OPTIMISING INTENSIVE GREEN ROOF ENVIRONMENTAL PERFORMANCE TOWARDS CARBON SEQUESTRATION RATE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

FEBRUARY 2021

DEDICATION

To my beloved family

ACKNOWLEDGEMENT

Firstly, I am grateful to the mighty God, Allah S.W.T for enabling me the strength and opportunity to complete the whole thesis. There are a few people that I would like to express my appreciation, especially those who had encouraged me to complete my thesis.

I would particularly like to express my special thanks and gratitude to Assoc. Prof. Dr. Mat Naim Abdullah @ Mohd. Asmoni, my main supervisor, and Dr. Nurul Syakima Bt Mohd Yusoff, my co-supervisor for their countless assistance, guidance, and encouragement for me to complete this thesis.

I would like to thank Dr. Low Sheau Ting, the Program Coordinator for her help and support to smoothen the journey.

To all participants in this study, I would like to thank you for your valuable time and assistance. I am sincerely grateful for your time and effort.

My thanks and gratitude are also dedicated to my fellow friends who have been involved directly or indirectly in completing this thesis.

Last but not least, I would like to acknowledge my special thanks to my beloved family, my dear husband, Md Aswai Ismail, my lovely kids, Shaqeer, Raiesya, and Zuhayr, and my beloved mum, Hajah Faizah Mohd Zain for giving me their biggest support, prayers, and understanding throughout this Ph.D. journey.

ABSTRACT

Despite the abundant studies on the environmental performance of green roofs, studies related to carbon sequestration have received less attention from researchers. Previous studies have revealed that carbon sequestration contribution is limited compared to the amount of CO_2 emitted by buildings. Furthermore, no research has been done to investigate the ways to improve carbon sequestration performance through intensive green roofs, which is crucial to offset CO_2 emission. To address this gap, this research was undertaken with four research objectives which are to identify the factors affecting carbon sequestration on intensive green roofs, to investigate the current intensive green roof practice on carbon sequestration performance, to estimate the amount of carbon sequestration on intensive green roofs, and to determine the significant factors for improving carbon sequestration performance on intensive green roofs. The research objectives were achieved through 3 phases. Phase 1 was conducted through an extensive literature review and verification by experts to achieve the first objective. 20 sub-factors affecting carbon sequestration on intensive green roofs were identified and classified into 3 main factors, namely plants, the physical of green roofs, and maintenance. Phase 2 included an investigation involving nine (9) case studies with multisource evidence such as field surveys, semi-structured interviews, document reviews, and observations to achieve the second and third objectives. The investigation disclosed the current practice of intensive green roofs with three different typologies termed as Type A, Type B, and Type C. Based on the ranked factors and the rate of carbon sequestration, Type B is the best for optimising carbon sequestration performance. Overall, the nine case studies contributed to 3,601 tree planting and the average number of trees for each case study was 400 with an average density of 0.126 per tree per square metre of green roofs, while 39% of the tree species were made up of *Syzygium oleina*. Meanwhile, the total estimated amount of carbon sequestration for all case studies is 48,410 kg CO_2 per year with an average of 5378.90 kg CO_2 per year for each case study. Each tree was also estimated to sequester carbon at 11.72 kg CO_2 per year. The estimated amount of carbon sequestration for one square metre of intensive green roof was 1.69 kg CO_2 per year with the highest amount estimated at 7.305 kg CO_2 per year. The final phase of the study achieved the fourth objective by which the data collected from the case studies were analysed using regression analysis. The analysis revealed two significant factors affecting the carbon sequestration performance of intensive green roof which are green area percentage and plant diversity. The findings provided useful guidance to policymakers, designers, facility managers, and building owners to maximise carbon sequestration on intensive green roofs to reduce global warming.

