

DEVELOPMENT OF AFFORDABLE AND USER
FRIENDLY COST MODELLING TOOL FOR
MALAYSIA CONSTRUCTION PROJECT

BY

NURUL AKMAM NAAMANDADIN

A thesis submitted in fulfilment of the requirement for the
degree of Doctor of Philosophy (Built Environment)

Kulliyyah of Architecture and Environmental Design
International Islamic University Malaysia

JUNE 2019

ABSTRACT

The focus of this research is to develop cost modelling tool which can help the designer to estimate affordable green home. This is in line with the aspiration of this country to become a developed and sustainable community. Therefore, this research aims to develop cost modelling tool for the construction project which is affordable and user-friendly. In order to achieve the aim and the objectives of this research, the theoretical framework was developed as a basis for establishing the cost modelling framework. It was started by identifying the green criteria which can be possibly implementing during planning, design and construction. Then it followed by determining the most appropriate cost model which can help the designers to predict the green home project at the design stages. The process continued with the development of the cost modelling tool by utilising Microsoft Excel (MS Excel) software to make it interactive and handy. This tool is expected to compliment with the shortfall of BIM (Revit software as for example) as it still lacking a real-time base cost modelling tool which can merge between green design and cost. Functional Testing was conducted once the cost model completed then it was calibrated to adapt with the environment of its use. User Acceptance Test (UAT) has been conducted to ensure that the tool is easy to use and operate. The result from UAT shows that the tool is user-friendly, handiness and economical to evaluate construction project especially green home. It also allows the designers to estimate and conduct comparative cost studies on the economics of the project during the design stage without going through the conventional process.

خلاصة البحث

يركز هذا البحث على تطوير أداة نمذجة التكلفة التي يمكن أن تساعد المصمم على تقدير المنزل الأخضر الميسور التكلفة. وهذا يتماشى مع طموح هذا البلد ليصبح مجتمعًا متطورًا ومستدامًا. لذلك، يهدف هذا البحث إلى تطوير أداة نمذجة التكلفة لمشروع البناء الذي يكون بأسعار معقولة وسهلة الاستخدام. من أجل تحقيق أهداف هذا البحث، لقد تم تطوير الإطار النظري كأساس لوضع إطار نمذجة التكلفة. وقد بدأ بتحديد المعايير الخضراء التي يمكن تنفيذها أثناء التخطيط والتصميم والبناء. ثم يلي ذلك تحديد نموذج التكلفة الأنسب الذي يمكن أن يساعد المصممين على التنبؤ بمشروع المنزل الأخضر في مراحل التصميم. واستمرت العملية مع تطوير أداة نمذجة التكلفة من خلال استخدام برنامج (MS Excel) لجعلها تفاعلية وسهلة الاستخدام. من المتوقع أن تكمل هذه الأداة النقص في برنامج BIM (برنامج Revit على سبيل المثال) لأنه لا يزال يفتقر إلى أداة نمذجة التكلفة الأساسية في الوقت الفعلي والتي يمكن دمجها بين التصميم الأخضر والتكلفة. تم إجراء الاختبار الوظيفي بمجرد الانتهاء من نموذج التكلفة، ثم تمت معايرته للتكيف مع بيئة استخدامه. وتم إجراء اختبار قبول المستخدم (UAT) لضمان سهولة استخدام الأداة وتشغيلها. تظهر نتيجة UAT أن الأداة سهلة الاستخدام وسهلة الإدارة واقتصادية لتقييم مشروع البناء وخاصةً المنزل الأخضر. كما يسمح للمصممين بتقدير وإجراء دراسات التكلفة المقارنة على اقتصاديات المشروع خلال مرحلة التصميم دون الدخول في العملية التقليدية.

APPROVAL PAGE

The thesis of Nurul Akmam Naamandadin has been approved by the following:

Abdul Razak Sopian
Supervisor

Sharifah Mazlina Syed Khuzzan
Co-Supervisor

Elias Salleh
Internal Examiner

Hafez Salleh
External Examiner

Mohd. Faris Khamidi
External Examiner

Saim Kayadibi
Chairman

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nurul Akmam Naamandadin

Signature

Date

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**DEVELOPMENT OF AFFORDABLE AND USER FRIENDLY
COST MODELLING TOOL FOR CONSTRUCTION PROJECT**

I declare that the copyright holders of this thesis are jointly owned by the student and IIUM.

Copyright © 2019 Nurul Akmam Naamandadin. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understood the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Nurul Akmam Naamandadin

.....
Signature

.....
Date

ACKNOWLEDGEMENTS

Alhamdulillah, all praise to Allah for the strengths and His blessing for this lonely journey while completing this thesis.

