GREEN ROOFS IN NORTH AMERICA

Selecting suitable plants for the North American Climate.

Monica Vogt, B.Comm, MLA Candidate
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Abstract

Plants that succeed on green roofs in North America is an area that has not been researched to the full extent. Selecting the right plants is one of the foremost challenges of green roof plantings (Snodgrass et al, 30) and so a clear framework outlining how to do this would be helpful for designers. Snodgrass confirms this theory, when he mentions that "green roofs are still so new to North America that no tried-and-true plant list exists for use here" (Snodgrass et al, 13). The following paper investigates the factors affecting plants in order to better understand them, the benefits and challenges of green roof plants, and finally a flowchart to help guide the decision making process including recommendations on which plants are ideal choices.

Introduction

A common misconception is the assumption that one can move the vegetation that is found on the ground and plant it in green roof growing medium. However, this is not ideal because green roofs are fabricated systems, and there is no equivalent in nature. (Snodgrass et al, 28) Soil composition, nutrients and maintenance differ. Edmund and Lucie Snodgrass summarize these conditions quite well: "Without irrigation and at least 8 inches of mostly organic medium, most green roofs in North America cannot sustain the wide variety of plant species that appear in traditional gardens. Since extensive roofs are traditionally non-irrigated and consist mostly of lightweight, inorganic medium, a plant specification list for a green roof is quite different from one for a ground-level garden" (30). Regarding the green roof industry itself, North America is behind Europe in terms of quantity of installed roofs, technology and knowledge of green roof plants. To put this into context, in Stuttgart, Germany, 25% of the city's flat roofs are green (Stutz, 1).

FIGURE 1.
Green roofs in Stuttgart (outlined in green). Source: Googlemaps

This amounts to millions of square feet. In comparison, this is the same amount of square feet that were installed in 2004 on the entire continent of North America. What are the reasons for this discrepancy? A major contributor is policy. Germany has strong incentives, tax reductions and regulations, resulting in 10% of all roofs in Germany consisting of green roofs (Stutz, 1).

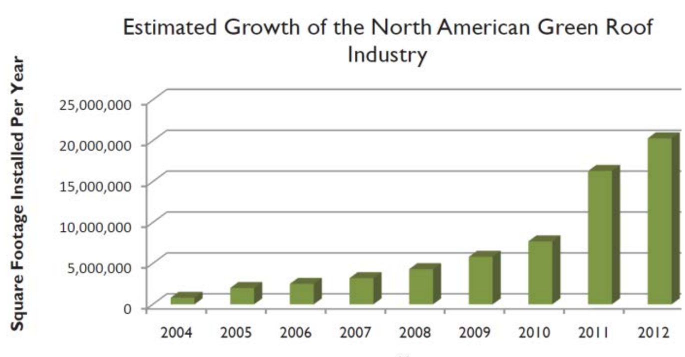


FIGURE 2.
Green Roof Growth in North America (Source: www.greenroofs.org)

Attention

On a positive note, North America is catching up, and significant growth is happening in cities such as Washington, Chicago, and New York (see Fig. 3).

Interestingly, the majority of research that is being produced is not coming from these cities, but from prominent universities in other locations. The issue with this lack of correlation between research and implementation is that there are differences in the local microclimates which are not accounted for. Furthermore, data from short term controlled experiments at Universities with limited species is different from large scale green roofs installed on buildings with fully established plants. Carlisle states that "while such research is empirically valuable, it is difficult to transfer the results of this research to practice. Green roofs installed on actual buildings bear little resemblance to the highly controlled and extensively maintained small-scale plots utilized by researchers, many of which are abandoned before plant communities are fully established" (2).

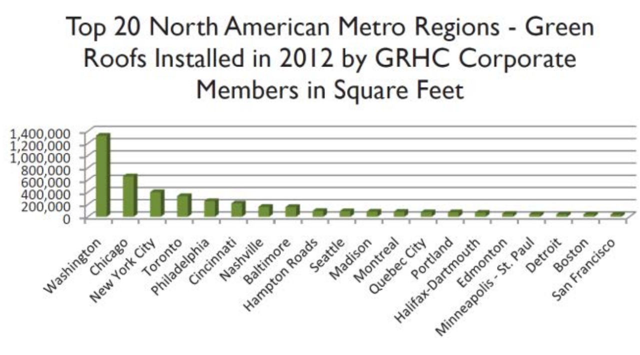


FIGURE 3.
Green Roof Growth in North America (Source: www.greenroofs.org)

Another barrier to the growth of green roof implementation is the industry's causality dilemma. On the one hand, the industry needs to prove the performance of the technology and establish economies of scale, which would reduce costs for materials and installation. But there are not enough established roofs to collect data from. Older roofs are quite different from newly installed roofs, and data should be available that covers different stages of a roof's lifespan. Understandably, people are hesitant to install green roofs if there isn't enough sufficient data about them. Snodgrass and McIntyre believe it is the industry's role to "move to the next level and prove that it can build projects on a large scale at a reasonable cost that perform successfully and predictably" (98).

There is also a shortage of research on the long-term dynamics of green roof plant communities (Carlisle 2). Generally, most roofs have been planted with Sedum, but many people are promoting the planting of a more diverse set of plants. Butler notes that "the performance of other species has been mixed and this necessitates greater focus on both patterns and mechanisms of plant growth and survival" (1).

Although it may seem possible to apply data from Europe to North America, this is not the case due to the difference in climate. Past efforts to adapt plant lists from Germany, where the climate is milder and more predictably moist, have been largely unsuccessful (Snodgrass E, and L. Snodgrass, 12).

