APPLICATION OF COCONUT WASTE AS GREEN ROOF MATERIALS FOR STORMWATER RUNOFF CONTROL

NUR ATIQAH BINTI DASRUL

Diploma in Civil Engineering

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NUR ATIQAH BINTI DASRUL

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ABSTRAK

Bumbung hijau semakin popular di seluruh dunia kerana nilai alam sekitar, ekonomi, estetika dan terkenal dengan keupayaannya untuk mengekalkan air hujan dan meningkatkan kualiti air larian. Pembandaran merupakan masalah utama yang menyebabkan pelbagai masalah alam sekitar berlaku terutamanya banjir kilat. Tidak dapat dinafikan bahawa kawasan yang tidak telap akibat pembangunan pesat di bandar telah menyebabkan peningkatan jumlah air larian dalam masa yang singkat dan membawa kepada bencana banjir kilat yang cepat. Memandangkan Malaysia terus berkembang menjadi sebuah negara yang lebih membangun, penebangan hutan demi pembangunan ekonomi dan masa depan adalah tidak dapat dielakkan. Tambahan, penggunaan bumbung hijau di Malaysia adalah terhad, dan literatur mengenai hal ini adalah sedikit. Aplikasi penerapan bumbung hijau telah diiktiraf sebagai teknologi baru untuk mengurangkan masalah utama dan ditubuhkan tujuannya untuk menguruskan air ribut dengan menahan serta melambatkan perkembangan air larian. Satu ujikaji telah dibuat untuk menilai prestasi hidrologi bumbung hijau dalam meningkatkan prestasi kuantiti air larian. Satu eksperimen menggunakan simulasi air hujan dengan model prototaip berskala makmal untuk menganalisis prestasi hidrologi bumbung hijau dalam menambah baik larian air larian. Sebanyak 3 model telah dibina yang terdiri daripada model bumbung biasa (model kawalan), model sisa kitar semula, dan model komersial. Model kitar semula dibina menggunakan bahan buangan dan mengandungi 5 lapisan iaitu lapisan tumbuh-tumbuhan, tanah terbakar (lapisan substrat), sabut kelapa (lapisan penapis), tempurung kelapa yang dibakar (lapisan saliran) dan bitumen (lapisan kalis air). Komponen model dibahagikan kepada dua bahagian; bumbung dan badan. Dimensi badan ialah 0.6m x 0.6m x 0.45m. Berdasarkan penemuan, peratusan pengurangan aliran puncak bagi model kitar semula dan model komersial masing-masing adalah antara 38% hingga 46% dan 19% hingga 31%. Selain itu, bumbung hijau kitar semula dengan penggunaan sisa kelapa sebagai bahan utama terbukti menunjukkan prestasi yang lebih baik dalam mengurangkan larian air ribut iaitu 7×10 -5 m^3/s berbanding bumbung hijau komersial iaitu 9×10 -5 m^3. /s untuk keamatan hujan 0.15 mm/min. Di samping itu, penemuan menunjukkan bahawa larian air ribut meningkat, keupayaan lebih lebat hujan, lebih rendah keupayaan bumbung hijau untuk mengurangkan jumlah aliran puncak.

ABSTRACT

Green roofs are growing more popular across the world due to their environmental, economic, aesthetical value and well-known for their ability to retain rainwater and improve runoff quality. Urbanization is a major problem that causes various environmental problems, especially urban flash floods. There is no denying the fact that impervious areas due to rapid development in cities have caused an increasing volume of stormwater runoff in a short amount of time and led to disastrous urban flash floods. As Malaysia continues to evolve into a more developing country, it is inevitable to undertake deforestation for the sake of economic and future development. Thus, the use of green roofs in Malaysia is limited, and literature on the subject is few. The application of green roof practices has been recognized as a newfound technology to mitigate the leading problem and is established for its purposes to manage stormwater by retaining rainwater and delaying the progression of runoff. An attempt has been made to assess the hydrological performance of green roofs in improving the water quantity of stormwater runoff. An experiment using a rainfall stimulator with a lab-scale prototype in order to analyze the hydrological performance of a green roof in improving stormwater runoff. A total of three models were built which consist of a non-vegetated model (control model), a recycled waste model, and a commercial model. The recycled green roof model was constructed using waste materials and contained five layers which are the vegetation layer, burnt soil (substrate layer), coconut fibre (filter layer), burnt- coconut shell (drainage layer) and bitumen sealant (waterproofing layer). The components of the model are divided into two parts; roof and body. The dimension of the body is 0.6m x 0.6m x 0.45m. Based on the findings, the percentage of peak flow reduction for recycled green roof and commercial green roof is between 38% to 46% and 19% to 31% respectively. Besides, the recycled green roof with the application of coconut waste as green roof material proved to show a better performance in decreasing stormwater runoff which is 7×10^{-5} m^3/s compared to the commercial green roof which is 9×10^{-5} m^3/s for a 0.15 mm/min rainfall intensity. In addition, the discovery shows that the stormwater runoff increases, the capability heavier the rainfall, the lesser the capability of green roof to reduce peak flow volume.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
m^3/s	Meter cube per second
m/s	Meter per second
L/m^2	Litre per metre square
cm^3/min	Centimetre cube per minute
mm/min	Millimetre per minute
mm/hr	Millimetre per hour
km^2	Kilometre square
pH	Power of hydrogen
min	Minute
m	Metre
cm	Centimetre
mm	Millimetre
°C	Celcius

LIST OF ABBREVIATIONS

UHI	Urban Heat Island
UMP	Universiti Malaysia Pahang
GTMP	Green Technology Master Plan
SDG	Sustainable Development Goals
NGTP	National Green Technology Policy
UK	United Kingdom
CAM	Crassulacean acid metabolism
PET	Polyethylene terephthalate
MATLAB	Matrix Laboratory
EPDM	Elastomeric Membrane

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Urbanization is a worldwide trend, with an increasing amount of world’s population currently living in cities. The urbanization process is an anthropic action that generates major environmental impacts, basically due to the consequences resulting from changes in the original characteristics of land use. Cities are expanding to accommodate an increase in rural migration to urban regions (Cascone, 2019). The creation of impenetrable areas in place of forests, meadows, and croplands such as buildings and roadways greatly increases stormwater runoff and impervious areas. As a result, less water can permeate the soil, increasing the frequency and severity of floods in urban areas (Hashemi et al., 2015). Besides, another environmental problem that is connected to excessively impervious surfaces is Urban Heat Island (UHI) which impacts the amount of temperature change and water balance due to unplanned urbanization. Therefore, this issue is worth discussing given the fact that nowadays, in emerging countries such as Malaysia, more natural resources would unavoidably be sacrificed for development and commercial purpose.

In Malaysia, approximately 29,800 km^2 or 9% of the total area of Malaysia is estimated to be vulnerable to flood disaster area and affects roughly 22% of the total Malaysian population (DID, 2009). A study by Kong et al. (2010), among the main causes and factors of flooding, is due to improper drainage systems, dam breaking, and improper management of the environment. Although avoiding natural disasters seems impossible, finding ways to mitigate and adapt to natural disasters might help reduce the risk and rate of a disaster. Hence, one of the innovative measures in mitigating flash floods includes implementing green roofs. The green roof system is one of the stormwater management strategies used today to regulate stormwater runoff. The idea of a green roof has been widely used around the world, regardless of climate or cultural context. Due to the idea's ability to reduce the effects of an increase in impervious surface, including reducing the urban heat island and retaining runoff in urban areas, green roof systems are generating a lot of attention.

Green roof technology can help to reduce the related hydrological problems due to hydrologic cycle change. It can retain the runoff for a longer period of time than a common roof (Shafique et al., 2018). It can delay peak discharge time and can also extenuate peak discharge volume. Due to the sorption of water in the green roof, part of the rainfall does not run off immediately, so the time required for complete runoff is extended by the relatively slow release of the additional water from the substrate layer. Green roofs may also reduce the pollution of urban rainwater runoff and contribute towards water quality improvement by absorbing and filtering pollutants, as the roof is covered with substrate and vegetation (Liu et al., 2019). In addition, green roofs are an impressive remedy for the heat island effect due to their use of watered vegetation. Green roofs or living roofs provide sanctuaries for animals, prevent noise pollution, and can be used as part of a plan to decrease traffic noise (Hashemi et al., 2015).

As stated by Asman et al. (2017) the standard approach to stormwater management, such as installing concrete drains in newly developed areas cannot fulfil the expectations for regulating runoff water quantity and quality. As a result, a green roof is a sustainable option. Green roof applications are common in other industrialized nations. However, in Malaysia, green roofs are a relatively new idea with limited applicability because only a few green buildings in Malaysia have built in recent years, yet the idea of green buildings for the general masses is in the outset stage. Hence, conducting a study on green roofs is essential to evaluate their potential for Malaysia’s implementation and to test the capability of green roof and their efficiency in reducing the peak runoff of stormwater.

