The University of Texas at Arlington Extensive Green Roof

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Introduction

The University of Texas at Arlington (UT-Arlington) installed the first extensive green roof in the Dallas/Fort Worth area in April of 2008. The roof was researched, designed, and is being managed by UT-Arlington associate professor and landscape architect David Hopman, ASLA. The approach to the roof is in keeping with the professional priorities of landscape architects and is not a narrowly focused scientific study such as the green roof research at Texas A&M University in College Station, Texas or the ongoing studies at The Ladybird Johnson Wildflower Center in Austin, Texas. The test roof at UT-Arlington is 1000 sf. with approximately 35 species of plants that are heavily biased towards native and near native species. The green roof is divided into two 500 sf. sections. Each section has an industry standard roofing system, irrigation system, and a proprietary soil mix. Detailed information on each of these elements is provided below, including the results of ongoing plant census data. At the time of this writing, the roof is well into a third growing season and is proving the viability of this technology in North Texas.

Background

The idea for the UT-Arlington green roof project took form in February of 2007 at a meeting convened by Kent Hurst, then a PHD candidate in the UT-Arlington School of Urban and Public Affairs. The green roof was initially envisioned to be mainly for aesthetic and recreational purposes. Green roofs are a technology that captures the public imagination and enjoys broad support due to their high visibility as sustainability features. Professor David Hopman and graduate student Amanda Popken agreed to co-chair a green roof committee. By the time the roof was implemented in April of 2008, Ms. Popken, the volunteer coordinator, had developed a committee of over 90 students, professors and community members committed to developing the project.

Students were eager to start planting and professor Hopman agreed to study two or three successful examples in North Texas to determine best practices for the project. A search determined that as of the winter of 2007, no *extensive* green roof had been constructed in the Dallas/Fort Worth area. An extensive green roof is generally defined as a roof with six inches or less of growing medium that is designed to maximize environmental, biological, and aesthetic services with a bare minimum of resources required for installation and for maintenance. [i]

The Ladybird Johnson Wildflower Center (LJWC) was a primary resource for implementation information (see Simmons et al, 2007). Mark Simmons provided advice on plants, roofing systems, and growing media based on their 24 test plots installed in 2006. It was assumed that the climate in Austin is close enough to the climate in North Texas to provide some transferability of their results. Additionally, green roof vendors with extensive green roof experience in other areas were contacted. Their advice proved to be only partially useful as almost all of the extensive green roofs in the United States have been constructed in more temperate climates such as those in Illinois, Washington State, and Canada.

The Site

The site for the installation was chosen for a variety of reasons:

1. The roof is accessible by elevator,
2. the existing ballast roof over concrete is strong enough to support the weight,
3. The roof is in full sun and is therefore a better test area than a roof in partial shade,
4. water and electricity are easily brought to the project as there is an existing greenhouse on the roof, and
5. the roof of the life sciences building gives many potential student and faculty researchers easy access to the roof.

Approach

Many approaches to a creating an extensive green roof are possible based on the growing media, amount of irrigation, and plant palette. Four of these approaches were considered for the UT-Arlington green roof.

Prairie Barrens Approach

The Botanical Research Institute of Texas (BRIT) has taken a very visionary approach to their research on extensive green roofs based on biomimicry. Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems sustainably (http://www.biomimicryinstitute.org). Environmental Science graduate students Jon Kinder and Dave Williams from Texas Christian University and BRIT Resident Research Associate, Robert J. O'Kennon are studying how the Fort Worth Prairie Barrens ecosystem might be reproduced on an extensive green roof. This native plant community naturally grows in very thin soils over a solid limestone base--conditions that the closest in nature to a proposed 90,000 sf. extensive green roof on the new BRIT building currently under construction in the Fort Worth Botanic Garden.

Figure 1: Fort Worth Prairie Barrens

Figure 2: Bob O'Kennon at the Fort Worth Nature Center studying the test plots for the proposed BRIT roof

The biomimicry approach by BRIT shows great promise. However, it was not deemed appropriate for the UT-Arlington roof for a number of reasons. First, the vast majority of the plants being tested are not currently in the nursery industry. This will make a roof using this plant palette very costly and time consuming to reproduce, thereby limiting its utility as a pilot roof for the area. Second, the specialized palette of plants requires soil with higher clay content than is typical for green roof installations. This creates further complications for roofing systems and irrigation, particularly the filter fabrics used to keep the growing media out of roof drains. BRIT has the resources and expertise to overcome these issues over a long time frame in a way that most people interested in installing and extensive green roof installation can't. We will continue to follow this important research and implement its findings where practicable.