ABSTRAK

Walaupun terdapat banyak kajian berkenaan prestasi alam sekitar bumbung hijau, kajian yang berkaitan dengan penyerapan karbon kurang mendapat perhatian daripada penyelidik. Kajian terdahulu telah menunjukkan bahawa sumbangan penyerapan karbon adalah terhad berbanding dengan jumlah CO_2 yang dihasilkan oleh bangunan. Selain itu, tiada penyelidikan yang dijalankan bagi mengkaji cara meningkatkan prestasi penyerapan karbon oleh bumbung hijau jenis intensif yang sangat penting untuk mengimbangi pelepasan CO_2. Untuk menangani jurang ini, kajian ini dijalankan dengan empat objektif kajian iaitu mengenal pasti faktor-faktor yang mempengaruhi penyerapan karbon di bumbung hijau jenis intensif, untuk mengkaji amalan semasa mengenai prestasi penyerapan karbon, untuk menganggarkan jumlah penyerapan karbon pada bumbung hijau jenis intensif, dan untuk menentukan faktor utama untuk meningkatkan prestasi penyerapan karbon bagi bumbung hijau jenis intensif. Objektif kajian dicapai melalui 3 fasa. Fasa 1 dijalankan menerusi tinjauan literatur dan pengesahan yang mendalam oleh pakar bagi mencapai objektif pertama. 20 sub-faktor yang mempengaruhi penyerapan karbon pada bumbung hijau jenis intensif telah dikenal pasti dan diklasifikasikan kepada 3 faktor utama iaitu tumbuh-tumbuhan, fizikal bumbung hijau dan penyelenggaraan. Fasa 2 meliputi kajian yang melibatkan sembilan (9) kajian kes dengan pelbagai sumber bukti seperti tinjauan lapangan, temu bual separa berstruktur, semakan dokumen dan pemerhatian untuk mencapai objektif kedua dan ketiga. Kajian ini mendedahkan amalan semasa bumbung hijau jenis intensif dengan 3 tipologi berbeza yang dinamakan sebagai Jenis A, B dan C. Berdasarkan faktor-faktor yang disusun dan kadar penyerapan karbon, tipologi Jenis B adalah yang terbaik dalam mengoptimumkan jumlah kadar penyerapan karbon. Secara keseluruhan, sembilan kajian kes menyumbang kepada 3,601 penanaman pokok dan purata bilangan pokok bagi setiap kajian kes adalah 400 dengan purata kepadatan sebanyak 0.126 pokok per meter persegi bumbung hijau, manakala 39% spesis pokok terdiri dari spesis *Syzygium oleina*. Sementara itu, anggaran kadar penyerapan karbon tahunan bagi semua kajian kes adalah 48,410 kg CO_2 setiap tahun dengan purata 5378.90 kg CO_2 setiap tahun bagi setiap kajian kes. Setiap pokok juga dianggarkan menyerapkan karbon pada kadar 11.72 kg CO_2 setiap tahun. Jumlah anggaran penyerapan karbon untuk satu meter persegi bumbung hijau jenis intensif adalah 1.69 kg CO_2 setiap tahun dengan jumlah tertinggi dianggarkan pada 7.305 kg CO_2 setiap tahun. Fasa terakhir kajian mencapai objektif keempat di mana data yang dikumpulkan dari kajian kes dianalisis menggunakan analisis regresi. Analisis menunjukkan dua faktor penting yang mempengaruhi prestasi penyerapan karbon bumbung hijau jenis intensif iaitu peratusan kawasan hijau dan kepelbagaian tumbuh-tumbuhan. Penemuan ini memberikan panduan berguna kepada penggubal dasar, pereka bentuk, pengurus fasiliti dan pemilik bangunan untuk memaksimumkan prestasi penyerapan karbon di bumbung hijau jenis intensif bagi mengurangkan pemanasan global.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

i.e	-	Id est
FM	-	Facility Management
GHGs	-	Greenhouse Gasses
MyCREST	-	Malaysian Carbon Reduction and Environment Sustainability Tool
SFM	-	Sustainable Facilities Management
IFMA	-	International Facility Management Association
LCA	-	Lifecycle Assessment
GST	-	General System Theory
UHI	-	Urban Heat Island
DBH	-	Diameter at Breast Height
CTCC	-	CUFR Tree Carbon Calculator
TGW	-	Total Green Weight
TDW	-	Total Dry Weight
TCW	-	Total Carbon Weight
LAI	-	Leaf Area Index
vs	-	Versus