1.2 Problem statement

Increased impermeable areas caused by rapid urbanization have made drainage systems ineffective for handling peak runoff volumes in a short amount of time. As a result, during heavy rainfall, the continuous runoff would lead to increased flow downstream, making the sewage and domestic waste overflow. Due to increased stormwater runoff and increased impenetrable area, less water can be absorbed into the soil, and the frequency and severity of flooding in urban regions increase. These phenomena have raised much concern and many researchers agree that one of the major issues in urbanization is the increase in stormwater runoff volume and the degradation of water quality caused by a land surface change (Rahmah & Ayub, 2020). Therefore, in highly populated metropolitan areas, where it is necessary to retrofit existing structures, the use of a green roof system may be the best way to control stormwater(Locatelli et al., 2014). Green roofs are able to reduce the generation of runoff from the resumption of hydrological cycle processes (plant interception, evapotranspiration, infiltration, and eventually substrate retention). By delaying or retaining stormwater runoff, green roofs reduce the danger of floods and are viewed as a key tool in the prevention and management of stormwater runoff (Silva et al., 2019).

However, a study conducted by Ismail et al. (2018) states that green roof implementation in Malaysia is still low. This is because of lack of green roof knowledge, maintenance knowledge, limited local expertise, lack of scientific research on green roof and absent of guidelines and standards for green roof. Green roofs are regarded relatively new in Malaysia, despite the numerous benefits they provide. The use of green roofs is limited since only a few buildings in Malaysia use green roof construction on structures. There are several successful green roof systems applied in Malaysian buildings such as Putrajaya International Convention Centre, Sime Darby Oasis, Kl Sentral Park @ Platinum, and many more (Siew et al., 2019). Thus, it is an urge to study the performance of green roofs as a stormwater management alternative for environmental sustainability. Therefore, in order to create our green roof guidelines in Malaysia, a comprehensive study on the design and performance of a green roof system must be conducted with the goal of examining the potential of green roofs.

1.3 Objective

The main aim of this study is to evaluate the performance of green roofs during different storm events and their potential for surface runoff attenuation. The key objectives of this study are as follows:

i. To construct a lab-scale prototype model in terms of vegetation used, materials for each layer and dimension of the system.
ii. To assess the hydrological performance of green roofs in terms of peak flow reduction.

1.4 Scope of study

The scope of this study is solely focusing to evaluate green roof in terms of its hydrological performance namely the improvement in stormwater discharge and peak flow reduction. Beyond the purview of this investigation, rainfall/runoff retention determination is not possible and is outside the scope of this research. The hydrological parameters were obtained by testing the performance of three lab-scale prototype green roof models, which are non-vegetated roof model (control), recycled waste green roof and commercial green roof. The experiment was carried out in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering Technology, Universiti Malaysia Pahang (UMP), Gambang. The experiment is based on a lab-scale setup and rain simulation is employed using the real rainwater.

1.5 Significant of Study

To aid in the management of stormwater, particularly for runoff control, the study of green roofs is essential. Green roofs in Malaysia are considered as a fairly new although lots of benefits are offered. Therefore, it is also meant to promote the adoption of green roofing systems in Malaysia which is to identify how green roof act as a strategy to manage stormwater runoff. In light of this, the study highlighting the effectiveness of recycled waste material for green roof systems is convincing to deal with peak flow stormwater.

Recently, environmental sustainability has become a global concern. The usage of waste resources is critical to ensuring environmental sustainability (Shahid et al., 2016). Therefore, using coconut waste as green roof material help to reduce waste materials arising in the landfill area, improve the quality of the urban environment and contribute towards Sustainable Development Goals (SDG) 11 which is supporting sustainable cities and communities. Moreover, with regard to this study, The Green Technology Master Plan (GTMP) which is a direct result of the Eleventh Malaysia Plan (2016-2020), can be profited to establish a framework to assist the incorporation of green technology into Malaysia's planned developments while taking into account the four pillars outlined in the National Green Technology Policy (NGTP). The GTMP focuses on six important sectors: energy, manufacturing, transportation, building, waste, and water.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of study

The urbanisation process increases the accumulation of pollutants in the catchment surface area, deteriorating water quality. This is due to the fact as the presence of rainproof areas such as roads, driveways, rooftops, which lead to constantly rise in flow downstream thus reducing the amount of water from flowing into subgrade. This change of land surface is gradually replacing green spaces in cities, resulting in increased precipitation flow and less water absorbed into the soil, resulting in flash floods. Furthermore, it is well recognized that many new development areas are built in the higher or upstream portions of major cities, limiting the present drainage systems' ability to convey huge quantities of stormwater runoff from such locations during rainy events. As a result, during a severe rainfall event, the accumulation of precipitation on the catchment surface grows fast, resulting in an urban flash flood.

Graceson et al. (2013) state that green roofs can contribute to minimizing flood risk by being a part of the drainage and irrigation management system. Besides, the restoration of green landscapes in urban areas via a system of green roofs can assist to mitigate many of the negative effects of urbanization without significantly altering the current infrastructure. Commonly known as eco-roofs, roof gardens, and living roofs, the green roof’s essential components are composed of a substrate layer, plant layer, drainage layer, filter layer, and waterproofing layer. These layers work together to enhance the amount and quality of stormwater runoff.

Nevertheless, green roof techniques are still insufficient despite Malaysia's high risk of experiencing flash floods and major floods. This is because since only a small number of structures in Malaysia use green roof development, the concept might be seen as novel and have limited application. This chapter introduces the idea and earlier works on the use of green roofs from past researchers with the intention of examining the potential of green roofs in improving water quantity. This section also emphasizes the explanation of the design of the green roof, including the choice of a prospective plant for the vegetation layer and the identification of materials for each additional green roof layer. As stated by (Kok et al., 2016), a good knowledge of engineering is essential in designing a green roof since all the critical aspects of the design must be included such as the plant selection, environment at the region and the weight of the system itself.

2.2 Modern Green Roof Technology Application

Existing research demonstrates that passive cooling techniques such as covering a structure's rooftop with soil, moistening the soil, and shadowing the wet soil's surface have been employed for ages in many nations, with confirmed benefits in a variety of climatic situations and building types (Cascone, 2019). In early age, The Hanging Gardens of Babylon were built in the fifth century and are acknowledged as the first instances of greenery systems, making them one of the most renowned ancient green roofs. In the ziggurats of ancient Mesopotamia, living roofs were also used. Moreover, Roman and Greek architecture used similar methods during their respective times, much like Babylon. Different plants, especially vines, were used in the Mediterranean area to shield the building exterior from the summer sun and to make the interior of a building colder and more pleasant for its inhabitants. However, nowadays green roof application is seen more in developed countries such as Germany, Japan, Singapore, etc. Green roofs gained popularity also in Austria, Switzerland and United Kingdom (UK) in the same years, however, Germany is regarded the world leader in the employment of this strategy, because green roofs on the large scale were being developed, designed and implemented(Manso & Castro-Gomes, 2015).

2.3 Benefits of Green Roof

Green roofs are a solution to increase the sustainability and energy conservation of buildings, but they produce several other benefits to urban areas in terms of social, economic, and environmental advantages. Some of these advantages can be seen in the following ways: lowering greenhouse gas emissions and the urban heat island effect; preventing acid rain by raising pH levels and enhancing air quality by increasing oxygen production and carbon dioxide sequestration. Other benefits of green roofs are the enhancement of aesthetic value in urban environments and the improvement of the life quality of dwellers by creating recreational activities (Cascone, 2019).

Green roofs are well-known for their ability to regulate stormwater by absorbing rainfall and retaining runoff. Retention refers to the ability of a green roof to store water or rainfall that is held inside the roof system rather than departing as runoff. Water is maintained in the system by plant, substrate, and layered materials, allowing stormwater to be managed by providing runoff retention capacity (Kasmin et al., 2016). Contrarily, detention, on the other hand, is the time lag between precipitation that is not held, impacting the roof, and exiting as runoff (Stovin et al., 2015).

Several studies stressed the advantages of urban hydrology and stormwater management, focusing on the ability of green roofs to minimize the risks of flooding by reducing water runoff while improving its quality (Gregoire & Clausen, 2011). As a result of this improvement, due to the absorption of rainfall in the soil, the burden on water treatment facilities is reduced. Green roofs can also reduce sound exposure near or inside a building by mitigating diffracting sound waves over (parts of) roofs and by reducing sound transmission through the roof system (Van Renterghem & Botteldooren, 2011). Commonly used porous growing substrates were shown to have good sound-absorbing properties when dry (Fabiani et al., 2018).

2.4 Green Roof Design and Components

There are two types of green roofs mainly extensive and intensive green roof. Intensive green roofs are often roof gardens with a significant substrate depth more than 15-20 cm, a large range of plants (comparable to ground-level landscapes), high water retention capacity, high capital expenses, and heavyweight construction. On the other hand, extensive green roofs have a shorter depth of substrate layer (less than 15cm) and weigh less than intense green roofs. Because of the thin base layer, extended roofs can only use a few species of plants, such as grasses, mosses, and a few succulents (Cascone, 2019). However, because of its low weight, lack of need for irrigation, and lower capital and maintenance expenses, extended roofs are the most frequent form across the world. The key advantages of extensive roofing systems over intensive roofs are the lower capital cost, maintenance, and water needs. These roofs are typically lightweight and functional, particularly when no further structural support is required (Cascone, 2019).

As a developing country, there is a lot of potentials to incorporate green roofs either in newly constructed or existing buildings. Therefore, there are a few characteristics in designing a green roof that needs to be considered to guarantee a properly functional green roof puts forth its optimum performance. Figure 2.1 shows the cross-section of a green roof broken down by layer. The plant, growth medium, filter sheet, drainage layer, and waterproofing layer are the key components of the green roof (Cascone, 2019). In addition, various components like thermal insulation, irrigation, and leak detection systems may be incorporated into the green roof layers based on the budget cost.

