Green Roof Monitoring

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Chapter 1- INTRODUCTION

1.1 Background

Rapid increase in organization has a direct impact on the local biodiversity and ecological changes. Implementation of resistant surface can help to increase the surface exposure with reduced infiltration effects and maintained surface runoff (Bendtsson 2010). The major considerations regarding the future objectives are made during the design stage. The appropriate management of urbanization effects for green roofs is important to channel an upright geomorphology with a balanced aquatic ecology and to prevent the soil degradation, steam based flow, and diminishing of area quality due to certain environmental and ecological factors. All these factors are important to be considered in order for the roof sustainability and preventing it from encountering flooding or increased frequency of unfavourable factors (Voyde, 2011).

The imperviousness of the soil is one of the most important factors that encounter gradual changes in response to the temperature, climate, and biodiversity change. If the soil quality is compromised with the course of time, it may eventually lead to some drastic affects including the flooding and changes in the stream channel geomorphology (Dhalla and Zimmer, 2010). Soil erosion is another problem that is usually occurs with the roofs. The conditions are usually slow progressing and tend to destroy the riparian buffer zones leading to decreased steam depth during the dry seasons (Henry et al, 2003). The gradual erosion leads to increase load sedimentations while altering the steam bed composition. The situation leads to compromise the aquatic ecology. The monitoring of Bishopsgate will help to mitigate the gradual responses that arise with the course of time. The monitoring will help to note the precise timings for the occurrence of each event and will help to invent the solutions on time.

1.2 Water Retention

The falling of rain or storm water over the impervious surface, the green roofs generate the water runoff. It has been found out that the placement of impervious surfaces with permeable surface may help to reduce the runoff of water and therefore reduces the downstream effects. By virtue, the green roof surfaces are permeable and provide alternative pathways of water retention instead of infiltrating them in the ground. Retention is described as the capturing of the amount of rainfall in the green roof substrate. The storing of rain water in the media takes place due to the action of capillary forces and then gradually evaporates over the course of time. This In turn facilitates the regeneration of storage capacity for capturing of subsequent precipitation. The water retention is calculated as a percentage with the help of the given formula

$$Retention\ (\%) = \frac{Rainfall\ (mm) - Runoff\ (mm)}{Rainfall\ (mm)} \cdot 100$$

There are number of factors that influence the rate of retention and quality of performance. This includes the study characteristics such as instrumentation, study duration or the roof design components including the depth, roof, vegetation, and age. The literature dealing with the retention of water performance has emphasized upon the need of a suitable combination of design components. The monitoring of Bishopsgate will help to modulate the interaction of different forces that impacts the flow of water and moisture content for unveiling different opportunities of modifying the roof.

According to Mentens et al (2006), the long term assessments i.e. yearly and seasonal measurements of the cumulative retention of water is important to provide realistic indications to choose a pathway to deliver the expected rate of performance for green roof on a lifetime basis. Monitoring would help to assess the retention performance and essential values to moderate the performance variations that may occur due to the seasonal changes and an unpredictable nature of the rain event. Monitoring is required to be embedded with the simple metrics as a way to assess through the annual cumulative retention to develop valuable policies and design guidelines.

1.3 Case Study of the Area

There have been a number of green roofs in London. However, the 201 Bishopsgate has been chosen for the implementation of monitoring system. The 201 Bishopsgate is located beside the Broadgate tower in the east part of the London city. The green roof exemplifies both the extensive and vertical green wall with the mixture of native ivy and Boston ivy at ground level. The architect of the green roof is designed by the EDCO Design London. The total area of the green roof is 2200 meter square with 34% green roof coverage and 750 landscaping. The land comprised of an extensive green roof and a mixture of three substrates. The extensive green roof reflects a wasteland habitat with sedum substrate with a depth of 100-150 nm and the brown roof substrate with a depth of 30-150 nm. Contrastingly, the three different substrates contain fine grade crushed brick concrete mix, a larger roof shingle mix, and medium grade concrete rubble mix.

This green roof was designed with the aim to foster sustainable office development. The major ideas were to design the roof exclusively to attain promising biodiversity features. Since its inauguration, the reports have revealed its progression for attracting carious targeted urban species. The enrichment of raw plants, substrate, and an aesthetic combination of wild flowers has made it a pleasant habitat for a number of species as well it intrigues the surrounding overlooking buildings.

The major barriers faced in the designing of this roof are well-documented. The original idea was to design the roof with concentration on sedum with a twelve plan species. However, the idea was dismissed by the BREEAM report due its less potential ecological value. The BREEAM report recommended for some other advancements that could credibly increase the ecological value and earn some more BREEAM credits. As a result, the design was amended and included an additional twenty typical urban wild flower species.

Aside from other variables, this green roof concentrates upon the biodiversity values with the on-site 100 meter square green wall and roof. Evidences have proven the design efficacy of this roof to attract wildlife. Great attraction towards hoverflies, butterflies, and bees were recorded in 2009. Flocks of Black Redstart are also been reported in the roof surroundings. It is predicted that this bird species will use the space for foraging. Moreover, it has also been the foraging habitat for House sparrows, House Matins, swifts, and bats. However, the nesting sites for nesting of larger species are restricted by not installing the roost boxes. The site evaluation strictly follows the criteria set out by the UK Green building Council, the Biodiversity Action Plan, and specie management for Greater London Area.

Monitoring of the roof will help to evaluate the real resources that are further needed to enrich the conceptual design stage for each of the scheme readily implemented. Monitoring will help to evaluate the conceptual solutions by not undergoing abortive work. Monitoring will substantially result in the roof progress and modification while enabling the researchers to introduce more realistic, compatible, and pragmatic solutions towards the structure and design of the build site ensuring its high credibility to different environmental factors besides biodiversity.