Sedum Roof Approach

The majority of vendors who have been active in extensive green roof installations recommended a sedum roof consisting of exotic sedum species that have performed well in other areas. Five sedum species were tested (see plant trial results below). The trial results on Sedums indicate that they have two major problems. First, they require water, as do native species, in order to not go dormant or die in the summer. The second, and much more serious, problem is that during hot rainy weather some species can rot. These two limitations and the non-regional origins of the sedums led to this approach being rejected. A specialized regional palette of plants, with a heavy bias towards natives and near natives, was deemed more desirable than reliance on a few exotic species. A balance of *both* ecological and environmental benefits is the goal. We did not want create a first precedent for extensive green roofs

in the area that encourages exotic species. A few donated sedums were tried and one native Texas sedum is currently in trials with results still too preliminary to be meaningful.

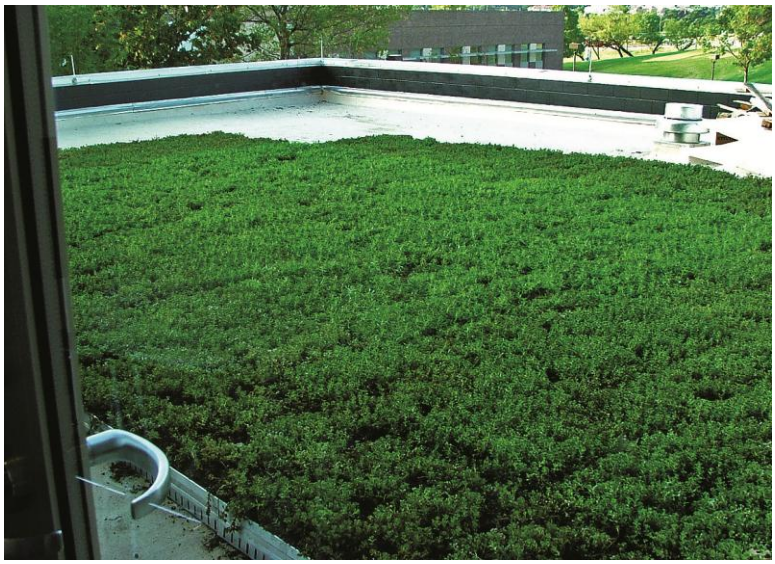


Figure 3: Sedum Roof at Northlake College in Irving, Texas soon after installation. The Sedum was pre-grown using the "Live Roof" system.

The American Society of landscape architects has a demonstration roof at its headquarters in Washington DC. The picture is from a visit in 2009 and shows two alternative plant palettes. One that is primarily European Sedums, and the other with a variety of forbs and grasses, similar to the approach taken with the UT-Arlington green roof (see http://www.asla.org/greenroofeducation/).

Figure 1: ASLA roof in Washington, DC showing forbs and grasses

Figure 2: ASLA roof in Washington, DC showing European Sedums

Prairie Restoration Approach

The final approach that was considered was to plant a native grassland on the roof. The Ladybird Johnson Wildflower Center has tested a variety of native grasses. Their results show that many do well in rooftop conditions. Species with roots that would normally go deep will produce long roots that spread laterally. The UTA roof project is testing four species of grasses but has not focused primarily on them. There is a concern that the large mass of dormant grass in the winter could be a fire hazard. There is also a desire to determine a few evergreen species for clients that may want a green, rather than a brown, roof in the winter. The Trinity River Audubon Center in Dallas has taken the approach of using native grass species on its roof with mixed success as of the summer of 2010. The plant trials results below show that two of the three native grass species performed very well in our trials (Blue Grama and Sideoats Grama) and one did not (Prairie Buffalo Grass).

UT-Arlington Approach

The decision was made that as the first extensive green roof test roof in the area, the roof needed to test all the components that are needed to make subsequent roofs on campus and in the area a success. The roof had to be reproducible at a reasonable cost and feature a wide enough variety of plant material that subsequent roofs with a variety of goals can be accommodated. As landscape architects, we also wanted a broad palette of textures, sizes, colors, bloom periods etc. that will permit formal principles of planting design to be utilized for future roofs if desired by clients.

Roofing Systems

Based on the test results from the LJWC, two vendors were chosen for contrasting roofing systems and growing media. Both companies agreed to donate all the materials required for 500 sf. of their respective systems. The green roof project at UT-Arlington would not have been possible without this generous support. One system was a monolithic system where all the growing media is placed in one 500 sf. container and the other is a modular system with 2'x4' trays.