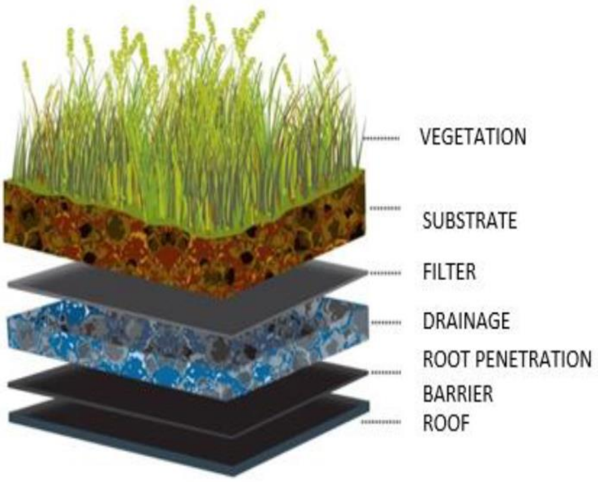


Figure 2.1 Component in extensive green roof system
Source: Siew et al. (2019)

2.4.1 Vegetation

The health of the plants is largely responsible for a green roof's performance, particularly in terms of living up to long-term client expectations. Since plants improve both the quality of the water and air as well as thermal performance, the advantages mostly rely on the plant type. Additionally, the flora gives the green roof its distinctive aesthetic, reduces substrate erosion, and offers protection to a variety of animal species, including arthropods and birds. Climate factors including rainfall frequency, humidity, wind speed, and sun radiation should be taken into account while choosing vegetation. The plant species that can be installed are also impacted by the substrate combination, particularly in terms of pH, salinity, and nutrients. Therefore, it is important to choose vegetation that suits the growth media (Cascone, 2019).

Plants with strong ground covering, short and soft roots, phytoremediation, the capacity to live in adverse climate conditions and with few nutrients, low care, and rapid development are advantageous for extensive green roofs. Even if it is challenging to discover plant species with all of these essential traits, there has been a significant improvement in the selection of appropriate vegetation. Succulent plants have been selected by several researchers as the species with the best performance for extensive green roofs. Sedum species are the most frequent among them because of their ability to limit transpiration and store extra water in leaves, allowing them to resist dry conditions. Furthermore, sedum species have crassulacean acid metabolism (CAM), which increases water-use efficiency by allowing stomatal opening and storage at night, when evaporation rates are lower than during the day. Sedum species, on the other hand, are unable to use more water (Dunnett et al., 2008).

Table 2.1 shows findings by some researchers related to the characteristics of extensive green roof vegetation used towards water retention capacity. It should be noted that the diversity of plant species employed can impact runoff amount and have different evapotranspiration rates.

Table 2.1 Type of vegetation for green roof

Author	**Vegetation Used**	**Advantages**	**Main Findings**
Silva et al. (2019)	Bromeliad (Neoregelia Cruenta)	Not requiring high frequencies of irrigation and low maintenance. It can also resist intense solar radiation	The green roof has a retention value of 70% and 80% at rainfall intensities of 110 mm/hr and 150

			mm/hr.
Liu et al. (2019)	Radix Ophiopogonis Sedum Spectabile	Grows quickly and requires little upkeep. Sedum is capable of storing water and extending its roots	The Sedum Spectabile (31.3%) is outperformed in terms of water retention by the Radix Ophiopogonis (21.0%).
Krishnan & Ahmad (2014)	Polypodiaceae (Fern) Poaceae (Grass) Zingiberaceae (Herb) Crassulaceae (Succulent)	Ferns are fast-growing plants with extensive roots that have a pinnate structure to their linear leaves. Grass develops as a spreading stalk and has lanceolate leaves. Herbs have thick, wide, dense leaves that extend into the bulb and are low-growing. Succulent has a thick rosette of ovate-shaped leaves and have strong tolerance for dryness	Herbs, Sedum, and grass were the next most successful types as they managed to minimize runoff from 299.2 mm of rainfall depth by 55%, followed by succulents (49%) and grass (42%)
Kok et al. (2016)	Zoysia japonica (Japan Grass)	Ensure ground cover and root expansion	The percentage of peak flow reduction is 24.4%, 40.7% and 47.3% for 146.6 mm/hr, 86mm/hr, and 49.9mm/hr of rainfall intensity respectively.

2.4.2 Substrate Layer

Growth medium or substrate layer is normally projected to incorporate nutrients to encourage vegetative development. Therefore, it is crucial that the substrate supply nutrients to the green roof. The ability to sustain the physical, chemical, and biological conditions necessary for the proper vegetative development is known as agronomic capacity, and it is controlled by the substrate. This provides establishment and stability, which is vital for plant growth. Runoff quality varies depending on the type of substrate, the depth of the substrate, the vegetation, the age of the green roof, fertilization and maintenance procedures, as well as the physical and chemical characteristics of pollutants (Gregoire & Clausen, 2011). According to Schultz et al.

(2018), vegetative roofs with a thickness of 125 mm and 75 mm retained 32.9% and 23.2%, respectively, of all precipitation by volume. Therefore, it is important to determine a suitable depth of substrate layer that could sustain the required biological, chemical, and physical conditions. Moreover, physical variables such as density, particle size, water permeability, maximum water volume, and maximum air volume under saturated conditions need to be taken into account.

2.4.3 Filter Layer

The geotextile layer is a filtering material that separates the vegetation and substrate layers from the draining layer. This layer was installed for the purpose of protecting both the drainage layer and the drains (Silva et al., 2019). The primary function of this layer is to keep smaller particles (such as fine soils and plant debris) from getting into the drainage layer and clogging it, which would eventually lower the drainage layer's performance. This layer, once penetrated, may encourage the growth of plants inside the drainage layer or clog the drains, leading to infiltrations and stopping the entire greening system.

The filter layer should allow the permeability of water through it. Therefore, small pores should be included in the filter layer to enable high water permeability at least ten times greater than that of the substrate. As per ASTM D4751, the filter material should have an opening size of ≥ 0.06mm ≤ 0.2mm. Geotextile materials are often utilized for the filter layer. According to Cascone, (2019), non-woven geotextiles with water permeability greater than 0.3×10^{-3} m/s, are able to absorb 1.5 L/m^2 of water.

2.4.4 Drainage Layer

For a green roof to flourish properly, the drainage layer is essential. The objective of a drainage layer is to obtain an optimal balance between air and water in the green roof system. Accordingly, the drainage layer must be able to retain water when it rains, ensuring good drainage and aeration of the substrate and roots (Pérez et al., 2012). As most plant requires a ventilated and non-waterlogged substrate, this layer tries to drain excess water from the substrate, allowing for an appropriate balance of air and water and enough ventilation for the roots. In addition, by removing excess water, the strain on the building structure is reduced, as are the chances of mechanical failure. Furthermore, the drainage layer defends the waterproof membrane and enhances thermal performance. As a result, the potential to block tiny particles without compromising permeability is an important attribute to monitor.

A thick drainage layer can cause the soil to dry at the bottom meanwhile a green roof without a drainage layer may cause water logging due to lack of aeration. Therefore, the drainage layer's determination must be able to hold water when it rains for that reason. According to Cascone, (2019), the selection of a suitable drainage layer varies greatly according to the rainfall characteristics of the site, construction needs, structural requirements, costs, green roof size, roof slope, quantity and flow of discharges, and plant species. Moreover, the choice of the drainage layer depends on the hydraulic flow and the vertical load, since, during the operative phase, there is either a compaction (for granular materials) or a deformation (for plastic materials).

The volume of recycled products has increased. Many studies are already using recovered waste materials as drainage layers. This is owing to the high amount of garbage generated by companies. One of the biggest issues facing the companies involved in this sector is finding alternate applications for these materials in the building industry. Therefore, to look for other alternatives, past researchers have been recycling and reusing them. It is usually preferable to use locally available waste materials as doing so can make the creation of a green roof less expensive. Tires and rubber crumbs are classic example. Rubber crumbs as a drainage layer have a wide range of effects. The study discovered that because the rubber crumbs have a lower bulk density, the material's green roof has a somewhat superior drain capacity (Asman et al., 2017). Besides, a study by Nagase, (2020) has shown that reused materials (cocopeat, PET bottle, and bamboo) were observed to function well as commercial green roof materials.

2.4.5 Waterproofing Layer

A waterproofing layer or membrane is also indeed a critical component of green roof. It shields the building from any infiltration brought on by the high-water content of the top layers and protects the green roof body from the roots, but in turn, the vegetative roof protects it from temperature changes and sun radiation, which can cause the membrane's function to degrade quickly(Cascone, 2019). The key criterion for this layer is watertightness. Additionally, it should also be noted that keeping this layer takes a great deal of complexity because all the layers must be removed if a leak occurs in a green roof system. Therefore, it is essential to plan ahead for ways to stop horizontal water flow below the membrane, to slow down deterioration, and to enable the discovery of any infiltration locations. These outcomes may be attained either through the waterproof membrane's flawless attachment to the bearing structure or by compartmented membrane sectors. Moreover, other characteristics of the waterproofing layer must be controlled are dimensional stability, cold flexibility, resistance to static loads (to ensure that the membrane can withstand both intentional and unintentional loads), and artificial aging (through long-term exposure to high temperatures). Bituminous membranes can be installed in a single layer or two layers. Typically, thicknesses of 3 or 4 mm are utilized.