Since the list of plants suitable for European roofs cannot be applied, the performance of the plants in insulating is also under-researched for the North American context. This is described by Snodgrass: "although European green roofs have proven cost effective in the long run, particularly in reducing energy usage in the summer months, no such data exists yet for North America." (31)

Now that we have a general understanding of the industry, barriers and general context, the remainder of this paper investigates factors at the individual roof scale. Essentially the scope is above the red filter mat in Figure 4, which are the vegetation and substrate layers.

Focusing on two layers narrows the scope of this paper. Moreover, the layers below are often standardized and most of them are not in direct contact with the plants. "Whereas the physical construction materials used for roof greening will be largely similar the world over, the plants chosen will have to be selected for the climatic conditions prevailing at the site and often for the particular substrates that are available locally." (Dunnett and Kingsbury 127). Since the substrate and plants are

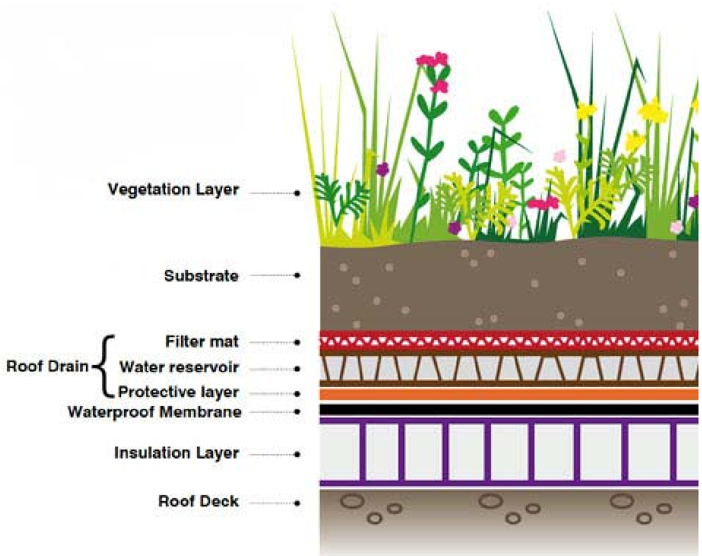


FIGURE 4.
Green Roof Layers (Source: http://www.thecodestore.co.uk)

the most locally customizable parts of a green roof, guidance on selecting these is necessary.

Objective

The objective is to create a framework that can be used for selecting plants at a local scale. The end result will be a plant palette that works for the North American climate. In a broader sense, understanding the long term performance of green roof plants is crucial if green roofs serve as green infrastructure solutions for an increasingly urbanising planet (Thuring and Dunnett 4).

Methodology

During the research stage, relevant data sources were identified and consulted. These included journal articles, news articles, books, site visits to VanDusen botanical gardens and the Vancouver convention center, an interview with Goya Ngan, and case studies of 3 green roof projects.

Design considerations

Major design considerations include a list of general factors, benefits of plants, drawbacks, possible plants to use and planting methods.
The first of these is general factors to consider, which includes the following sub-categories:

1. Environmental
2. Client
3. Stormwater Management
4. Structural
5. Growing Medium
6. Ecological
7. Slope
8. Temperature
9. Aesthetic
10. Conflict of Interest

Environmental

Environmental conditions include wind, frost, hardiness zones, microclimate, and salt.

WIND
The first of these is wind, which should not be underestimated. As wind reaches the top of a roof, the high pressure air rises (refer to the turquoise

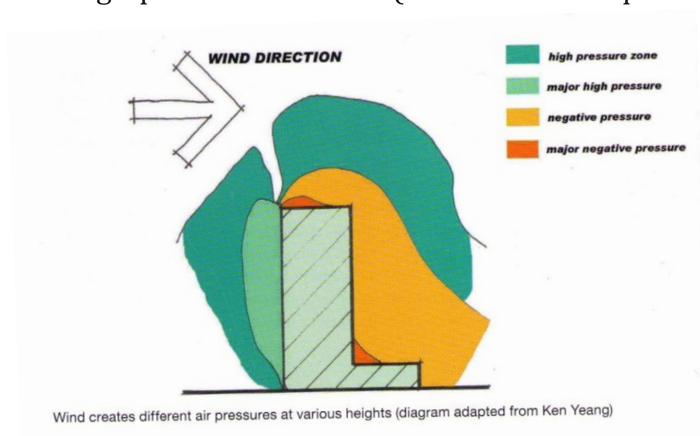


FIGURE 5.
Wind forces on a roof (Source: Hopkins et al, 50)

area in the image below) and creates a low pressure area on the roof (orange area in figure 5.)The critical height of a building is 10 floors. Above this height, velocity increases dramatically. (Hopkins and Goodwin 50). The higher the rooftop, the greater the wind speed and negative pressure that occurs. This force can transport small plants and deposit them into the street (Hopkins and Goodwin 54). More wind also means increased evaporation, which stresses plants. (Hopkins and Goodwin 51).

A way to block wind is to add a taller parapet at the roof edge, which provides some protection. "If the roof is surrounded by a solid parapet, it will be possible to grow taller plants in the increased

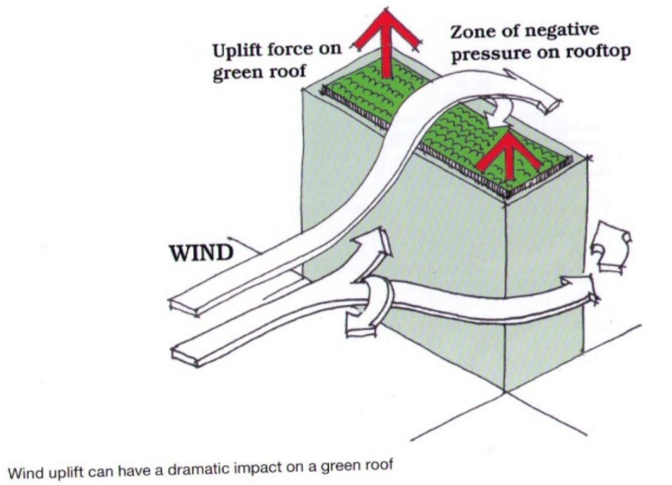


FIGURE 6.
Wind forces on a roof (Source: Hopkins et al, 54)

shelter." (Dunnett and Kingsbury 137).