LIST OF SYMBOLS

CO_2	-	Carbon Dioxide
O_2	-	Oxygen
H_2O	-	Water Vapour
N_2O	-	Nitrous Oxide
CH_4	-	Methane
O_3	-	Ozone
Kg	-	Kilogram
dB	-	Decibel
Hz	-	Hertz
cm	-	Centimetre
m	-	Metre
m^2	-	Square Metre
%	-	Percentage
R^2	-	R-Square

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Facility Management (FM) is a thriving industry in today's built environment. As defined by the International Facility Management Association (IFMA, 2019), FM is "a profession that encompasses multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process, and technology". FM is a key player in the built environment industry. This definition emphasises the role of FM in integrating all aspects within a building's boundary throughout the building life according to the agreed needs. Consequently, FM is a profession that is responsible to manage resources more than other professions. Meanwhile, in managing today's built environment that contributes to the world's use of energy, water, and waste production especially greenhouse gasses (GHGs), sustainability has become one of the key components in FM. Sustainability is an agenda that is familiar in the FM industry for managing all resources efficiently in order to meet the needs within the agreed costs (Hodges and Sekula, 2013). The idea of sustainable facilities is to make the facility long-lasting and perform according to organisational needs and consistent with the organisation's vision, mission, and values as well as improving building performance and minimizing the environmental impacts from the built environment and its operation (Degani and Cardoso, 2010).

The building sector has been identified as a key mitigation strategy for carbon reduction as it emits a significant amount of GHGs. In 2010, 32 percent of global final energy consumption and 19 percent of related carbon emissions reportedly came from the building sector (IPCC, 2014a). According to KKR, CIDB, and JKR (2015), buildings emit up to 80 percent of carbon dioxide (CO_2) during the operational phase, namely the operational carbon. By the year 2030, they aim to reduce the operational carbon at 0% and as such, strategies for carbon emission reduction are crucial. FM plays a key role in strategizing the reduction in a building's operational carbon; thus, all possible strategies should be explored. The strategies for carbon emission reduction frequently involve energy efficiency and reducing energy consumption practices at buildings. Other reduction strategies also include passive design techniques (Bessa & Prado, 2015), renewal energy (Chua, Yang, Er, & Ho, 2014; Mithraratne, 2009), low carbon materials (Cabeza et al., 2013; Ye, 2013; Zhang, Liu, Xiao, & Li, 2011) and building greenery (Marchi et al., 2015; Luo et al., 2015). In strategizing the environmental performance of a building, apart from practicing energy efficiency and consuming less energy, increasing carbon sequestration through greenery elements is also part of the strategy even though it has received less attention. However, based on the systematic literature review on the assessment of building environmental performance by Maslesa, Jensen, and Birkved (2018), none of the previous studies have covered carbon sequestration performance thus far. Indeed, the integration of intensive green roofs helps to counterbalance a building's CO_2 emission mainly during the operational stage of the building.

Green roofs are recognised throughout the world as part of the adaptation and mitigation strategy for climate change (Brudermann and Sangkakool, 2017) and as a solution for space scarcity in urban areas. This remarkable recognition worldwide is a result of green roofs possessing a plethora of proven benefits based on many studies conducted across regions. Green roofs can be categorised into intensive, extensive, and semi-extensive. Intensive green roofs are similar to the old rooftop garden that is intended for human use, which needs more maintenance and deeper substrate. Meanwhile, extensive green roofs are not intended for human use and they require less maintenance is and thin substrate, whereas semi-extensive green roofs are the combination of both (Dunnett and Kingsbury, 2008). The benefits of green roofs cover the economic, environmental, and aesthetic benefits; hence, they provide a potential contribution to the improvement of building environmental performance. Green roofs are among the building green features that can improve building environmental performance (Hong et al., 2012) as they can provide natural ventilation, greenery, and recreational space for high-rise communities (Liyin et al., 2006). However, green roof environmental performance towards eliminating climate change has received less attention since studies have only attempted to convert a wide range of green roof performance into economic values such as energy efficiency performance (Peng and

Jim, 2015). This was supported by Berardi et al. (2014), whose research on green roof environmental performance in local climate mainly focuses on energy-related performance.