1.4 Aim of the Project

In the UK, the importance of green roofs is now increasingly recognized, including through planning policy. For example, the recent update to the London Plan included a policy requiring major developments to incorporate ‘living roofs’ wherever feasible. This project involves the installation of a monitoring system on a green roof on 201 Bishopsgate British Land. This provides a unique opportunity as this will be the only monitored green roof in the London Area. The study will utilize a low cost monitoring system based on Arduino to monitor the inflow, outflow, and moisture content of the selected green roof.

1.5 Research Objectives

The objective of this research is to implement an effective low cost monitoring system based on Arduino to monitor the green roof at 201 Bishopsgate, London. The monitoring system will focus upon the moisture content, inflow, outflow of water in the respective area. The objectives to be achieved are demonstrated as follows

- To assess the ability of Bishopsgate green roof in London to withstand the water flow
- To assess the ability of Bishopsgate green roof to attenuate the water flow
- To assess the effect of water accumulation over soil content
- To assess the impact that Bishopsgate faces for capillary storage, gravity storage, and field capacity
- To understand the responses of Bishopsgate towards water capturing and flow

1.6 Scope

The monitoring of Bishopsgate will make it the first monitored green roof in London. It will help the ecologists to apply modelling techniques based on the assessments to simulate the green roof hydrographs for future implications. The monitoring will help to quantify the model parameters and measurement of useful data to develop a predictive model.

Chapter 2: LITERATURE REVIEW

2.1 History

Green roofs are an advanced phenomena regarding vegetation which is referred as the arranged vegetation systems over roofs to withstand the effects of sun, rain, and wind. Gedge and Kadas (2005) have attributed the green roofs as a remarkable attempt to maintain a balance for urban ecology. This return to urban ecology approach is vastly implied in London and particularly the Thames Gateway area. However, the green roofs are sometimes vulnerable to create problems such as leakage or extra weight. Therefore, they require a deliberate series of membrane that provides strength to their structure and provides a favourable growing medium. It might be the sedum mat or soil-based system. According to Carson (2014), the green roofs are an attractive strategy to re-introduce the former and dense urban environment surfaces with the roof tops that offers plausible resistant against water flow. They have been adopted as an active art of the storm water management plans in cities across the world.

Berardi, GhaffarianHoseini et al. (2014) has quoted the Hanging Gardens of Babylon as the most ancient and historical reference towards the inception of green roofs. In view of author, the very first green roofs were developed to provide shade. However, later the Roman Empire exploited green roofs as the rooftop gardens for growing food and social interactions. In view of Keeley (2003), the concept of green roofs was first emerged in the 1960s in Germany where the designs were suggested to make different environmental implications. According to Magill (2011), the Germans have played a remarkable role in promoting advanced green roofing by following a system of planned vegetation on rooftops with an idea of covering them with the substrate to halt the rooftop fires. Since then, the construction of the modern green roofs began. The idea was manlyderived from the perspectives of urban ecology. The concept gained pace in the 1980s when green roofs were implemented for water conservation to prevent the amount runoff. They came down as a great way for ecologists to preserve the benefits of storm water and to ameliorate their hazardous effects. Conversely, according to Uhl and Shiedt (2008), the conventional green roof systems have been in practice since the two decades. During the course of time, the systems have emerged from a range of thin layer systems to succulent green roof top gardens that embed bushes and even small trees. In view of the author, this emergence has created positive effects on the urban microclimate and ecology. The monitoring of green roof is beneficial and deliberately needed to continue the ecological development in urban areas as it unveils the different combinations that are characteristically demanded by the different water sensitive areas. Monitoring can help to choose one best from the several options to improve the green roof performance for a particular area. Over the decades, the technology for green roofs has emerged up to a pole where it is substantiated with a number of water proofing membranes. Several ideas for managing drainage course have been implied and it has outgrown from the concepts of shading and vegetation. They are complimented with the idea of additional geosynthetic layers that prevents the penetration and damage from plant roots and provides additional water storage.

2.2 Types of Green Roofs

The green roofs are majorly classified as the extensive, intensive, or semi-intensive based on the thickness of growing substrate layer. The extensive green roof is characterized by the use of small sedums, grass, herbs, and flowing of herbaceous plants. The require lowered maintenance efforts and no permanent irrigation. These green roofs are considered ideal for an efficient software management.The extensive substrate layers are approximately 15 cm thick or may be less and provide short rooting and drought resistant plants like sedum. On the other hand, the intensive layers are thicker than 15 cm and support the diverse vegetation with long roots including tees, crops, and shrubs (Mentens et al, 2006).The intensive green roof system is comprise of a variety of vegetation ranging from herbaceous plants to small trees. They require top-notch maintenance and advanced green roof irrigation systems. They offers a great potential for design and biodiversity. This system is beneficial as it supports every kind of site ranging from small personal/home gardens to full scale public parks. The selection and desigining of plants affects the maintenance for these roofs. Majorly, r Rooftop farms, urban roof farms or vegetable farms on roofs are clearly intensive green roofs. The nutrient applications are comparatively higher for this kind of green roof.

There lies a price difference between the two roof designs where the extensive layers are cheaper per unit area as compared to the intensive layers. Moreover, they are easy to maintain and are lighter than intensive layers. This is the reason the extensive systems are implemented more regularly as they may prove beneficial for any existing building block where the weight limitations are also applied.A medial of these roofs is the semi-intensive roof that is made of ground covers, small shrubs, grasses, and herbaceous plants. They require moderate maintenance and occasional irrigation. A typical growing medium depth for a semi-intensive green roof is 6 to 12 inches. The system is capable to withstand more storm water as compared to the extensive syste and provides a greater ecological value. It also exhibits the potential equivalent to a formal garden effect.