To my life-coach, Salmiah: because I owe it all to you. Love You, Mak!

I am grateful to her, who have provided me with moral and emotional support in my life. I am also grateful to all my family members, uncles, aunties, cousins and friends who have supported me along the way.

My sincere gratitude goes to my advisor Prof Ar. Dr. Abdul Razak, for has been there providing his great support and guidance at all times and has given me invaluable guidance, and inspiration. Also, to my co-advisor, Dr. Sharifah Mazlina, her lovely thought, heartfelt support and suggestions in my quest for knowledge could be the most meaningful.

A very special gratitude goes out to all friends and colleagues for proving valuable information to carry out this research. Thanks, to Ar. Ismaliza, Ar. Teoh, Assoc. Prof. Dr. Mohd Wira, Assoc. Prof. Sr. Azlan Raofuddin and all IIUM, USM, UniMAP lecturers as well. My appreciation goes out to them who are rich of experiences and inspirations that provided consistent momentum to expand my boundaries of perception and intellect.

Thanks for all your encouragement!

TABLE OF CONTENTS

Abstract	ii
Abstract In Arabic	iii
Approval Page.....	iv
Declaration	v
Copyright Page.....	vi
Acknowledgements	vii
List of Tables	xiv
List of Figures	xvi
List of Abbreviations	xix
List of Symbols	xxi
List of Green Assessments Code	xxii
List of User Interface Code	xxix
List of Formula	xxxiv

CHAPTER ONE : INTRODUCTION	1
1.1 Research Background	1
1.2 Statement of The Problem	3
1.3 Research Gap	8
1.4 Research Questions	8
1.5 Research Aim and Objectives	8
1.6 Research Methodology	9
1.6.1 Section A: Identify the Green Criteria	10
1.6.2 Section B: Determining the Most Appropriate Cost Model	11
1.6.3 Section C: Development of Cost Modelling Tool	11
1.6.4 Section D: Testing and Validating the Cost Modelling Tool.....	12
1.7 Scope and Limitations of Research	13
1.8 Significance of This Research and Contribution to the Nation.....	13
1.9 Chapter Summary	14

CHAPTER TWO : LITERATURE REVIEW	15
PART ONE: Cost Model As a Tool to Estimate Affordable Green Home	15
2.1 Introduction: Part One	15
2.2 Cost Modelling: A Definition	15
2.3 The Need Of Cost Modelling Tool	16
2.4 Types of Cost Models	20
2.4.1 Empirical	20
2.4.2 Regression	21
2.4.3 Analogy	22
2.4.4 Simulation	22
2.4.5 Expert Judgment	22
2.4.6 Model-Based Technique	23
2.4.7 Cost Estimation Models Software.....	23
2.5 Tools As an Aid to Estimate Cost	24
2.6 Conclusion: Part One	33

PART TWO: Building Information Modelling and Cost Modelling Tool User	
Interface.....	34
2.7 General View	34
2.8 BIM and Green Design	34
2.9 BIM and Cost Estimating.....	35
2.10 Software Options for BIM Cost Estimating.....	37
2.11 User Interface	39
2.12 Information Requirements for Cost Estimating	39
2.13 Cost Data Preparation	40
2.14 Software Project Requirements.....	41
2.15 Creating a Cost-Estimation Model.....	41
2.16 Tool Development Consideration.....	42
2.16.1 Functional (User) Requirements	42
2.16.2 Non-Functional (User) Requirements.....	42
2.16.3 Technical (build) Requirements.....	43
2.17 Conclusion: Part Two	43
PART THREE: Green Home.....	44
2.18 Definitions	44
2.18.1 High-Performance Home	44
2.18.2 Intelligent Home	45
2.18.3 Energy Efficient Home	45
2.18.4 Conclusion to the Above Definitions.....	46
2.19 Green Assessment Tools	47
2.20 Affordability of Buying a Green Home.....	48
2.21 Cost and Green Design.....	50
2.22 Holistic Design Approach	51
2.22.1 Orientation and Site Planning	52
2.22.2 Window Openings and Façade Design.....	53
2.22.3 Natural Ventilation.....	56
2.22.4 Energy Efficiency	57
2.22.5 Water.....	58
2.22.6 Good Indoor Air Quality.....	58
2.23 House Construction	60
2.23.1 Sub-Structure	61
2.23.2 Super-Structure	65
2.23.2.1 Frame	66
2.23.2.2 Upper floor	66
2.23.2.3 Roof	68
2.23.2.4 Staircase.....	71
2.23.2.5 Walls.....	73
2.23.2.6 Windows and Doors	73
2.23.3 Finishes	75
2.23.3.1 Wall finishes.....	75
2.23.3.2 Floor Finishes	76
2.23.3.3 Ceiling Finishes	77
2.23.3.4 External Finishes	78
2.23.4 Sanitary Appliances	78
2.23.5 Plumbing Services.....	78
2.23.5.1 Water Installation	79

