GREEN ROOF

An Independent Study about Extensive Green Roof

"A building without a biodiverse green roof is wasting space."

- Matt Shardlow

Director of Buglife-The Invertebrate Conservation Trust

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ACKNOWLEDGEMENT

This independent study about green roof would not have been complete without the support of many people. First and foremost, I would like to thank my instructor of this project, Eva Monheim for the valuable guidance and advice. Her willingness to providing support regarding the field trip and outreach. Special thanks to Louise Clark for sharing the invaluable knowledge about the design, construction, and maintenance of a green roof. I would also like to thank Dominique Bayne, general manager of Green Roof Plants Nursery, who gave a wonderful and informative tour about the green roof plants.

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PROJECT SCOPE

This scope of this independent study about green roof is to develop a thorough understanding of the basic green roof assembly (extensive green roof especially), the general design process and the maintenance management. The knowledge then can be applied to the capstone design in North of Lehigh – Kensington in Philadelphia in 2017 spring, which green roof will be one of the proposed design elements.

GREEN ROOF INTRODUCTION

Definition

According to Edmund, a green roof is a roof or part of the roof that is vegetated to improve a roof's performance, appearance, or both. (Snodgrass and McIntyre 2010)

Category

Generally speaking, the green roof can be grouped into two categories: extensive and intensive. The differences between extensive and intensive green roofs are summarized in **Table 1.** Extensive green roofs are lighter and thinner in profile with relatively limited plant selections compared with intensive green roofs. For the future design purpose in the capstone site, this independent study will mostly focus on the extensive green roof.

Table 1. Extensive and Intensive Green Roof Comparison

TYPE >	EXTENSIVE	INTENSIVE
Use	Ecological landscape	Garden/park
Type of vegetation	Moss-herbs-grasses	Perennials-shrubs-trees
Benefit	Water, thermal, biodiversity	Water, thermal, biodiversity, amenity
Depth of substrate	3-6in	> 6in
Average weight	12.3-30.7 pound/square foot	36.9-102.4 pound/square foot
Cost	Low	High
Maintenance	Low	High

("Livingroofs.Org, The Leading UK Green Roof Website" 2016)

Benefits

In general, there are many benefits that green roofs can bring to the urban environment and improve the ecosystem services, ecologically, economically and psychologically. Actual benefits being provided by green roofs will vary depending on their particular locations and project scopes.

Ecological benefits

"The skin of the city can be transformed into a living landscape." – Walls and Pavements (1993)

- Reduce stormwater runoff

One of the greatest benefits of green roofs is to reduce the on-site stormwater runoff. Depending on the different types of plant community and substrate, the runoff co-efficients for

green roofs vary. Green roofs will typically be able to intercept first 5mm rainfall and retain between 15-90% rainwater in short term and up to 20% up to 3 months. By up taking the water in plants and retaining most of the rainfall in its substrate, green roofs could decrease the stormwater runoff volume and delay the peak flow rate of runoff entering the sewer system. ("Greenroofs101: Ecological Advantages" 2016)

Table 2. Runoff Co-efficients for Green Roofs

Type of Green Roof	Depth [mm]	Vegetation	Water Retention Annual Average [%]	Coefficient
Extensive	20-40	Moss/sedum	40	0.6
-	40-60	Sedum/Moss	45	0.55
-	60-100	Sedum/Moss/Herbs	50	0.5
-	100-150	Sedum/Moss/Grass	55	0.45
-	150-200	Grass/Herbs	60	0.4
Intensive	150-250	Lawns/Shrubs	60	0.4
-	250-500	Lawns/Shrubs	70	0.3
-	500+	Lawns/Shrubs/Trees	90+	0.1

("Livingroofs.Org, The Leading UK Green Roof Website" 2016)

- Improve water quality

Heavy metals and excessive nutrients in the rainfall will be absorbed by plants and bounded in the substrate so that fewer pollutants are being discharged into the groundwater, streams, and rivers. According to the London Ecology Unit, over 95% of cadmium, copper and lead and 16% zinc can be trapped in the vegetation and substrate. ("Greenroofs101: Ecological Advantages" 2016)