There have been three major construction types emerged that classifies the extensive green roofs including modular tray systems, built-in-space, and vegetated mat (Oberndorfer et al, 2007). Both the vegetated and built-in-space systems require a specialized drainage system to control its moisture content. The ponding of surface flow is important for the extensive green roofs or it may lead to cause substrate erosion. Therefore, a specialized drainage system is always required for the vegetated and built-in-space systems to prevent ponding and surface flow. Nevertheless, the two systems are different in the aspect how they are installed. The growing substrate in the mat construction is bound with geo-composite that is often used for off-site pre-planting. Conversely, the substrate used for built-in-spaces are implied to border the rooftop regions and for on-site plantation as well. Contrastingly, the walls of modular trays withstand the surface runoff whereas the based supports it by providing a corrugate air space for drainage. Thus, these systems can suitably be placed on the roof's water proof membrane.

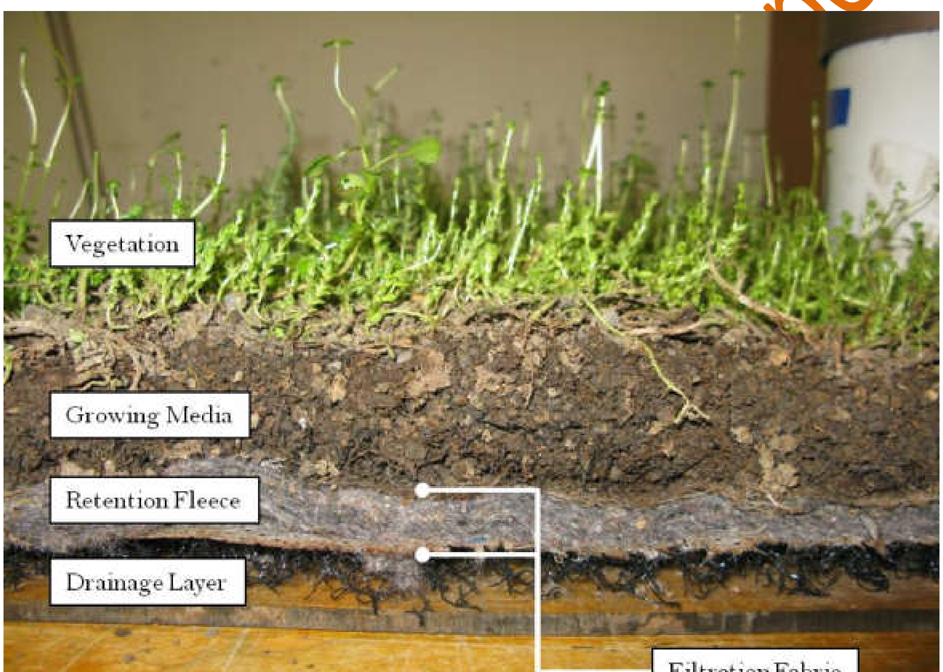

Figure: Showing the structure of a green roof (Carson, 2014)

Dhalla and Zimmer (2010) have highlighted the three setups are used in forming green roofs. These include the complete system, pre-cultivated systems, or the modular systems. The pre-cultivated system comprises of an array of pre-grown vegetables whereas the complete system is typically a traditional form of implied installation techniques. In the complete system, the green roofs are implemented on the basis of their component layers. This provides a good basis for plant growth where the plants are sown or inserted as plugs. Conversely, the modular system involves the assembling of a collection of pre-planted trays to form a green roof.

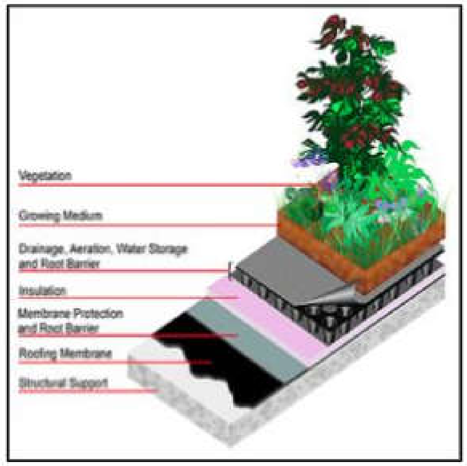

Figure 2: An overview to the conventional green roof(Dhalla and Zimmer, 2010)

2.3 Functionality

There have been a range of benefits that lies within the green roofs. Sailor and Hagos (2011) have accredited as a remarkable way to provide building insulation where as Bianchini and Hewage (2012) and Yang et al (2008) have attributed as useful for removing the airborne pollutants. According to Blanusa et al (2013) and Susca et al (2011), the green roofs are important to mitigate urban heat island while Peck et al (1999; CookPatton and Baurele, 2012; Francis and Lorimer, 2011; Yuen and Hien, 2005) have proven it useful for providing amenity and a cradle for urban diversity. In view of Bendtsson et al (2009), the primary achievement with the implementation of green roofs that ecologists have attained is the capability to retain, delay, and detain the flow of storm or rainwater. Nevertheless, the idea of monitoring of roofs has made it credible to quantify the extent of water inflow and outflow and the moisture content by the systems to bring relevant international researches (Blank et al, 2013).

