EVALUATING THE VIABILITY OF SUSPENDED RAINGARDENS FOR STORMWATER TREATMENT

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ABSTRACT

Biofiltration low impact designs (LID) such as raingardens are proven Stormwater treatment technologies. However, with Auckland and other cities of New Zealand witnessing increasingly high density developments, the land required for such traditional LID is not readily available. While green roofs are a possible LID alternative, in high density developments their suitability depends on the angle or pitch of the roofs. Suspended raingardens can be an ideal LID alternative for urban environments, providing a runoff treatment without needing land space. This is a multi-stage research project aimed at creating a novel approach to stormwater treatment in urban environments. The first stage of this research is focused on finding suitable lightweight media for suspended raingardens. To ensure that this new approach is reasonably equivalent to the treatment efficiencies of conventional practices, we tested different light-weight media compositions with densities in the order of 350 kg/m^3 in the laboratory. Our trials were batch experiments focused on assessing their efficacy of removing total suspended solids (TSS) and dissolved metals: lead (Pb), zinc (Zn) and copper (Cu) from Stormwater runoff. The media we tested complied with TP10 regulations from Auckland Council in terms of TSS removal. The removal of all three heavy metals was significant too. However, we also encountered some practical challenges with the use of these media during our experimental runs. This paper discusses these findings and the viability of suspended raingardens as an effective stormwater treatment alternative for high density urban environments.

KEYWORDS

LID, Stormwater Runoff, Raingardens, Suspended Raingardens, Stormwater Treatment, Green Roofs, Bridge Drainage, Contaminant Removal

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1 INTRODUCTION

Biofiltration low impact designs (LIDs) we typically see in developments are constructed wetland ponds. They are downstream regional stormwater treatment systems. Constructed wetlands are preferred because of the multiple environmental benefits they offer ranging from flow attenuation and treatment to enhancing the aesthetics, convenience, and ecological value. However, water sensitive urban design guiding principles promote at-source treatment measures. This is predominantly because 'there is seldom sufficient room downstream of heavily urbanized areas to provide for regional stormwater treatment systems' (Allison & Taylor, 2004). Moreover, at-source treatment measures can provide treatment of small catchments effectively (Allison & Taylor, 2004). As such we are now seeing other LIDs like bio-retention swales, raingardens, and green roofs. In the recent years, more and more developers are focusing on green developments incorporating LIDs to mitigate the adverse impact of urban pollutants on our environment. There are a number of drivers behind the increased popularity of green developments that incorporate LIDs. The key drivers being, an increased environmental awareness and convenience of incorporating LIDs in developments.

The environmental awareness has gained significant momentum, especially in the last decade. Mainly, it is due to the recognition of environmental problems among general public alongside with visible climate change impacts on our environment. Another major contributor to the increase of awareness is the impact of environmental education on youth (Grimmette, 2014). As a result, the support of environmental protection has extended from the U.S., Japan, and Europe, which have been traditionally the countries advocating it to the rest of the world (Cohen, 2015).

It is now even more convenient to incorporate LIDs in developments. There is a range of LID proprietary products such as filtration units, modular tree pit raingardens, and green roofs that are suitable for incorporation in a range of situations. A notable advantage of these green systems is that they are aesthetically pleasing, making them a perfect fit in the urban landscape. Designers and architects are now able to incorporate LIDs in their designs with relative ease. Some companies manufacture modular green systems that are easy to install (Figure 1). They also offer installation and maintenance services, making it very convenient for developers and property owners to install and maintain LIDs. Modular systems have also become more affordable today than a decade ago.

Figure 1: Typical Stormwater Bioretention Filtration System

(Source http://www.stormwater360.co.nz/assets/Uploads/Filterra-Product-Sheet-A4-.pdf)

Despite all of the incentives, developers and property owners still face a number of challenges when incorporating LIDs in their developments. A key challenge is the availability of land. The proportion of the world population living in urban environments has now surpassed the population living in rural areas (Brown et al. 2009). Like cities around the world, Auckland and other cities in New Zealand are witnessing increasingly high density developments to cope up with the population growth. The demand for housing and retail business has exceeded the supply of land. This situation had inevitably led to the steep increase in the cost of land. This forces developers to focus on high density developments to maintain the affordability of housing and commercial developments. These circumstances reduce the options of LIDs suitable for urban developments despite the wide range available.