- Reduce Urban Heat Island Effect (UHIE)

Green roof plants and soils (like other green space) evaporate moisture, which can cool the air around buildings. Because of the cooler roof surfaces, the need for air conditioning consume is

reduced, which contributes to the reduction of the UHIE. ("Livingroofs.Org, The Leading UK Green Roof Website" 2016)

- Improve air quality

On one hand, plants reduce carbon dioxide and produce oxygen. On the other hand, plants can help to filter air, bind dust particles, and deposit in the growing medium, thus improve the air quality. Although this benefit would specifically have a noticeable effect when having a large area of green roofs, which small individual green roofs may contribute little positive impact. It has been proved that 1000 ft^2 of vegetated roofs could remove 41 lbs. of airborne particles per year. ("Greenroofs101: Ecological Advantages" 2016)

- Provide wildlife habitats and increase biodiversity

Researchers in Switzerland and the United Kingdom have clearly shown that green roofs can provide some habitats for wildlife in varying degree. Even simple sedum blankets can support a limited range of invertebrates and pollinators, especially bees during blooming time. ("Livingroofs.Org, The Leading UK Green Roof Website" 2016) The size of green roofs, plant selections, the depth of the substrate, microenvironments, and other factors will contribute restoring habitats and increase the biodiversity in an urban context.

- Recycled materials

Various green roof components are made of recycled materials. For example, the drainage panels (from greenroofsolutions) are made of 100% recycled high-density polypropylene (HDPP). ("Drainage | Green Roof Products | Green Roof Solutions" 2016)

Economic benefits

"The initial extra short-term capital costs of green roof construction can be offset through long-term energy and maintenance savings."- http://www.greenroofs.com

- Less energy cost

  Several studies have shown that a green roof can help to significantly reduce the energy cost of the building by providing better roof surface insulation. A study from Nottingham Trent University had compared the temperatures under roof membranes of a normal conventional roof and a green roof. The data is shown in **Table 3**.

Table 3. Membrane Temperature Comparison between a Conventional and a Green Roof

ROOF TYPE >	CONVENTIONAL	GREEN ROOF
Winter (Mean Temperature 0˚C)	0.2˚C	4.7˚C
Winter (Mean Temperature 18.4˚C)	32˚C	17.1˚C

("Green Roofs And Energy Conservation" 2016)

- Longer roof life

Green roofs can protect the roof membrane from harsh weather conditions (such as UV radiation, frost, ice and extreme temperatures) and prevent roof system from leaks and erosions. ("Greenroofs101: Economic Advantages" 2016)

- Increase brand value and potential market profits

Installing green roofs can largely increase the brand value of a public or private sector. For example, incorporating with PECO 2020 initiatives, a 47000 sq ft green roof was constructed on headquarter,