The green roofs are majorly comprised of vegetation layer, growing media, drainage layer, and a water proofing membrane. The vegetation layer functions to reduce wind erosion and veils the substrate by providing shading. The veiling of substrate helps to reduce the temperature during the day hours and warm seasons when the sunlight at its peak (Voyde, 2011; Dhalla and Zimmer, 2010). The transpiration occurring within the vegetation layers restores the water storage capacity to the media. Additionally, the canopy provides interception storage. According to Snodgrass (2014), the plant selection in most of the cases is restrained for a variety of native grasses and sedums. Another layer is the growing media that is a commercial layers comprised of an engineered substrate the generally contains gravel, sand, organics, and crushed rocks. The layer is used to impart capability of saturated hydraulic conductivity to the green roofs. It also promises a balance of pH, organic content, nutrients, and the grain size distribution. The major purpose of engineering these layers is to manage the moisture content by enabling roofs to store an excessive rainfall along with nourishing the plant lives (Voyde, 2011). The third layer is the drainage layer that is a typical synthetic mat comprised of porous media. It provides a certain level of permeability to the roofs through permitting the conveyance of excessive precipitation to outlets and roof drains. The water proofing membrane is used as the first layer that is applied directly to the conventional surface. Its major function is to provide insulation. The insulation is provided either at one or both sides (above and below) of the water proofing membrane. Insulation is also provided to form a root barrier that could potentially stop the invasion (Voyde, 2011; Dhalla and Zimmer, 2010).

A number of new modular systems are being proposed and implemented as an effort to combine the different layers together for more beneficial working. However, each type of the green roof system shares some distinguishing performance feature that is characteristic to their environment. Therefore, each of the system requires an exclusively designed maintenance mechanism that can provide the initial maintenance in with respect to the nature of pre-cultivated plants as plugs and sown seeds. Once the vegetation is established, it requires a modest continual maintenance like weeding which is plays an essential role in the encouragement of green roof consistency.

2.4Benefits of Green Roof

Teemust and Mander (2007) have found out that green roofs are able to neutralize the acidity of rainfall. Conversely Bendtsson (2010) has reported the tendency of green roof to manage water runoff reduction by 99%. According to Steusloff (1998), the green roof can reduce the runoff for Zinc by 96%, for copper by 97%, and for Cadmium by 92%. The reduction in heavy metals results from the total pollutant load reduction due to retention rather than an effective filtration process. The fertilization methods used for the green roofs specify the nutrient concentration in the effluent.

Green roofs help in the reduction of energy consumption by providing affluent energy saving options. They are suitable to be implemented in the poorly insulated buildings due to their energy saving capability. In the warm seasons, the green roofs provide cool shading for the building while absorbing all the direct solar radiations through adding extra insulation. Moreover, they are also able to stabilize the daily temperature fluctuations (GhaffarianHoseini et al, 2014). Liu and Baskaran (2003) found that the green roofs can withstand temperature fluctuation up to 54 degree centigrade. According to Weng (2004) and Liu et al (2004), the green roof vegetation make use of about 60% of the total incoming solar radiations for photosynthesis with an albedo of 0.7-0.8. This, therefore, results in the availability of less energy to heat the media.

Urbanization pertains to high air pollution and green roofs helps to replace the vegetation that tends to reduce increased urbanization effects. According to Rothwell, 2014), the green roofs are able to remove the NOx and SO2 particles. Yok and Sia (2005) measured the concentration of SO2 after and before the installation of green roofs in Singapore and concluded that it helped to reduce the SO2 concentration by 37%. Currie and Bass (2008) modelled he green roofs and found that 109 Ha of green roofs can potentially remove the 7.87 tons of pollutants from the air. Additionally, it has also been found out that within the 13 years of green roof operation, they can reach to offset the air pollution occurring due to manufacturing of materials (Bianchini and Hewage, 2012).

The green roofs reduce the heat transfer and also mitigate the effects of impervious surfaces by controlling the quality and quantity of the storm water. They create a thick and cool structure that does not reflects the sunlight to adjacent buildings, but instead they make use of the radiant energy to cool the ambient air. Moreover, they can withstand and mitigate the effects of UV radiation. Implementing of green roofs protects the roofing membranes and increases their longevity. They provide a radiant green space with valuable aestheticism. The noise effects are also reduced as the sound waves are readily absorbed by the soil medium.According to Yang and Kang et al (2012), the green roofs have promising effects on reducing the acoustics and noise. Vegetation and soil helps to absorb the noise affects that in the urban setting. The media depth used for the green roofs are directly related to the noise reduction. The higher the depth increase, the higher is the improved noise reduction experienced. Dunnett and Kingsburry (2008) have described the green roofs are the carriers of ecological preservation. They are able to augment the fruit and vegetable production and provide the habitat for small insects and creatures. Maclvor and Lundhold (2011) has described it as the suitable framework for capacitating

Killdeer, Canadian 12 geese, bees, grasshoppers, spiders, caterpillars, and the beetles that are usually noticed on the green roofs in London.

Susca (2011) and Gaffin et al (2011) have identified the promising attitude towards decreasing the heat island effects. They exhibit a higher degree of albedo as compared to the black roofs and on average offers a suitable ambient air temperature above the roofs that 1.5- 2 degrees centigrade cooler. Green roofs also have increased the production of latent energy and provide greater evaporative cooling effects in comparison to the bare roofs that exhibit the dominance of heat ambient air that is contradictory to sensible energy fluxes. As demonstrated by Clark et al (2010) and Niu (2010), the green roofs are able to maintain the life of a 10-20 year guaranteed water proofing layer to 50 years)

2.5 DisAdvantages of Green Roofs

There have been disadvantages for using green roofs as compared to the reflective roofs. First of all, they are highly costly because they require additional stuffing of different materials as well as their installation cost is much higher than the reflective roofs. The maintenance cost is also higher as the plant care is costly and require deliberate measures to the keep the plants up until they are fully established. Some additional costs required as of fertilizers, vegetation processing, and frequent checking of plants. The plants are vulnerable to get affected by high winds and storms and can mechanically deform them. If damage is occurred to the roof, it is difficult to detect the leaks in the water proofing material. Moreover, it is also difficult to protect the water proofing material from roof penetration. Green roofs do not play efficiently if they are built over very steep slopes (Saadatian et al, 2013).