Green Roofs (Figures 2 & 3) present themselves as a suitable LIDs alternative in urban environments. As such, green roofs are gaining popularity in the recent times as a means of mitigating the adverse impact of buildings on our ecosystem (Vijayaraghavan & Raja, 2014). In addition to not requiring land, their popularity is also high because of the following key reasons:

1. They are attractive to designers and architects because of their aesthetic appeal.

2. They are available as modular systems. As such, they can be purchased off the shelf with full-grown plants. Modular green roof suppliers offer supply, installation and maintenance services.

3. They offer multiple benefits. In addition to removing sediments and nutrients from stormwater, they offer runoff control, evaporative cooling effect, heat insulation and noise reduction (Fasman-Beck et al., 2013).

Figure 2: Typical Green Roof System

(Source: http://www.greenroofs.com/projects/pview.php?id=593)

Figure 3: Modular Green Roof Unit

(Source: http://www.stormwater360.co.nz/products/green-infrastructure/living-roofs/prod/liveroof)

Countries like Singapore and the US run programs that provide incentives for developers for installation of green roofs. Other countries go further, for example in 2015 France introduced a new environmental legislation according to which all new buildings constructed in commercial areas must accommodate either a green roof, solar panels or both (Guardian, 2015). Similar legislations exist in some other European countries as well as in the city of Toronto, Canada.

Green Roofs are suitable for roofs with a relatively flatter pitch. If the roof pitch is more than 9° (15%) anti-shear/slip protection will be required to install green roofs. It becomes impracticable to install them when the roof pitch is in excess of 30° (57.7%) (Fassman et al., 2010). Another challenge in using Green Roofs is the lack of direct exposure to sunlight. When building sites are substantially shaded by taller buildings in the vicinity, plants may not be able to survive without direct exposure to sunlight for required periods of time. The other challenges in installing green roofs include the potential of roots penetrating waterproofing membrane which needs to be mitigated using a root barrier (Fassman et al., 2010) or a suitable proprietary Green Roof system. In essence, Green Roofs are not universally applicable LIDs in an urban environment.

In addition to taking other green initiatives, a growing number of urban communities are seeking to reduce their impact on already degrading water resources. Designing to ensure our water environments are protected is today's emerging challenge. Substantial progress has been made in the field of sustainable water management in cities around the world. In particular, there is marked progress in the innovation of sustainable technologies that change community values around the environment and waterways. Despite such innovations critics fell the progress thus far is too slow. This is because of the increasingly complex and multi-faceted challenges urban water managers are facing due to growing societal expectations and exploitation of natural resources reaching their limits (Brown et al., 2009).

More innovation is necessary in the field of LIDs to be attractive in the future. They need to offer multiple benefits to developers and property owners while maintaining their functionality and aesthetics. They also need to beat the competition for space by allowing installation in unconventional ways and in unconventional locations. This extends the opportunity to develop a new system – Suspended Raingardens. This the first stage of the multi-stage research project aimed at creating suspended raingardens to Stormwater treatment in urban environments. The first stage of this research is focused on finding suitable lightweight media for the suspended raingardens.

