CONSIDERATIONS FOR PLANT SELECTION IN GREEN ROOFS

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ABSTRACT

It is the vegetation layer that creates the living skin on the rooftop in green roofs, controls the long-term effect of any green roof installation and provides a naturally evolving and changing roofscape. Therefore, plant layer is the most challenging and important element of green roofs. A successful green roof system needs a meticulous plant selection. Considering aesthetic values, different designs are available which incorporate various plant species, but the vegetative layer requires wise consideration in terms of the projected goals and existing conditions. Design goals of the roof define the plant selection process, whether the goals are linked to aesthetic values, performance, education or function. Like any landscape at ground level, vegetative layer that propagate primarily on a green roof may not continue to flourish in the long term as a result of fluctuation in climate and other critical factors. While, aesthetic values and ecological aspects are crucial criteria in roofscape, the selected plants must first be survivable. The plant selection process relies on the building structure, aesthetic values, micro-climate condition, existing maintenance and the condition of growing medium.

Necessarily, green roof vegetation must be less nutrient-reliant and tougher than plant species currently found in ground level landscape. In this case Crassulacean acid metabolism (CAM) plants are suggested. In Overall, the best plants for green roofs environment are cold, heat, drought, wind, sun, disease and insect tolerant and preferably native plant species. Drought resistant, durable and low maintenance plant species are recommended for extensive green roofs; however, almost infinite plant selection is used for intensive green roofs.

Keywords: native plant species, vegetative layer, green roofs, Crassulacean acid metabolism plants

1. INTRODUCTION

In recent years, green roofs converted from a horticultural use to a flourishing growth industry - mainly because the environmental benefits of green roofs are now beyond dispute, whether for governmental or industrial complexes or for residential buildings in urban or suburban context [1]. Green roofs provide ecosystem facilities in cities, including mitigated urban heat island effect, balancing of building temperature, improved run-off water management, and improved urban biodiversity [2].

Renzo Piano, the contemporary architect, likened the green roof "like lifting up a piece of the park and putting a building under it" [3]. Burke (2003) has the same opinion about the green roofs :"Imagine a building design in which the native landscape on the site is merely lifted up into the sky, and the building program is placed underneath."[4] Both Burke's and Piano's statements show one dimension of current philosophy about the green roofs as an extension or continuation of ground-level landscaping. Another philosophy refers to a different opinion which believes that a rooftop has a different micro-climate. As the roofscape is a basically different environment than the ground level landscape, using local plants on rooftops is not very simple and if done inappropriately can lead to wide mortality of plants [5].

Designers try to improve the environmental sustainability of their society by adding more vegetation through green roofs, but without enough knowledge about the suitable greenery system for green roofs, the effort will be a failure. Examples of these failures are Manhattan's green roofs [6]. Plant species selection for vegetative layer of a green roof is a crucial decision that determines the viability of the green roof during a long period [7]. In order to select the suitable plant species, the purpose and type of the green roof must be considered [1]. Plant selection process can be sophisticated and problematic; however, there are certain properties and characteristics in a plant species that can be useful in the selection process [7].

In this paper, the selection process of vegetative layer in green roofs was described.

2. PLANT SELECTION PROCESS

Since a large number of plant species exist in each region, selecting a suitable plant for green roofs is difficult. Each green roof should be survivable in the regional climate in addition to its own particular microclimate. With these limitations, information must be gathered from various conditions and climates to be able to propose the best plant species for the green roof. Each green roof designer, installer, contractor and owner must do their duties properly to prevent recognized problems. Use of research resources to perform a correct decision on a green roof project, can save time and resources drastically [7].
Plants selection in green roofs has many criteria which are interrelated. Climate and micro-climate and environmental factors have a significant role in the selection of plant species. Especially, average low and high temperatures, extreme cold and hot temperatures, irradiance level, wind speed, and the distribution and amount of rainfall throughout the year will specify what species can survive in a specific region. Drought resistance is important as a high rate of irradiance and low soil moisture characteristics are integrated to shallow growing medium systems [8, 9]. Succulents like sedums, are usually selected in green roofs due to their capability to survive harsh conditions. More accurate maintenance and deeper growing medium allow to use plants that they show less resistance against drought [10]. Appropriate selection of plant species guarantees the survival of each plant and stability of their population [8], which impacts the extent of advantages that is received from a green roof [8, 10, 11].

