BUILDING INFORMATION MODELLING-BASED APPROACH FOR ASPECTS OF GREEN BUILDING EVALUATION

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DEDICATION

To My Beloved Parents, I Dedicate All the Success.
"May Allah Grant You Paradise"
Your Youngest Son.

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ABSTRACT

Green Building Rating Systems (GBRS) have been developed around the world to guide project teams in achieving sustainable building goals. However, the current practice of assessing building sustainability under these rating systems is based on a fragmented process, which relies on paper-based work and manual data input. Building Information Modelling (BIM) technology and design process, on the other hand, are based on the use of intelligent data-rich models, where the required data can be extracted automatically and used to assist green building assessment. This study developed an integrated BIM-based approach for green building assessment that supports GreenRE rating system developed by Real Estate and Housing Developers' Association (REHDA). Initially, an exploratory study was conducted to investigate the current practice of green building assessment under GreenRE and the feasibility of using BIM technologies to tackle the current issues. Then, a BIM-GreenRE assessment method was established based on the match-up of GreenRE requirements and the BIM design process required for sustainability assessment. Based on the conceptual framework of this assessment method, a pragmatic solution consisting of Passive Design Toolkit (PDT) was developed using a visual programming tool called Dynamo. The PDT automates the assessment of two passive design prerequisites under GreenRE rating tool, namely the Overall Value of Thermal Transfer Value (OTTV) and Concrete Usage Index (CUI). Finally, the PDT procedure was tested and demonstrated through a case study, and the generated results were validated against manual calculations. The validation experiment showed a higher automation with greater accuracy during the assessment process of the OTTV (measured 56.24 W/m^2) and CUI (measured 0.255 m^3/m^2) of the case study and this took less than one minute to complete each procedure. This research has established and demonstrated a BIM-based strategy for integrating BIM to the process of assessing building sustainability under GreenRE requirements. The newly developed PDT could be used to assist project teams during the design decision-making regarding building envelop thermal performance such as OTTV, and Concrete Usage Index (CUI) assessment that would enable them to test and compare the performance of several design options early in the design stage.

ABSTRAK

Sistem Penarafan Bangunan Lestari (GBRS) telah dibangunkan di seluruh dunia bagi membantu pasukan projek mencapai matlamat bangunan lestari. Walau bagaimanapun, amalan yang dipraktikkan sekarang untuk menilai bangunan lestari menggunakan sistem penarafan tersebut adalah berdasarkan proses berasingan yang bergantung kepada borang kertas dan input data secara manual. Sebaliknya, teknologi dan proses mereka bentuk Permodelan Bangunan Bermaklumat (BIM) adalah berdasarkan penggunaan kepintaran model yang kaya dengan data, dimana data yang diperlukan boleh diambil secara automatik dan digunakan untuk membantu penilaian bangunan lestari. Kajian yang telah dikendalikan ini untuk membangunkan penarafan berintegrasi yang berasaskan BIM untuk membantu penilaian bangunan lestari bagi sistem penilaian GreenRE, yang telah dibangunkan oleh Persatuan Pemaju Hartanah dan Perumahan (REHDA). Kajian ini dimulai dengan menjalankan satu kajian penerokaan untuk menyiasat amalan terkini semasa menilai bangunan lestari di bawah GreenRE, dan kebolehlaksanaan untuk menggunakan teknologi BIM untuk meyelesaikan isu-isu semasa. Kemudian, satu kaedah penilaian BIM-GreenRE telah dibangunkan berdasarkan kepada gabungan keperluan GreenRE dan proses reka bentuk BIM yang diperlukan untuk penilaian lestari. Berdasarkan kepada kerangka konseptual teoritikal untuk kaedah penilaian ini, satu penyelesaian pragmatik yang terdiri daripada alatan reka bentuk pasif (PDT) telah dibangunkan dengan menggunakan bahasa pengaturcaraan visual (VPL) yang dipanggil Dynamo. PDT membuat penilaian secara automatik untuk dua prasyarat reka bentuk pasif di bawah alatan penarafan GreenRE, iaitu nilai keseluruhan pemindahan haba (OTTV) dan indeks penggunaan konkrit (CUI). Akhir sekali, prosedur PDT telah diuji dan dibandingkan melalui satu kajian kes dan hasil yang diperolehi telah disahkan melalui kaedah pengiraan manual. Eksperimen validasi telah menunjukkan automasi yang lebih tinggi dengan ketepatan yang lebih tepat semasa proses penilaian OTTV (diukur 56.24 W/m2) dan CUI (diukur 0.255 m^3/m^2) untuk kajian kes yang mengambil kurang daripada satu minit untuk setiap prosedur. Kajian ini telah membuktikan dan menunjukkan satu strategi berdasarkan BIM untuk mengintegrasikan BIM ke dalam proses penilaian bangunan lestari di bawah keperluan GreenRE. PDT yang dicadangkan dapat membantu pasukan projek semasa fasa membuat keputusan reka bentuk yang merangkumi reka bentuk sampul bangunan dan penilaian indeks seperti OTTV dan CUI yang membolehkan mereka menguji dan membandingkan kecekapan beberapa pilihan reka bentuk di peringkat awal fasa mereka bentuk.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	-	Three-dimensional
2D	-	Two-dimensional
AC	-	Air-Conditioned
CAD	-	Computer-aided design
AEC	-	Architecture, Engineering and Construction
AIA	-	American Institute of Architects
APA	-	Application Programming Interface
ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
BCA	-	Building and Construction Authority
BEAM	-	Building Environmental Assessment Method
BEI	-	Building Energy Index
BEIT	-	Building Energy Index Tool
BIM	-	Building Information Modelling
BREEAM	-	Building Research Establishment Environmental Assessment Method
CASBEE	-	Comprehensive Assessment System for Built Environment Efficiency
CF	-	Correction Factor
CIDB	-	Construction Industry Development Board
CUI	-	Concrete Usage Index
DLL	-	Dynamic Link Libraries
DOE	-	Department of Energy, United States
DSS	-	Decision Support System
DXF	-	Drawing Exchange Format
EE	-	Energy Efficiency
EP	-	Environmental Protection
EPD	-	Environmental Product Declaration
ETTV	-	Envelope Thermal Transfer Value
IES <VE>	-	Integrated Environment Solution <Virtual