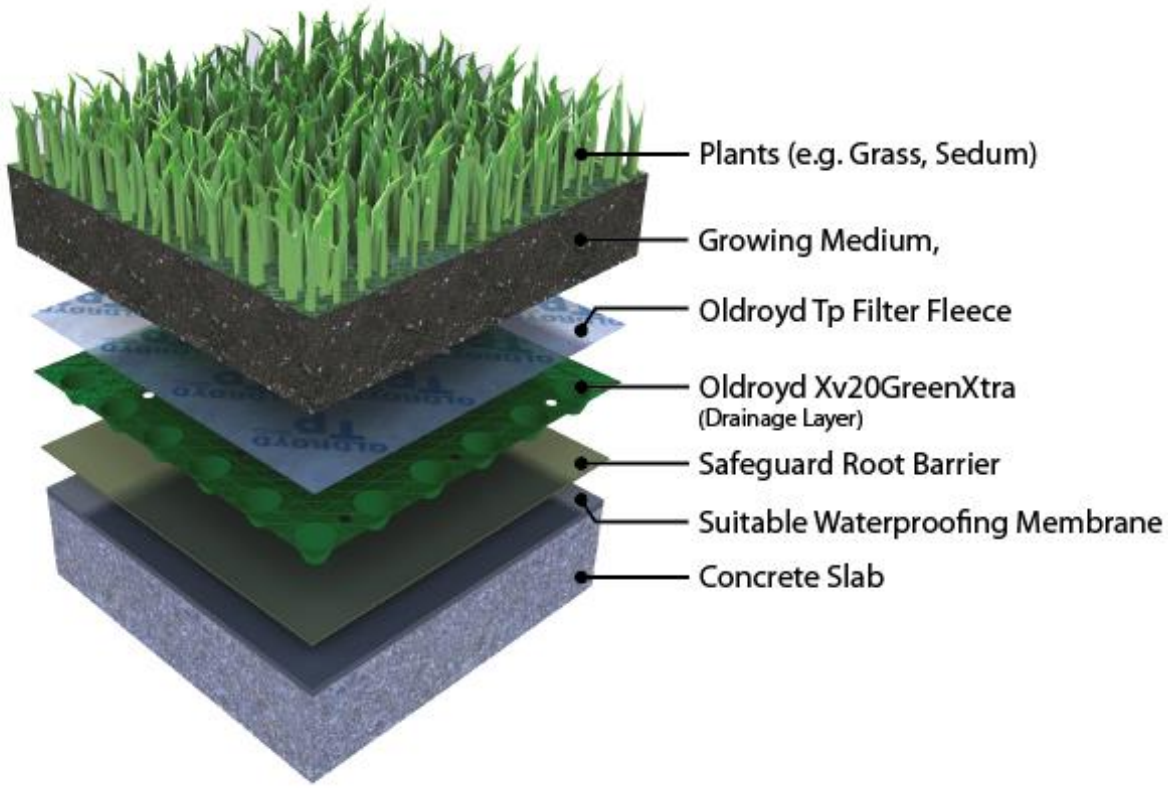
which made PECO a leadership role in becoming better environmental stewards. (Denis O'Brien, President and CEO of PECO Energy Co.)

Aesthetic and psychological benefits

Green roofs can enhance building aesthetics and help visually ease the stress created by a lack of green space in urban communities. ("4.3 Green Roofs | Philadelphia Water Stormwater Plan Review" 2016)

Components

Figure 1. Green Roof Layers



A typical green roof layers, from bottom to top, include waterproofing membrane, root barrier, drainage layer, filter fleece, growing medium, and plants.

Protection and moisture storage layer

- Air layer creates space for air to evaporate to alleviate constant moisture against the roof membrane (see **Figure 2**).

Figure 2. Air Layer

- Root Barriers prevent roots from penetrating the roof membrane (6-12” overlapping, taped with Root Barrier Tape to provide a continuous layer, see **Figure 3** and **Figure 4**).

Figure 3. Root Barrier

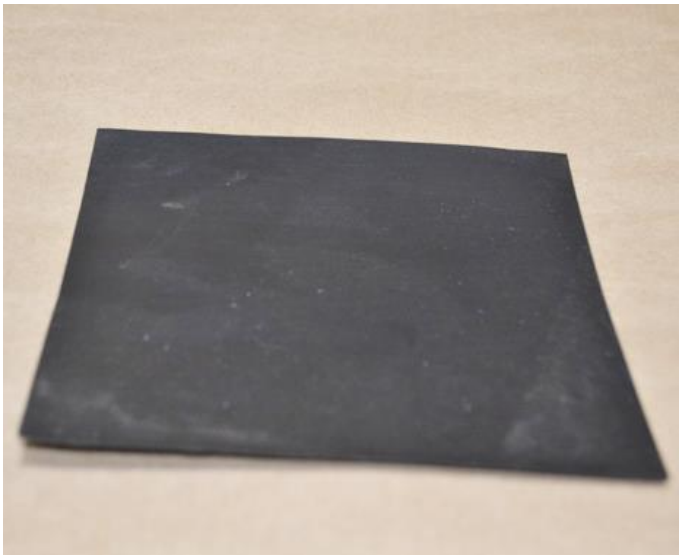
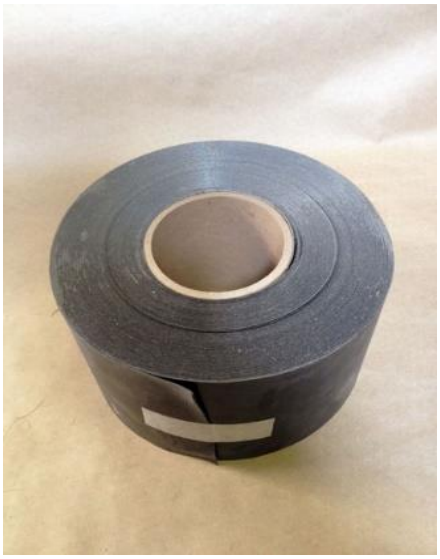