The Monolithic Roofing System

A monolithic system from American Hydrotech comprises ½ of the UT-Arlington green roof or 500 sf. The "Garden Roof Assembly" by Hydrotech, comprises a number of layers as shown in figure 1. Not all layers were utilized as this installation was over an existing roof with existing insulation below the concrete.

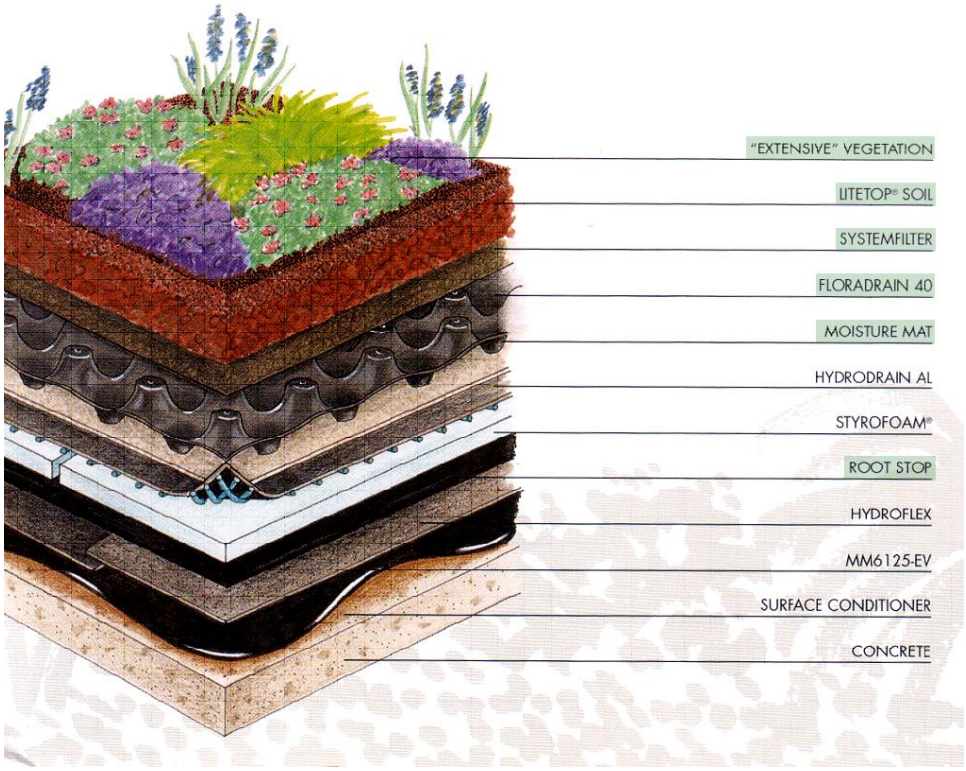


Figure 3: Hydrotech Garden Roof Assembly. Layers shaded green were used for UT-Arlington installation

Two layers of plastic root barrier were used to assure that no roots make their way through to the existing ballast roof. The moisture mat placed above the root barrier is a thick layer of felt that is designed to capture water and slowly release it as water vapor that precipitates off of the filter fabric and back into the Floradrain. The Floradrain was placed with the holes on the highest points and with expanded shale placed in the small egg-cupped shaped valleys. This was on the advice of Hydrotech for the extreme environment of North Texas. The next layer above the Floradrain was filter fabric, followed by 4 inches of growing media. This media is a proprietary formulation of sand, expanded shale, and a small amount of compost to get the plants started. It is produced locally and arrives in 1500 lb grow bags. It should be noted that there is considerable amount of settling of the soil and an excess of 10 to 15 percent above the calculated quantity or more may be required to achieve the desired depth. More soil was added to this roof after installation to keep the level closer to 4 inches. The saturated weight for the entire system is calculated by American Hydrotech at 30 lbs/sf. or less. A coconut fiber 'moisture mat' was added over the media a few weeks after installation to prevent fine particles (sand and compost) from blowing away in the strong winds on the roof. The mat was removed in July when the winds died down in order not to impede plants from spreading.

Figures ? through ? show the installation of the Garden Roof Assembly at UT Arlington. See http://www.hydrotechusa.com/components.htm for further information.