2.23.5.2	Flushing Water Installation	80
2.24	Building Materials	81
2.25	Enhancing Quality Of Materials.....	82
2.25.1	Building Materials by Nature.....	84
2.25.1.1	Cementitious Materials.....	84
2.25.1.2	Wood	86
2.25.1.3	Glass	87
2.25.1.4	Steel	87
2.25.1.5	Common Brick	88
2.25.1.6	Vinyl	88
2.25.2	Industrial by-Products	90
2.25.2.1	Gypsum by-Product.....	90
2.25.2.2	Sulphur.....	91
2.25.2.3	Fly Ash	92
2.25.2.4	Silicate Dust.....	92
2.26	Conclusion: Part Three	92
2.27	Chapter Conclusion	93

CHAPTER THREE : RESEARCH METHODOLOGY	94	
3.1	Introduction	94
3.2	Section A – Identifying the Scope of Green Home	96
3.2.1	Step 1 – Comparative Analysis Green Home Assessment	96
3.2.1.1	Green Residential Rating System.....	96
3.2.1.2	Summary of the Selected Green Residential Assessment.....	97
3.2.2	Step 2 and 3 – Review the Green Criteria and Identify the Green Sub-Criteria in Relation to the Building Cost.....	100
3.2.4.1	Management / Project Management	102
3.2.4.2	Energy.....	103
3.2.4.3	Transportation.....	105
3.2.4.4	Water	106
3.2.4.5	Materials & Resources / Ensuring A Long Service Life.....	108
3.2.4.6	Land Use / Ecology / Site / Environmental Protection / Townscape.....	110
3.2.4.7	Pollution, Emissions, Effluents & Other Impact / Waste	112
3.2.4.8	Indoor Environmental Quality / Health & Comfort	114
3.2.4.9	Innovation / Design / Construction Process	116
3.2.4.10	Summary.....	116
3.3	Section B – Determining The Most Appropriate Cost Model.....	117
3.4	Section C – Development Of Cost Modelling Tool For Green Home ..	120
3.4.1	CEA: Summary Interface.....	122
3.4.2	ECA G and ECA C: Elemental Cost Analysis Interfaces	122
3.4.2.1	Inventory of Medium Cost Double Storey Green Terrace House in Malaysia	124
3.4.2.2	Result of Inventory	124
3.4.3	Raw Material Interfaces and Build-up Rate Interfaces	145
3.4.3.1	Preparation of Raw Material Interfaces.....	146

3.4.3.2	Preparation of Build-up Rate	147
3.4.4	Analysed Rate Interfaces	157
3.4.5	Summary of the Tool's Development	159
3.4.6	Step 6 – Testing and Verification	159
3.4.6.1	Functional Testing	160
3.4.6.2	User Acceptance Testing (UAT)	166
3.4.6.3	Test User Selection	168
3.4.6.4	User Acceptance Test Questionnaires	170
3.5	Chapter Summary	170
CHAPTER FOUR : DATA ANALYSIS		172
4.1	Introduction	172
4.2	Functional Testing of Cost Modelling Tool	172
4.2.1	Navigation of Cost Modelling Tool in MS Excel	173
4.2.2	The process of Trace Error, Error Checking and Remove Error	175
4.2.3	Data Validation	175
4.2.3.1	Sub-structure Works	176
4.2.3.2	Super-structure Works	178
4.2.3.3	Finishes Works	179
4.2.3.4	External Works within Lot Boundary, Mechanical and Electrical Within Lot Boundary	180
4.2.3.5	Construction Cost and Project Cost	180
4.2.4	Result from the Functional Testing	183
4.2.5	Summary from the Functional Testing	188
4.3	User Acceptance Testing and Verification of The Cost Modelling Tool	189
4.3.1	Pilot Test	189
4.3.2	Test User Selection	190
4.3.2.1	User Acceptance Testing (UAT) Process:	191
4.3.3	UAT Reviews	194
4.3.4	Summary of User Acceptance Test and Verification of the Cost Modelling Tool	203
CHAPTER FIVE : CONCLUSION AND RECOMMENDATIONS		196
5.1	Introduction	196
5.2	Revisiting the Research Objectives	196
5.2.1	To Identify the Green Criteria Which Can Possibility Implementing During Planning, Design and Construction of the Housing Project	197
5.2.2	To Determine the Most Appropriate Cost Models which Can Help the Designers to Predict the Green Home Project at the Design Stages	197
5.2.3	To Develop Cost Modelling Tool for Green Home	198
5.2.4	Testing and Validating the Cost Modelling Tool	198
5.3	Proof of Fulfilment of The Research Objectives	199
5.4	Recommendations for Future Research	199
5.5	Suggestion to Increase GBI Points By Using Cost Modelling Tool	200
5.5.1	Material Reuse and Selection	200