Figure 4. Root Barrier Tape



- Protection Mat (above Root Barrier) protects against mechanical damage and damage during construction (see **Figure 5**).

Figure 5. Protection Mat

Drainage layer

Above the root barrier layer, a drainage layer should be installed that serve purposes of carrying away excess water and holding enough water for plant growth. (Snodgrass and McIntyre 2010) A Drainage layer usually consists of aggregate drain, geocomposite drain, or a combination of these two (see **Table 4**).

Table 4. Comparison of Aggregate Drain and Geocomposite Drain

DRAINAGE TYPES>	AGGREGATE	GEOCOMPOSITE
Picture		
Advantage	Holds more water/Offers a more hospitable environment for root to spread and establish	Lighter/Cost less/Less labor-intensive/Shedding water quickly
Disadvantage	Heavier/Less suitable in higher humidity areas	Not provide the same horticultural benefits for plants

(Snodgrass and McIntyre 2010)

Drainage outlets, such as roof drains, gutters, scuppers and associated piping, must be taken into consideration and be accessible to maintenance. In addition, it is important to know that drainage capacity must increase to the roof drainage outlets so that large quantities of drainage material, usually rounded stones, are installed along the eaves and near outlets – surface drains, pipes, gutters, downspout, and other means. ("Greenroofs101: Drainage" 2016) Additionally, it is recommended to provide additional drainage and maintenance access by install a shallow layer of gravel along the roof perimeter ("March 2005 Guest Feature" 2016) (see

Figure 6).

Figure 6. Shallow Layer of Gravel along the Roof Perimeter

Filter layer

A filter fabric should be installed in between the growing media and the drainage layer, which will keep the “media from clogging up the drainage while allowing water to flow freely.” ("Drainage | Green Roof Products | Green Roof Solutions" 2016)

Growing medium (substrate)

The green roof growing medium is one of the most critical factors for a project success. It is not typical garden soil nor nursery medium, which are fine, earthy, heavy, and nutrient-rich. The key characteristics of the growing medium include:

- Good drainage and aeration
- Lightweight
- Structurally stable

- Resistance to decomposition and compression

For extensive green roof (less than 6 inches), it is recommended that a blend of at least 80 percent coarse lightweight mineral aggregate and up to 20 percent organic material to limit weeds establishment.

Figure 7. Green Roof Growing Medium

Credit: Jing Bian

Green roof plants

According to Snodgrass, suitable green roof plants should be easily established, lightweight when mature, shallow lateral root system, resistant to windy and harsh environment, and require less nutrient and maintenance. (Snodgrass and McIntyre 2010) Hardy succulents including *Sedum*, *Sempervivum*, *Talinum*, *Jovibarba*, and *Delosperma*, and some cacti (*Opuntia*) have been found to become most suitable green roof plants. Snodgrass also suggested that annuals, perennial, grasses, and bulbs should be blended in to help fill in bare spots, add a pop of colors and different textures.

(Snodgrass and McIntyre 2010) Common methods of green roof planting include cutting, plugs, seeds, and prevegetated modules. (See **Table 5**)

Table 5. Green Roof Planting Methods

METHOD >	CUTTINGS	PLUGS	SEEDS	MODULES/MATS
Picture				
Advantage	Establish quickly if properly installed /Less complex process/ Inexpensive	More ambitious planting design	NOT RECOMMEND if planted exclusively on green roof	Good for windy and steeper sloped locations/ Rapid uniform cover/Effectively prevent weeds
Disadvantage	Limited plant choices/Less detailed design planting/Require some expertise to install	Different growth rates of different plants	Take too long to establish	Expensive/Limited plants palette/ Heavy/Usually need irrigation during establishment
Planting Time	Spring/Autumn	Growing period (avoid summer)	Spring/Autumn	Any time