Even though many studies on green roofs are well-researched and established especially in some European, American, and Asian countries, it is also important to conduct local research for the extensive success of green roofs (Vijayaraghavan, 2016). In the Malaysian context, based on the literature review, several studies have been conducted on numerous research areas of green roofs and most of the studies have covered issues related to environmental performance. While the global warming issue and the rise of temperature mainly contributed to the research motivation, other topics have also focused on green roof benefits (Wan Ismail and Abdullah, 2016) (Abdul Rahman and Ahmad, 2008), perceptions (Rafida et al., 2015; Wan Ismail, Sh Ahmad, Kamarudin, Ithnin, 2014; Zahir et al., 2014), awareness (Rahman et al., 2013), guidelines (Aziz and Ismail, 2011), obstacles (Ismail et al., 2012), maintenance (Wan Ismail, Muhamad Ariff, et al., 2016), and building assessment (Hussin and Raid, 2013; Fauzi and Malek, 2013).

Since green roof environmental performance has been widely studied and acknowledged, research on carbon sequestration performance, however, is very scarce, especially the studies involving intensive green roofs. As CO_2 is one of the factors that contribute to global warming, research on the potential reduction of CO_2 through carbon sequestration at green roofs should, thus, be stressed. In addition, most of the studies involve extensive types of green roofs and none for intensive green roofs, which provide better potential for environmental performance (Berardi et al., 2014). Hence, the findings from the literature review (Chapter 2 of the thesis) resulted in the establishment of the problem statement and objectives of the current study.

1.2 Problem Statement

The widespread application of intensive green roofs as part of building facilities at high-rise buildings nowadays should be an opportunity to maximise carbon sequestration. Intensive green roofs are an apt strategy for increasing carbon sequestration in urban areas. Besides, plants at intensive green roofs have the ability to sequester CO_2 through its photosynthesis process (Rowe and Getter, 2010). Ideally, the application of intensive green roofs that imitate a natural ground landscape can contribute to the reduction of CO_2 through its natural techniques of carbon sequestration; hence, more intensive green roofs offer more carbon sequestration potential contribution.

However, such potential contribution has been overlooked by researchers since no studies have been done thus far on carbon sequestration performance relative to intensive green roofs. Several studies, nonetheless, have focused on extensive green roofs. For example, in the United States, Getter et al. (2009) quantified carbon storage potential at 12 extensive green roof projects. Based on the study, the findings indicated that the entire extensive green roof system sequestered 375 g Cm^{-2} in above and below-ground biomass and substrate organic matter. This significant finding has proven that green roofs can sequester CO_2 even though the amount of carbon sequestered is small. In Malaysia, a study has been conducted by Ismail, Abdul Samad, Rahman, and Yeok (2012) on the contribution of extensive green roof performance in carbon uptake. The study was conducted through an experimental plot on a roof covered with potted plants known as *Ipomoea pes-caprae* (Figure 1.1).

Figure 1. 1 Ipomoea pes-caprae or beach morning glory (Chen, Foong, Ng, Teo, & Tang, 2003)

Evidently, their research results have shown that the amount of CO_2 uptake for 1 pot of *Ipomoea pes-caprae* was estimated at 48.19 kg CO_2 per year (0.048 tonnes CO_2/year). Considering that the study conducted by Ismail et al. (2012) only employed a small-scale case study filled with limited potted plants, the real scale of green roofs will, therefore, offer a greater potential of carbon sequestration that may contribute to the implementation of intensive green roofs.

Even though the previous studies have shown the potential contribution of green roofs, some studies have also claimed the contribution as a secondary benefit. Peng (2015) contended that the total CO_2 emission over an entire building lifecycle is much greater than carbon sequestration by the vegetation. Meanwhile, research by Whittinghill, Rowe, Schutzki, and Cregg (2014) has compared green roof carbon sequestration with the ground landscape and they found that the ground landscape can sequester carbon greater than the green roofs. Additionally, research by Janner et al. (2018) on optimizing the ecosystem services of green roofs further highlighted that the contribution of carbon sequestration is low due to several limitations that exist for extensive green roofs such as extreme weather conditions.