5.5.2 Regional Materials.....	203
5.5.3 Sustainable Timber.....	206
5.5.4 Construction Waste Management.....	208
5.5.5 Conclusion of the Suggestion to Increase GBI Points by Using Cost Modelling Tool.....	210
5.6 Chapter Conclusion.....	210
REFERENCES.....	211
APPENDIX 2.1 : INDOOR AIR POLLUTANTS OVERVIEW.....	222
APPENDIX 2.2 : INDOOR SOURCES OF SELECTED VOCS.....	226
APPENDIX 2.3 : TYPE OF ROOF COVERING, INSULATION AND WATERPROOFING.....	227
APPENDIX 2.4 : TYPE OF WINDOWS.....	230
APPENDIX 2.5 : PIPE MATERIALS.....	232
APPENDIX 2.6 : CEMENTITIOUS PRODUCTS.....	233
APPENDIX 2.7 : RIBA PLAN OF WORK 2013.....	235
APPENDIX 3.1 : MANAGEMENT / PROJECT MANAGEMENT.....	236
APPENDIX 3.2 : ENERGY.....	238
APPENDIX 3.3 : TRANSPORTATION.....	252
APPENDIX 3.4 : WATER.....	254
APPENDIX 3.5 : MATERIALS & RESOURCES / ENSURING A LONG SERVICE LIFE.....	259
APPENDIX 3.6 : LAND USE / ECOLOGY / SITE / ENVIRONMENTAL PROTECTION / TOWNSCAPE.....	271
APPENDIX 3.7 : POLLUTION, EMISSIONS, EFFLUENTS AND OTHER IMPACT / WASTE.....	274
APPENDIX 3.8 : INDOOR ENVIRONMENTAL QUALITY / HEALTH & COMFORT.....	277
APPENDIX 3.9 : INNOVATION / DESIGN / CONSTRUCTION PROCESS.....	281
APPENDIX 3.10 : ELEMENTAL COST ANALYSIS FORM 1.....	283
APPENDIX 3.11 : ELEMENTAL COST ANALYSIS FORM 2.....	284
APPENDIX 3.12 : ELEMENTAL COST ANALYSIS FORM 3.....	285
APPENDIX 3.13 : BUILDING MATERIALS PRICE.....	286
APPENDIX 3.14 : CONSTRUCTION WORKER AND MACHINE OPERATOR WAGE RATE.....	287
APPENDIX 3.15 : CONSTRUCTION MACHINERIES RENTAL RATE.....	288
APPENDIX 3.16 : DATA SHEET ECA.....	289
APPENDIX 3.17 : ELEMENTAL COST ANALYSIS.....	290
APPENDIX 3.18 : CHECK LIST OF DEFECTS DOCUMENTED.....	291
APPENDIX 4.1 : FUNCTIONAL TESTING CHECKLIST.....	296
APPENDIX 4.2 : 'MS' - MEASUREMENT SHEET.....	301
APPENDIX 4.3 : 'VL' VENTILATION AND LIGHTING AREA.....	302
APPENDIX 4.4 : BUILD-UP RATE ANALYSIS OF PRICE.....	303
APPENDIX 4.5 : BUILD-UP RATE SPREADSHEET (INTERFACE).....	304
APPENDIX 4.6 : THE MEMORANDUM OF AGREEMENT OF ALL PARTIES BETWEEN THE GOVERNMENT OF MALAYSIA.....	305

APPENDIX 4.7 : UBBL (SECTION III, CLAUSE 39)	311
APPENDIX 4.8 : SMM2 SECTION M, SECTION M.19 – M.22 AND SECTION P, CLAUSE P.3	312
APPENDIX 5 : USER INTERFACES	313
APPENDIX 6 : COPYRIGHT OF COST MODELLING PREDICTION TOOL FOR GREEN HOME	314
APPENDIX 7 : ABSTRACT OF PUBLISHED PAPERS BY THE AUTHOR	319