("Greenroofs101: Plant Material" 2016, Snodgrass and McIntyre 2010)

Other elements

- Consider to incorporate irrigation system in the green roof design. Green roofs may require additional water, especially during the plant's establishment period.
- Safety control needs to be integrated into the design for fall protection and maintenance access. For example, railing along the roof edge (see **Figure 8**), or safety anchors/railing every certain distance (see **Figure 9** and **Figure 10**).

Figure 8. Railing along the Roof Edge

Figure 9. Fall-protection Anchor

Figure 10. Fall-protection Railing

Credit: Jing Bian

Maintenance

Long-term maintenance is essential and required to ensure a successful green roof project. According to the Philadelphia Water Department Green Roof Design Guideline, green roofs must be inspected and maintained during early establishment and regularly, see **Table 6**.

Table 6.1. Green Roof Early Maintenance Schedule

Early Maintenance Activity	Frequency
Water vegetation at the end of each day for two weeks after planting is completed.	Daily for two weeks after installation
Water vegetation regularly to ensure successful establishment.	Every four days during periods of four or more days without rain, June through August for the first year after installation
Hand-weed non-target/invasive plants	Four times per year for the first 24 months after planting
Inspect vegetation for signs of disease or distress.	Biweekly for the first year after installation

("4.3 Green Roofs | Philadelphia Water Stormwater Plan Review" 2016)

Table 6.2. Green Roof Ongoing Maintenance Schedule

Ongoing Maintenance Activity	Frequency
Roof drains must be cleared when soil substrate, vegetation, debris or other materials clog the drain inlet. Under normal operating conditions, all roof discharge must be filtered and medium must not be vulnerable to migration toward the drains. Sources of sediment and debris must be identified and corrected.	As needed
Plant material must be maintained to provide a minimum of 90% foliage cover during warm months. If coverage rate is declining, determine the reason (e.g., soil nutrition or soil moisture conditions) and implement remedial measures.	As needed
Preferentially, weeding must be done manually, with herbicide use limited to extreme instances of weed infestations that compromise the plant cover integrity. Weeds must be removed entirely.	As needed
Inspect root development. If root zone is not well developed, determine the reason (e.g., soil nutrition or soil moisture conditions) and implement remedial measures.	Quarterly
Projects with permanent irrigation must be inspected and irrigation dosing rates adjusted to optimize plant performance and water use efficiency.	Quarterly
Growing medium must be inspected for evidence of erosion from wind or water. If erosion channels are evident, a problem with the drainage system or with the green roof medium is indicated. Surface ponding or runoff must not occur except during very large rainfall events. After correcting the problem, refresh the affected areas with additional growth medium and provide temporary soil stabilization.	Quarterly
Manually cut detrital herbaceous vegetation from the previous growing season to four to six inches above the ground.	Annually
Inspect drain inlet pipe and containment system.	Annually
Test growing medium for soluble nitrogen content. Fertilize as needed.	Annually

("4.3 Green Roofs | Philadelphia Water Stormwater Plan Review" 2016

CASE STUDIES

Case Study I – Morris Arboretum Horticulture Center, 9/17/2016

Introduction

Two green roofs were constructed in 2010 at Morris Arboretum Horticulture Center at Bloomfield Farm, in Philadelphia. One is 2500 sq ft extensive roof with 4 inches of media (see **Figure 11**). The other one is 3650 sq ft intensive roof with 8 inches of media (see **Figure 12**).

