
1	Very weak Association of Life Cycle Cost
2	Weak Association of Life Cycle Cost
3	Moderate Association of Life Cycle Cost
4	Strong Association of Life Cycle Cost
5	Very Strong Association of Life Cycle Cost

		LCC ASSOCIATION																																					
EE	**ENERGY EFFICIENCY**	**Management cost**					**Operation Cost**					**Maintenance Cost**					**Replacement Cost**					**Construction & Installation Cost**					**Development Cost**					**Contingencies /Risk cost**				
EE1	**Minimum EE Performance**																																						
Establish minimum energy efficiency (EE) performance to reduce energy consumption in buildings, thus reducing CO2 emission to the atmosphere. Meet the following minimum EE requirements as stipulated in MS 1525:2007: 1) OTTV ≤ 50, RTTV ≤ 25. Submit calculations using the BEIT software or other GBI approved software(s), AND 2) Provision of Energy Management Control system where Air-conditioned space ≥ 4000m2		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
EE2	**Lighting Zoning**																																						
Provide flexible lighting controls to optimise energy savings: All individual or enclosed spaces to be individually switched; and the size of individually switched lighting zones shall not exceed 100m² for 90% of the NLA; with switching clearly labelled and easily accessible by building occupants. Provide auto-sensor controlled lighting in conjunction with daylighting strategy for all perimeter zones and day light areas, if any.		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
EE3	**Electrical Sub-metering**																																						

Monitor energy consumption of key building services as well as all tenancy areas: Provide sub-metering for all energy uses of ≥ 100kVA; with separate sub-metering for lighting and separately for power at each floor or tenancy, whichever is smaller.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
EE4 **Renewable Energy**																																			
Encourage use of renewable energy: Where 0.5 % or 5 kWp whichever is the greater, of the total electricity consumption is generated by renewable energy, OR Where 1.0 % or 10 kWp whichever is the greater, of the total electricity consumption is generated by renewable energy, OR Where 1.5 % or 20 kWp whichever is the greater, of the total electricity consumption is generated by renewable energy, OR Where 2.0 % or 40 kWp whichever is the greater, of the total electricity consumption is generated by renewable energy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
EE5 **Advanced EE Performance - BEI**																																			
Exceed Energy Efficiency (EE) performance better than the baseline minimum to reduce energy consumption in the building. Achieve Building Energy Intensity (BEI) ≤ 150 kWh/m2yr as defined under GBI reference (using BEIT Software or other GBI approved software(s)), OR BEI ≤ 140, OR BEI ≤ 130, OR BEI ≤ 120, OR BEI ≤ 110, OR BEI ≤ 100, OR BEI ≤ 90,	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Appendix B Sample of Questionnaire Survey Validation

RESEARCH VALIDATION SURVEY 2018

THE AUTOMATION OF LIFE CYCLE COST ANALYSIS IN EVALUATING GREEN BUILDING INDEX ENERGY EFFICIENCY CRITERIA

FACULTY OF CIVIL ENGINEERING (FKA)

UNIVERSITI TEKNOLOGI MALAYSIA

THE AUTOMATION OF LIFE CYCLE COST ANALYSIS IN EVALUATING GREEN BUILDING INDEX ENERGY EFFICIENCY CRITERIA

Dear respondent,

We are pleased to have your expert review for a PhD research on the above topic; your prior expertises and specialization is warmly welcome to provide contribution to the outcome of this research. This questionnaire contains of **TWO (2)** sections and will take **15 minutes** (approx) of your precious time.

Thank you so much for your kind consideration and sparing time, your contribution and participation is highly appreciated.

All responses will be kept **strictly confidential** and exclusively for **academic purposes.**

Thank you

Prepared By: Rosli Bin Ahmad (PhD Student)
Supervised By: Assoc. Prof. Dr. Rozana Zakaria
Faculty of Civil Engineering, Universiti Teknologi Malaysia
81300 Skudai, Johor Bahru,
Contact No: 0163088671
Email: rosli.ahmad858@yahoo.com.my

SECTION A: Demographic Information

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l) Others please specify: ……..

Qualified Professional (QP):

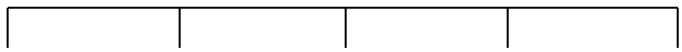
(Please mention such as GBI, MYCREST, LEED, BREEAM etc)

Years of experience dealing with Green Projects:

PART B: *This study is to identify the agreement level of user on the running of programmed interface of GBI (EE) – LCC using PHP programming. Please tick (√) in the appropriate box provided alongside each statement.*

The criteria rank from 1- 5 level of agreement.

AGREEMENT LEVEL



1 2 3 4 5

6- Strongly Disagree
7- Disagree
8- Moderate
9- Agree
10- Strongly Agree

This questionnaire consists only the Energy Efficiency main criteria in GBI and LCC association which have been identified in earlier studies with the expert.