2.5 The application of Recycled Waste for Green Roof Materials

Environmental sustainability is a global issue recently. Nonetheless, despite the rising amount of waste, the use of recycled waste for green roof material has been adopted globally by many researchers in order to develop a new, alternative profound approach to green roof systems without relying on commercial materials. The application of recycled waste for green roof material has been taken as an opportunity to reduce the everyday wastes produced by the community by developing sustainable and inexpensive green roof. There are plenty of reused materials that can be potentially used as green roof components, therefore, further studies are required to show the performance of these materials in different countries and regions (Asman et al.,2017). Table 2.2 shows the related recycled waste material for green roof that has been adopted by some researchers.

Table 2.2 Lists the recycled waste materials for green roofs that have been used by various studies

Author	Recycled Material Used	Main Findings
Bisceglie et al. (2014)	Waste of granular Autoclaved Aerated Concrete	The demand for high water retention capacity was completely satisfied by the value of 222.62% of the mass of water absorbed relative to the mass of the dry sample.
Asman et al. (2017)	Rubber crumbs, palm oil shell, and polyfoam	Rubber crumbs have the lowest peak flow in all experiments data with the different slope in the range 17.67 to 26.00 cm^3/min followed by polyfoam and palm oil shells. Rubber crumbs are also suitable as a drainage layer and a proposed slope of 6% are suitable for lightweight green roofs
Nagase (2020)	Cocopeat, PET bottle, and bamboo	PET bottle caps and bamboo nodes, showed higher final plant coverage than commercial drainage layers in cocopeat
Shahid et al. (2016)	Palm oil clinker	By installing the green roofs in experimental cubicles, it can contribute to the reduction of indoor air temperature in the range of 1°C to 6°C

2.6 Hydrological Performance of Green Roof in Improving Stormwater Management

Numerous investigations and studies carried out worldwide have demonstrated that installing a green roof can reduce peak discharge and thermal reduction. Green roofs reduce run-off by delaying the initial time of run-off due to the absorption of water in the green roof, reducing the total run-off by retaining part of the rainfall, and spreading the residual run-off over a long time period through a relatively slow release of the excess water that is stored in the substrate layer (Kok et al., 2016).

Compared to a normal roof, a green roof system performs differently hydrologically. A study was carried out by Kok et al. (2016) to evaluate the hydrological (quantity and quality) and thermal performance of a substantial green roof system at HTC, Malaysia. The results demonstrate that in the tropical environment in the area, extensive green roof systems function favourably. When compared to a concrete tile roof, the large green roof system shown in this study lowers the peak discharge by up to 26% for actual storms and up to 47% for design storms. The stormwater modelling program (XP-SWMM) was utilized in the experiment to generate a stimulated green roof hydrograph. By comparing the simulated green roof hydrograph with the stimulated conventional roof hydrograph, the decrease in peak flow was estimated.

Meanwhile, Shafique et al. (2018) conducted an experiment to test the efficacy of a green roof system in stormwater management South Korea. They conducted the experiment with several storm occurrences that demonstrated the impact on water retention and the result shows that discharge water runoff was reduced by 10% to 60% when compared to real rainfall, resulting in less stormwater entering the sewage system during various storm events. The equipment used in this study is Ultrasonic open channel flow meters and OTT Orpheus small water level loggers to measure the water discharges.

Moreover, Kasmin et al. (2016) in their study reported that a similarly configured green roof in a Malaysian climate could reduce run-off by 84% on a per-event basis and achieve a 51% overall volumetric retention. The main hydrological mechanisms in green coverings during a rain event are the interception and retention of rain by vegetation, infiltration, and retention in the substrate and storage in the drainage layer. The experiment is based on the conceptual water balance-based retention model and the estimation on the runoff values has been determined using two input data; the daily rainfall time-series and the monthly PET rates. The rainfall data was read with the help of MATLAB software.

A study by Silva et al. (2019) conduct an experiment to assess the efficiency of using a green roofing technique to reduce the peak flow and the retention capacity in heavy rains circumstances. They investigated the retention capacity of green roofs using an experimental green roof prototype and simulated rainfall while the data collection is done using a Pluviometer. Bromeliad was employed as the vegetative layer, a substrate mix of peat, sand, pine bark, and charcoal, a geotextile filter layer, an expanded clay drainage layer, and a waterproofing mass made up of cement, sand, and Vedacit for the waterproofing layer. The result demonstrates an exceptional efficiency of green roof performance, with the green roof retaining 70% to 80% of rainfall intensities of 110 mm/hr and 150 mm/hr.

2.7 Summary

In short, there are a few considerations that need to be focused on in designing a green roof system. First of all, the maximum overall thickness of an extensive green roof is 200 mm. The characteristics of each layer come next. The material used is used must be able to function in accordance with the layer as the success of the green roof system and an efficient water flow through will result from the choice of a suitable material and layer thickness. Finally, it can be said that recycled waste materials have a lot of promise for use as green roof materials in addition to regular commercial materials. Based on previous studies could confirm that the use of recycled waste material produces a better result and is on par with commercial ones.

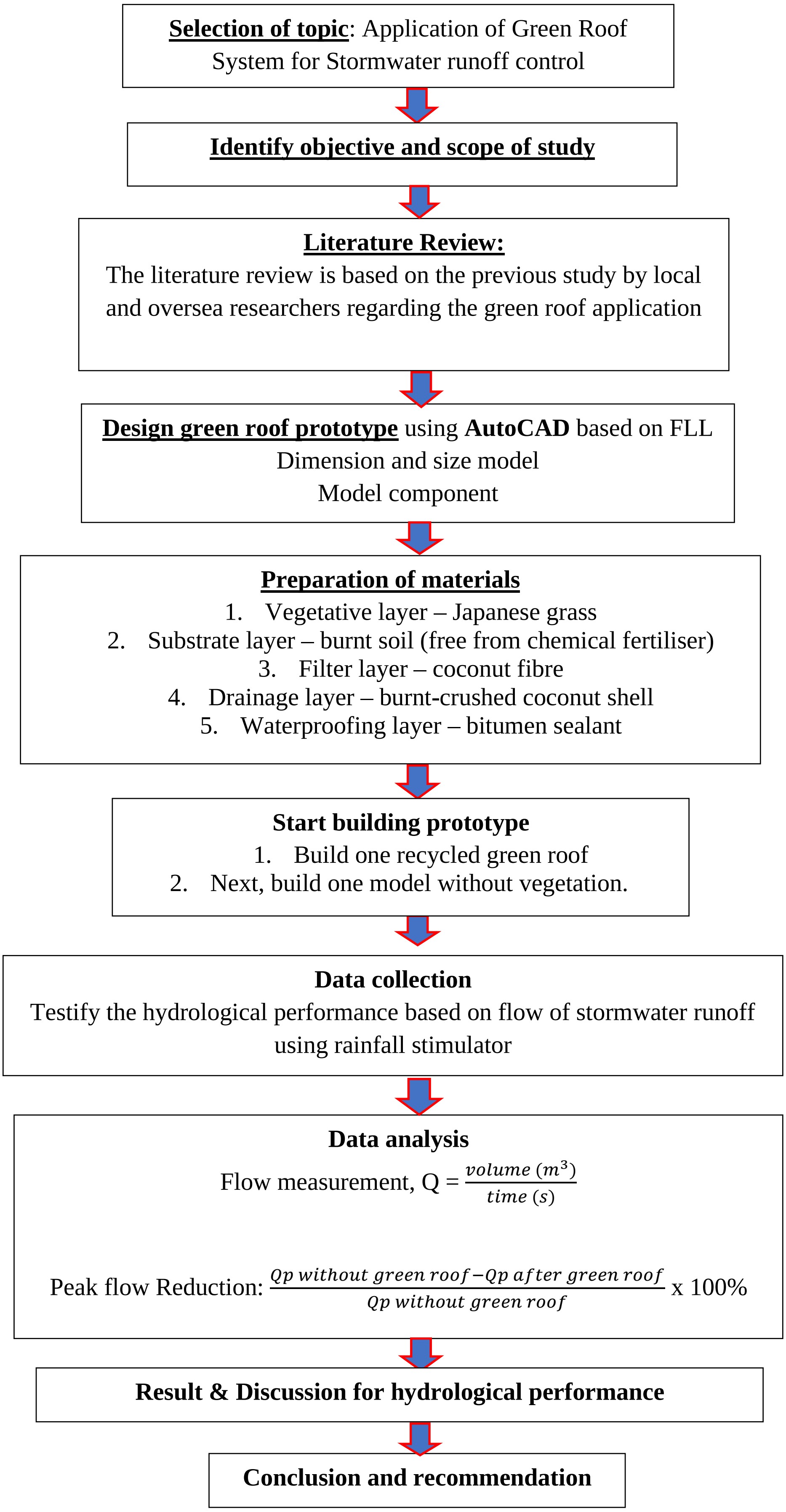
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides an overview of the methodology used to accomplish the study's goals, including the construction of a lab-scale prototype model, the selection of vegetation and materials for each layer, and the assessment of the hydrological performance of green roofs in reducing stormwater runoff by measuring the flow rates between non-vegetated conventional roofs, commercial buildings, and recycled waste green roof models.

