GREEN ROOF PERFORMANCE STUDY USING RUBBER CRUMB, OIL PALM WASTE MATERIAL AND NATURAL FIBRES FOR STORMWATER RUNOFF MITIGATION

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FACULTY OF ENGINEERING
UNIVERSITY MALAYSIA SABAH

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ABSTRACT

The purpose of this study is to investigate the green roof performance study using waste material and natural fibres for storm water runoff mitigation. The data were collected from different test bed under simulated rainfall with the intensity of 200 mm/h and testing were done for 0, 2 and 6% of slope. The design of green roof layers consists of waterproofing, drainage, filter, substrate and a vegetation layer. In this research, waste materials (WM) and natural fibres (NF) are used on the drainage and filter layer, respectively. Three stages involved during the data collecting process. Stage 1 is the drainage layer, followed by stage 2 (drainage layer with filter layer) and finally the stage 3 (drainage, filter, substrate and vegetation layer). A test bed with waterproofing layer as a control and three types of waste are selected for each test bed which is rubber crumbs, oil palm shells and polyfoam. Natural fibres as the filter layer in green roofs are placed on top of the drainage layer. Natural fibres chosen are coconut fibre, oil palm fibre and sugarcanes fibres. The plant used in the green roof is Arachis pintoi, which known for its hardy and vigorous growth across all seasons. Physical properties of materials are analysed to determine the diameter of fibres using a scanning electron microscope (SEM), the density of materials (specific gravity test) and, the water absorption of both natural fibres and waste materials. The weights of green roofs were measured before and after each stage for all the samples to determine the dry and wet weight of green roofs. The hydrological parameters recorded are the hydrograph and peak runoff, peak attenuation and water retention. The result indicates that the water retention percentages are higher as the slope increases and after the layer is added. For all simulation testing of green roofs made from WM and NF on hydrological performances, the water retention (RPI) are within the range of 31.92% to 87.09% and peak attenuation (PDPI) of 55.85% to 94.83%. OPSSF with a higher wet weight and live load of 19.19 kg/m^2 are acceptable. In conclusion, oil palm shells and sugarcanes fibres combinations perform the best hydrologically which have highest peak runoff, lowest peak attenuation and water retention compared to other combinations on 6% slope of green roof. The roof slope of 6% will give the best hydrological performance compared to the roofs laid flat or on 2% slope. Finally, the live load are higher that the control (drainage layer only) more than 34% on complete green roof systems.

ABSTRAK

KAJIAN PRESTASI BUMBUNG HIJAU MENGGUNAKAN SERBUK GETAH, KELAPA SAWIT SEBAGAI BAHAN BUANGAN DAN SERAT SEMULAJADI UNTUK MITIGASI LARIAN AIR HUJAN

Tujuan kajian ini adalah untuk menyiasat kajian prestasi bumbung hijau menggunakan bahan buangan dan serat semulajadi untuk untuk mengurangkan larian air hujan. Data yang dikumpul dari katil ujian yang berbeza di bawah hujan simulasi dengan intensiti 200 mm/j dan ujian dilakukan untuk 0, 2 dan 6% cerun. Reka bentuk lapisan bumbung hijau terdiri daripada kalis air, saliran, penapis, substrat dan lapisan vegetasi. Dalam kajian ini, bahan buangan (WM) dan gentian semulajadi (NF) digunakan pada saliran dan lapisan penapis. Tiga peringkat yang terlibat semasa proses pengumpulan data. Tahap 1 ialah lapisan saliran, diikuti oleh tahap 2 (lapisan saliran dengan lapisan penapis) dan akhirnya tahap 3 (saliran, penapis, substrat dan lapisan vegetasi). Satu katil ujian dengan lapisan kalis air sebagai kawalan dan tiga jenis sisa dipilih untuk setiap katil ujian iaitu serbuk getah, kelapa sawit dan polyfoam. Serat semulajadi sebagai lapisan penapis di bumbung hijau diletakkan di atas lapisan saliran. Serat semulajadi yang dipilih adalah serat kelapa, gentian kelapa sawit dan serat tebu. Tumbuhan yang digunakan di bumbung hijau adalah Arachis pintoi, yang terkenal dengan pertumbuhannya yang kuat dan bertenaga sepanjang musim. Ciri-ciri fizikal bahan dianalisis untuk menentukan diameter gentian menggunakan mikroskop elektron imbasan (SEM), ketumpatan bahan (ujian graviti spesifik) dan, penyerapan air kedua-dua serat semula jadi dan bahan buangan. Berat bumbung hijau diukur sebelum dan selepas setiap peringkat untuk semua sampel untuk menentukan berat kering dan basah bumbung hijau. Parameter hidrologi yang direkodkan ialah larian hidrograf dan puncak, puncak pelemahan dan pengekalan air. Hasilnya menunjukkan bahawa peratusan pengekalan air lebih tinggi apabila cerun meningkat dan selepas lapisan ditambah. Bagi semua ujian simulasi bumbung hijau yang diperbuat daripada WM dan NF dalam prestasi hidrologi, pengekalan air (RPI) berada dalam lingkungan 31.92% hingga 87.09% dan puncak pengurangan (PDPI) sebanyak 55.85% kepada 94.83%. OPSSF dengan berat basah yang lebih tinggi dan beban hidup 19,19 kg/m^2 boleh diterima. Sebagai kesimpulan, gabungan minyak kelapa sawit dan gula serat melakukan hidrologi yang terbaik yang mempunyai larian puncak tertinggi, pelemahan puncak terendah dan pengekalan air berbanding kombinasi lain pada cerun 6% bumbung hijau. Cerun bumbung 6% akan memberikan prestasi hidrologi terbaik berbanding dengan bumbung yang rata atau pada cerun 2%. Akhirnya, beban hidup lebih tinggi iaitu kawalan (lapisan saliran sahaja) lebih daripada 34% pada sistem bumbung hijau yang lengkap.