		Environment >
FAB	-	Faculty of Built Environment
FFI	-	Foreign Function Interface
FGD	-	Focus Group Discussion
GA	-	GreenRE Assessor
GBAT	-	Green Building Assessment Tool
GBI	-	Green Building Index
GBS	-	Green Building Studio
GBRS	-	Green Building Rating System
gbXML	-	Green Building XML
GFA	-	Gross Floor Area
GHG	-	Greenhouse Gas
GIS	-	Geographic Information System
GMDB	-	Green Materials Database
GnPR	-	Green Plot Ratio
GTFS	-	Green Technology Financing Scheme
GUI	-	Graphical User Interface
HVAC	-	Heating, Ventilation and Air-Conditioning
IEQ	-	Indoor Environmental Quality
IES <VE>	-	Integrated Environment Solution <Virtual Environment
IFC	-	Industry Foundation Classes
IN	-	Innovation
IT	-	Information Technology
JB	-	Johor Bahru
JKR	-	Jabatan Kerja Raya
KeTTHA	-	Ministry of Energy, Green Technology and Water of Malaysia
LCA	-	Life-cycle Assessment
LCCF	-	Low Carbon City Framework
LEED	-	Leadership in Energy and Environmental Design
LOD	-	Level of Development
MOO	-	Multi-objective Optimisation
MS	-	Malaysian Standard

MTO	-	Material Take-Off
MyCREST	-	Malaysian Carbon Reduction and Environmental Sustainability Tool
NBS	-	National BIM Standards
NRB	-	Non Residential Building
NRNC	-	Non-residential New Construction
NV	-	Natural Ventilation
OF	-	Solar Orientation Factor
OGF	-	Other Green Features
OandM	-	Operations and Maintenance
OPC	-	Ordinary Portland Cement
OTTV	-	Overall Thermal Transfer Value
PAM	-	Architectural Association of Malaysia
PDT	-	Passive Design Toolkit
PHP	-	Personal Home Page
PV	-	Photovoltaic
PWD	-	Public Works Department
REHDA	-	Real Estate and Housing Developers' Association
RES	-	Residential Building
RETV	-	Residential Envelop Transmittance Value
RNC	-	Residential New Construction
ROI	-	Return on Investment
SC	-	Shading Coefficient
SHGC	-	Solar Heat Gain Coefficient
USGBC	-	U.S. Green Building Council
UTM	-	Universiti Teknologi Malaysia
WC	-	Water-Closets
WE	-	Water Efficiency
WEPLES	-	Water Efficient Product Labelling Scheme
WWR	-	Window-to-wall Ratio
V	-	Variable
VPL	-	Visual Programming Language

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Worldwide, the building construction industry is considered as one of the most challenging and complex industries. Unfortunately, it has been heavily criticised for its high impact on the natural environment and the role that it plays in increasing greenhouse gas emissions and the degradation of the planet resources (Jones *et al.*, 2010; Stadel *et al.*, 2011). As a consequence, it is now believed that building professionals and stakeholders should act in order to alleviate climate change threats and the extensive impact of constructions on the environment by adopting sustainable practices in building design (Dixon *et al.*, 2012; Wu, 2010).