Other determinant factors in plant selection process are the project purpose and the favourite roof appearance. If a more natural environment is the aim of the project, local species may be chosen. Irrigation is, however, typically important not only to use native plants on the roof [12], but for long term survival of individual plants and the plant community as a whole (Durhman, Rowe, & Rugh, 2006), leading to the need for further maintenance (Leigh Jane Whittinghill, 2012).

Another factor that influences the plant selection process is the canopy structure of plant species. Plants should be selected that have mostly horizontal leaf distribution and/or an extensive foliage development, in order to reduce the transmission of solar radiation. It should be noted that the main role of canopy in green roofs is shading (Barrio, 1998).

With a suitable green roof structure and sufficient depth of growing medium (with higher water supply, nutrients and root penetration volume) growing a variety of plant species in complex mixtures is possible. The use of different plant species including herbs, grasses, perennials and trees help to make the roofscape a natural environment.

Other factors that should be considered when selecting plants, include the rate of plant growth, nutrient needs, and sensitivity to pollution. The type of plant species and their location on the roofs also depend on the geographical location, the rate of air pollution, rooftop height, shade, growing medium depth and composition, accessibility of roof, run-off water management purposes, irrigation method, thermal insulation purposes, installation techniques and maintenance. The capability of plants to survive in a roofscape environment is directly related to the amount of budget and maintenance time allocated to the project, especially in the first two years when they are in growth stage and sensitive.

Similarly, microclimates in the roofscape must be considered. Roof orientation and slope may affect the intensity of the solar radiation and growing medium humidity, adjacent buildings may shade a part of the roof, air vents from air conditioning and heating units may dry the soil out, and industrial chimneys may stunt the plant growth by chemical pollution.

Furthermore, installation technique may impact plant choice. They can be established on the ground as plugs or established on a mat, tray or blanket, and then positioned on the roof directly - or on the roof growing medium through seed, plugs, or cuttings seed. The availability of the plants in each of these forms may affect the selection of plant species. Additionally, the installation method may determine the amount of irrigation needed throughout the initial installation. And the long-term need for irrigation is another important factor in plant selection process. And the long-term need of individual species for irrigation will also be an issue in plant selection (Getter & Rowe, 2008).

2.1. Sedums

Sedum is a very suitable and common plant for using on a green roof. These small plants grow horizontally rather be rising vertically. They create good coverage and protect the roof membranes against sun light. Sedum is available in mats, which can be easily rolled onto a rooftop after installing the insulation and drainage system (Lambeth, 2014)..They are resistant to high temperatures, drying winds and long periods of drought, as many are succulents. Sedums have high water-use efficiency and are able to store water in their leaves which enables them to survive drought conditions where other plants might not. Sedum plants in a 6-centimeter growth media depth could support growth with 28 days between watering. This is an important benefit when irrigation on a rooftop is limited or non-existent (Luckett, 2009) means that they need minimum support and are easy to be installed as a component of a roofscape (Castleton, Stovin, Beck, & Davison, 2010). The photo below displays a type of sedum known as Spurium Summer Glory. Many various types of sedum exist. But generally they are very similar which makes them a proper choice for roofscape environment.

Figure 1: Sedum (Spurium Summer Glory) plants on a green roof

Sedums utilize many of the survival methods that most drought and high-temperature-tolerant plants employ, including storage of water in leaves and stems, Crassulacean acid metabolism (CAM) photosynthesis (which means that these plants fix CO_2 at night and, therefore, reduce water loss), and shallow root system.

Many types of sedum are succulent low-growing plants that grow in the hot sun and long periods of drought, but have the capability to grow in shade and low temperature as well. Sedums are also generally long-lived and are self-propagating or re-rooting plants which help make them a cost-effective choice for the roof. Most sedums are also famous for the capability to simply propagate and to provide quick coverage over a rooftop (Luckett, 2009).

2.1.1.The Benefits of Installing Sedum Roofs

The benefits of installing sedum roofs include:The sedum roofs improve the thermal comfort of the occupants drastically: The sedum mats protect the roof from direct sunlight in summertime, absorb less heat and help to cool down the interior spaces consequently. In wintertime, they act as an insulating layer and prevent heat loss. Besides, by preventing the solar radiation strike to roof's membranes, they extend the lifespan of roofs. They absorb the rainfall water and prevent the flash floods in urban areas and consequently decrease the load on sewer system. They improve the air quality and help to increase the biodiversity in urban areas, especially; they are considered a proper nest for rare invertebrate organisms (Lambeth, 2014).