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LIST OF ABBREVIATIONS

ANSI	**-**	American National Standards Institute
ASTM	**-**	American Society for Testing and Materials
C	**-**	Control
DL	-	Dead Load
GR	-	Green Roof
IBC	**-**	International Building Code
LL	**-**	Live load
NF	-	Natural Fibre
NRCA	**-**	National Roofing Contractors Association
OPF	**-**	Oil Palm Fibre
OPS	-	Oil Palm Shell
PDPI	-	Peak Discharge Performance Index
PF	**-**	Polyfoam
RII	**-**	Relative Importance Index
RPI	-	Retention Performance Index
R	-	Runoff
RC	-	Rubber Crumbs
SA	**-**	Surface Area
SF	-	Sugarcane Fibre
WBDG	**-**	Whole Building Design Guide
WM	**-**	Waste Materials

LIST OF SYMBOLS

Δt	-	Duration of the test
ρ	-	Bulk density (kg/m^3)
ρW	-	Water density at 24ºC (1000 kg/m^3)
A	-	Cross-section area of the flow
H	-	Hydraulic pressure difference
Ks	-	Saturated hydraulic conductivity
L	-	Length of sample in column
M_a	-	Mass in air
M_w	-	Mass in water
SF	-	Sugarcane Fibre
SG	-	Specific gravity
V	-	Cumulative volume of percolated water
W	-	Water absorption capacity
W_d	-	Weight during dry conditions
W_w	-	Weight during wet conditions
W_{sw}	-	Weight of soaked
W_{ad}	-	Weight of air dried

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The United Nations (2012) predicted that the developing countries population will rise from 5.9 billion in 2013 to 8.2 billion in 2050. Hence, to cater for space expansion due to population rise, urbanization such land clearing and deforestation increase the impervious surface on urban catchments. Additionally, studies indicate global warming may cause increased frequency of rainfall events, leading to increased localized and flash floods (Berndtsson, 2010). Sustainable Urban Design System (SUDS), Best Management Practices (BMPs), Low impact Development (LID) and Water Sensitive Urban Design (WSUD) offers new insight to reduction controls, such as green roofs, can provide temporary storage spaces and promoting infiltration, thus mimic pre-development natural hydrologic functions.

In general, green roof are usually formed by the following layers (Pérez, Vila, Rincón, Solé, and Cabeza, 2012):

- Vegetation layer: upper layer in the GR system which consists of a plant that intercepts the water during rainfall.
- Substrate layer: usually top soil or garden soil. It is the physical support for the plants, where it provides nutrients and should have the capacity to retain water.
- Filter layer: usually geotextiles membranes. It allows water to cross but not of the substrate small particulates that could clog the cavities in the drainage layer.
- Drainage layer: must be able to retain water when it rains, while ensuring good drainage and aeration of the substrate and roots.

- Waterproofing layer: protects the building from the roots and water.