Building practitioners have realised the importance of having consistent metrics for the quantitative and qualitative evaluation of building performance in order to efficiently guide and rate the design and construction of green buildings (Wu, 2010). As a result, many Green Building Rating Systems (GBRS), such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), Green Mark (Singapore), Green building Index (GBI) and GreenRE (Malaysia) have been developed and adopted by different countries around the world to assess and certify green buildings. A GBRS is a point-based system which consists of several categories for the benchmarking of building design performances and its surrounding environment (Sharaf and Al-Salaymeh, 2012). These categories cover standard requirements including but not limited to building Energy Efficiency (EE), Indoor Air Quality (IAQ), water efficiency, materials and resources usage, and others. Achieving points in these targeted areas will mean the building will likely be more environmentally friendly than those that do not address the issues (Gowri, 2004).

Energy Efficiency (EE) has always been the one of most concern under the majority of GBRS, and weighted the highest portion of achievable credit points (e.g. 31.9% of credit in BREEAM and 19% in LEED). According to Sadineni *et al.*, (2011) building Energy Efficiency can be improved either by passive and/or active technologies. Active design focus mainly on the optimization of building services which includes heating, ventilation, air-conditioning (HVAC) systems, hot water production and lighting. In contrast, passive design strategies seeks to provide more energy efficient building envelope, shape and layout, which are constrained by the building structure. Recently, an increased interest has appeared among building practitioners in passive design strategies because of its low extra capital investment cost compared to the potential benefit in energy saving (Chen *et al.* 2015). Therefore, several passive design requirements become incorporated in the various GBRS to ensure the achievement of energy saving at the initial architectural design stage.

A recent trend of research works started to investigate how Building Information Modelling (BIM) design process and tools could be implemented to assist green building evaluation under the different GBRS requirements. By definition, Building Information Modelling (BIM) is a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Penttilä, 2006). BIM-based design process relies on object-oriented database which is made up of intelligent objects, 3D representation of integrated information and a relational database that is interconnected (Eastman, 2011). According to Smith and Tardiff (2009) and Eastman (2011), most of the information used in a construction project originates in CAD drawings. Though, these have limited capability to serve as a data repository, are labour intensive, time consuming to produce and un-computable. Therefore, it may create much room for error in the information production and flow. On the other hand, BIM approach to building design does not only lie on the advantages of 3D parametric modelling, but also the structured information that is organized, defined and exchangeable (Haron, 2013). The structured information can be used to support decision-making early in the design process by increasing the design certainty, easing the coordination of design production and providing a seamless information flow and communication between project stakeholders (Smith and Tardiff, 2009).

Krygiel and Nies (2008), Eastman (2011) and many other scholars think that BIM can help to improve building industry productivity as well as support green building evaluation and certification. For example, according to Jalaei (2015) BIM tools have the ability to provide users with an opportunity to explore diverse energy saving alternatives at the early design stage by avoiding time-consuming process of re-entering all building geometry and supporting information necessary for complete energy analysis. Moreover, due to the integration of Visual Programming Languages (VPL) to the BIM tools, designers without background in programming are now able to develop graphical scripts for automated data extraction and management. For instance, the linkage of visual programming tools (e.g. Dynamo) to the BIM authoring tools (e.g. Revit) allows designer to create automated workflows for the extraction of the data that can be used for building sustainability analysis (Wong and Kuan, 2014; Kensek, 2015; Konis *et al.*, 2016).

Currently, much effort is carried out for BIM adoption around the world including Malaysia. However, in the Malaysian building industry, BIM application in green building assessment and certification are still in its infancy stages. This study aims to address the challenges of integrating BIM technologies with one Green building rating tool in Malaysia, namely GreenRE. The main output of this study consists of the proposed BIM-GreenRE assessment method in addition to the developed Passive Design Toolkit (PDT). The availability of such a BIM-based assessment method and Toolkit will support project teams in the implementation of BIM-based efficient workflows for the automation of green building evaluation early in the design stages.