2 SUSPENDED RAINGARDENS AS A CONCEPT

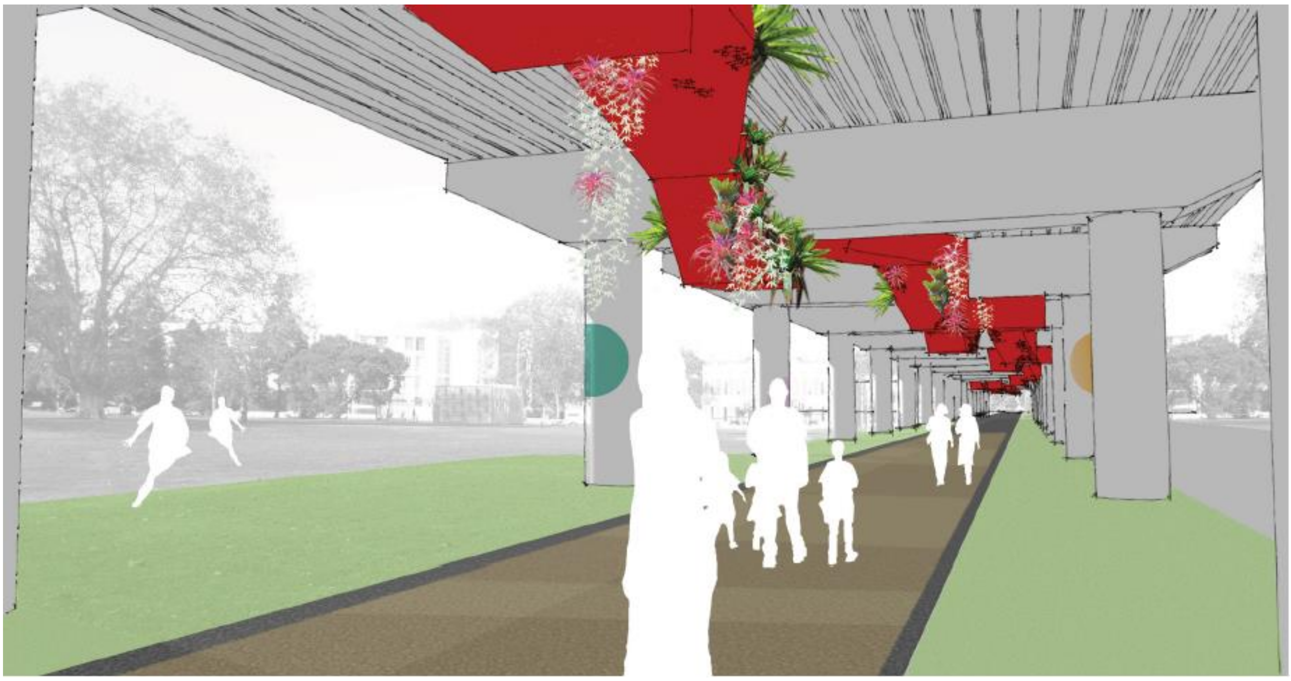
Hanging or suspended gardens are not a new concept. They have been around for more than 2500 years. The most famous of them being the Hanging Gardens of Babylon: a wonder of the ancient world built by King Nebuchadnezzar (Figure 4).

Figure 4: Hanging Gardens of Babylon

(Source: http://www.intechopen.com/books/advances-in-landscape-architecture/vertical-gardens.

The concept of a suspended raingardens seeks to incorporate stormwater treatment aspect into conventional hanging gardens that can be suspended from building and structures or between two buildings/structures (Figure 5). A system of this kind will extend the number of places and LID can be incorporated in urban environments.

Figure 5: An Artist's vision of a suspended raingarden under a bridge



Integrating plants on buildings offers substantial benefits from the aspect of sustainable construction. They offer energy savings, reduce ambient temperature and urban heat island effect. The most innovative and popular systems of integrating plants on buildings are the green walls or facades (Coma et al., 2014). Green walls (Figures 6 & 7) can be spectacularly beautiful. As such enliven the ambiance and space around them. Like with other forms of integrated plants on buildings, they reduce ambient temperature, improve air quality and reduce noise pollution (Timur & Karaca, 2013). As such, there are multiple benefits becoming attractive for developments in urban environments. A key benefit of green walls is that it allows water to be recycled by purifing it through the garden. This reduces flow attenuation benefits and offers the opportunity of treating stormwater to protect our waterways

(Timur & Karaca, 2013). There are now a number of companies manufacturing and supplying modular Green walls systems. These systems typically come in three distinct types – panel systems, felt systems and container & trellis systems (Loh, 2008). Of these three the panel and container & trellis systems allow the planting medium to be used for stormwater treatment.

Figure 6: The green wall of a commercial building in Tokyo, Japan

(Source: http://www.livingwallart.com/)

Figure 7:Vertical vegetable garden on a residential building

(Source: http://gardenious.com/vertical-vegetable-gardening/)

Architects and designers are already incorporating LIDs in urban design by changing everyday experiences of people to achieve change in societal attitudes towards water sensitive designs (Ryan, 2004). One such attempt was the Up Among the Clouds (Figure 8), a multi-level planting and a water-inspired soundscape that contributed to the sense of an urban retreat, where visitors could relax and immerse themselves in the landscape built during the 2013 Melbourne Food and Wine Festival. The work was created by HASSELL, an international design practice, working closely with Melbourne Water. It consisted of ground-level raingardens located around the site featuring drought-tolerant plants and demonstrating vegetable patches in reclaimed 40-gallon drums. The objective of this work was to showcase how water, Mother Nature's most precious resource captured, filtered and reused before it is discharged into the downstream water environment.

Figure 8: Up Among the Clouds. Designed by international design practice HASSELL, from a concept dreamt up by the team at Melbourne Food and Wine Festival (2013)

Source: http://www.landezine.com/index.php/2014/03/among-clouds-hassell/

Suspended raingardens can fit in a variety of urban developments ranging from commercial building, multistoried apartments to individual residential buildings.