FROST
If frost is a major issue, then it is advisable not to plant Sedum, as these will not do as well. "In a Canadian study on six different herbaceous plant species grown in a range of substrate depths, the Sedum species included suffered greater frost damage at the thinner depth than the other species." (Boivin et al, 2001)." (Dunnett and Kingsbury 159). Although frost injures plants, snow cover is actually effective for insulating plants against winter cold injury.

HARDINESS ZONES
Hardiness zones apply mainly to the ground. They do not account for shade, the urban heat island effect, structures, humidity and other factors (Snodgrass E, and L. Snodgrass, 48). These factors have a stronger influence on plants than hardiness zones do, as described in the microclimate section below.

MICROCLIMATES
Green roofs have their own microclimates, and studies have shown that most perennials, including natives, that otherwise might work well for the hardiness zone of a given roof still will not be suitable for a green roof microclimate (Snodgrass E, and L. Snodgrass, 30).

Using parapet walls can make the microclimate less harsh. Parapet walls absorb heat during the day and reradiate it at night, which evens out the temperature (Dunnett and Kingsbury 125). Similarly, depending on the building material, "heat from the building can be transmitted through the roof. Hot or cold air may come through the roof from vents and blow onto nearby plants." (Dunnett and Kingsbury 125).

SOLAR RADIATION
Solar radiation is rarely evenly spread over a site (Carlisle et al, 2). In the case study at Cornell, which is explained at the end of this paper, exposure to partial shade had a positive influence on the plants, resulting in increased diversity.
The neighborhood and surrounding landscape elements change with time, and this can affect sun and wind. Often these factors are out of control of the planning and designing of the green roof but they are still factors to be aware of.

To summarize, microclimates are more important than following hardiness zones. Sun, heat and wind are more damaging to plants on a roof and can lead to plant stress and death more than other factors. (Snodgrass E, and L. Snodgrass, 48)

SALT
Salt from de-icing roads and paths affects plants. Salt in soil leads to plant death more frequently than salt spray. Signs that there is too much salt in the soil are chlorosis and fewer and smaller leaves. With salt spray, the majority of damage appears as reduced health and biomass of the plants, as well as some leaf discoloration and dieback (Whittinghill and Bradley 792).

Client

Often, the client's opinion can drive design. It is important to consider their needs and expected outcomes, budget, maintenance, roof's planned life expectancy, accessibility and safety (Snodgrass E, and L. Snodgrass, 47) Level of use is also important, since one should select durable materials and plants that tolerate foot traffic if it is to be heavily used.

Stormwater Management

Rainfall is a design consideration in itself, if a roof is not irrigated. For example, 15cm of medium in Portland will support more varied vegetation than 15cm of medium in Houston, Texas (Snodgrass E, and L. Snodgrass, 52). With irrigation, the plant palette grows considerably. If stormwater retention is the main goal of the design, one should select plants that absorb the most stormwater.

- A 1-inch deep moss and Sedum layer over a 2-inch gravel bed retains about 58% of the water.
- A 2.5-inch deep Sedum and grass layer retains about 67% of the water.
- A 4-inch layer of grass and herbaceous vegetation retains about 71% of the water.

(LID, 2014).

Structural

Weight is a critical factor, as heavier trees and shrubs add considerable weight to the building and require the structure to be able to support this additional load. Please refer to section on "Drawbacks of Plants" for further information.

Growing Medium

Plants grow best in their native soils, which often have a high content of organic matter and available nutrients. Unfortunately these cannot be used in green roof systems because they would compact and clog the filter fabric. Additionally, there is a weight problem. Natural soil types, such as sandy loams, can weigh about 10lbs/sq ft per inch. meaning that natural soils are too heavy (Weiler and Scholz-Barth 166).

The guideline for growing medium composition is using approximately 75% lightweight aggregate to 25% organic matter (Weiler and Scholz-Barth 168). With time, soil PH decreases, the depth decreases and the organic content builds up (Thurig and Dunnett, 6). Plants that prefer low pH will enjoy this improvement in conditions over time.

Ecological

It is advisable to choose plants that are sociable1 otherwise the roof may become a monoculture over time (unless this is the desired intent). Sociability also applies to weeds, which can compete for resources on the roof. Wet soil can "create a beneficial germination climate for weed seeds" (Snodgrass E, and L. Snodgrass, 50).

Furthermore, it has been proven that "the deeper and more organic the medium, the more planting options are available." (Snodgrass E, and L. Snodgrass, 69). But having too much organic matter will hold more water, shrink over time, and more weeds will grow. Finding the right balance between too much and too little water, as well as an appropriate level of organic matter can be a challenge.

Latin Name	% Cover	Image
Schizachyrium scoparium	66	 2
Panicum virgatum	20	 3
Helianthus mollis	20	

FIGURE 7.
Plants that exclude other plantings. 2:http://davisla3.files.wordpress.com. 3: www.bluestem.ca. 4:www.fs.fed.us

Stephanie Carlisle measured sociability in one of her studies. The following plants shown in figures 7 and 8 had the highest sociability ratings (meaning that they exclude other species), while those species shown in figure 9 and 10 had low sociability, and did not exclude other species to a great degree.