1.2 Problem Statement

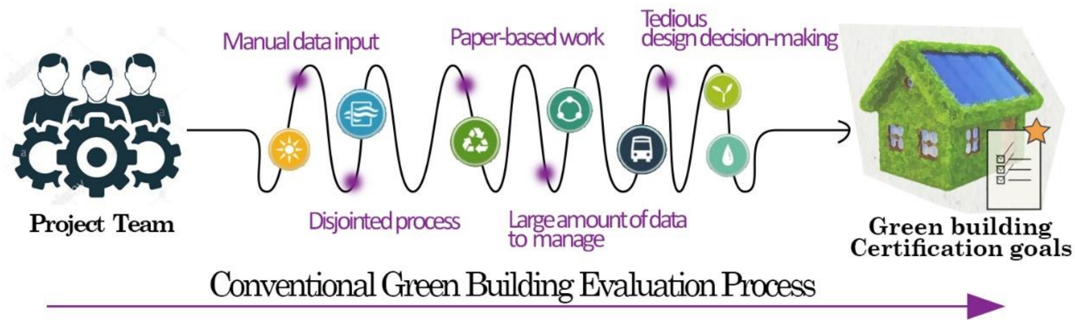

Figure 1.1 Research problem

The current practice of building design to achieve a specific green building certification goals is highly-complex, rigorous and costly (Kasim, 2015). As shown in Figure 1.1, it is based on a disjointed process which relies on manual calculation, paper-based work and manual data input (Jalaei, 2015; Kasim, 2015; Wong and Kuan, 2014; Wu, 2010). Moreover, it often requires the management of a large amount of data at every stage of building sustainability assessment, which increases the possibility of having inaccurate assessment results at the end of the assessment process (Cole, 2005). For instance, materials selection in green buildings become dependent on several sustainability criteria and regulations, such as materials embodied energy, carbon emissions, concrete usage index (CUI), local material and so on. Because of the interference between these sustainability criteria, it is not easy to predict the impact of one material choice on the overall building sustainability, especially in the early stages of building design (Trusty, 2003). One design option could achieve an excellent thermal performance of the indoor building environment; however, the same choice could have a negative impact on the environment (e.g. in term of embodied carbon).

Design decision-making in green building projects and building sustainability assessment processes are very time consuming due to the fact that collecting, managing and documenting the relevant data is a very laborious process (Ilhan and Yaman, 2016; Jalaei and Jrade, 2015; Kasim, 2015; Lim *et al.*, 2016; Wong and Kuan, 2014; Wu, 2010). Additionally, applying passive design strategies to optimise the envelop of the building can be very tedious (Konis *et al.*, 2016). As a consequence, designers and architects tend to rely on their previous experience outcomes to make a design decision. Therefore, they may create several design options and then they manually test them against past cases to select what they think is the best solution

(Sukreet and Kensek, 2014). Nonetheless, taking the appropriate steps to automate the process of gathering the necessary information for building environmental analysis is argued by Biswas *et al.* (2013) to be very crucial. Therefore, design team nowadays needs more data-driven workflows and tools to automate the assessment process and cope with these new challenges.

It has been argued in the previous research that BIM can support design decision-making and sustainability analysis in the very early design stages (Azhar *et al.,* 2011; Jalaei and Jrade, 2015; Ilhan and Yaman, 2016). Numerous BIM-based methods, tools, and frameworks have been developed around the world, though most of the proposed solutions were developed specifically to comply with the requirements of well-known green building rating systems such as LEED and BREEAM (Lim *et al.,* 2016). Therefore, it is necessary to develop a BIM-based method for green building assessment which complies with the standards and regulation of the Malaysian green building industry. Furthermore, there is a lack of data related to the current practice of green building assessment under the Malaysian green building certifications such as GreenRE. It is not clear yet if green building professionals in the Malaysian building industry are aware of the benefits of using BIM technologies to support the assessment of building sustainability during the design process. Thus, an explorative study on how BIM tools and design process can improve the current practice of green building evaluation is needed.