The study's methodology is displayed as shown in the flowchart in Figure 3.1. Identification of the goals and objectives, which include designing the green roof in terms of the vegetation, materials utilized, and system dimensions comes first. After that, a literature study based on earlier green roof investigations was carried out. Information such as methods of green roof evaluation that can significantly minimize surface water runoff in comparison to other roofing types was acquired. After that, the green roof model and the green roof layers were designed dimensionally according to FLL Green Roof Guidelines. Then, the construction of the models begins with materials for each layer prepared in advance before testing the green roof. Then, data collection was conducted to obtain data on the stormwater flow rate. Next, the data analysis comparing the vegetated green roof to the conventional one was done by calculating the peak flow reduction. Finally, the conclusions and suggestions of the findings were then presented.



Selection of topic: Application of Green Roof System for Stormwater runoff control

Identify objective and scope of study

Literature Review:
The literature review is based on the previous study by local and oversea researchers regarding the green roof application

Design green roof prototype using **AutoCAD** based on FLL
Dimension and size model
Model component

Preparation of materials

1. Vegetative layer – Japanese grass
2. Substrate layer – burnt soil (free from chemical fertiliser)
3. Filter layer – coconut fibre
4. Drainage layer – burnt-crushed coconut shell
5. Waterproofing layer – bitumen sealant

Start building prototype

1. Build one recycled green roof
2. Next, build one model without vegetation.

Data collection
Testify the hydrological performance based on flow of stormwater runoff using rainfall stimulator

Data analysis

Flow measurement, $Q = \frac{volume\ (m^3)}{time\ (s)}$

Peak flow Reduction: $\frac{Qp\ without\ green\ roof - Qp\ after\ green\ roof}{Qp\ without\ green\ roof}$ x 100%

Result & Discussion for hydrological performance

Conclusion and recommendation

Figure 3.1 Flowchart of study methodology

3.2 Construction of Green Roof Model

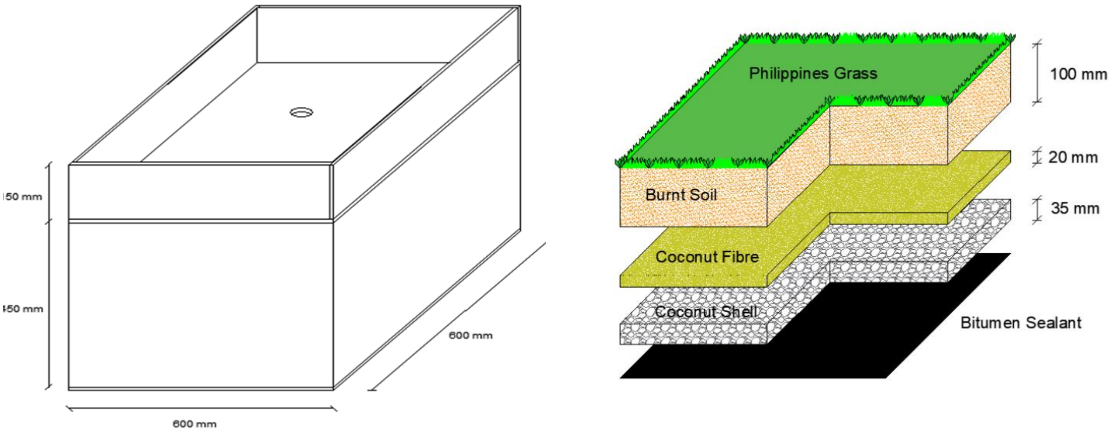
3.2.1 Green Roof Guidelines

The design and related green roof test were determined based on the study by Dunnett et al. (2008) and the FLL Green Roof Guidelines adopted from Losken et al. (2008). As there are no specific green roof standard and guidelines available for Malaysia, the technical regulations issued by the FLL guidelines, as well as Dunnett et al. (2008) was used in the construction and evaluation of the green roof system in this study. The guidelines for the planning, construction and maintenance of green roofs consist of several scopes including the legal framework condition, types of green roof and forms of vegetation, and the functional and effects of green roof. The guideline also outlines the requirements for construction and building materials.

All three prototype models were constructed based on the dimension proposed by Dunnett et al. (2008) in which the area of the body is 0.6 m x 0.6 m while the height is 0.45 m. Meanwhile, for the determination of the depth of the extensive green roof's layers, the FLL guideline for green roof design was taken for reference. The selected depth for the substrate layer is 10cm while the depth for the filter layer and drainage layer is chosen to be 2 cm and 3 cm respectively. Extensive green roofs are meant to need little care. Vegetation has developed, and the chosen plant types are Phillippine grass such that the roof does not require supplemental irrigation and only requires little, infrequent fertilizer.

3.2.2 Proposed of Green Roof Models

The three prototype models such as are non-vegetative green roof model (control), commercial green roof, and recycled waste green roof was constructed using gypsum board as the body compartments. The model is divided mainly into two parts that is the roof and room. The roof is where all the layers were layered and is exposed to the sun. Meanwhile, the room is an empty space representing a room in a house. The surface area of the body is 0.6 m x 0.6 m while the height is 0.45 m. The area is decided based on the previous work done by Dunnet et.al. (2008) while the selection of each of the layers' height is chosen according to FLL guidelines for green roof design. The outlet pipe was installed at the roof part to collect the volume of runoff. Figures 3.2 (a) and b show the picture of the green roof prototype and the arrangement of the green roof material respectively.



(a) (b)

Figure 3.2 (a) Green roof prototype model and (b) the arrangement of green roof material

The body of the green roof component model is prepared using a gypsum board and is sealed with construction sealant to glue the board together. Five layers of the vegetative model were constructed after the body is finished that consisting of a vegetation layer, substrate layer, filter layer, drainage layer, and waterproofing layer. The procedure of green roof model construction and production of the layer of the model can be seen in Figure 3.3 (a) until (j). The first step was cutting the gypsum board precisely to the required dimensions. After that, use the construction sealant to attach the gypsum board. Making a hole for the pipe exit comes next. The bituminous sealant was applied after that. After applying the bitumen layer, the model has to sit still to allow it to dry for a short period of time. Fill the roof model with the burnt-crushed coconut shell as the drainage layer. Then, on top of the burnt-crushed coconut shell, place the coconut fibre. Lastly, place the burnt soil into the prototype model before planting the vegetation, Philippine grass.

(a) Cutting the gypsum board

(b) Apply the construction sealant

(c) Allow the gypsum board to dry

(d) Drilling the hole to insert pipe

(e) Apply bitument sealant

(f) Pour the burnt-crushed coconut shell

(g) Place the coconut fibre

(h) Pour the burnt soil

(i) Plant the vegetation

(j) The completed prototype model

Figure 3.3 The Construction Process of Green Roof Model

3.2.3 Preparation of Coconut Shell as Drainage Layer

Basically, there are a few process of preparing the coconut shell as the drainage layer as shown in Figure 3.4. The coconut waste was first collected near a nearby store. Secondly, the coconut shell was washed and cleaned from any waste milk inside them. Then, the coconut shell was air-dried under sunlight. Later, the coconut shell was burnt to allow carbon activation. Then, the coconut shell was crushed and sieved using a 2mm - 5mm sieve.