Sedum sexangulare	54	 5
Sedum spurium 'Fuldaglut'	55	 6
Sporobolus heterolepsis	37	 7

FIGURE 8.
Plants that exclude other plantings. 5 www.image.gardening.eu . 6: www.wikimedia.org . 7: www.finegardening.com

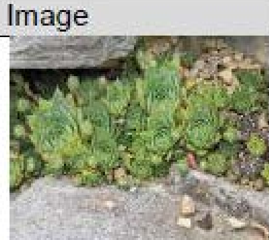
Latin Name	% Cover	Image
Sempervivum	2	 8
Heliopsis helianthoides	5	 9

FIGURE 9.
Plants that do not exclude other plantings. 8: www.wikipedia.org . 9: www.cavesfolly.com

Geranium maculatum	2	 10
Festuca ovina	8	 11
Arctostaphylos uva-ursi	8	 12

FIGURE 10.
Plants that do not exclude other plantings. 10: www.cod.edu. 11: http://planning.city.cleveland.oh.us. 12: www.wikipedia.org

Slope

Slope poses an additional set of harsh conditions to plants on a roof. More exposed areas will require tougher plants. If there is an irrigation system, slopes require more water than other areas (Snodgrass and McIntyre 221).

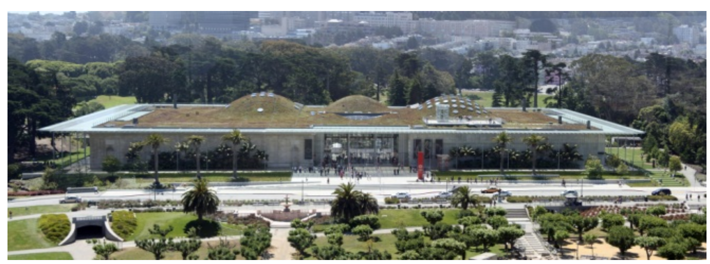


FIGURE 11.
Extreme slope at the California Academy of Science (Source: Wikipedia)

Temperature

If mitigating the urban heat island effect and providing insulation are the most important considerations, then it is advisable to use grass and forb mixtures. These "are more effective at winter insulation than pure grass mixtures. It can be assumed that evergreens would also be more effective at insulation than deciduous species." (Dunnett and Kingsbury 139).

Aesthetic

With green roofs there is more focus on the functional rather than the aesthetic (Dunnett and Kingsbury 128). However, if aesthetics are very important (say for example, the roof can be accessed, or viewed from an office) then in order achieve the most appealing design one needs to understand preferences and provide a good base for a variety of plants. To facilitate this, a range of different soil depths is recommended because the deeper the soil, the more plant species there are to choose from and an increased combination of colours, textures, etc.

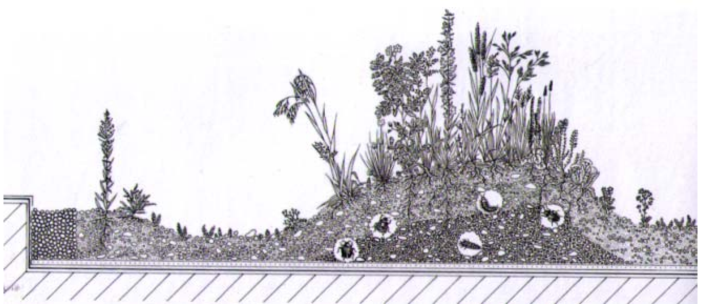


FIGURE 12.
Varied Soil Depths (Dunnett and Kingsbury, 50)

Regarding aesthetic design considerations, moderately diverse plantings are preferred (Lee 153). Green foliage is preferred over grey or red. (Lee 156) Tall vegetation such as trees are preferred (Ulrich, 1986) but they are not always practical, given the extra structural support required.

Turf is seen as degraded, but messier plantings are generally perceived as more sustainable, (Lee 153) and higher in ecological function (Gobster, 1994). Therefore, overall preference depends on how much ecology is valued.

Viewing distance also matters. When viewing the roof from far away, monocultural blocks of species are effective. When viewing from up close or accessing the roof then meadow vegetation is preferred (Dunnett and Kingsbury 137).

With respect to aesthetics, some things to consider are seasonal interest, variety of form, variety of foliage texture. (Dunnett and Kingsbury 138).

To summarize, use different soil depths, green foliage, taller vegetation, a messier aesthetic, and plantings in blocks if viewed from far away or mixed if viewed up close.

Conflict of Interest

With so many design considerations, conflict of interest can easily occur. For example, succulents store the maximum amount of water (Snodgrass E, and L. Snodgrass, 35) but are not as visually pleasing as other plants (according to aesthetics studies by Lee). One has to weigh these considerations in terms of personal preference and choose accordingly.

Benefits of Plants

The Green Roof Infrastructure Technology Demonstration Project conducted a study. They assumed 6% green roof coverage (65 million sq ft). in the city of Toronto. Investment required would be $45.5 million per year for 10 years.
The following benefits would occur as a result:

- Temperature would be reduced by by 1˚C overall, and in some areas 2˚C. (Chrisman 128) Plants protect the roof from the extreme temperature fluctuations and UV rays that degrade traditional exposed roofing membranes. (Snodgrass E, and L. Snodgrass, 27).
- Smog alerts 5-10% lower (Chrisman 128) .Green roofs absorb noise, trap dust, recycle carbon dioxide, and absorb pollutants, bringing them into the soil where microbes break them down. (Dunnett and Kingsbury, 11).
- Stormwater: 127 million cubic feet of stormwater retained annually. (Chrisman 128).
- Heating costs reduced by $1 million annually (Chrisman 128).
- Greenhouse emissionsreduced by 0.72 megatons annually (Chrisman 128).
- Immeasurable benefits: biodiversity, recreational, psychological benefits of vegetation (Kaplan and Ulrich have researched this), increased concentration and cognitive restoration in workers (Lee 158).
- Larger building footprint : Sometimes policy allows for green roofs to replace remediation measures (such as detention ponds on the

ground). In return the building footprint can be larger. Snodgrass E, and L. Snodgrass, 27)