In the era of BIM application for green building evaluation, often the proposed methods and frameworks are further developed as tangible solutions, which include tools and decision support systems (DSS). Technically speaking, the conventional approaches in developing these solutions can be categorized into two categories; the development of plug-ins or tools integrated to the BIM tools which can analyse the compliance of the building design against several sustainability criteria (Ilhan and Yaman, 2016; Jalaei and Jrade, 2015; Jrade and Jalaei, 2013; Kasim, 2015; Wu, 2010). On the other hand, the second category of solutions relies on the usage the built-in functionalities of the BIM software such as Quantity Take-off (QTO) functionality of Autodesk Revit (Wong and Kuan, 2014; Lim *et al.,* 2016). This method is relatively more straightforward compared to the previous method, it requires only knowledge about the usage of the BIM tool and its functionalities, though the automation of data management in this method is relatively low and can be considered as semi-automated.

On the other end of the spectrum, recent research have proven that computational BIM design workflows and tools (e.g. Dynamo) have a high potential in automating data extraction and management as well as supporting building sustainability analysis (Asl *et al.*, 2015; Kensek, 2015). Though, most of the very few proposed BIM-based models and tools for green building evaluation in Malaysia are still based on semi-automated technics for data extraction (i.e. Material Take-off). Therefore it is needed to explore the potential of using visual programming to develop automated assessment workflows for green building evaluation. The following table (Table 1.1) summarises the characteristics of some previous research which have proposed BIM-based tools for green building evaluation.

Table 1.1 Previous studies related to the application of BIM for green building evaluation

GBRS	Author	Categories	Stage	Related BIM tools/functionality /concepts
LEED (USA)	(Barnes and Castro-Lacouture, 2009)	Building Material	Assessment stage	Revit
LEED (USA)	(Wu, 2010)	Building Material	Assessment stage	Revit, Revit API, design assistance, certification management
LEED (USA)	(Azhar *et al.*, 2011)	Energy and Water	Assessment stage	Revit, gbXML, IES-VE
BEAM-plus (Hong-Kong)	(Wong and Kuan, 2014)	Building Material	Assessment stage	Revit, parameters, material take-off, Scheduling
LEED (Canada)	(Jalaei and Jrade, 2015)	Energy and Material	Conceptual design stages	Revit, Revit API, Material Database,
BREEAM (Europe)	(Kasim, 2015)	Holistic	Assessment stage	IFC, Rules, Decision logic, Bentley, Revit
LEED, ASHRAE standards	(Asl *et al.*, 2015)	Energy and daylighting	Assessment/ Design stage	Autodesk Revit, Dynamo
BREEAM (Europe)	(Ilhan and Yaman, 2016)	Building Material	Conceptual design stages	ArchiCAD, Green Material Database, IFC, template

1.3 Research Questions

1. What are the challenges, needs, and gaps in the current practice of green building design under the requirement of GreenRE certification?
2. What are the expectations of building practitioners about the potential of BIM technologies in supporting green building assessment under GreenRE requirement?
3. What are the design variables under each GreenRE requirement and in which level of design process these variables can be managed and extracted from the BIM model?
4. What desirable functionalities that BIM applications can provide to generate GreenRE requested data?
5. How can computational BIM workflows be implemented to automate the assessment of the passive requirements under GreenRE certification?
6. To what extent the proposed Passive Design toolkit is feasible?

1.4 Research Aim

This research aims to develop a BIM-based method to support design decision-making during the evaluation of green buildings under GreenRE tool. This will allow architects and designers to achieve the targeted green building certification goals more efficiently during the design stages.

1.5 Research Objectives

i. To investigate with GreenRE assessors and managers the feasibility of using BIM tools to support the current practice of green building evaluation under GreenRE requirements.
ii. To develop a BIM-GreenRE assessment method based on the integration of GreenRE requirements, Revit functionalities and the required BIM Level of Development (LOD) for data extraction.

iii. To develop a computational BIM-based passive design toolkit (PDT) for the assessment of the passive design prerequisites under GreenRE tools.

iv. To demonstrate the feasibility of the proposed Passive Design Toolkit (PDT) through a case study building.

1.6 Research Design

The overall research design includes two main parts: the first part is designed to explore the current practice of green building assessment and rating under GreenRE rating tools. Hence, it investigates the current challenges, needs, and gaps. Moreover, in this part, the opinion of GreenRE Managers (GM) and GreenRE assessors (GA) about the feasibility of BIM tools integration to the GreenRE requirement is also investigated. The second part consists of proposing BIM-based solutions for the current issues which include the development of a BIM-GreenRE assessment method and a Passive Design Toolkit (PDT) for green building assessment and rating support during the design stage.