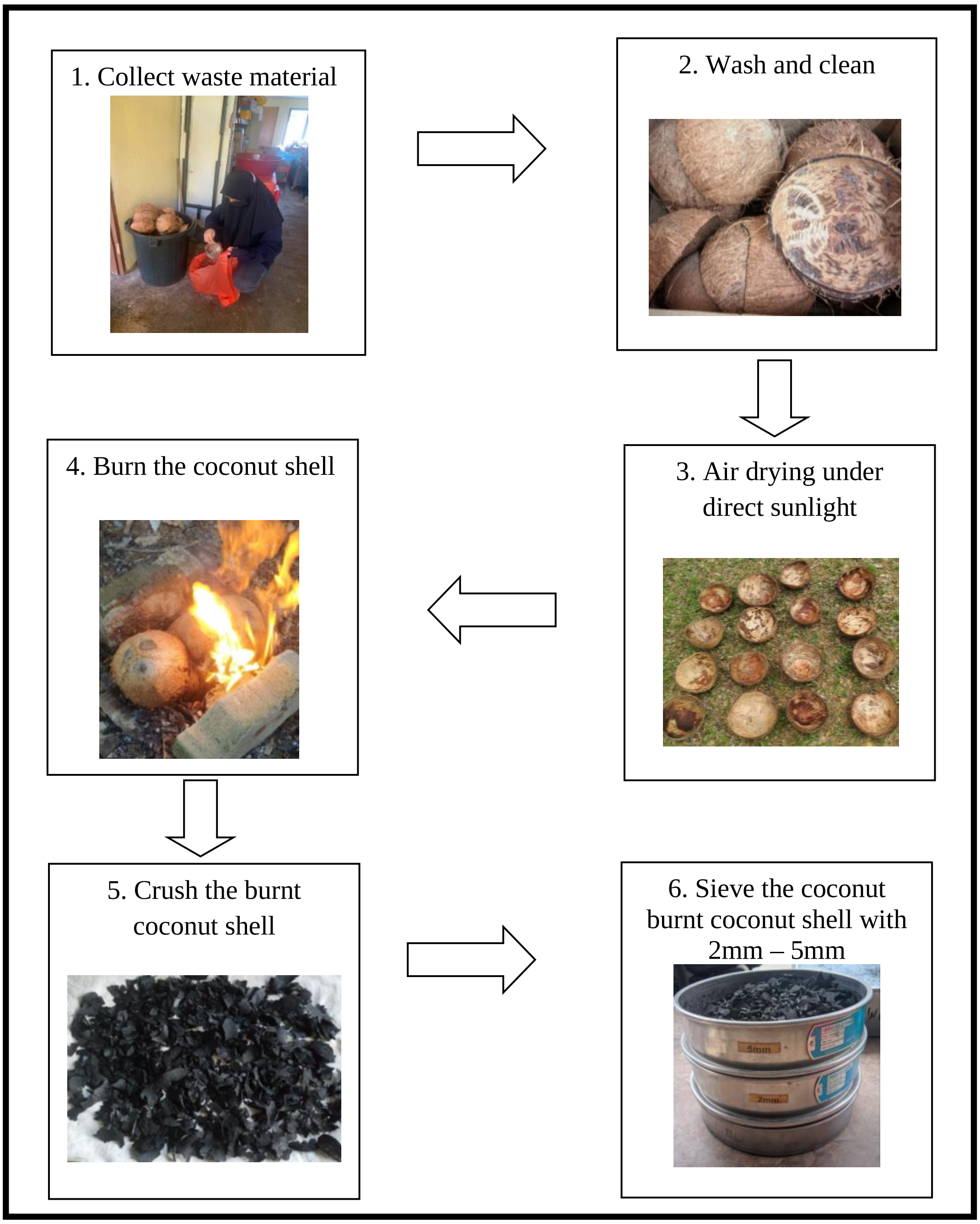


Figure 3.4 Production process of coconut shell

3.2.4 Preparation of Coconut Fibre as Filter layer

As indicated in Figure 3.5, there are a few steps to prepare the coconut fibre as the filter layer. The coconut waste was initially gathered were cleaned. After that, the coconut fibre was then air-dried by leaving the coconut fibre under direct sunlight. The coconut fibre was afterwards was teared into pieces.

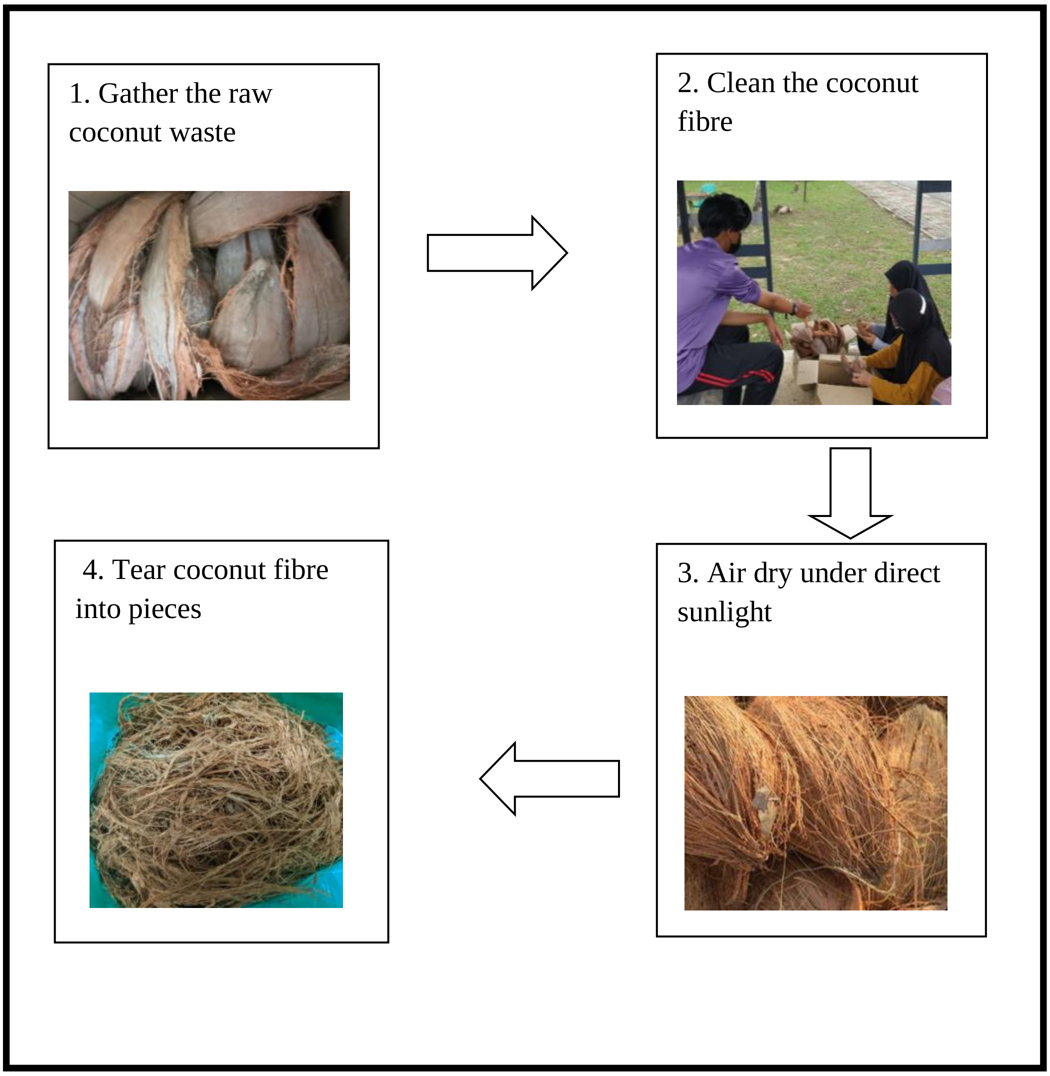


Figure 3.5 Production process of coconut fibre

3.2.5 Preparation of Green Roof Layers

3.2.5.1 Vegetation layer

Selected vegetation was planted on top of the topsoil that is the philippine grass. Stormwater runoff reduction varies significantly depending on the type of plant used. Vegetation species, growth status (plant height and vegetation coverage), and structure significantly influence the amount of water runoff (Gong et al., 2019). Therefore, according to Liu et al. (2019), fern possesses the ideal features of green roof vegetation, such as linear leaves that create a pinnate shape, quick growth, and thick roots. Besides, green roof plants are usually selected based on their drought tolerance and aesthetics (Monterusso et al., 2005).

Figure 3.6 shows the selected plant as a vegetation layer of the green roof which is philippine grass. The reason for this choice is that such plant uses considerably less watering and has far lower maintenance costs than other vegetation kinds. The grass does not need fertilizers and is also resistant to wind, heat, and drought. This is suitable as the plant could tolerate with the hot climate in Malaysia if exposed to direct sunlight.

Figure 3.6 The vegetation layer (Philippine grass)

3.2.5.2 Substrate Layer

Green roof retention performance are substrate physical properties, such as substrate material, depth, porosity and density. In fact, hydrologic attributes of the substrate material, such as wet weight and retentive capacity, determine retention performance (Liu et al., 2019). This is to ensure the green roof's effectiveness at retaining stormwater. Therefore, the ideal characteristics for green roof substrates should be lightweight and possess high water retention capacity, hydraulic conductivity, and air-filled porosity (Vijayaraghavan, 2016). The substrate can be mixed with aggregate material or organic content to serve as nutrients to the plan.

The type of soil used as the substrate layer is burnt soil as shown in Figure 3.7 due to its lightweight and less load on the existing roof structure. Next, the soil can absorb and stores water well. Additionally, it is devoid of any organic or chemical fertilizers that might harm the purity of the water.

Figure 3.7 The burnt soil substrate layer in green roof system

3.2.5.3 Filter layer

The filter layer material must be capable of preventing tiny particles from the top layer from accessing the drainage layer and clogging it (Cascone, 2019). For the selection of filter layer, recycled coconut fibre as shown in Figure 3.8 is chosen as a substitute of commercial material, geotextile. It is also lightweight, making it ideal for use on a green roof. Furthermore, coconut fibre from coconut waste is one of the easily accessible waste elements and is widely grown in Malaysia. Coconut fiber is a robust, long-lasting substance resistant to degradation, with a high water absorption capacity and thermal resistance to sound and heat.

Figure 3.8 The coconut fibre filter layer in green roof system

3.2.5.4 Drainage layer

The drainage layer's function is to quickly remove overflowing or underflowing water in order to avoid oversaturation. It is used to establish the optimum possible balance of water and air in the green roof system. The drainage layer must let the passage of extra water in order to guarantee proper aeration of the substrate and roots. The stratum of drainage in rare cases, it may also serve as a way to introduce irrigation (Dunnett et al., 2008). The drainage layer in this study was formed of burned coconut shells, as seen in Figure 3.9 The burnt and crushed coconut shell waste has a high potential for use in the drainage layer to improve the hydrological performance of the green roof, which serves to store rainwater and thus minimize the runoff.