LIFE CYCLE COST ANALYSIS AUTOMATION FOR ACHIEVING ENERGY EFFICIENCY POINTS OF GREEN BUILDING INDEX

No	STATEMENT	AGREEMENT LEVEL					SUGGESTION IF DISAGREE
		1	2	3	4	5	
1	Architectural system for the user interface is in order with the running of GBI-LCC programming.						
2	Architectural system for user profile registration and project registration is in order with the running of GBI-LCC programming.						
3	The achievement level of point scoring of GBI-(EE) is complying with the manual GBI-(EE) score sheet.						
4	The LCC elements are in order and allows user to assess various stages/phases and elements associated with project. (such as LED/Green technology) etc.						
5	The interface of GBI-LCC is attractive and user friendly.						
6	The GBI-LCC programmed interface adequately provides Net Value and Future Cost of the project with user need and input based.						
7	This has very potential to be enhanced at higher level of latest complete Green Building Assessment Tool such as (GBI, MyCrest etc) with LCC association.						
8	This tool provides an effective and efficient platform to perform green building assessment significantly knowing cost association.						

(a) **End of questionnaire, thanks for your support!**

Any comments/further suggestion can be emailed to rosli.ahmad858@yahoo.com.my

Appendix C Example of GBI Rating Tool

CRITERIA	SUB-CRITERIA	GBI POINT	TOTAL POINTS
EE	ENERGY EFFICIENCY		
Design			35
EE1	Minimum EE Performance	1	
EE2	Lighting Zoning	3	
EE3	Electrical Sub-metering	1	
EE4	Renewable Energy	5	
EE5	Advanced EE Performance - BEI	15	
Commissioning			
EE6	Enhanced Commissioning	3	
EE7	Post Occupancy Commissioning	2	
Verification & Maintenance			
EE8	EE Verification	2	
EE9	Sustainable Maintenance	3	
EQ	INDOOR ENVIRONMENTAL QUALITY		
Air Quality			
EQ1	Minimum IAQ Performance	1	21
EQ2	Environmental Tobacco Smoke (ETS) Control	1	
EQ3	Carbon Dioxide Monitoring and Control	1	
EQ4	Indoor Air Pollutants	2	
EQ5	Mould Prevention	1	
Thermal Comfort			
EQ6	Thermal Comfort: Design & Controllability of Systems	2	
EQ7	Air Change Effectiveness	1	
Lighting, Visual & Acoustic Comfort			
EQ8	Day lighting	2	
EQ9	Daylight Glare Control	1	
EQ10	Electric Lighting Levels	1	
EQ11	High Frequency Ballasts	1	
EQ12	External Views	2	
EQ13	Internal Noise Levels	1	
Verification			
EQ14	IAS Before & During Occupancy	2	
EQ15	Post Occupancy Comfort Survey: Verification	2	
SM	SUSTAINABLE SITE PLANNING & MANAGEMENT		
Site Planning			
SM1	Site Selection	1	
SM2	Brownfield Redevelopment	1	
SM3	Development Density & Community Connectivity	2	
SM4	Environment Management	2	

CRITERIA	SUB-CRITERIA	GBI	TOTAL POINTS
Construction Management			18
SM5	Earthworks – Construction Activity Pollution Control		
SM6	QLASSIC		
SM7	Workers' Site Amenities		
Transportation			
SM8	Public Transportation Access		
SM9	Green Vehicle Priority		
SM10	Parking Capacity		
Design			
SM11	Storm water Design – Quantity &Quality Control		
SM12	Greenery & Roof		
SM13	Building User Manual		
MR	**MATERIALS & RESOURCES**		
Reused & Recycled Materials			11
MR1	Materials reuse and selection		
MR2	Recycled content materials		
Sustainable Resources			
MR3	Regional Materials		
MR4	Sustainable Timber		
Waste management			
MR5	Storage & Collection of recyclables		
MR6	Construction waste management		
Green Products			
MR7			
WE	**WATER EFFICIENCY**		
Water Harvesting & Recycling			10
WE1	Rainwater harvesting		
WE2	Water Recycling		
Increased Efficiency			
WE3	Water efficient – Irrigation/Landscaping		
WE4	Water Efficient Fittings		
WE5	Metering & Leak Detection System		
IN	**INNOVATION**		
IN1	Innovation in Design & Environmental Design Initiatives		7
IN2	Green Building Index Accredited Facilitator		
			100

LIST OF PUBLICATIONS

Khan, J. S., Zakaria, R., Aminuddin, E., Abidin, N. I., Sahamir, S. R., Ahmad, R., & Abas, D. N. (2018). Web-based automation of green building rating index and life cycle cost analysis. *IOP Conference Series: Earth and Environmental Science*, *143*(1). https://doi.org/10.1088/1755-1315/143/1/012062

Zakaria, R., Dodo, Y. A., Ahmad, R., & Izieadiana, N. (2016). Proposed Market Survey Framework for Build Green in Malaysia. Journal of Applied Sciences & Environmental Sustainability. *2*(5), 115–125.

Zakaria, R., Dodo, Y. A., Ahmad, R., & Izieadiana, N. (2016). Penetrating Marketing Strategies Framework for BuildGreen in Malaysia. Proceedings of the 2nd International Conference on Science, Technology and Social Sciences 2016 (IGSESS2016).