Another major disadvantage of green roofs is that the height of module is responsible for dictating which greatly limits the design flexibility. It also imposes load restrictions and makes the design unsuitable for the retrofit. Green roofs are quite heavy and require a crane for placement followed by a forklift and manual labor. Additionally, some designs are made of plastic material and can degrade over time. The coordination of scheduling and preplanting along with the high costs limits their wider use of modular systems (Clark et al, 2008).

2.6Green Roof Monitoring

For about more than 20 years, the runoff characteristics of green roofs are under high consideration, particularly in the parts of Europe. The year 1987-2003 has addressed a number of useful studies that flickered the idea of monitoring to focus on the peak flow and saturated substrate characteristics to direct the experiments for green roofs and making them enable to withstand the seasonal runoffs during different weather conditions (Mentens et al, 2006; Kolb et al, 2006). A number of experiment based studies thrived during the last 15 years that revealed great tendencies of green roofs through effective monitoring. Mentens et al (2003) studied the small scale evaporations taking place on green roofs for various weather conditions. Likewise, VanWoert et al(2005) conducted two detailed studies that focused on the run off processes during real weather conditions. LaBerge and Withington (2005) investigated the temperature issues in association with the storm water at 6 test roofs. Stovin et al (2007) began the research for green roof tendencies under the maritime climate condition in Sheffield. There are a several researchers that exploited green roof monitoring based on different technologies to evaluate different parameters to consider different green roof advancement opportunities (Johnston et al, 2004; Wachter et al, 2007; Seters et al, 2007; Moran et al, 2004;Taylor, 2006; Hutchinson et al 2003)

The ideas for executing improved benefits are gaining attention globally. The green roofs have been deduced a versatile new environmental mitigation technologies. The implications of gaining data and information from their performance are gradually gaining pace. The implications seem more pertinent with the mitigation of island heats and the runoff of storm water. The research stations based on monitoring systems are being deployed on a diverse array of green roofs through different monitoring technologies to fetch the competitive advantages (Oberndorfer et al, 2007). In view of Goffin et al (2009), the monitoring of green roof monitoring systems is a significant idea that will certainly open new opportunities for maintaining energy balance. Weiler and Scholz-Barth (2009) have argued that building green roofs is not just the matter of building green environments by harnessing natural resources, but they are equally responsible for make substantial contributions towards life sustainment and also encourage the regeneration of natural resources. The last five years has emerged with greater ecological and social significance. They are been considered as vital for biodiversity, reducing the pollutions, balancing ecological, mitigation of large scale storm water, urban heat island, substantial utilization of the urban land, and climate perspectives, and exhibit a great deal of social significance. Doron (2005) has reviewed green roofs as the next design revolution of urban agriculture. In view of the author, monitoring of the roof-sites will help to explain the horticultural aspects of the area, which is apparently a remote subject and still at hand to the contemporary architects. Thus, the monitoring of life roofs will help to ripe the potential ideas for upbringing of economic, social, and economical benefits towards the city residents.

According to Carter and Jackson (2007), the green roofs monitoring will enhance the curriculums for strong water management. Mentens et al (2006) has also lauded green roofs as a remarkable implementation for storing water and mitigation of rainfall events. The monitoring of these systems through different channels of technology would help to unveil the underlying black boxes that still need to be discovered to make the system facilitation more efficient and durable for urban implementations. Green roofs prevent water runoff by delaying the initial time of runoff. As a result, the infiltration is increased that tends to reduce the volume outflow by retaining a significant part of rain fall and evapotranspiration through vegetation. The monitoring systems may help to evenly calculate the precise timings volume detainment and outflow. This would help in creating the high porosity structures and drainage layers.

Bengtsson (2005) has attributed the stratigraphy as responsible for retaining the volume of water. The author has also referred the vegetation typology, density, and the hydraulic properties of the green roof as the main elements whose variability can change the precise timings for water retention and outflow. Monterusso et al (2004) has construed monitoring of green roofs as important to nail out the possibilities that could be harnessed to improve the working efficiency of these roofs. They potentially reduce the storm water runoff effects as much as 40-80% of the total rain volume. Moreover, the magnitude of the peak attenuation depends upon the duration and intensity of rainfall as well as the soil moisture conditions (VanWoert et al, 2005). According to Getter et al (2007), monitoring of green roofs helps to evaluate the detention capacity and enables the ecologists and analysts to gauge the substrate depth, slope condition optimal technical solutions that can suitably be implied to withstand the ecological conditions of the respective area. The author has verified that green roof is proven to decrease the storm water runoff by 60-80%.

According to Palla et al (2011), the idea of monitoring a green roof is advantageous as it aids in the measurement of total rainfall depth, the flow peak rate, and also helps to analyse the different synthetic variables that are important in quantification of the hydrologic performances of the green roofs with respect to each rainfall event. Monitoring facilitates event based reporting that helps in understanding the mean standard deviation values. The idea for manifesting monitoring systems for green roofs has helped the researchers to provide solutions for improving the hydrologic performance of roofs by analysing the outflow hydrograph delay, retained volume, and the peak flow reduction (Palla, 2009).