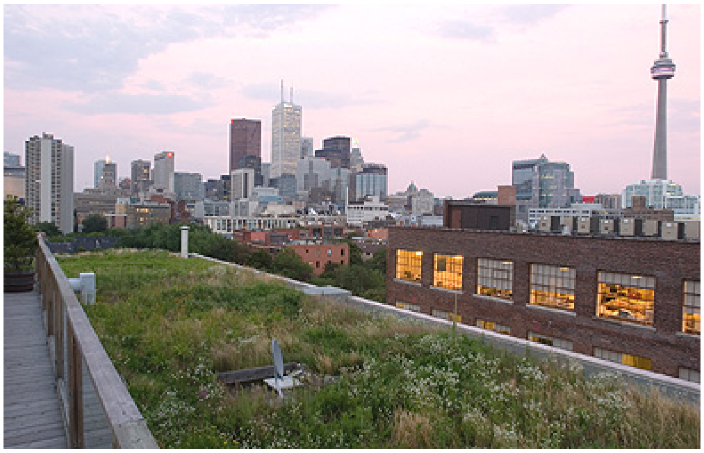


FIGURE 13.
Robertson Building Roof, Toronto.
(Source: www.cbc.ca)

Drawbacks of Plants

FIRE HAZARD
At first glance, one might assume that drought-resistant plants are a good choice for green roofs. In fact, “they could add a potential fire hazard, because while in their native environment these plants have access to a high water table or aquifer, in a non-irrigated living green roof the grasses may dry out.” (Weiler and Scholz-Barth 169) A solution to this risk is installing precast pavers every 20 yards or so to provide a fire break. (Weiler and Scholz-Barth 301).

WEIGHT
There is a tradeoff between the plant palette and weight. Perennials increase roof load by 2 to 5 pounds per square foot (Snodgrass E, and L. Snodgrass, 52) whereas Sedum weigh a fraction of this amount. Not only does the weight of plants have to be considered but the weight of the growing media itself. Plant survival is more likely in deeper substrates, but the deeper the substrate the more weight needs to be taken into account (Dunnett and Kingsbury 126).

SEEDS
Airborne seeds can create unintended outcroppings on the roof itself or in nearby ground gardens, or disturb the surrounding ecosystem. On the plus side, plant seeds are also a way to attract wildlife, whether intended or unintended (Chrisman, 136).

CHANGE OVER TIME
A reality is that green roofs are unpredictable. “No matter how well a green roof is initially designed and specified, all living systems grow and change over time. Over the life cycle of a building, plants installed on a green roof become established, mature, die, and regenerate as the roof is exposed to disturbances.” (Carlisle et al, 2). This non-permanent condition is something to consider and can be a challenge for designers.

FIGURE 14.
Roof at the University of Saskatchewan College of Law
(Source: Goya Ngan)

Potential Plant Species

General criteria to follow when selecting plants are:

- Shallow dense root systems (Snodgrass E, and L. Snodgrass, 30) for survival, due to lack of depth in medium. If the plant is damaged the roots still hold the substrate together.
- An ability to store water (Snodgrass E, and L. Snodgrass, 30).
- Toughness: heat, cold, sun, wind drought, salt, insect and disease tolerant. (Snodgrass E, and L. Snodgrass, 48).
- Tolerate some wet roots (Snodgrass E, and L. Snodgrass, 49).
- Long life expectancy or the ability to self-propagate (Snodgrass E, and L. Snodgrass, 49).
- Minimal nutrients required (Snodgrass E, and L. Snodgrass, 49).
- Low mat forming growth (less susceptible to wind) (Dunnet and Kingsbury).
- Curved leaves reduce the angle of impact of solar radiation (Dunnet and Kingsbury).

- Grey or silver foliage (hairs or wax, both reduce water loss) (Dunnet and Kingsbury).
- Evergreen foliage.
- Resistance to damage from insects and disease (Snodgrass and McIntyre 65).
- Lack of windborne seeds (Snodgrass and McIntyre 65).
- Lightweight at maturity (Snodgrass and McIntyre 65).
- Low maintenance.

Plant Species

Keeping the above criteria in mind, the following plants categories and families are recommended.

HERBS
Thymus, Origanum, Salvia, Allium

BULBS
choices are limited, but they can be great accent plants. Examples are dwarf irises, tulips, daffodils, hyacinths and crocuses (Snodgrass E, and L. Snodgrass, 60)

GRASSES
It is important to note that there are maintenance issues associated with these. Some grasses are dormant in winter and some need to be cut back before new growth begins. They may also leave bare spots. (Snodgrass E, and L. Snodgrass, 59) Recommended grasses are Festuca, Carex and Deschampsia. A native prairie is not an option because they require fire to perpetuate themselves over time (Snodgrass E, and L. Snodgrass, 65). They require plant communities that work together which is hard to replicate especially in shallow soil.

ANNUALS
For the life expectancy reason, annuals are not recommended unless they are an accent piece in planters on an intensive green roof.