A mixed method that includes a web-based survey (quantitative) and Focus Group Discussion (qualitative) was carried out for data collection to answer the question related to first part of this study (the current practice and the feasibility study). However, the BIM-GreenRE assessment method is developed based on the integration of the BIM functionalities (e.g. Material take-off) provided by the BIM tools with GreenRE requirements. This was done after reviewing the relevant literature and guidelines related to GreenRE requirements and the functionalities provided by the BIM software. The Passive Design Toolkit (PDT) is developed using a Visual Programming Language tool called Dynamo. The developed PDT was tested on a case study building, and its output was validated against manual calculations.

The research design is shown in Figure 1.2. The research approach adopted in this study is expected to answer the formulated research questions and achieve the objectives stated in this chapter. The choice to implement such an approach is influenced by the available resources such as time, skills and accessibility to data.

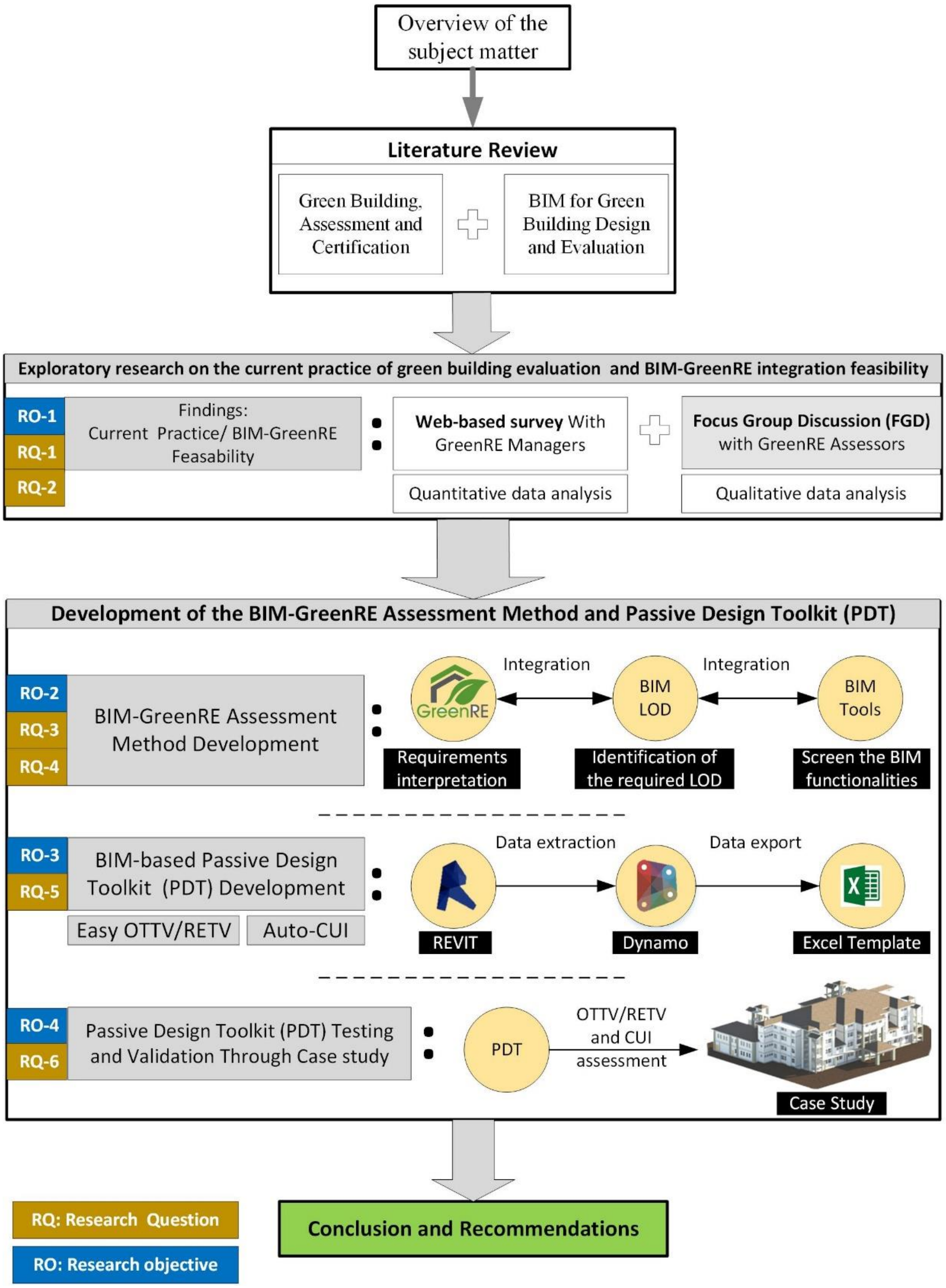

Figure 1.2 Research Design

1.7 Research Motivation

Several aspects and facts are motivating the current research. Firstly, the increasing demand for BIM related research that supports its adoption in the Malaysian construction sector and more especially in the green building industry (Latiffi *et al.*, 2013). Secondly, the fact that the establishment of new building regulations and performance standards by the Malaysian government regarding 2030 Agenda (Prime Minister's Department, 2017), has led to a growing demand for environmentally friendly buildings as well as increasing the complexity in green building design and certification process (Jrade and Jalaei, 2013; Kasim, 2015; Ilhan and Yaman, 2016; Lim et *al.*, 2016). Accordingly, there is a need to develop new workflows and methods to cope with these new arising challenges. Thirdly, the lack of a comprehensive BIM-based assessment method integrated with the available Green Building Rating Systems (GBRS) in Malaysia, although several assessment methods, models, and tools have been developed around the world for other green rating systems such as LEED (US) (Azhar, *et al.*, 2009; Wu, 2010; Azhar *et al.*, 2011), LEED (Canada) (Jrade and Jalaei, 2013), BREEAM (UK) (Kasim, 2015), and BEAM Plus (Wong and Kuan, 2014) to name few.

1.8 Research Scope

This study focuses on GreenRE rating tools for new buildings (residential buildings (RES) and non-residential buildings (NRB)) developed by REHDA. Though, only the criteria included in GreenRE rating tool V3.0 for new residential buildings is used as a case in this study because most of these criteria are shared ones between both rating tools (RES and NRB). Refer to section 2.7 for comparison of RES and RNB criteria.