Green roofs are typically divided into two main engineering categories: intensive and extensive (Berndtsson, 2010). Intensive green roofs are recognized with deep substrate layers, which can support larger plants, require frequent maintenance and the total depth is more than 150 mm. Extensive green roofs are established with thin substrate layers, supports smaller plants and typically maintenance free. The total depth of an extensive green roof is normally less than 150 mm (Berretta, Poë, and Stovin, 2014; Carter and Rasmussen, 2006; Mentens et al., 2006; Molineux, Fentiman, and Gange, 2009; Ouldboukhitine, Belarbi, and Djedjig, 2012; Pérez et al., 2012; Rincón et al., 2014; Stovin et al., 2012; VanWoert et al., 2005; Voyde, Fassman, and Simcock, 2010; Wong and Jim, 2014). The extensive green roof also much favored for retrofitting purposes and light-weight compared to intensive green roof. Voyde et al. (2010) fixed its target maximum wet weight somewhat arbitrarily set at 100 kg/m^2 as its green roof design goal and work backwards to calculate the depth of the substrate layer (50 mm). Rincón et al. (2014) found that the green roofs used in the research to the conventional roof with gravel one (918 kg or 102 kg/m^2). In striving to find the optimum and sustainable extensive green roof design, the issue of the live load in wet conditions is hence, very important.

The most complete and recognized set of green roofs standards and guidelines are the "Guideline for the Planning, Construction and Maintenance of Green Roofing". These guidelines are published by the German organization Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) and are commonly referred to as the German FLL Guidelines. In addition to FLL guidelines, in North America the industry of green roof has developed further guidance, specific to North American design and construction procedures. A sampling of these codes and standards include International Building Code (IBC), American Society for Testing and Materials (ASTM), National Roofing Contractors Association (NRCA), Whole Building Design Guide (WBDG) and American National Standards Institute (ANSI) (ISWMM, 2015). The standard guide for green roof systems are based on ASTM E2777-15.

Several studies have been previously conducted to study various aspects of green roofs runoff performance using conventional materials on flat roofs, where this topic as far from being exhausted as the research area. Specifically, due to the need for sustainable practices to be implemented in construction, new studies can be conducted in the area of green roof performance for stormwater runoff using green and economical materials in the green roof layers with different percentage of green roof slope. The green roof limitations are access to the rooftop, installation cost and building capacity to support structure.

The success of the extensive green roof in mitigating stormwater runoff lies on its water retention capacity and runoff dynamics. One of the factors influencing green roof water retention capacity and runoff dynamics is the roof slope (Berndtsson, 2010). However, the different studies on slope influences on green roofs runoff retention capacity bring different results. VanWoert et al. (2005) observes that runoff retention may depend on a slope. The effect of runoff retention can be seen with the influence of roof slopes coupled with other factors such as the design of green roof layers and the presence of different type drainage materials.

Green roofs may work as a source control measure as they have capability of retaining the rainfall by and distributing the runoff slowly through the green roof layers. This technology helping in reducing the runoff discharges which contributing to reduce flash floods. It is proven by several research that highlight the importance of green roof application including the ability of green roof to retain stormwater (VanWoert et al., 2005), delay peak discharge time (Carter and Rasmussen, 2006) and attenuate peak discharge volume (Mentens, Raes, and Hermy, 2006; Stovin, Vesuviano, and Kasmin, 2012).

Potential applications can be gained by implementation of green roofs using natural fibres and waste materials which are (i) external or internal thermal reduction for thermal comforts in residential buildings; (ii) reducing noise and air pollutions in urban catchments; (iii) sustainable green materials to be used in producing green roofs and green buildings; (iv) green roofs can be way to reduce stormwater runoff and flooding in urban catchments in Malaysia; and (iv) using green and economical waste materials in green roof is sustainable and may lead to cost-savings in building constructions.

1.2 Research Problem

Green building technology is currently a popular research around the world. As cited Anne (2010) his her research stated that the engineers and scientist are focusing on green building by trying to reduce the energy consumption and global warming. However, most of these researches done by the United States and European nations might not be suitable to be applied in Malaysia buildings setting. Other than that, green building technologies has not achieve a abundant attention from local researchers to create the green technology that could be adapted by engineers and contractors to be practical into typical building in Malaysia.

Malaysia climate considered as a dry hot all over the year with heavy rain on specific periods. Due to its geographical location with an average rainfall over 2000mm per year, is prone to suffer from floods and flash floods especially during cyclical monsoon cold surge episodes which are characterized by extreme rainfall from roughly November to February (Ayog, 2017).

Green roofs are the new technology of green building which represented by the vegetative layer of the roof. The conventional roof of buildings in Malaysia is made from zinc. As part of this project, the performance of green roof would be investigated for the hydrological performance in term of (i) runoff hydrograph and peak runoff, (ii) peak attenuation and the water retention.

Many researchers have studied the cooling effect of the green roof without focusing on an alternative to replacing the conventional material in the green roof system. In the same time, Malaysia is facing a waste material problem because there is not enough technology to reduce this waste material by recycling or reusing as substitution material in other material's component. The best practice is