PERENNIALS
Snodgrass recommends low-growing, shallow rooted perennials such as Petrorhagia, Dianthus, Phlox, Campanula, Teucreum, Allium, Potentilla, Achillea and Prunella. (Snodgrass E, and L. Snodgrass, 51)

SUCCULENTS
Recommended succulents are Sedum, Sempervivum, Talinum, Jovibarba and Delosperma. (Snodgrass E, and L. Snodgrass, 53) There are over 600 species of Sedum. Recommended Sedum species according to Dunnett and Kingsbury are Sedum album, Sedum floriferum, Sedum hispanicum, Sedum kamtschaticum, Sedum rupestre, Sedum sexangulare, Sedum spathulifolium and Sedum spurim.
One study showed that Sedum decreases temp by 5-7˚C. It reduced neighbor growth during wet periods, but increased neighbor performance during summer water deficit. The palette of green roof plants can be expanded by using Sedum species as nurse plants. (Butler, 1)
Sedum specific benefits are that it flowers, lives in harsh conditions, is not invasive, comes in a variety of colours, and attracts birds and insects. (Snodgrass E, and L. Snodgrass, 56).

Planting Methods

The majority of plants on green roofs are installed using plugs and cuttings (Snodgrass E, and L. Snodgrass, 75). Shrubs and trees come in nursery containers while Sedum can be purchased as vegetated mats or in modules. As of yet, "no wholly seeded green roof installations exist in North America" (Snodgrass E, and L. Snodgrass, 72).

FIGURE 15.
Planting Plugs (Source: www.Scott Arboretum.org)

Maintenance

Ideally, green roofs should not require much maintenance. The majority of maintenance occurs immediately after installation, such as "hand-watering during installation and the adaptation period, weeding, fertilizing and spot repair. Over the long term, planting maintenance is minimal." (Weiler and Scholz-Barth 169)

CASE-STUDY 1:
University of Saskatchewan
Saskatoon, SK

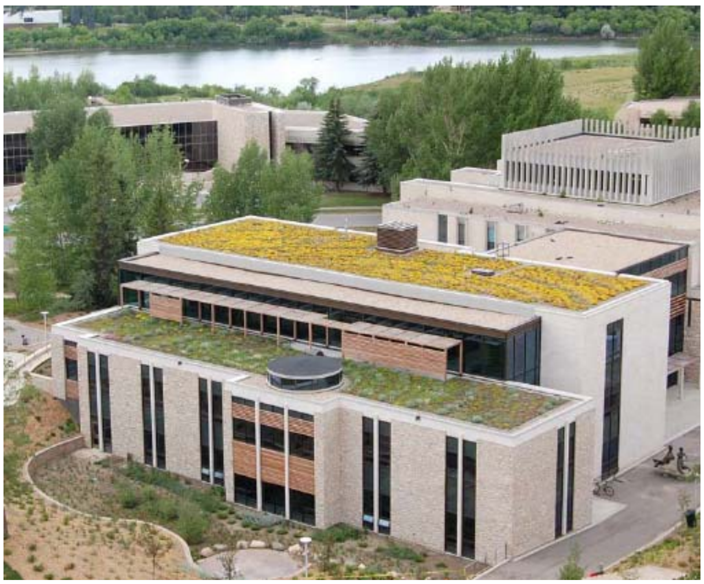


FIGURE 16.
College of Law, 2009 (Source: Goya Ngan)

OVERVIEW
- Two green roofs on the College of Law, 2007, at the University
- of Saskatchewan.
- Findings are intended to assist Facilities Management of the University of Saskatchewan design, build and maintain more green roofs on campus
- Results from this study were presented at the CitiesAliveconference in Vancouver in 2010.

CLIMATE
- Dry and sunny climate
- Precipitation is 350 mm annually (whereas Vancouver is1001mm annually).
- Mean Jan temp -22.3°C, mean July temp 24.9°C, and one of the goals is using green roofs for possible energy efficiencies.

PLANTINGS
Upper roof:
- Yellow colour scheme
- Ridges planted with two types of native grass and valleys planted with five types of Sedum.

Lower roof:
- Silver and red foliage, pink blue and white flowers
- Ridges planted with 11 species of mixed perennials and valleys were planted with four types of Sedum and one thyme.

Both roofs have full sun exposure.

GOALS
- Goya Ngan looked at: growth, survival and % vegetation cover
- (visually estimated).
- 90% cover was the target, and this was surpassed (reached 95%).

RECOMMENDATIONS
- The recommended best plants for survival are: Bouteloua Gracilis, Koeleria cristata, Sedum kamtschatikum 'Variegatum',Sedum floriferum 'Weihenstephaner Gold',Sedum ewersii, Sedum pluricaule(S), Antenneria rosea and Artemisia frigida. Please refer to Figure 17 for more detailed results.

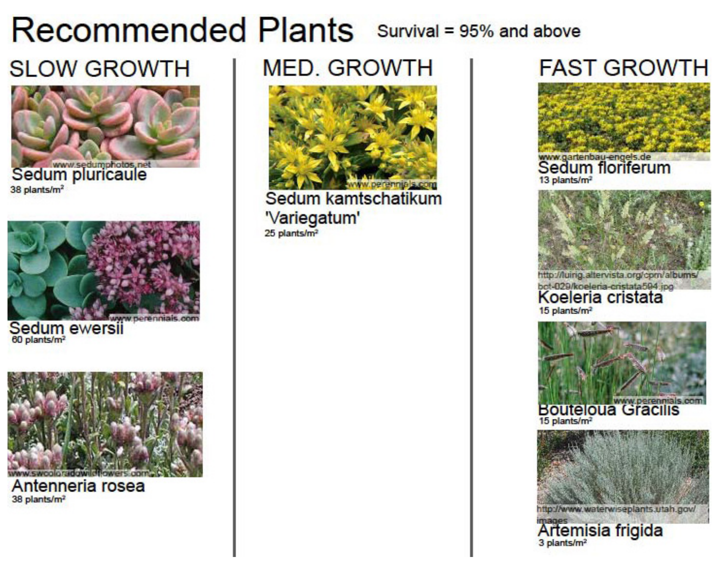


FIGURE 17.
Figure 13: Recommended Perennials (Image: Vogt, Information: Ngan).