Figure 3.9 The coconut shell drainage layer in the green roof system

3.2.5.5 Waterproofing layer

Waterproofing materials come in a variety of forms, polyurethane, bituminous membrane, thermoplastic membranes, polyvinyl chloride waterproofing membrane, thermoplastic membrane, and elastomeric membrane (EPDM). It protects the below part of the model from intrusion brought on by the high water content by creating a barrier to prevent water passage (Carson et al., 2013).

The waterproofing layer (Figure 3.10) is produced by spreading the bitumen sealant across the bottom area of the prototype model. It is basically chosen because bitumen is an effective waterproofing material as it provides a strong water-resistant coating. It is suitable as a surface dressing on felt roofs and as a waterproofing membrane on flat concrete roofs. Therefore, Bituminous waterproofing coating is potent at protecting the prototype model from water, due to its hydrophobic property, it naturally impedes water and blocks moisture.

Figure 3.10 The bitumen waterproofing layer at the bottom layer

3.3 Tested Parameter

Capabilities of green roof in flow attenuation are widely studied. The varieties of green roof itself, as well as the research site, are thought to be some of the elements that affect the outcomes, which vary. Besides, studies on green roofs must concentrate on the properties of rainfall and air temperature. The performance of green roofs in improving stormwater quantity was observed based on the reduction of peak discharge. There are a total of two events that have different rainfall intensities. The 10 min duration and 20 min duration design storm were applied to each of all three prototype models which are the non-vegetated prototype model (control), vegetated prototype model ie; recycled model, and commercial model. The intended result of the experiment should be that as the intensity of the rainfall increases, the result of the reduction percentage decreases.

3.4 Evaluation for Green Roof Performance

Based on the two rainfall intensity events, the performance of the green roof system in enhancing the stormwater quantity and lowering peak flow was observed. The 10 min and 20 min rainfall duration were assigned to each of all three prototype models which are the non-vegetated prototype model (control), recycled green roof model, and the commercial green roof model. After that, the Hydrograph that is flow rate in m^3 /s against the time interval was plotted.

The water discharge for three models was computed to show and illustrate the relevance of peak flow. Based on peak discharge reduction, the efficacy of green roofs in improving stormwater quantity was established. To investigate the performance of green roofs in attenuating peak flow, Equation 3.1 was applied.

$$\text{Percentage of peak flow reduction} = \frac{Qp\ without\ green\ roof - Qp\ with\ green\ roof}{Qp\ without\ green\ roof} \text{ x } 100 \qquad (3.1)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This section highlights the results of evaluation of green roofs using recycled material from coconut waste to improve stormwater runoff. Hydrological parameter for stormwater runoff improvement is assessed based on the plotted hydrograph and the percentage of peak runoff reduction. This chapter also give the associated data from the rainfall-runoff test, which was done for all green roof models primarily on two distinct storm intensities and examined to see which one performed the best out of all three.

4.2 Stormwater hydrograph

Three types of green roof models are used in the testing, and simulated rainfall has been done for two different storm intensities. Table 4.1 summarizes the evaluation of rainfall intensity for Event 1 which is 0.15 mm/min and on Table 4.2, shows the related 0.175 mm/min for Event 2. Figures 4.1 and 4.2 illustrate the hydrograph of water discharge against time for Events 1 and 2 repectively, which compare the efficiency of green roofs in minimizing peak runoff. Peak runoff was found to differ across conventional roofs, commercial green roofs, and recycled waste green roofs. In comparison to the commercial green roof, the results showed that the green roof that employs recycled waste material had the greatest potential for lowering peak flow. The control model had the maximum peak flow of $13 \times 10^{5-}$ m^3/s during Event 1 and 14.17×10^{-5} m^3/s at Event 2. Meanwhile, the peak flow of the recycled waste green roof is the lowest when compared to the commercial green roof for both rainfall events which are 7×10^{-5} m^3/s and 8.83×10^{-5} m^3/. A similar trend is portrayed in Figure 4.2, where the peak flow of the recycled trash green roof (8.83×10^{-5} m^3/s) is lower than that of the commercial green roof (11.5×10^{-5} m^3/s). Therefore, it can be inferred that the use of recycled waste material, improves the hydrological performance of green roofs significantly.

Table 4.1 The Stormwater Intensity for 1st Event

Rainfall depth (mm)	1.5 mm
Storm duration (min)	10 min
Intensity (mm/min)	0.15

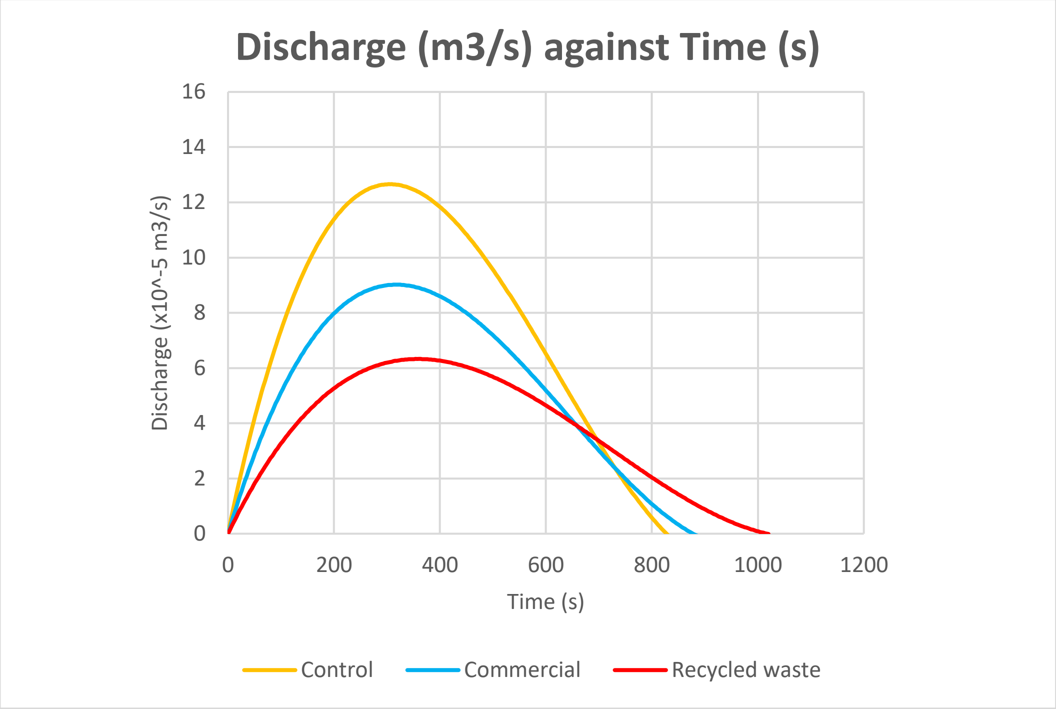


Figure 4.2 Hydrograph of Event 1 for all green roof prototype model

Table 4.2 The Stormwater Intensity for 2nd Event

Rainfall depth (mm)	3.5 mm
Storm duration (min)	20 min
Intensity (mm/min)	0.175

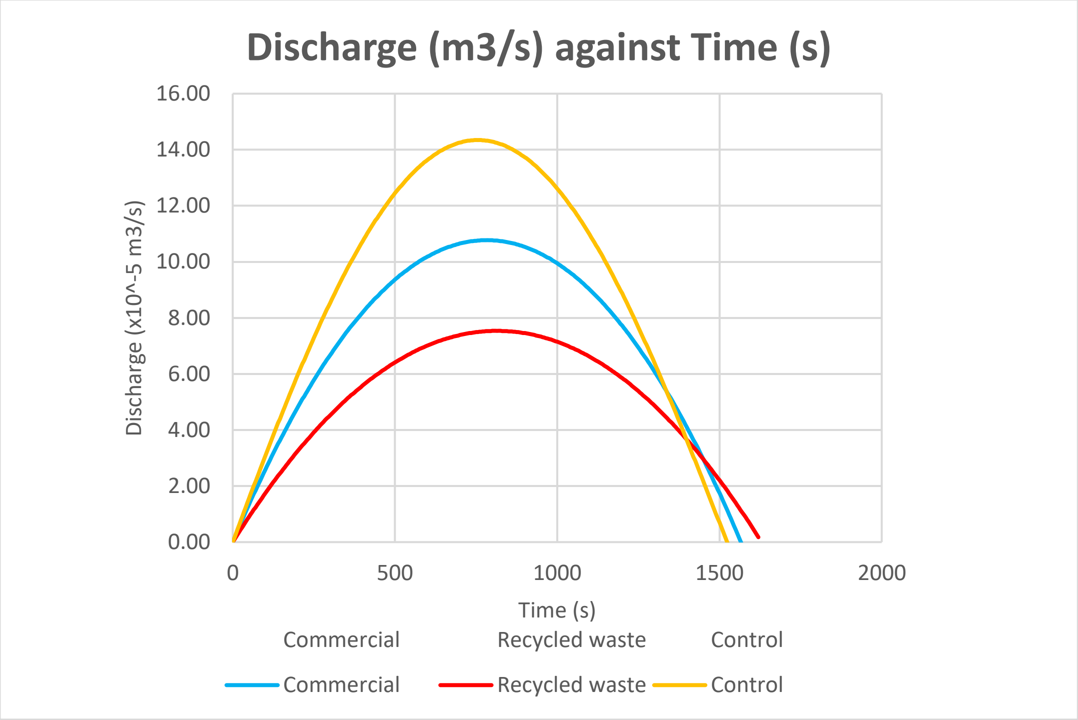


Figure 4.2 Hydrograph of Event 2 for all green roof prototype model

4.3 Peak flow reduction

The peak stormwater flow for non-vegetation green roof (control), commercial green roof and recycled waste green roof is shown in Table 4.3 for all events. Overall, as shown in Figure 4.3, when compared to the peak flow by the control model, the green roof with recycled waste material exhibits the lowest peak flow value, followed by the commercial green roof. Additionally, it can be seen that Table 4.4 compares peak flow decrease in terms of percentages. Figure 4.4 depicts the results as well. The green roof with recycled waste material reduces peak flow better than the commercial one by 46% from 13 × 10 $^{-5}$ m³/s and 7 × 10 $^{-5}$ m³/s in Event 1. The results were also the same for Event 2 where the discharge peak flow for the recycled waste green roof model is greater than the commercial which is a 38% reduction from 14.17× 10 $^{-5}$ m³/s to 8.83 × 10 $^{-5}$ m³/s. This proves that the percentages of reduction for green roofs drop as the stormwater rainfall intensity increases.