Figure 11. Extensive Green Roof

Figure 12. Intensive Green Roof

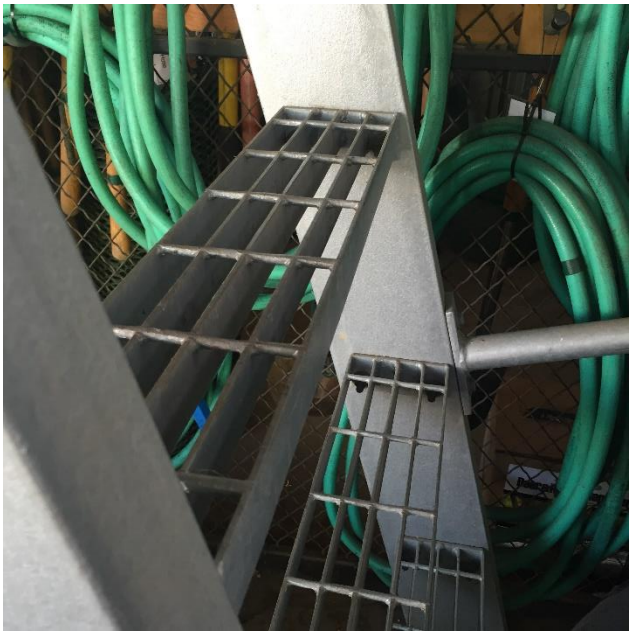
Credits: Jing Bian

Key lessons

- Design
    - It is important to take into account that how to get the supplies and tools up to the green roof. Currently, the tools are transported by a bully assembly with a basket.

- Irrigation system needs to be taken into account especially for an intensive green roof, in order to help newly installed plugs to establish successfully.
- Another safety factor: steel grid stairs to hold on while climbing. (see **Figure 13**)

Figure 13. Access Stair up to Green Roof at Broomfield Farm



- Pre-construction
  - Know the growing medium pH. It will affect the plant palette. It is recommended that a pH of 6.0 to 7.5 for green roof soil.
  - Rich soil is not recommended which will encourage weeds.
  - Good to seed around October.
- Maintenance
  - It is recommended that leave the grasses or dead growth in winter for wildlife habitat and fall/winter interest.
  - Only use hand tools for green roof maintenance to prevent penetrating the membrane.

- Fungicide, pesticides, and fertilizers are not recommended during maintenance to suppress weeds.

Case Study II – PECO Green Roof in Downtown Philadelphia, 10/18/2016

Introduction

The PECO Green Roof was completed in 2009. It is a 47,000 sq ft retrofit green roof on the eighth floor of PECO's headquarters in downtown Philadelphia. 90% of the area was covered with TYPE I - extensive roof with low-growing sedums (see **Figure 14**) and 10% of the area received TYPE III- intensive roof treatment with native grasses and perennials along the pedestrian walk (see **Figure 15**).

Figure 14. TYPE I

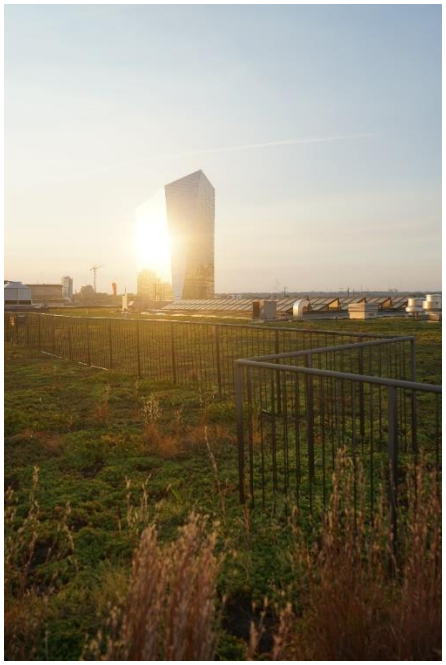
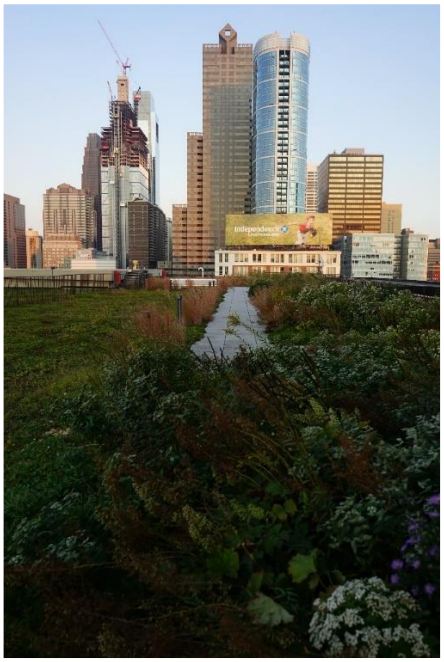


Figure 15. TYPE III



Credit: Jing Bian

“The selection of green roof types for this project was driven partially by the needs to have a lightweight system in the area of this size,” said by Charlie Miller, President of Roofscapes, Inc. The site is currently maintained by PHS 4-5 times a year.