CASE-STUDY 2:
Cornell University Residences
Ithaca, NY

OVERVIEW

- Two green roofs on residence buildings
- They had 5 years of undisturbed growth before they were monitored.
- Each roof is similar in scale and location but have different planting and microclimatic conditions.

CLIMATE

- Annual Precipitation is 94 cm
- Jan average temperature is -2˚C and July is 20˚C

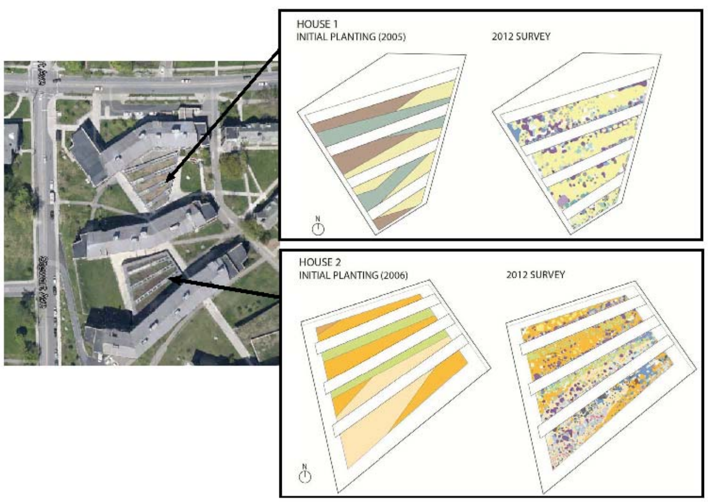


FIGURE 18.
Alice H. Cook House and Carl L. Becker House (Source: Googlemaps and Carlisle)

PLANTINGS

- Intensive Roof 1: 20.32 cm, 16 species
- Extensive Roof 2: 12.70 cm 5 species

GOALS

- They looked at indicators, including species richness, cover and biodiversity
- Wanted to see differences between initial planting and emergent species
- Additionally, they modeled solar radiation exposure, to see hoW it influences community dynamics (Carlisle et. al, 1).

RECOMMENDATIONS

- It is not recommended to plant Schizachyrium scoparium (broom grass). In the seven years since initial planting, Roof 1 had transitioned from a mixed meadow roof of 16 species to a single-species dominated roof system (Carlisle 5). It lost biodiversity over time but on the plus side, the roof maintained nearly full coverage (93%).
- Microhabitat conditions associated in part with solar exposure and increase in shelter from the neighboring building resulted in highest biodiversity.

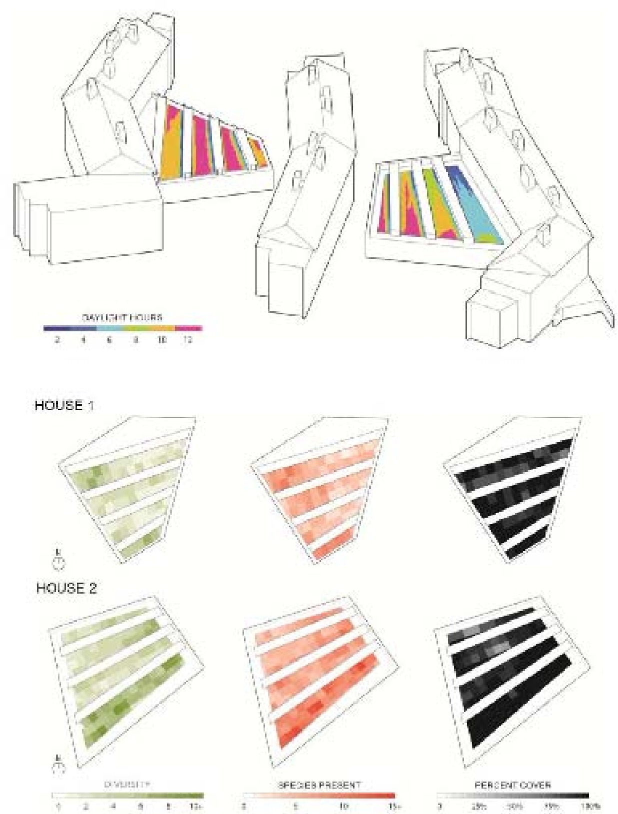


FIGURE 19.
Analysis showing that the shaded roof area has more diversity, species present and percent cover. (Source: Carlisle)

CASE-STUDY 3:
Michigan State University
Ann Arbour, MI

OVERVIEW
- Research center aims to provide scientific evidence of the performance of green roofs and to promote their use.

CLIMATE
- Similar climate to New York
- Annual precipitation is 94 cm
- January mean temperature is -4˚C and July is 22˚C

PLANTINGS
- 10 cm of substrate, 9 Sedum species and 18 Michigan native species

GOALS
- They investigated performance with and without irrigation

RECOMMENDATIONS
- The 9 Sedum species “vastly outperformed 18 Michigan natives in every instance.” (Monterusso et al. 2005).
- All 9 species of Sedum survived and provided 100% coverage without irrigation. “The Michigan natives did well when irrigated, but irrigation adds maintenance and cost.” (Snodgrass E, and L. Snodgrass, 55)

FIGURE 20.
Horticulture Teaching and Research Center research platforms (2001) (Source: Michigan State University website)

Results

Given that moisture determines a plant’s growth and survival even more than substrate depth (Thuring 2005), the beginning of the decision making process should consider this fact.

If there are non-irrigated harsh conditions, it is recommended to use Sedum, as they can survive an astonishing 88 days without water (Van Woert et al, 2005). They visually change during this time. “Drought-stressed Sedum roofs turn from a lush green to a dull purple.” (Dunnett and Kingsbury 159).