There are three main reasons for choosing GreenRE rating system in this study. Firstly, based on the previous research (Ilhan and Yaman, 2016; Jalaei and Jrade, 2015; Wong and Kuan, 2014; Wu, 2010), the integration of BIM to GBRSs has always taken only one rating system as a case study. This is because GBRS requirements and certification process differ from one GBRS to another, therefore it is needed to select one specific GBRS to use its assessment framework as a case. Secondly, there is a lack of studies on the integration of GreenRE and BIM; most of the very few proposed models and frameworks in Malaysia focused on Green Building Index (GBI) rating tools as it is the first GBRS introduced in Malaysia (Lim *et al.,* 2016). Thirdly, as discussed in section 2.9 the comparison of the different rating systems available in Malaysia (GreenRE, Green Building Index and MyCREST) revealed that GreenRE rating system allocates more credit points to the criteria related to architectural design compared to other rating system. This is important for this research as it aims to support designer and architect during design decision-making by taking advantage of BIM technologies.

On the other hand, as suggested by GreenRE assessors in the focus group discussion (FGD), working on the passive design requirements (e.g. OTTV/RETV, CUI) under GreenRE criteria is very important and should be taken as a priority. Project teams should think first on the passive design strategies before thinking in the installation of sophisticated active technologies which are often costly and need regular maintenance. In contrast, the right passive design strategy could have a significant impact on building performance, in some cases with no additional costs. Moreover, According GreenRE assessors and mangers, the assessment process of Energy Efficiency (EE) related requirements including OTTV/RETV is among the challenging criteria under GreenRE. In fact, based on the survey findings, most of the project teams are assessing these criteria manually using simple excel template. Thus, data input in this workflow is done manually due to the lack of tools which can extract the required data automatically from the BIM model. Accordingly, due to the importance of working on the passive design criteria and the challenges that project teams are facing during the assessment process, the proposed toolkit will focus only on two passive design criteria under GreenRE tool, mainly the Overall Thermal Transfer Value (OTTV/RETV) and Concrete Usage Index (CUI) criteria. The potential score of these two criteria is up to 15 points and 5 points respectively for OTTV/RETV and CUI.

1.9 Significance of the Study

The contribution of this research can be classified into three outputs: firstly, the investigation of the current practice of green building assessment and rating in the Malaysian context and specifically under GreenRE rating tool will help in understanding the existing challenges, the current way of green building evaluation and to what extent BIM can assist. Secondly, it is expected that the BIM-GreenRE assessment method will contribute to the current body of knowledge of BIM implementation in Malaysia by creating a foundation of tangible application of BIM to support green building assessment and rating under GreenRE rating tool. Finally, the developed Passive Design Toolkit (PDT) can be used by the building practitioners and even the students working under GreenRE certification requirements to assist them in assessing OTTV/RETV and CUI criteria. This is beneficial as the user of the PDT will get simultaneous feedback of the earned/lost credit points while designing. Accordingly, this kind of automation will speed up the design process by allowing designers to avoid assessment rework. Thus, designers will focus more on design ideas instead of benchmarking and chasing credit points.