2.2. Native Plant Species

The origins of modern green roofs were in Europe, where they were primarily used for run-off water management. Generally, these roofs were planted with succulent, drought-tolerant, low-growing, plant species, particularly Sedum. In addition to sedum, native plants are used in green roofs. Nowadays, there is a great interest to use a variety of plant species, with a especial focus on native plants in green roofs (Kephart, 2005; MacDonagh, Hallyn, & Rolph, 2006; Schroll, Lambrinos, & Sandrock, 2009). In Peck's (2008) book, Award Winning Green Roof Designs, 45% of green roofs that have been awarded used native plant species as vegetative layer. Green roofs covered by local plants include over half (59%) of the case studies about green roofs(Cantor, 2008).

In traditional gardening, native plants are suggested due to lower cost. They typically do not need too much soil preparation, irrigation, fertilizers, or pruning. Native plants are also bring native fauna to the roofscape and contribute to increase the urban biodiversity (Luckett, 2009).

It is known that they have evolved to survive and grow in their regional meteorological conditions, diseases and pests (Dewey, Johnson, & Kjelgren, 2004; White & Snodgrass, 2003). Planning green roofs with native plant species, wherever possible in addition to decreasing the need for maintenance and irrigation, improves the pollination, habitat and food resources for local fauna (Brenneisen, 2006; Lundholm, 2006). Incentives or policies for nature and biodiversity conservation may support green roofs with native plant communities (Oberndorfer et al., 2007).

However, the drought tolerance of selected species, depth of substrate, and management practices, should be considered in design and planning stage

(Pledge, 2005). In recent years, interest in the production of vegetables and herbs on green roofs has been increasing (Loder & Peck, 2004; Pledge, 2005; Leigh Jane Whittinghill, 2012; Leigh J Whittinghill & Rowe, 2012).

Dvorak and Volder (2010) persuade study of local plant species since as ecologist Aldo Leopold points out, "The native plants and animals keep the energy circuit open; others may or may not (p. 255)". (Leopold, 2009).

2.2.1. Negative Aspects of Choosing Native Plant Species in Green Roofs

There are some problems in connection with using native plants in green roofs environment. As previously mentioned, the green roof environment is not like a typical garden environment in ground level. As a result, the green roof faces many environmental problems that are unique and are not found in a typical ground level garden (Luckett, 2009). While it should be expected that green roofs with local vegetation provide more biodiversity than sedum roofs, in certain geographical areas there may not be local plant species capable to survive from the stresses existing in a green roof (Getter & Rowe, 2006). In addition, as some local species have grown in deep soils of especial nutrient regimes and microbial communities that are not simple to reproduce on roofs, the green roof environment is not sometime an appropriate match for native plant species (Brenneisen, 2006; Dunnett & Kingsbury, 2004; White & Snodgrass, 2003). Prairie plants usually need deeper growing media depths (typically more than 40 cm in depth) than can be provided on a green roof. Grasses also make a greater size of biomass, which can create a fire hazard as well as structural roof loading problems. In addition, most local prairies also require intervallic fires to keep their natural balance, which is not possible to replicate on green roofs. Furthermore, using native plant species on green roofs is usually further restricted by a lack of experience and skill for maintenance. Seeds do not simply bud on rooftops (White & Snodgrass, 2003) The other problem is the type of local plant species existing in a special area(Luckett, 2009). For above reasons, many local plants are not suitable to be used in green roofs (Luckett, 2009). Therefore greenhouse experimentation and trials become essential to decrease potential error and cost.

2.3. Crassulacean Acid Metabolism (Cam Plants)

Greenery systems have different strategies for coping with thermal, drought, and light stress. The three strategies affect each other. High level of temperature and light in the environments simply lead to drought stress. Therefore, drought coping mechanisms like evaporative cooling, leaf position change and leaf reflection are emerged. As the water is an essential element for plants to live, drought stress is a necessary factor in their survival. The level of drought resistance is the crucial factor for creating a successful thin layer vegetation in green roofs (Dunnett & Kingsbury, 2004; T.-C. Liu et al., 2012)

The crassulaceae family includes the succulent plants that exist in arid, dry environments where water is the scarcest resource. the genus Sedum is a member of the crassulaceae family which has evolved as one of the hardiest succulents that have the capability to survive the severe green roof environment (Luckett, 2009).