3 MAKING SUSPENDED RAINGARDENS WORK

A number of challenges need to be addressed to make suspended raingardens a viable LID. As with any new engineering idea, rigorous consideration needs to be given to all aspects of the suspended raingardens to ensure the design is robust and the system functions as intended in the intended environments. For the entire system to function effectively, the key components of the system need to function effectively. In the case of a suspended raingarden, the key components are the planting media, plants and the structure of the suspended raingarden. The suspended raingardens will need to be constructed in a variety forms to ensure their suitability for a range of site conditions and aesthetic design requrirements. As such the raingarden media will need to be able to remove pollutants for a range of flow regimes.

3.1 MEDIA SELECTION

Like green roofs, suspended raingardens create additional load on structures. In a retrofit situation, the extent to which an existent building or a structure can take additional load could vary significantly. Therefore, some existing buildings are able to accommodate load only from lightweight treatment devices (Greater London Authority, 2008). Therefore, weight minimisation of the whole system is one of the primary considerations in the design of suspended raingardens. As the intent was to extend the use of hanging gardens to include stormwater treatment, we have not included identifying lightweight materials suitable for the structure as a part of this research. Therefore, our focus is only on finding and testing various lightweight media. The main criterion we established for green roof media are: it needs to be porous for air, water, and gas exchange, and drainage; it needs to have organic content and retain moisture to support plant growth similar to green roofs (Fassman & Simcock, 2012). We have considered the same set of selection criteria while identifying a suitable media for suspended raingardens. Auckland Council (2013) suggests that substrate media for green roofs also needs to have sufficient resistance to degradation and adequate bearing strength to prevent compaction. Both of these recommendations are relevant for suspended raingardens. Thus, we have taken them into account when selecting media for our laboratory trials. As the selected media has to be effective in trapping targeted pollutants in stormwater, we have focused on media similar to that used in green roofs instead of the media currently being used in suspended raingardens. Lightweight media typically have high permeability and therefore, it is important that sufficient levels of moisture and nutrients are captured to support plant growth (Fassman & Simcock, 2012). The depth of substrate media will be considerably less than in traditional raingardens considering how and where hanging raingardens will be installed. Therefore, the depth of media available in suspended raingardens for treatment will similar to that in simple intensive green roofs (Forschungsgessellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002). Taking into account these considerations, we have focused the initial trial runs on verifying the chosen lightweight media for effectiveness in trapping stormwater pollutants while retaining moisture and nutrients.

3.2 PLANT SELECTION

Plants play an integral role in stormwater treatment devices. Apart from absorbing nutrients and retaining pollutants in stormwater, plants need to meet aesthetic expectations of designers. To be viable for suspended raingardens, plants have to address a number of desired characteristics.

For commercial and institutional buildings plant selection should include inexpensive, easily available, ornamental plants. The choice of ornamental plant is dictated by the fact that aesthetically pleasing suspended raingardens will receive much more attention of public (Auckland Council, 2013). There are a number or aesthetically appealing plants that are currently being used in green walls and suspended gardens. Not all of them may be suitable for suspended raingardens. Some of them may not be suitable for growing in the chosen media and some of them may not be suitable for nutrient removal to the desired extent.

The plant selection needs to include ornamental plants, herbs or vegetables for universal acceptance in residential developments. Using edible plants in LIDs is not new. It has been used in green roofs in the past. A recent extensive 3-years study by Whittinghill, et al. (2013), conducted in the US concluded that there is no noticeable difference in yield harvested from a vegetated green roof and traditional in-ground farm.

The current green walls and suspended gardens use a sprinkler system for irrigation and fertilizers supply, it is not vital for plants to be drought tolerant. Therefore, we have not considered this as a criterion in selecting suitable plants for hanging raingardens. However, the residence time of stormwater in suspended raingardens could be less than that in conventional raingardens. Therefore, there is lesser time available for plants to absorb nutrients and metals from stormwater to provide effective treatment. Careful consideration needs to be given to ensure the removal of nutrients and metals is effective so that suspended gardens can function as LIDs.

The last challenge to overcome in ensuring suspended raingardens function as intended is, ensuring effective filtration of pollutants by the media. While traditional raingardens and green roofs rely on vertical flow, certain arrangements of suspended raingardens may have horizontal flow regime. Horizontal filtration can be more effective than vertical on small land parcels provided it is ensured that water inside the suspended raingardens does not create a channel of low resistance (Mossad & Aral, 2010). Careful consideration needs to be given to this issue in suspended raingardens.