LIST OF TABLES

Table 1.1	Summary of Research Objectives, Research Methodology and Expected Output/Hypothesis by Research Questions	12
Table 2.1	Development Cycle	19
Table 2.2	Summary of traditional cost models, their functions, advantages and disadvantages/limitation from various sources.	27
Table 2.3	Window Design (Malaysian Standard, 2017)	55
Table 2.4	Building Elements with Green Material Substitutions	89
Table 3.1	Green Assessment tools widely used in the six different countries chosen.	96
Table 3.2	Summary of the Selected Green Residential Assessment	98
Table 3.3	A summary of overall assessment criteria for each of green home assessments	99
Table 3.4	Summary of assessment criteria no 1 under Management/ Project Management which has been arranged according to the RIBA Plan of Work 2013	102
Table 3.5	Summary of assessment criteria no 2 under Energy which has been arranged according to the RIBA Plan of Work 2013	103
Table 3.6	Summary of assessment criteria no 3 under Transportation which has been arranged according to the RIBA Plan of Work 2013	105
Table 3.7	Summary of assessment criteria no 4 under Water which has been arranged according to the RIBA Plan of Work 2013	106
Table 3.8	Summary of assessment criteria no 5 under Materials & Resources/ Ensuring A Long Service Life which has been arranged according to the RIBA Plan of Work 2013	108
Table 3.9	Summary of assessment criteria no 6 under Land Use/ Ecology/ Site/ Environmental Protection/ Townscape which has been arranged according to the RIBA Plan of Work 2013	110
Table 3.10	Summary of assessment criteria no 7 under Pollution, Emissions, Effluents & Other Impact / Waste which has been arranged according to the RIBA Plan of Work 2013	112

Table 3.11	Summary of assessment criteria no 8 under Indoor Environmental Quality / Health & Comfort which has been arranged according to the RIBA Plan of Work 2013	114
Table 3.12	Summary of assessment criteria no 9 under Innovation / Design / Construction Process which has been arranged according to the RIBA Plan of Work 2013	116
Table 3.13	The justification and attributing green criteria of the selected cost model	118
Table 3.14	Minimum areas and dimensions of rooms in a double-storey terrace house	125
Table 3.15	Floor areas of Type 1 and 1A	130
Table 3.16	Cost Analysis based on the tender drawings (priced Bills of Quantities) for intermediate lot Type 1 and 1A	131
Table 3.17	Floor areas of Type 2A, 2B, 2C and 2D	133
Table 3.18	Cost Analysis based on the tender drawings (priced Bills of Quantities) for corner lot Type 2A, 2B, 2C and 2D	134
Table 3.19	Floor areas of Type 3A, 3B, 3C and 3D	136
Table 3.20	Cost Analysis based on the tender drawings (priced Bills of Quantities) for end lot Type 3A, 3B, 3C and 3D.	137
Table 3.21	Floor areas of Type 4A, 4B, 4C, 4C1, 4D and 4D1	139
Table 3.22	Cost Analysis based on the tender drawings for end lot Type 4A, 4B, and 4C	140
Table 3.23	Cost Analysis based on the tender drawings for end lot Type 4C1, 4D, and 4D1	141
Table 3.24	Summary of overall Cost Analysis based on the tender drawings	142
Table 3.25	Average cost per GFA of 16 different types of double-storey terrace houses	143
Table 3.26	Average cost per GFA of 16 different types of double-storey terrace houses	145
Table 3.27	List of Defects Documented	166
Table 4.1	Benchmark for Cost Planning	182
Table 4.2	Project Cost Comparison for one unit	185
Table 4.3	Project Cost Comparison for 24 units	186

LIST OF FIGURES

Figure 1.1	Stages of the Methodological Frameworks	10
Figure 2.1	Types of Construction Cost Modelling	25
Figure 2.2	Detailed Bottom-Up Cost Estimating Process	40
Figure 2.3	Façade on Which It Is Reflected In the Architectural Design	61
Figure 2.4	The Components of Sub-Structure	63
Figure 2.5	The Components of Sub-Structure	64
Figure 2.6	The Location of Upper Floor Level	67
Figure 2.7	The Location of Roof	70
Figure 2.8	Stair Treads and Risers	71
Figure 2.9	Staircase Plans and Cross Sections	72
Figure 2.10	Door and Windows	74
Figure 2.11	Example of Floor Finish	77
Figure 2.12	Plumbing System	79
Figure 3.1	Stages of Methodology Framework	95
Figure 3.2	World Map and Selected Green Assessments All Over the World	97
Figure 3.3	Step 2 – RIBA Plan of Works 2013	101
Figure 3.4	Cost Models	117
Figure 3.5	Navigation Spreadsheets of Cost Modelling Tool	121
Figure 3.6	'ECA G' and 'ECA C' Interfaces Data Input Navigation	123
Figure 3.7	Option 1: Floor Plan with 20' x 65'	127
Figure 3.8	Option 2: Floor Plan with 20' x 65'	128
Figure 3.9	Type 1 and 1A Floor Plans	129