Based on all of the research findings, carbon sequestration is considered a secondary benefit to the green roofs, which contrasts with the environmental performance of other green roofs. Carbon sequestration performance is not encouraging even though plants are one of the main components of intensive green roofs; hence, it needs to be improved in order for the carbon sequestration performance to make a significant contribution. As highlighted by Vijayaraghavan (2016), research on green roof environmental improvement is crucial as the benefits of an improvement. Nevertheless, there is a lack of studies on how to improve carbon sequestration performance at intensive green roofs, hence the major research gap. Therefore, this study aims to improve carbon sequestration performance at intensive green roofs.

To address the research gap, several studies on improving building environmental performance were reviewed (Kim et al., 2016; Summerbell et al., 2016; Lamnatou and Chemisana, 2015). Findings from the studies highlighted the variables (factors, input, or parameters) affecting building environmental performance and the variables will determine the output of the building performance that is crucial to be identified. In essence, identifying the factors would provide valuable information in optimizing carbon sequestration performance (Othman et al., 2015).

A few studies on green roof carbon sequestration have highlighted the factors affecting carbon sequestration. For example, Getter et al. (2009) highlighted that the amount of carbon sequestration on extensive green roofs depends on the types of plants and substrate in that the plants have a different ability to sequester CO_2 while deeper substrate can sequester more CO_2 than the shallow substrate. Similarly, a study by A. Ismail (2009) found that the plant species and leaf colour are among the important factors of carbon sequestration. As a result of limited data on the factors affecting carbon sequestration at intensive green roofs, research on general tree carbon sequestration was reviewed. Research by Afzal and Akhtar (2013) through a field measurement and linear regression analysis found that the diameter of trees is a significant factor affecting carbon sequestration in addition to the age of trees. Another study by Whittinghill et al. (2014) additionally found that the diversity of species, depth of the substrate, and practical management reportedly affect carbon sequestration. Meanwhile, Karteris, Mallinis, and Tsiros (2016) listed that the vegetation type, CO_2 atmospheric concentration, climatic condition, and management practice are the factors affecting carbon sequestration. All disjointed factors justify the need to conduct a comprehensive study on the factors affecting carbon sequestration. Therefore, the current study is undertaken to identify the factors affecting carbon sequestration at intensive green roofs to improve carbon sequestration performance.

In Malaysia, as defined by JPBD (2012), a green roof is defined as a garden located on the roof including below, on the intermediate floor level, and podium deck of a building. Due to the lack of studies on intensive green roofs, there is no data available that can be referred to, neither from the literature nor the relevant authorities on the intensive green roof practice. Hence, the practice of intensive green roofs in Malaysia remains vague, especially one that involves carbon sequestration performance. As such, the absence of data on green areas, number of trees, tree species, tree height, tree diameter, and many more asserts the need to investigate the current practice on carbon sequestration performance. Apart from that, due to the different green roof designs typology for each building, the design typology that apt for improving the performance of carbon sequestration is also crucial to be investigated. Hence, the data are vital for informing the current practice and its potential for performance improvement.

Additionally, performance assessment is compulsory to improve carbon sequestration performance. The assessment outcomes will enable the researchers to know how the performance can be improved, validate the performance, and recognise underperforming areas (UK Green Building Council, 2016). Thus, the measurement elements must be performed as measurability is the crucial key principle (Douglas, 1996). As mentioned by Hu, O'Donnell, Corry, Turner, and Curry (2016, p. 51), the statement that "one cannot manage what one does not measure" has justified the importance of measurement elements in building performance. The carbon sequestration performance can be assessed by estimating the amount of carbon sequestration at intensive green roofs. Besides, the current carbon sequestration amount can be set as a baseline for the fundamental performance requirements (Misni et al., 2015). Even though the estimation of carbon sequestration has been conducted by Getter et al. (2009) and Ismail (2009), their studies only involve extensive green roofs. Additionally, Rowe (2011) suggested the need for research that quantifies carbon sequestration potential at a more sophisticated roof that consists of different trees and plants. However, there is no data on how much the intensive green roofs can sequester carbon; therefore, the estimated amount of carbon sequestration can be used as a baseline for carbon sequestration performance improvement.