Figure 2: succulent plants, crassulaceae family, genus Sedum

Succulent plants resist drought stress through strategies like surface cuticles, succulent foliage, hairs or spines, the Crassulacean acid metabolism (CAM), and mucilaginous substances (Kluge, 1977; H. Lee & Griffiths, 1987). CAM plants deal with drought stress by accumulating malice acids, succulent flesh of their leaves and through closing stomata (K. S. Lee & Kim, 1994). CAM plants existing in arid regions have coped with high fluctuation of temperature between night and day, and may store large quantities of organic acid. Therefore, the proper environment for desert-adjusted CAM plants is extremely comparable to roofscape environment, which makes them appropriate plants for cultivation on rooftop. Rainforest epiphytes are not proper for thin layer of vegetation in green roofs (T. C. Liu, G. S. Shyu, W. T. Fang, S. Y. Liu, & B. Y. Cheng, 2012). Epiphyte is a plant that grows on another plant and use it as substrate but is not parasitic, such as the numerous bromeliads, ferns, orchids and air plants growing on tree trunks in tropics.

Figure 2: Epiphyte plant which grows on another plant

3. VISUAL APPEARANCE

As we are human beings, our expectations of aesthetics must be met. During the process of plant selection, it is necessary to think about the favourite appearance of the roofscape. Different class of green roofs consist of eco-roofs, which are green roofs with vegetation that seasonally turn brown as a result of seasonal climatic changes for instance, many local perennials and prairie grasses will normally brown and dry in the summer. However, it is a natural occurrence, some may reject this phenomenon (Rowe & Getter, 2010), and brown roofs, which are roofs covered with growing mediums and vegetation to recreate or imitate environment of brown-field sites (Tay & Sia, 2008). The appearance of green roofs will vary periodically. During the cold season or seasons with little precipitation, certain vegetation which may have been colourful and bright throughout the summer season may look dull and grey (Tay & Sia, 2008). Evergreen plant species can be considered in green roofs system in order to stay green constantly (GODFREY ROOFING INC). In the case that the roofscape is not visible and was installed principally for its practical characteristics like runoff-water retention, visual appearance may not be an important issue. Extensive green roofs can provide this capability, probably without the added costs of structural reinforcement to the construction. The aesthetic value of the green roof will continuously vary during the growing season and over time. Plant succession and competition will happen as in any landscape. In the same way, identical plant palettes will behave and look differently as a result of local climate (Getter & Rowe, 2006).

Higher humidity levels and deeper growing medium makes it possible for a bigger number of plant species to survive, but also lets weeds to invade. On a shallow extensive roof, most herbs and grasses cannot survive due to the shortage of moisture, consequently making them relatively low maintenance roofs, as very little weeding is required.

Lots of people prefer naturalistic weedy roofscapes not aesthetically pleasing. However, people will usually accept naturalistic roofscapes if it is clear that the roofscape was designed and is being controlled (Nassauer, 1995).

4. PLANTS FOR EXTENSIVE GREEN ROOFS

Plant species in extensive green roofs have to survive drought, intense wind exposure, solar radiation, low nutrient supply, extreme temperatures, and limited root area (MacIvor & Lundholm, 2011).

Qualified plant varieties are those growing in harsh geographical locations with restricted nutrient supply and inadequate moisture, like arid mountain environment, dry and semi desert meadows and coasts. The main varieties belong to the succulent plants. These plants have the potential to accumulate high quantities of water in their leaves, are stress tolerant and survive simply from drought periods. It is essential that plant species which are local be considered in order to improve biodiversity (MacIvor & Lundholm, 2011).

Industry experience and long-term research have led professionals to suggest extensive green roof vegetation be low-growing, fast-establishing, cushion-forming or mat-forming with succulent leaves and capability to accumulate water, efficient reproduction and shallow spreading roots (Dunnett & Kingsbury, 2004; MacIvor & Lundholm, 2011; Snodgrass & Snodgrass, 2006; White & Snodgrass, 2003).