4 MATERIAL AND METHODOLOGY OF LABORATORY TRIALS.

Our laboratory trials of the media consisted of bench-scale experiments. We tested three different media for their efficiency in removing some of the typical stormwater pollutants – TSS and dissolved metals such as copper(dCu), lead (dPb) and zinc (dZn) (Moores, et al., 2010). For the three media used in our laboratory tests, we used a mix of inexpensive materials available on the local market: sawdust, coconut coir, sphagnum moss, perlite, vermiculite. We used a small percentage of activated carbon, zeolite, and biochar in the media mixes to enhance adsorption of dissolved metals. All of these materials are used as planting media in hanging gardens and many LIDs. Moreover, they have been used in various studies and batch experiments in the past (Bratieres, et al., 2008; Al-Anbari, et al., 2008) for treating stormwater runoff. All three resulting media were lightweight with the heaviest media measuring at around 400 kg/m^3. This is 2-3 times lighter than the traditional media for raingardens (Malcolm & Lewis, 2008) and lighter than the media used for green roofs that typically range between 450 kg/m^3 and 670 kg/m^3 (Olszewski & Young, 2011).

Prepared in the laboratory, semi-artificial stormwater runoff was used as a source of contaminants. Each media was gently compacted in plastic tubs (Figure 9). After initial saturation, four runs were performed to determine the pollutant concentrations in the outflow.

Figure 9: Laboratory bench-scale set up for stormwater runoff treatment

All three substrates showed more than 90% removal rate of TSS. This result looks promising as local authorities in New Zealand currently require removal of only 75% of TSS. In terms of dissolved metals removal, three media showed different results with the most effective removal rate of 88.9 +/- 4.1 % for dZn and least effective removal rate for dCu measured at 41.8 +/- 15.3 %.

During the experiments, the buoyancy of the media was identified as an issue. The situation was improved after additional compaction of media. This issue will need to be resolved in the future stages of this research. Nonetheless, our batch experiments have confirmed that suspended raingardens can be a viable option for treating stormwater runoff. In the next stage of this research will look into a selection of plants that will be suitable for these raingardens.

5 ECONOMICS OF HANGING RAINGARDENS

Assessing the viability of suspended raingardens would be incomplete without an assessment of their economic viability. The concept of hanging raingardens seeks to incorporate stormwater treatment element into hanging gardens currently being used. If the cost of media used for hanging raingardens is comparable to the media currently being in other LIDs and hanging gardens, the concept of hanging raingardens will be economically attractive. As discussed earlier, the materials we used for media mixes were relatively inexpensive and were locally available. Moreover, they are currently being used in other LIDs and hanging raingardens. Therefore, the media cost is comparable to that of other LID media currently being used. Likewise, the cost of planting material, containers and fasteners are expected to be comparable with that hanging gardens currently being used. All of these comparisons provides us with the confidence that the hanging raingardens will be economically attractive for developers and owners to incorporate them in their developments.

6 OPERATION AND MAINTENANCE

A potential drawback of suspended raingardens could be the need for additional maintenance compared to conventional raingardens. However, as discussed before, we are seeking to convert hanging gardens and green walls into raingardens. These raingrdens are dynamic systems like other conventional gardens, hanging garden, and green wall systems currently being used. As a part of the operation and maintenance regime, it will be necessary to regularly water the plants during dry periods. Media will also need to be weeded, fertilized and pruned from time to time. Most of this are being taken care of companies that supply hanging garden and green wall systems. These systems are being supplied with built-in irrigation systems on request (Plant Connection, 2016; Mini Garden, 2016). With some modifications, the same irrigation system could be used to run stormwater through the garden during storm events. Therefore watering these raingardens during dry periods neither does require additional efforts nor any additional operational cost. It may also be necessary to replace media and plant material at regular intervals. Our future trials to select suitable plants for these raingardens will determine the periodicity of plant and media replacement. However, these are operational and maintenance aspects routinely being undertaken by owners of other green wall and hanging garden systems. Therefore, we anticipate a similar regime in these hanging raingardens too.

7 CONCLUSION

Suspended raingardens offer all the benefits that developers and owners look for while selecting LIDs for urban environments. They can be developed as modular units making it convenient to install and maintain. As the concept of a suspended raingarden is only an extension of green walls, they are likely to be adopted by developers and owners easily. More importantly, they are effective in removing target pollutants from the stormwater runoff to the desired level as can be seen from our trial runs. Considering all the above aspects, suspended raingardens can be termed as a viable alternative LID for the future.

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