Figure 3.10	Type 2A, 2B, 2C and 2D Floor Plans	132
Figure 3.11	Type 3A, 3B, 3C and 3D Floor Plans	135
Figure 3.12	Type 4A, 4B, 4C1, 4D and 4D1 Floor Plans	138
Figure 3.13	Average Cost Per GFA for the Building Works by Elements	144
Figure 3.14	Process of Build-up Rates	147
Figure 3.15	Instructions in Build-Up Rates Interfaces	148
Figure 3.16	Element and Description Table in the Data Spreadsheet	149
Figure 3.17	Analysis Table (Material Rates)	150
Figure 3.18	Analysis Table (Labours Rate)	151
Figure 3.19	Analysis Table (Machineries Rate)	152
Figure 3.20	Analysis Table (Material Quantities)	153
Figure 3.21	Analysis Table (Profit Calculation)	154
Figure 3.22	Analysis Table (Total Amount)	155
Figure 3.23	Analysis Spreadsheet (Overall Build-up Rate Template)	156
Figure 3.24	Summary of Build-Up rate	158
Figure 3.25	'Measurement' Spreadsheet for the Area of Finishes	162
Figure 3.26	'Measurement' spreadsheet: <i>Length of Wall</i>	163
Figure 3.27	Minimum Area and Floor Height Set by the Ministry Of Housing	164
Figure 3.28	'Floor Type', 'Ceiling Type' and 'Wall Finish' columns	164
Figure 3.29	Example of Floor Finish code	165
Figure 3.30	Percentage Errors Found Versus Number of Users	169
Figure 4.1	Navigation spreadsheet of Cost Modelling Tool	174
Figure 4.2	Comparison Project Cost Summary between Green Home and Conventional House by Elements	184
Figure 4.3	User interface of 'EOI' Interface	188

Figure 4.4	Drop-Down Menu Show the Option Prices for the Excavation Work	189
Figure 5.1	Build-up Rate Formwork Option 1	201
Figure 5.2	Build-up Rate Formwork Option 2	202
Figure 5.3	Example of User Interface for Build-Up Rate	204
Figure 5.4	Example of User Interface for Build-Up Rate	205
Figure 5.5	Build-Up Rate Interface for Formwork	207
Figure 5.6	Build-Up Rate Interface for Excavation Oversight	209

LIST OF ABBREVIATIONS

3D	3–Dimension
4D	4–Dimension
5D	5–Dimension
ABS	Acrylonitrile Butylene Styrene
Al ₂ O ₃	Aluminium Oxide / Alumina
ASME	American Society of Mechanical Engineers
BAS	Building Automation Systems
BECS	Building Energy Consumption Simulation
BIM	Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aid Design
CaO	Calcium Oxide / Lime
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CaSO ₄ ·2H ₂ O	Crystalline Calcium Sulfate Dihydrate
CETDEM	Centre for Environment, Technology and Development, Malaysia
CFLs	Compact Fluorescent Lamps
CIDB	Construction Industrial Development Board
CO ₂	Carbon Dioxide
DU	Distribution Uniformity
ECA	Elemental Cost Analysis
EDC	Ethylene Dichloride
EE	Energy Efficient
EPA	Environmental Protection Agency
Fe ₂ O ₃	Ferric Oxide / Ferromagnetic
FEMP	Federal Energy Management Program
FSC	Forest Stewardship Council
FSC	Forest Stewardship Council
GBCA	Green Building Council of Australia
GBI	Green Building Index
GFA	Gross Floor Area
GMS	Green Marks
gpf	gallons per flush
gpm	gallon per minute
HVAC	Heat, Ventilation and Air Conditional
IEQ	Indoor Environmental Quality
IS	Information System
IWK	Indah Water Konsortium Sdn Bhd
JBA	Jabatan Bekalan Air
JPS	Jabatan Perparitan dan Saliran
LEED	Leadership in Energy and Environmental Design
M&E	Mechanical and Electrical