Media depth and composition have a key effect on plant selection for roofscape (Getter & Rowe, 2006). Plant species in extensive green roofs are typically restricted to grasses, moss, sedums, and herbs as a result of the shallow growing medium. Low height perennials are usually proper choices as they have shallow roots. Sedum plants with fibrous roots keep water, survive in droughts, and hold themselves in place throughout rain or wind. Similarly, Alpine plants have been chosen as they are very resistant to harsh weather conditions and have a similar condition to plants in roofscape. Drought resistant plants are normally more tolerant to hostile climatic conditions and comply well with the low maintenance requirements of an extensive green roof (GODFREY ROOFING INC).

The ideal growing medium of an extensive green roof includes a balance of well-drained, lightweight, materials, has sufficient nutrient and water-holding capacity, and will not decompose over time. Shallow media depths available on extensive green roofs may drop the humidity level very fast and typically do not support deep-rooted grasses, woody species, and many perennial or annual flowering plants. On the other hand, shallow growing medium usually prevent the growth of many unwanted weeds, and many desirable plants naturally can grow under these shallow conditions (Getter & Rowe, 2006).

5. PLANTS FOR INTENSIVE GREEN ROOFS

Intensive Green Roof, Roof Garden, Rooftop Garden, Garden Roof, -

Structural loads are a main concern when considering shrubbery and trees and for a roofscape. In order to increase the growing media depth in intensive roofs, supportive walls can be employed. Trees are higher and are more exposed to air flow pressure than other vegetation. Additionally, the size of crown and leaves in a tree influence its susceptibility to wind. In order to provide extra support, a tree typically should be integrated into the green roof system via cabling around the root ball; this is called anchoring .(GODFREY ROOFING INC)

An intensive green roof is recognized by its large domain of vegetation ranging from small trees to herbaceous plants with advanced irrigation systems and professional maintenance. A typical media depth of an intensive green roof is 15 cm or more. Intensive green roofs provide a great potential for biodiversity and design. This system includes every scale from small personal gardens to large scale public parks. Plant design and selection influence the maintenance requirements significantly. Urban roof farms, vegetable farms on roofs, or rooftop farms are obviously intensive green roofs and need higher nutrient supplies and maintenance (greenrooftechnology).

No	Plant Type	Positive Aspects	Negative Aspects
1	Sedum Mats or Pre-Grown Vegetation Blankets	Instant established and neat vegetation carpet.	Hi Cost
			Low Bio diversity potential
2	Plug Planting - Planted at densities of 15m^2	Can influence plant selection and design	May take time to establish
		Lower cost than mats	
3	Sowing Seeds or Cuttings	Selection and sowing of desired seeds	Takes 1-3 years to establish vegetation cover
		Cost effective	Sowing can only take place in spring or autumn
4	Natural Colonization	High Bio diversity	Takes time to establish
		Minimal Cost	Aesthetically not to everyone's taste

6. CONCLUSION

Plant selection process can be sophisticated and problematic; however, there are certain properties and characteristics in a plant species that can be useful in the selection process. The selected plants should be resistant against the climatic conditions of the specific location and geographical region. The best plants for green roofs environment are cold, heat, drought, wind, sun, disease and insect tolerant and preferably native plant species. Drought resistant, durable and low maintenance plant species are recommended for extensive green roofs. However, almost infinite plant selection is used for intensive green roofs. The long life expectancy, desired visual look, level of maintenance and low growing shallow roots which will be required must be considered [3-5]. Plants must also require little to no irrigation or fertilizer input [1]. The selected plants should be resistant against the climatic conditions of the specific location and geographical region. As a rooftop's exposure level to outdoor weather is high, climatic parameters are often magnified on a roof top. Therefore, it is necessary to take into account a plant species' ability to survive against meteorological fluctuations, temperature, sun/shade, humidity, frost, rainfall, and drought [3-5]. Besides the physical characteristics, a plant must also be cost effective and readily available to be a successful species in green roofs [1].

Table 1: Determining parameters in plant selection for green roofs

Determining Factors		
Climate condition	Maintenance requirements	Visual Appearance
Temperature	Solar radiation	-
Humidity	Irrigation	-
Precipitation	Weeding	-
Drought	Fertilization	-
Frost	replanting	-
Temperature fluctuations	Pruning and trimming	-
Solar radiation	-	-

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