To improve carbon sequestration performance, determining the significant factors is a key strategy. This was supported by Wong and Jim (2015), who highlighted that the key factors could inform the site choice and green roof design in maximising benefits. The different performance of green roofs will be affected by a different set of key factors. For example, a study by Brenneisen (2006) has found that the green roof design should encourage habitats, while the key factors that need to be considered are the substrates, lightweight solutions, species group, and diversity. Meanwhile, Lamnatou and Chemisana (2015) in their study recommended the important parameters to be considered in increasing photovoltaic-green roof performance such as plant species, climatic conditions, evapotranspiration, and albedo; however, the crucial parameter is the plant species. Similarly, Wong and Jim (2015) in their study suggested the best combination for the greatest contribution of green roofs for stormwater retention, such as the rainfall depth, antecedent dry weather period, wind speed, and solar radiation. Briefly, these previous studies have highlighted the significant factors to be considered for improving carbon sequestration performance. In addition, these key factors are an output that can provide feedback to the clients, designers, and facility managers since the decisions made at the early stage of building design can affect the performance. Pertaining to this concern, the researcher ought to take the initiative to determine the significant factors for improving carbon sequestration performance at intensive green roofs.

1.3 Research Questions

This study attempts to answer the following questions:

Q1 – What are the factors affecting carbon sequestration at intensive green roofs?

The answer to this question is needed to identify the factors affecting carbon sequestration at intensive green roofs through literature review and verification from the interview with experts.

Q2 - How far have the current intensive green roofs been built and met the carbon sequestration performance?

The answer to this question is necessary to inform the current practice of intensive green roofs on carbon sequestration performance based on the identified factors involving different types of case studies.

Q3- How much carbon can be sequestered on intensive green roofs?

To answer this question, the carbon sequestration performance will be assessed based on selected case studies. The performance measurement will be conducted to estimate the amount of carbon sequestration and the estimated amount will be set as a baseline for performance improvement.

Q4- What are the significant factors that need to be considered in improving carbon sequestration performance at intensive green roofs?

The answer to this question is required to assist in improving carbon sequestration performance at intensive green roofs by considering the significant factors through factor analysis.

1.4 Research Aim

This study aims to improve carbon sequestration performance at intensive green roofs. By improving the potential of carbon sequestration performance, intensive green roofs can be part of the building greening strategies that can enhance building environmental performance, thereby reducing excessive CO_2 in the atmosphere.

1.41 Research Objectives

Based on the problem statement, the gaps in green roof environmental performance literature, and the research questions derived in this chapter, this study is undertaken with the following research objectives:

(a) To identify the factors affecting carbon sequestration at intensive green roofs.

(b) To investigate the current practice of intensive green roofs towards carbon sequestration performance.

(c) To estimate the amount of carbon sequestration at intensive green roofs.

(d) To determine the significant factors for improving carbon sequestration performance at intensive green roofs.

1.5 Scope of the Study

The current study is focused on intensive green roofs. Due to building load limitations, costs, and maintenance, extensive green roofs are most common around the world compared to intensive green roofs. However, in Malaysia, the intensive green roofs are widely implemented as they duplicate regular gardens on the ground and are part of recreational areas for high-rise residential users. Green roof environmental performance is more promising for intensive green roofs as the deeper substrate provides more benefits for stormwater management and heat reduction whilst increasing biodiversity as well as reducing air pollution and carbon sequestration (Wan Ismail and Abdullah, 2016).

This study utilises intensive green roofs implemented at high-rise residential buildings at Klang Valley as case studies. As identified by Maslesa, Jensen, and Birkved (2018), the most recent study on building environmental performance focuses on residential buildings. Meanwhile, the selection of high-rise residential buildings is based on the study by Rahman et al. (2013), who indicated that most of the buildings implementing green roofs are residential types, which is due to the scarcity of land in the urban area. Therefore, this study will be carried out in the Klang Valley urban area due to the high number of residential buildings implementing intensive green roofs.