MANV	Mechanically Assisted Naturally Ventilated
MEF	Modified Energy Factor
MIEEIP	Malaysia Industrial Energy Efficiency Improvement Project
MS	Malaysian Standard
MS Excel	Microsoft Excel
MS2680:2017	Malaysian Standards Code of Practice for Energy Efficiency and Use of Renewable Energy for Residential Building
MTCS	Malaysian Timber Certification Scheme
NV	Natural Ventilation
PFCs	Perfluorinated Compounds
PFOA	Perfluorooctanoic Acid
PVC	Polyvinyl Chloride
QS	Quantity Surveyor
RH	Relative Humidity
RIBA	Royal Institution of British Architects
RICS	Royal Institution of Chartered Surveyor
RISM	Royal Intuition of Surveyor Malaysia
RM	Ringgit Malaysia
SiO ₂	Silicon Dioxide / Silica
SIRIM	Standard and Industrial Research Institute of Malaysia
SMM2	Standard Method of Measurement 2
SYABAS	Syarikat Bekalan Air Selangor Sdn. Bhd.
TM	Telekom Malaysia
TNB	Tenaga National Berhad
U.S. EPA	United States Environmental Protection Agency
UAT	User Acceptance Testing
UBBL	Uniform Building by Law
UK	United Kingdom
US	United State
USA	United State of America
VCM	Vinyl Chloride Monomer
VOC/VOCs	Volatile Organic Chemicals
WBLFF	Works Below Lowest Floor Finish
WELS	Water Efficiency Labelling Scheme
WF	Water Factor
WWR	Window to Wall Ratio

LIST OF SYMBOLS

$\%$	percent
d	optimum depth of a point measured on the working plan
ft^2	feet square
h	the vertical height of the window
l	the length of the window
L	liter
m	meter
m/s	meter per second
m^2	meter square
mm	millimeter
no	number
$^{\circ}$	degree
$^{\circ}C$	degree Celcius
pCi/L	Picocuries per litre
$W/m/K$	Watt per meter per Kelvin
x	the distance of a point measured on the working plan from room axis

LIST OF GREEN ASSESSMENTS CODE

Code Green Assessments

Management / Project Management

MAN 1	Home User Guide
MAN 2	Considerate Constructors
MAN 3	Construction Site Impacts
MAN 4	Security
MAN-1	Green Star Accredited Professional
MAN-2	Commissioning Clauses
MAN-3	Building Tuning
MAN-4	Independent Commissioning Agent
MAN-5	Building Users' Guide
MAN-6	Environmental Management
MAN-7	Waste Management
MAN-16	Metering
LH 3-3	Environmental Management Practice
LH 3-4	Stormwater Management
SM 5	Construction System and Site Management
SM 6	Stormwater Management
SM 7	Redevelopment of Existing Sites and Brownfield Redevelopment
SM 8	Avoiding Environmentally Sensitive Areas
SM 9	Building User Manual

Energy

EA 1	ENERGY STAR Labelled Home
EA 2	Insulation
EA 4	Windows Maximum
EA 5	Heating and Cooling Distribution System
EA 6	Space Heating and Cooling Equipment
EA 7	Water Heating
EA 10	Renewable Energy System
ENE 1	Dwelling Emission Rate
ENE 2	Building Fabric
ENE 3	Drying Space
ENE 4	Eco Labelled Goods
ENE 5	Internal Lighting
ENE 6	External Lighting
LR _H 1.1.1	Energy Saving through Building Innovation: Control of Thermal Load of Building
LR _H 1.1.2	Energy Saving through Building Innovation: Natural Energy Use