1.10 Thesis Organisation

The thesis is organised into seven chapters. Chapter 1 is an introduction of the thesis. Chapter 2 and 3 covers respectively the literature review of two main topics: Green building design related issues, the different environmental assessment methods, and rating systems are reviewed and discussed in this chapter. Meanwhile, Chapter 3 discusses the application of BIM for green building evaluation (Green BIM) and the usage of computational BIM and VPL for data extraction and automation.

Chapter 4 discusses the research methodology and justifies the research approach implemented in formulating and answering the research questions, the process of data collection, as well as the workflow implemented in the development of BIM-GreenRE assessment method and the toolkit are also explained.

In Chapter 5 the results related to the current practice under the GreenRE certification and the feasibility of the BIM-GreenRE integration (Web-based survey and Focus Group Discussion FGD) are presented and discussed.

Chapter 6 discusses the development of both the BIM-GreenRE integration assessment method and the Passive Design Toolkit (PDT) as well as the testing of the proposed PDT through a case study. The final chapter 7 concludes the overall research findings and suggests recommendations for future research.

The overall thesis organisation is illustrated in Figure 1.3

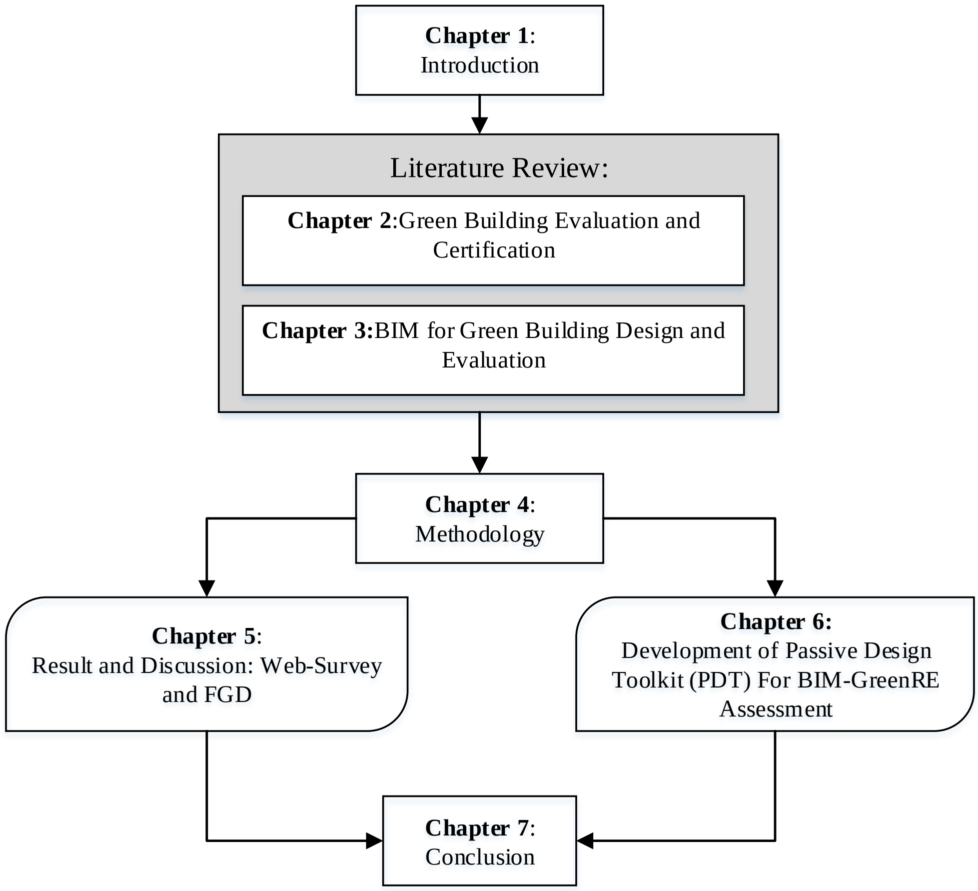

Figure 1.3 Thesis organization

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