Conclusion

Sedum species outperform native plants, and Sedum represents a type of climax community. It is a reliable plant to use but other choices are better in terms of aesthetics, ecology and other criteria. When deciding which other plants to use, consult the flowchart at Figure 21. At the same time, it is critical to understand the site. During the site analysis one should specifically look at all of these “General factors to consider”:

ENVIRONMENTAL:
- Wind
- Frost
- Hardiness Zone
- Microclimate
- Salt

CLIENT
STORMWATER MANAGEMENT
STRUCTURAL
GROWING MEDIUM
ECOLOGICAL
SLOPE
TEMPERATURE
AESTHETIC

It is suggested to rank them (based on your opinion, knowledge etc.). I ranked them in the order as shown here, with Environmental being most important. Plants that don’t meet the first few criteria should not be used.

As the case study at Cornell showed, even changing one of these attributes (ie. Providing a bit of shade and shelter means you get increased diversity and percent cover) makes a big difference. Keep in mind you really have to look at a site's microclimate, as the hardiness zone isn't enough to decide which plants to use. Experimenting with a few of these is best. Hopkins suggests optimizing conditions for plants during the design process by manipulating substrate depth, shade, aspect, slope and water-shedding surfaces (190).

Guidelines are useful, but it is difficult to achieve a desired outcome as green roofs are "dynamic ecological systems that respond to multivariate factors and are subject to change over time." (Thuring and Dunnett, 9). Edmund Snodgrass states that there is the need to keep experimenting, which is the case for now. "North America's wide range of weather patterns that extend from one extreme to another, combined with the nascent stage of the green roof market here, make it likely that experimentation and failure will go hand in hand for the foreseeable future." (Snodgrass E, and L. Snodgrass, 12).

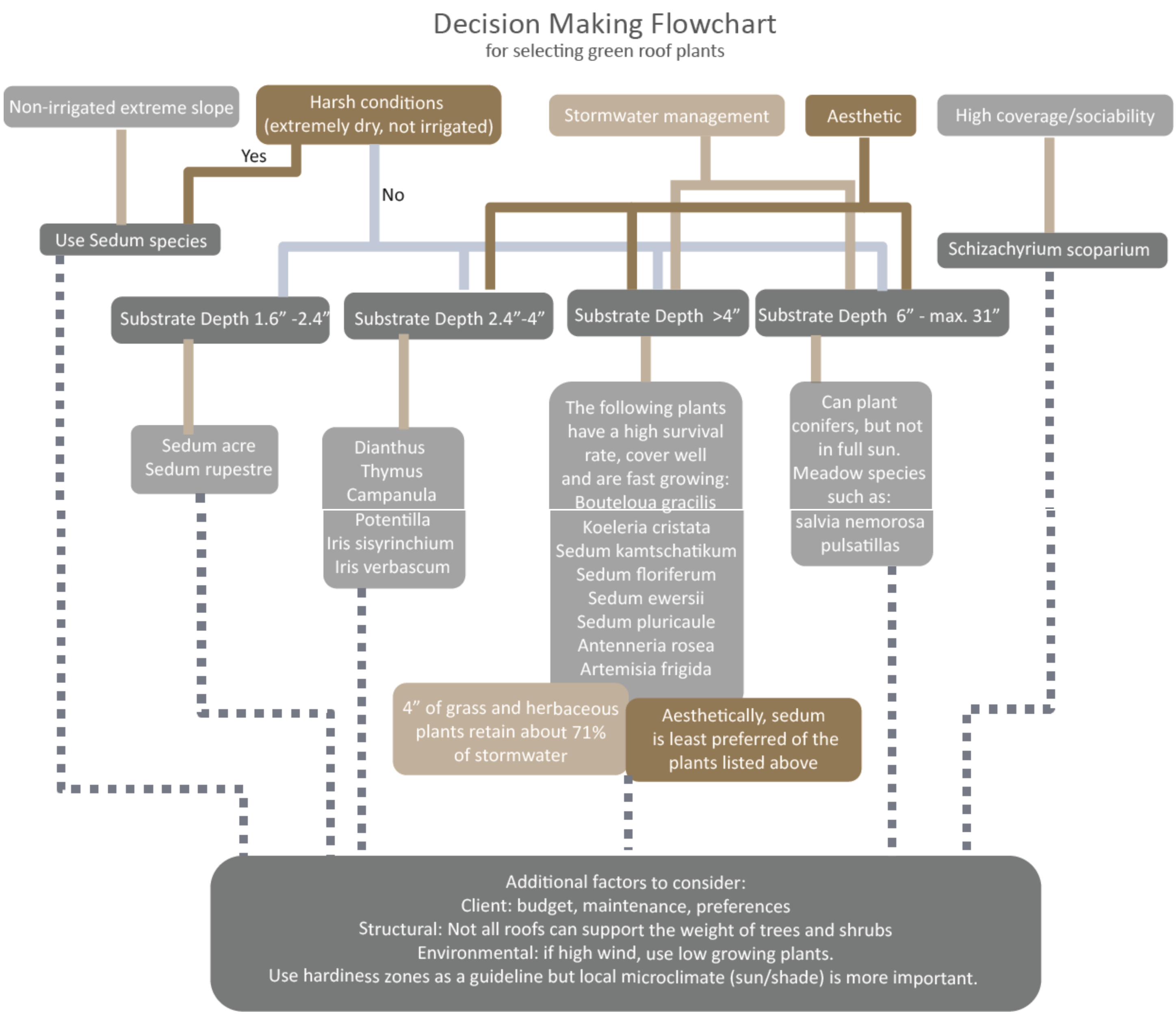


FIGURE 21.
Flowchart for assisting with the plant selection process (Vogt)

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