<i>LR_H1.2.1.1</i>	<i>Energy Saving through Equipment Performance: Air-Conditioning Systems – Heating system</i>
<i>LR_H1.2.1.2</i>	<i>Energy Saving through Equipment Performance: Air-Conditioning Systems – Cooling System</i>
<i>LR_H1.2.2.1</i>	<i>Energy Saving through Equipment Performance: Hot-water equipment – Hot-water Supply Equipment</i>
<i>LR_H1.2.2.2</i>	<i>Energy Saving through Equipment Performance: Hot-water equipment –Heat Insulation of Bathtub</i>
<i>LR_H1.2.3</i>	<i>Energy Saving through Equipment Performance: Lighting Fixtures, Home Electric Appliances, and Kitchen Equipment</i>
<i>LR_H1.2.4</i>	<i>Energy Saving through Equipment Performance: Ventilation System</i>
<i>LR_H1.2.5.1</i>	<i>Energy Saving through Equipment Performance: Highly Energy-Efficient Equipment – Home Cogeneration System</i>
<i>LR_H1.2.5.2</i>	<i>Energy Saving through Equipment Performance: Highly Energy-Efficient Equipment – Solar Power Generation System</i>
<i>ENE-CON</i>	<i>Conditional Requirement (Land Use & Ecology)</i>
<i>ENE-1</i>	<i>Greenhouse Gas Emissions</i>
<i>ENE-7</i>	<i>Unoccupied Areas</i>
<i>ENE-11</i>	<i>Energy Efficient Appliances</i>
<i>ENE-12</i>	<i>Peak Electricity Demand Reduction</i>
<i>LH 1-1</i>	<i>Optimised Building Orientation</i>
<i>LH 1-2</i>	<i>Window to Wall Ratio (WWR)</i>
<i>LH 1-3</i>	<i>Shading Device Design</i>
<i>LH 1-4</i>	<i>Maximum Permissible Wall U-Value</i>
<i>LH 1-5</i>	<i>Maximum Permissible Shading Coefficient (SC) Value of Glass</i>
<i>LH 1-6</i>	<i>Cross Ventilation for Habitable Rooms</i>
<i>LH 1-7</i>	<i>Open Space with Greenery Provision</i>
<i>LH 1-8</i>	<i>Covered Parking Space</i>
<i>LH 1-9</i>	<i>Daylighting Provision</i>
<i>LH 1-10</i>	<i>Cool / Green Ro</i>
<i>LH 1-11</i>	<i>Cool Hardscaped Areas</i>
<i>LH 1-12</i>	<i>Sustainable Landscape Design</i>
<i>EE 1</i>	<i>Minimum Energy Performance</i>
<i>EE 2</i>	<i>Renewable Energy</i>
<i>EE 3</i>	<i>Advanced EE Performance Based on OTTV & RTTV</i>
<i>EE 4</i>	<i>Home Office & Connectivity</i>
<i>EE 5</i>	<i>Sustainable Maintenance</i>

Transportation

<i>TRA 1</i>	<i>Public Transport</i>
<i>TRA 2</i>	<i>Cycle Storage</i>
<i>TRA 3</i>	<i>Local Amenities</i>
<i>TRA 4</i>	<i>Home Office</i>
<i>TRA-1</i>	<i>Provision of Car Parking</i>
<i>TRA-2</i>	<i>Fuel Efficient Transport</i>

TRA-3	<i>Cyclist Facilities</i>
TRA-4	<i>Commuting Mass Transport</i>
TRA-5	<i>Trip Reduction - Mixed Use</i>

Water

WE 1.1	<i>Rainwater Harvesting System</i>
WE 1.2	<i>Graywater Reuse System</i>
WE 1.3	<i>Use of Municipal Recycled Water System</i>
WE 2.1	<i>High-Efficiency Irrigation System</i>
WE 2.2	<i>Third-Party Inspection</i>
WE 2.3	<i>Reduce Overall Irrigation Demand</i>
WE 3.1	<i>High-Efficiency Fixtures</i>
WE 3.2	<i>Very High-Efficiency Fixtures and Fittings</i>
WAT 1	<i>Internal Potable Water Use</i>
WAT 2	<i>External Potable Water Use</i>
LR _{H1} .3.1	<i>Conserving Energy and Water: Water Conservation – Water Saving Systems</i>
LR _{H1} .3.2	<i>Conserving Energy and Water: Water Conservation – Rainwater Use</i>
WAT-1	<i>Occupant Amenity Water</i>
WAT-3	<i>Landscape Irrigation</i>
WAT-4	<i>Heat Rejection Water</i>
WAT-5	<i>Fire System Water</i>
WAT-7	<i>Water Efficient Appliances</i>
WAT-8	<i>Swimming Pool/Spa Water Efficiency</i>
LH 2-1	<i>Water Efficient Fittings</i>
LH 2-2	<i>Water Efficient Landscaping</i>
WE 1	<i>Rainwater Harvesting</i>
WE 2	<i>Water Recycling</i>
WE 3	<i>Water Efficient Landscaping</i>
WE 4	<i>Water Efficient Fittings</i>

Materials & Resources / Ensuring A Long Service Life

MR 1.1	<i>Framing Order Waste Factor Limit</i>
MR 1.2	<i>Detailed Framing Documents</i>
MR 1.3	<i>Detailed Cut List and Lumber Order</i>
MR 1.4	<i>Framing Efficiencies</i>
MR 1.5	<i>Off-Site Fabrication</i>
MR 2.1	<i>FSC Certified Tropical Wood</i>
MR 2.2	<i>Environmentally Preferable Products</i>
MR 3.1	<i>Construction Waste Management Planning</i>
MR 3.2	<i>Construction Waste Reduction</i>
MAT 1	<i>Environmental Impact of Materials</i>
MAT 2	<i>Responsible sourcing of Materials: Basic Building Elements</i>
MAT 3	<i>Responsible sourcing of Materials: Finishing Elements</i>
MAT 4	<i>Recycling Facilities</i>