The third scope of this study involves the literature and past research on green roofs and carbon sequestration performance. Due to the limited literature on green roof carbon sequestration, it is, therefore, important to obtain the data from the relevant research area. Research on carbon sequestration has been long established in the forestry and plantation industry. Due to the limited research data on urban tree carbon sequestration specifically in a tropical climate, the research data from the forestry and agricultural field from local and non-local studies were included to gain in-depth knowledge pertaining to this body of knowledge. In addition, expert interviews were conducted to verify the collected data in order to achieve the research objectives.

MyCREST Carbon Calculator will be used in this study to estimate the amount of carbon sequestration at the intensive green roofs, considering the unique condition of intensive green roofs with various plant species. As such, the need for robust data to generalise the current amount of carbon sequestration at intensive green roofs makes the use of a carbon calculator in this study the most pertinent.

1.6 Significance of the Study

This research is important and relevant to the theory, practice, and future research as mentioned below:

(a) The identification of factors affecting carbon sequestration at intensive green roofs has filled the knowledge gap that exists in the literature on carbon sequestration and green roofs. The identified factors can contribute to the new knowledge in academia, even though tree carbon sequestration has been specially established in forestry studies. Hence, the current study introduces a new understanding of carbon sequestration concepts and theories including the factors affecting carbon sequestration specifically at intensive green roofs.

(b) The investigation of intensive green roof application relative to carbon sequestration will reveal the current data and performance of green roofs, which is significant to FM in order to inform the potential contribution of intensive green roofs in offsetting CO_2. Apart from that, it can provide feedback to the designers and management on the less successful areas for further performance improvement. Besides, the amount of carbon sequestration is crucial as the baseline for intensive green roof performance strategy and guidance in formulating the policies related to carbon reduction.

(c) The determination of the significant factors affecting carbon sequestration will assist the designers in designing the green roofs that can improve performance since the decision at the design stage will give a significant impact on building environmental performance at the application stage. Consideration of the significant factors will be part of the strategies in CO_2 reduction through carbon sequestration strategy, thus improving environmental building performance and leading to the development of design guidelines.

The current study on carbon sequestration performance has initiated a new research area for FM. The research findings will create an impetus for other researchers to perform similar research besides encouraging more future research on sustainable facility management area, particularly on environmental performance improvement.

1.7 Organisation of Thesis

This thesis comprises 6 chapters. This section provides a brief review of the thesis structure. The arrangement of chapters in this thesis is as follows:

Chapter 2 begins with an introduction to the theoretical foundation of performance improvement, followed by an overview of facilities management, sustainable facilities, environmental performance, and building performance improvement. This chapter further discusses an overview of green roof application, which includes its types and classifications, components, green roof design consideration, and maintenance. This chapter also provides a review of green roof benefits and environmental performance. A brief introduction to climate change, which includes the causes, effects, and mitigation of climate change, greenhouse gasses, and carbon dioxide will also be discussed in this chapter. This chapter further discusses carbon sequestration that comprises its definition and concepts, the method to estimate carbon sequestration, green roof performance on carbon sequestration, and the factors affecting carbon sequestration at intensive green roofs. Finally, a list of factors affecting carbon sequestration at intensive green roofs will be presented. This chapter ends with a summary of 16 factors affecting carbon sequestration at intensive green roofs identified through a literature review and use at a subsequent stage.

The methodology employed in this study is described in Chapter 3, which includes an overview of the research methodology comprising the research strategy and research design. This chapter focuses on the justification of methods and techniques employed involving the selection of case studies, experts, carbon sequestration estimation, data collection techniques, and methods for data analysis.

Chapter 4 discusses the data analysis undertaken in this study, which will be performed based on the data collection phases to achieve the research objectives.

Chapter 5 highlights the results obtained from the analysis in detail and the extent to which the results have achieved the objectives addressed in this study.

Chapter 6 concludes the findings and the overall research works that have been undertaken by the researcher. This chapter provides the contributions and implications of the findings to the body of knowledge and the industry on sustainability facility management as well as building performance improvement. The limitations of the study and further potential for improvement are emphasised in this chapter. The final part of the chapter further highlights some recommendations for further research.

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