Key lessons

- Design
    - It is a good example of setting aside consciously apart from the roof where there was adequate load capacity to accommodate a more elaborate intensive landscape, where the rest of the roof as a backdrop. (see **Figure 15**)

      Figure 16. PECO Green Roof

Credits: Jing Bian

- Plants
    - The roof was originally planted with cuttings. However, due to the location’s high wind pressure and project’s late-season installation, sedum mats were finally used as a better approach.

- Four intensive planters increase the biodiversity of the project and add interest to the visual amenity. It is a way to make the space more engaging and more useful by using small components.

- Maintenance
  - Maintenance includes taking data (percent coverage, species coverage, medium conditions, weather conditions, heat sensor), taking annual soil samples, weeding, and spreading cuttings from the denser area of the roof on to the less dense area.

Case Study III – Green Roof Plants at Emory Knoll Farm, 11/14/2016

Introduction

Emory Knoll Farm in Maryland is the first nursery in North America to focus on green roof plants, and it has been the nation's leading green roof plants supplier and expertise (extensive green roof system especially) since 2000. They provide "over 100 varieties of green roof plants including sedums, ground covers, herbaceous perennials, and grasses." ("Emory Knoll Farms" 2016) The sedums are available in single species sedum cuttings and plugs (see **Figure 17**), as well as different mixed flats that can thrive in a wide range of project areas (see **Figure 18**), for example, Leafy Greens, which consists about 10% Sedum album (see **Figure 19**), about 10% Sedum rupestre 'Angelina' (see **Figure 20**), about 10-20% Sedum spurium (see **Figure 21**), and the rest are Phedimus takesimensis 'Golden Carpet' (See **Figure 22**). This trip to the green roof plants nursery is a great help to understand the green roof plant community. Two books written by Edmund C. Snodgrass – Green Roof Plants and The Green Roof Manual – are excellent sources and reference for green roof design.

Figure 17. *Sedum rupestre* 'Angelina' syn.

Figure 18. Mixed flats – Leafy Greens

Credits: Jing Bian

Figure 19. *Sedum album*

Figure 20. *Sedum rupestre* 'Angelina'

Figure 21. *Sedum spurium*

Figure 22. *Phedimus takesimensis* 'Golden Carpet'

Key lessons

Figure 23. Two Extensive Green Roof Demonstration at Knoll Farm

Credits: Jing Bian

- There are two extensive green roof demonstrations. They are both 4 inches depth. The left one contains 4 inches medium only, while the right one contains 2 inches of medium and 2 inches of rock layer. It is found that the left one with rock layer can retain as much as twice water in its system than the other one. (see **Figure 23**)
- Mixed flats are recommended since they consist a wider range of plant selections and thus prevent large dead patches.

- It is recommended to have fewer grass species on the extensive green roof unless full-time maintenance is available because they can be weedy, cause fire risk and compete with sedum.
- It is recommended to blend small percent of bulbs to boost the color and texture of the extensive green roof.
- Sedum hybridum “Immergrunchen”, is a beautiful and tough plant, creating nice fall color and it can keep its foliage during winter. However, one disadvantage is the foliage may look like dead patches. (see **Figure 24**) It is recommended to educate the client and the maintenance team.

Figure 24. *Sedum hybridum* “Immergrunchen”

Credits: Jing Bian

FUTURE IMPLEMENTATION

This independent study set up an excellent foundation knowledge of green roof, especially extensive green roof. The knowledge of design, plant selection, and maintenance management plan will be applied to the capstone design in North of Lehigh – Kensington in Philadelphia.

Louise, Eva and Jing at Emory Knoll Farm, 11/14/2016

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