Table 4.3 Discharge peak flow of conventional roof, commercial green roof, and recycled green roof

Events	Rainfall Intensity (mm/min)	k Flow, Q (× 10^{-5} m³/s)		
		Recycled Waste Green Roof	Commercial Green Roof	Non-vegetation Green Roof
1	0.15	7	9	13
2	0.175	8.83	11.5	14.17

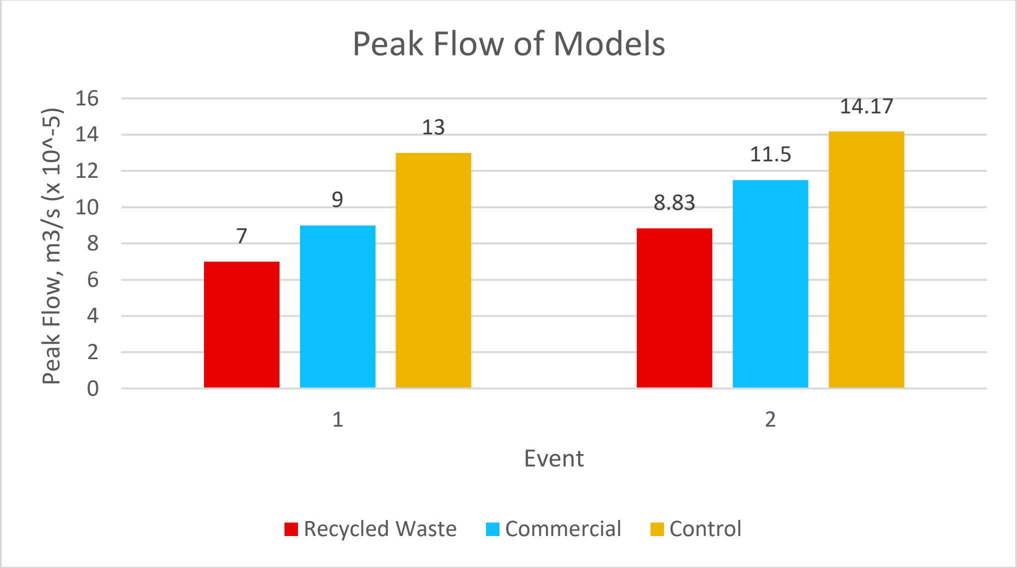


Figure 4.3 Comparison of discharge of peak flow for control model, commercial model and recycled waste green roof

Table 4.4 The percentage of peak flow reduction of commercial green roof and recycled waste green roof

Events	Rainfall Intensity (mm/min)	Peak Flow Reduction (%)		
		Non-vegetation Green Roof	Commercial Green Roof	Recycled Waste Green Roof
1	0.15	7	9	13
2	0.175	8.83	11.5	14.17

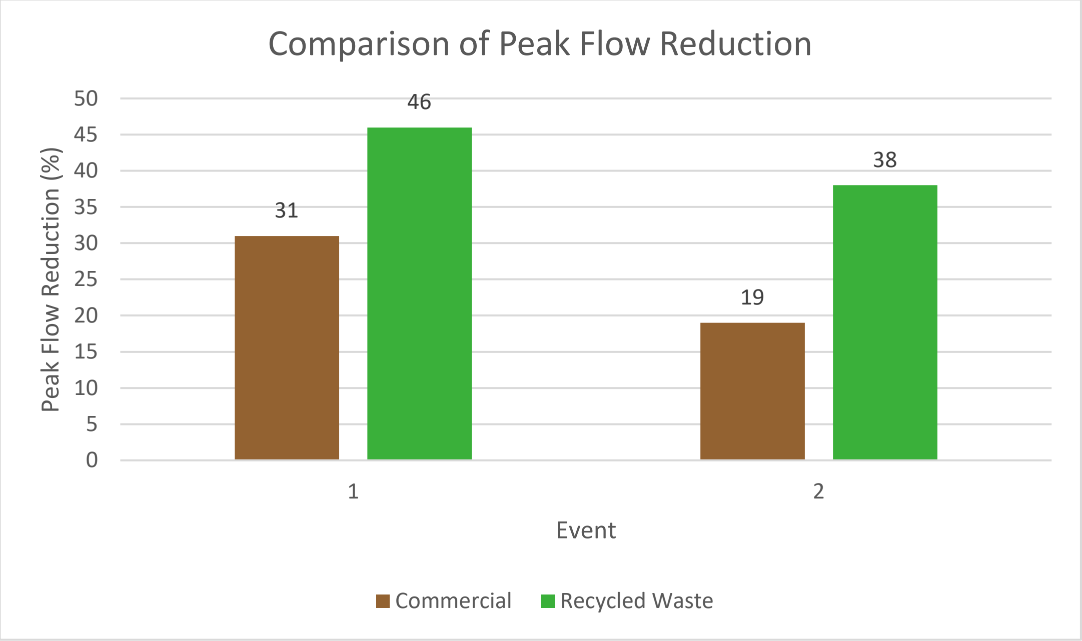


Figure 4.4 Comparison peak flow reduction for control model, commercial model and recycled waste green roof

CHAPTER 5

CONCLUSION

5.1 Introduction

The purpose of this research is to assess the performance of green roofs as a technique to aid in stormwater management specifically to look at the potential of green roof systems to reduce stormwater volume. Besides, the reduction of peak flow was also asses to examine the capability of green roofs in retaining and detaining water runoff. This section presents the study's findings in accordance with the study goals by employing a lab-scale prototype green roof with the specified plant and material for layers.

5.2 Conclusion

According to the findings of this study, the recycled waste green roof succeeded to minimise stormwater quantity by recording the lowest peak flow compared to the commercial green roof and non-vegetation roof (control) in all events. Next, in terms of peak flow reduction, the range of peak flow reduction of recycled waste green roof for event with 0.15 mm/min and 0.175 mm/min rainfall intensities falls in the range between 38% and 46% respectively. As a result, this shows that the green roof system managed to improve the stormwater runoff where the peak flow of the vegetated model is lower than the commercial green roof. Therefore, the use of coconut waste as green roof’s material such as burned coconut shells as a drainage layer and coconut fibre as a filter layer, performs admirably and may be a useful tool for stormwater management because it exhibits promising results, as shown below;

i. When compared to commercial green roof models (9×10^{-5} m³/s) and non-vegetated roofs (13×10^{-5} m³/s), the recycled waste model is capable of lowering the amount of stormwater runoff. The greatest result was obtained in Event 1 with the peak flow (7×10^{-5} m³/s).

ii. According to the results of discharge peak flow reduction, the recycled waste green roof model can lower peak flow by 38% and 46% when compared to a non-vegetated conventional roof, while the commercial green roof model can cut peak flow by 19% and 31%.

iii. In comparison to commercial green roof models, recycled waste green roof shows good performance because it has a higher percentage of peak flow reduction. The green roof systems that utilize recycled waste material (coconut fibre and coconut shell) outperform commercial green roof systems by as much as 46% in terms of peak flow reduction.

iv. From the findings, the performance of green roofs is controlled by rainfall intensity since it was discovered that the peak flow reduction increases as rainfall intensity decreases.

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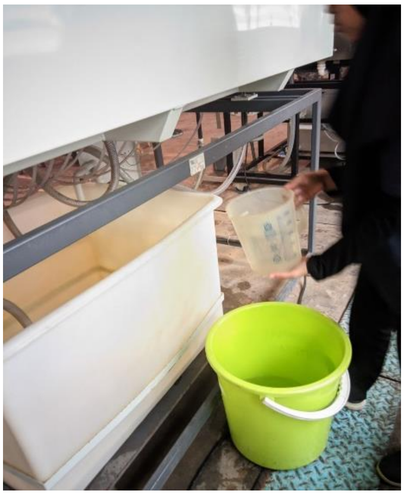
APPENDICES

Appendix A: Progress of lab work

Crushing burned coconut shell Cutting the board to specified sizes



Assemble of the model Pour rainwater into rainfall-runoff stimulator

Appendix B: Apparatus and equipment use for the experiment

Sample of rainwater

Rainfall stimulator

Stopwatch

Measuring cylinder