Mentens et al (2006) and Raes et al (2006) have compiled the results from 18 German papers and have significantly detailed the water retention performance foundations for green roofs. The combined results reveal that the media depths with extensive roofs ranging between 30 mm to 140 mm results in the cumulative retention values ranging from 27-81%. The results conclude that monitoring is essential to make design progression that ultimately results to maintain the consistency of green roof setups and also help to study the structures in comparison with the long-term retention trends. Rowe et al (2007) and Getter et al (2007) have assessed the storm water affects, effects of event size, and organization of events by dividing them into the three categories based on their intensity. The storms regarded as light with approximately 10mm waterfall retained the 94.2% water, medium up to 89.5%, and heavy up to 63.3%. These values are similar to those found by Rasmussen (2006) and Carpenter and Kaluvakolanu (2011). The results are prevalent that the trend of decreasing retention with increasing event size is persistent. However, an exception has been forwarded by Rothwell etal (2013) and Speak et al (2013). The findings from these authors reported that the light and medium sized events have an equal retention.

Study duration is an important factor to flawlessly monitor the changes taking place from different seasonal fluctuations. Monitoring helps the researchers and ecologists to keep an eye over the precise information. It enables the consideration seasonal and weather impact and the resulting changes from green roof performance and retention (Mentens et al, 2006; Raes et al, 2006; Beattie et al 2009; Stovin et al, 2012; Carter and Rasmussen; Berghage et al; 2009; Vesuviano et al, 2012). Each of the study has reported that there is usually increased water retention during the summer period with higher moisture content as compared to winter season. This is because there is more evapotranspiration during the warmer months that helps to replenish the storage capacity at a greater rate. Contrastingly, the studies by Fassman et al (2010); Voyde et al (2013); Rothwell et al (2013); and Speak et al (2013) have reported that there exists no certain period that exhibit the likely retention values. The situation is more pertinent among the areas where the climate and seasonal fluctuationsare petite such like the Auckland, New Zealand. In the light of contrasting results, it can be deduced that the identification of a substantial role of green roofs is questionable and require a thorough monitoring. However, various studies have considered registering the phenomena of water retention and moisture content, but each of them has applied a distinct design characteristic and study locations with a variety of monitoring and water management tools. The diverse responses regarding green roof literature with respect to the retention of performance has been attributed as the climate results. Conversely, none of the study has by far tried to assess the climatic effects on the green roof retention. This indicates for the need of an essential green roof research and monitoring systems to be implemented over the roofs for an effective assessment of the climatic effects on water retention performance of the green roofs.

There have been only a limited number of researches carried out to evaluate the green roof responses for large events that rests for a year or two. The monitoring is difficult and requires reasonable implications as the occurrence of events inherently takes place on an infrequent basis. Determination of green roof performance requires monitoring over large return periods for events to compare their effects for the water retention. There are some studies that have assessed the occasional large events that usually exceeds 45 mm or precipitation (Volder and Devorak, 2014; Rothwell et al, 2014; Vesuviano et al 2012; Stovin et al 2012; Speak et al

2014). However, the studies by Stovin et al (2012) and Vesuviano et al (2012) are the two of the few that have provided the thorough analysis of large scale events. They reported monitoring of 21 useable events over the period of more than one year. They implemented a roof test bed with dimensions 3m x 1m along with the substrate of 80 nm depth. Monitoring helped them to collect data over the period of 29 months in Sheffield, England. The average event retention noted was 30% for the 21 significant events. The recommendations made by the author emphasizes upon the conduction of researches that may monitor the green roofs for water retention based on the size of event. The data sets of appropriate events are important to substantiate the monitoring process so that the technical implementations may be able to withstand the climatic fluctuations and intensity of the event. Moreover, the monitoring seems more promising if it is able to analyse the events that last for a duration more than 20 years. According to Dhalla and Zimmer (2010), the chosen monitoring system must be able to comply with the changing weather conditions and can be used over a 2-year return period.

Villareal and Bengtsson (2005) have investigated the affectivity of water retention through inducing artificial storm effects. The study evaluated that events of constant intensity retained up to 20-29% of water whereas the events with varying intensity retained from 34-52%. There have been an ample literature evidences that supports the idea that the rainfall intensity impacts the retention level and moisture content (Fassman et al, 2010; Fassman-Beck et al, 2013; Speak et al, 2013; Rothwell et al, 2013; Hunt et al 2005; Bendtsson, 2010; Voyde, 2010. Nevertheless, not a single mentioned study has provided clear resolution towards this claim. For the most part, it is apparent that there has been no remarkable statistic correlation found between the rainfall intensity and retention.

2.7Green Roof Design Characteristics and the effects on Water retention, flow, and moisture content

There have been a number of diverse effects associated with designing paradigms of green roof. All these effects variable and can be altered from site to site. It is certain when a building is retrofitted with a green roof, there are some sites that offers higher substrate depth support where as some of the parts of roof tops does not offer the same. The variation of planting schemes relies upon the unveiling of characteristic factors that is achieved by efficient monitoring. The assessment of design components affects water in and outflow and leads the researcher to take appropriate measures for optimization of the on-site specific design.

The slope of the green roofs impacts the amount of water flow. It is eminent that the increase in gradient substantiates the increased water run off the roof. There have also been recommendations that suggest that the construction of green roof must not include any slopes that are more than offers more than 45 degree bending. There have been a number of studies that have pondered upon the effects of incorporating slopes in green roof (Schade, 2000; VanWoert et al, 2005; Villarreal and Bengstsson, 2005; Liesecke, 1998; Rowe et al, 2005; Getter et al, 2007). There has been a mixture of result presented. Studies that analysed the retention at slopes on green roofs found that within the field capacity, it the changes in slope creates no effect on retention (Villarreal and Bengtsson, 2005; Liesecke, 2000; Schade, 2000). Conversely, researches that offered coverage for various antecedent conditions deduced that the water retention is increased when the slope decreases (Getter et al, 2007; Rowe et al, 2007; VanWoert et al, 2005).

In view of Mentens et al (2006) and Raes et al (2006), the load bearing capacity of green roofs tends to limit the depth of media. The variations in depth of media theoretically impact the retention capability of green roofs as it results in the varying of available pore space for water storage. The amount of water flow and moisture content directly relates to the depth of substrate. However, a trend of increasing retention capabilities with increased depth of substrate have also been reported (Carson et al, 2013; Marasco et al 2013; Nardini , Andri et al, 2012; Rowe et al, 2005; Van Woert et al, 2005).

The genre of plants used for the green roof also impacts the vegetation coverage, penetration of root pathways in the media, root uptake, transpiration, and storage of water in plant tissues, shading of media, interception, and the rate of evaporation. Nagase and Dunnett (2012) conducted study by using 4 sedum species, 4 kinds of grass, and 4 different forbs as the monocultures. The author concluded that grasses are the most suitable type of vegetation that offers greater retention and moisture content while the forbs are second suitable options followed by the sedums. The research also concluded that utilization of tall heighted plants with larger root biomass helps to increase the retention. Contrastingly, the mat-forming sedum proved to retain most of the water in substrates when treated with different irrigation protocols. This implies that the mat-forming sedums increases the plant canopy coverage and tends to reduce the evaporation from substrate consequently leading to decreased storage availability during the precipitation event (Wolf and Lundholm, 2008). Conversely, Volder and Dvorak (2014) have investigated that the usage of broad leaved plants are able to provide increased transpiration and interception with greater storage capability. Contrastingly, Andri et al (2012) found no significant difference between the use of shrub and herbaceous for water retention. A number of researchers have agreed upon the fact that vegetated media offers greater water retention as compared to bare media (Ardini et al, 2012; VanWoert et al, 2005; Rowe et al, 2005; Volder and Dvorak, 2014). Nonetheless, Emilson and Rolf (2005) have concluded that the methods of panting vegetation have some minor effects on the retention. The prefabricated mats are found to offer increased plant coverage for the first few years of implementation as compared the plantations for plugs and shoots.

Changes in the substrate composition results as the plants continue to attain maturity and so the effectiveness of green roof is also altered over the course of time. There is a series of events that occur with the green roofs with the course of time. These include the physical and chemical changes taking place through loss of dissolvable substances, loss of fine soil particles, soil porosity and the changes in organic matter (Berndtsson, 2010). Rowe et al (2007) and Getter et al (2007) conducted an analysis for a green roof substrate aged for 5 years. The study found evidences of decomposition of organic matter and the doubling of pore spaces by the 2%. 4%, 41%, and 82% respectively. On the other hand, the water holding capacity increased from 17-67%. Perelli (2014) also found that degradation of roof media after the use of 5 years with decreased fines including grain size shrank to 150 μm. The deconstruction of the green roof was done to analyse the in-situ green roof modules. It was found that the soil at the top of module only had half of the fines as new substrates whereas the bottom layer of aged soil has 5-10% less fines as compared to the new soil. In the light of these findings, Perelli (2014) deduced that there is a downward transport of fines through the substrate that aggravates over time leaves through the drainage.

The hydraulic conductivity is considered to be the basic function of moisture content. Monitoring leads the analysis of medium event responses that helps to unveil the significant differences present in the retention performance. The findings can then be attributed to the soil moisture conditions at the start of each event. Correlation is required to be done between the initial moisture content and event retention. The results help to analyse the climatic aspects such as net radiation, temperature, and relative humidity and their effects on the retention performance of the green roof. Inflow and outflow of water impacts the storm water infrastructure designs and likewise the uncertainty of initial moisture content affects the permeability of green roofs during the peak consequently leading to smaller peak flow rates (Sims, 2015).

2.8Attenuation and Delay

Attenuation is referred as the reduction of flux intensity taking place due to transport through a medium. The concept of attenuation forms a major aspect of storm water engineering design where the concept of peal flow rate attenuation is applied to green roofs for the assessment of rainfall peak flows in comparison with the drainage peak flow. According to Henry et al (2003), the ideal urban development can achieved through effective monitoring of green roofs Detailed and precise assessments regarding the water inflow and outflow will help to determine the preservation challenges for the water peak flow rates.

A number of studies have conducted research for the peak flow rate attenuation from green roofs (Carter and Ramussen, 2006; Villarreal, 2007; Bengtsson, 2005; Uhl and Schiedt, 2008; Berghage et al, 2009; Voyde et al, 2010; Stovin et al, 2012; Fassman et al. 2010, Beattie et al. 2009 Carpenter and Kaluvakolanu 2011; Vesuviano et al. 2012; Fassman-Beck et al, 2013). Bengtsson (2005) conducted a detailed study regarding peak flow rate reduction by using a 3 cm deep green roof countering both the artificial and real events. It was deduced that the rain event with 0.5-year return period caused the runoff of 0.1-year. The peak flow rate attenuation is calculated as the percentage difference between the largest drainage peak and the largest rainfall peak during the event. The peak flow attenuation ranges are reported as 57% (Hunt et al, 2005; Moran et al, 2005; Stovin, 2010) and 93% (Voyde et al, 2013; Fassman-Beck et al, 2013).

Besides this, Villarreal (2007) conducted experiments by using an artificial rain where they reported an actual increase in the runoff flow rate by 5% with respect to the rainfall; this was attributed to potential overland flow. Since, there have been no conflicts in the concept and definition of attenuation in the current literature, there is still a limited understanding exhibited for attenuation. There have been no research acknowledged by far that has ever quantified the attenuation of various peaks within storm or different mechanisms that shares a great part in influencing these attenuations. Bengtsson (2005) has statistically confirmed that averaging time intervals that can suitably be used for the computation of flow rates are differs between the various studies and functions to alter the peak rainfall intensity magnitude. However, the general ones are reported as 5 minutes, 10 minutes, and 15 minutes. Alternatively, there are a couple of studies that have reported that attenuation measurement in relation of control roof provides conservative results (Abrams et al, 2003; Hutchinson et al, 2003; Carpenter and Kaluvakolanu 2011).

The general concept of attenuation is to establish a comparison between the largest rainfall peaks to the largest drainage peak. Though the naturally occurring rains exhibit higher intensities as compared to artificial rain, the green roofs capacitates it by providing an initial level storage.It is also pertinent that the peak drainage peaks and the rainfall peaks could be really unrelated peaks occurring from hour apart. The effective analysis of peak flow rates can be achieved by monitoring the multiple peaks for the storm and correlating with the subsequent peaks taking place in the runoff. There has been no clear notification of the dominant factors that really affects the peak flow rates; there is a lack of any reasonable measurement identified in the literature. However, Uh and Schiedt (2008) conducted a study to measure the effects of slope, depth, and layers of green roof on attenuation. The results concluded that there are no relationship impacts of any of these effects on attenuation. Alternatively, Hilten et al (2008) and Lawrence et al (2008) conducted a study based on HYDRUS simulations. The researches attributed the rain event size as the most important factor whereas Bengtsson (2005) proposed that neither the slope nor roof length creates any effect to the runoff. This implies that the vertical infiltration process holds a dominant place in the rain-runoff relationship.

Yet, still there have been definite identification of the key factors that causes attenuation. It is required that literature must consider the potential impacts that soil characteristics have on attenuation. A couple of studies have discussed the concept of field capacity in detail in relation to the retention of water (Jarrett et al, 2005; DeNardo et al, 2005; Hilten et al, 2008; Lawrence et al 2008; Bengtsson, 2005), but these studies also lacks the empirical reporting of field capability on green roof attenuation. There are number of definitions related to field concept in literature, but generally it is described as the point where the drainage through soil falls below a defined value (Twarakavi, Sakai et al. 2009; Assouline and Or, 2014). Conversely, it is defined as the amount of water that can be fully captured by the media as result of soil capillary forces and the exceeding force of gravity (She and Pang 2010). Literature reveals for a great opportunity for identification and quantification of the effects created by the field capacity on the green roof peak flow attenuation. Monitoring of water retention and moisture content may help to provide a valuable insight to evaluate the role of green roof media on attenuation. The research for monitoring 201 Bishopsgate in London will help to optimize the overall performance of green roof media.

2.9 Runoff Delay and Duration

Monitoring of delays in water flow through the green roof is important and helps to improve the runoff management from impervious surfaces. This is one of the concepts that are closely related with the retention and peak flow rate attenuation. Implying delays in the peaks of runoff hydrographs, delays in timing of initiation runoff, and increase in the runoff duration may help to reduce the both the combined sewer overflows and stream channel erosion (Henry et al, 2003). This may lead to reduce the load pollutants from the waterways (Babcock, 2014; Voyde, 2011; Dhalla and Zimmer, 2010).According to Abrams et al (2003) and Hutchinson (2003), the concept of time of concentration (Tc) is potentially used in relation to the runoff delay and travel times. Tc is referred as the time that is taken by water to runoff flow from a hydraulically furthest point towards the catchment in the outlet. Bengtsson (2005) has quantified Tc for a green roof study and has reported the 0.4 mm/min intensity Tc last for 16-20 minutes and 1.0 mm/min for 12-13 minutes.

Some previous studies have considered the peak flow rate delays analysis (Bengtsson, 2005 Getter et al, 2007; Villarreal, 2007; Carpenter and Kaluvakolana, 2011; Vesuviano et al. 2012; Jarrett et al, 2005; BeNardo et al, 2005). The studies by Jarrett et al (2005) and DeNardo et al (2005) accounted for delays in the peak flow rates that usually last for 2 hours on average.Carpenter and Kaluvakolanu (2011) deduced similar results with the average peak delays of 2.16 hours. However, Carter and Rasmussen (2006) have found comparatively smaller values for the peak delays. As accounted by the author, about 57% of storms delayed for 0-19 minutes with only the largest one approaching 2 hours. Contrastingly, Villarreal (2007) found the general delays of 1 minute in the peak flows while conducting an analysis for artificial rain events. The literature for peak delays with respect to green roofs is conflicting. Just like the peak flow attenuation, the peak delays are also calculated as the time between the peaks noted during rain intensity and the peaks acknowledged during runoff intensity. Since, green roofs offer an spacious storing element for water absorption and retention, there might the situations occur when the peak rain intensity does not coincides with the occurrence of peak drainage intensity. According to Stovin et al 2012; Vesuviano et al. 2012), this completely undermines the concept of peak delays for intense rain events. There are also evidences on another method for monitoring time delays. It is possible by calculating the time delay between rain centroid and the runoff hydrographs (Carpenter and Kaluvakolanu, 2011; Vesuviano et al. 2012; Stovin et al, 2012). By using this method, the general delay was around to be around one hour. Certain issues have been reported for using this method because this method does not promise to investigate the individual peaks during a storm. In order to execute an in depth analysis of the storm events, it is necessary to monitor the each respective peak formed with the event. It is important to find out the true peak to peak delay times. The evaluation of peak time delays of a green roof is daunting and can be achieved through effective monitoring which is capable to unveil the peaks taking place due to variables and time delays with clarity and consistency. Monitoring will enable closely look at each event at 201 Bishopsgate and will therefore help to determine the delays between rainfall and drainage in contrast to each respective peak within the event. It would be possible to conduct a detailed analysis and understanding of time delays.

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