Figure 4: Garden Roof frame provided by Hydrotech

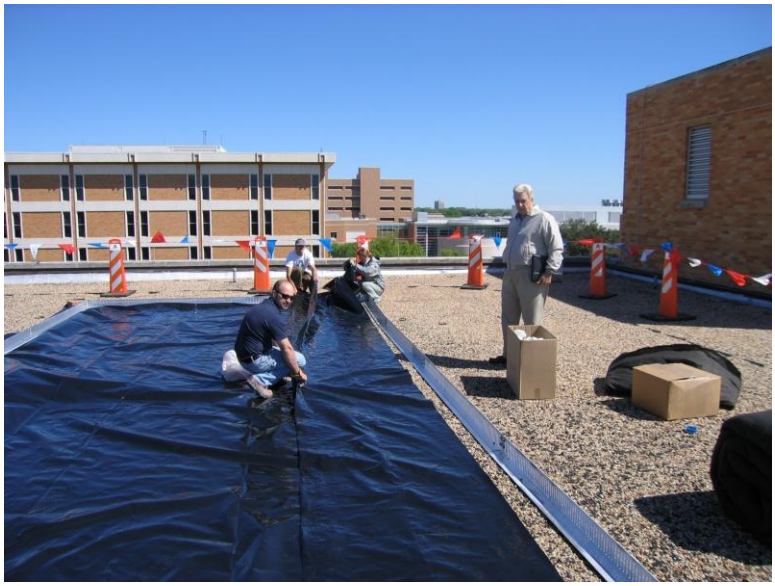


Figure 5: Installation of root barriers as Robert Nickel, of American Hydrotech, looks on

Figure 6: Students and other volunteers install moisture mat

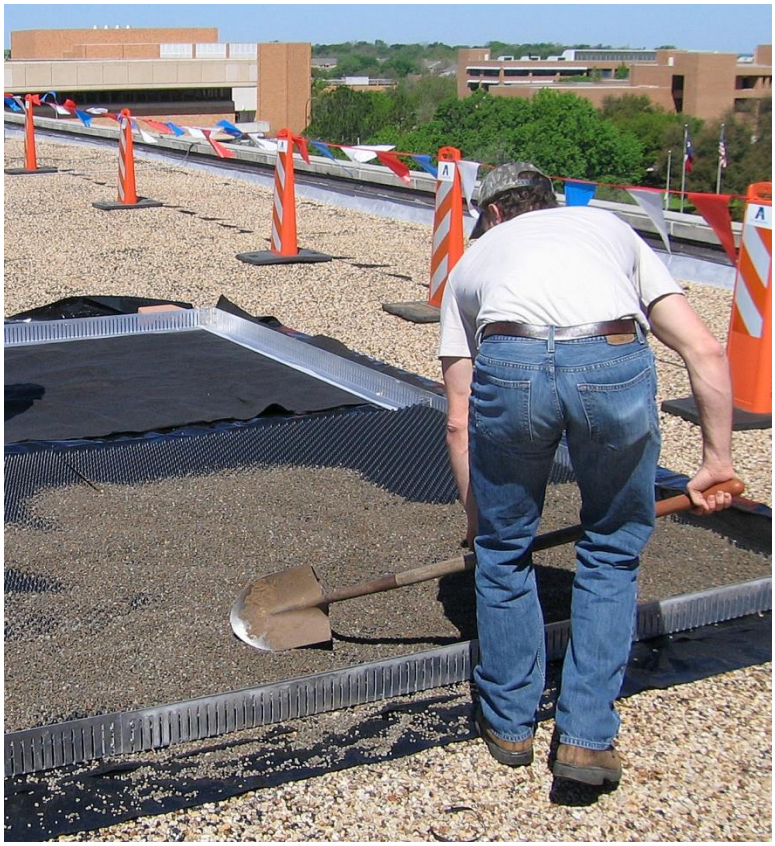


Figure 7: MLA student Joey Ball places expanded shale on top of the Floradrain

Figure 8: Growing media is placed over filter fabric

Figure 9: Netafim Drip Irrigation lines are snapped into 3-1/2 inch plastic rebar risers

Figure 10: installation of plants-most from 4" pots

Figure 11: A coconut fiber 'moisture mat' was installed for two months on the Hydrotech side to keep fine media particles from blowing away in hot, dry, windy, conditions.

The irrigation system installed on the Hydrotech side was a standard Netafim Drip System. There are headers on the two short sides of the rectangle. Techline CV12 pressure compensating dripperline is run between the headers and clipped into 3-1/2 inch plastic concrete rebar risers. The emitters are the slowest available releasing .25 gallons per hour. In the hottest and driest summer months, the system is run twice per week for 50 minutes at a time. This results in water usage of 212 gallons per week for the 500 sf. Netafim side. This rate was arrived at by allowing the media to dry out to the point that some of the plants were starting to wilt such as Rudbeckia, and Liatris. The system was then run until it started running off. The roof is irrigated about 4 months of the year on a regular basis and occasionally in fall and spring during extended dry periods. As an experiment, ½ of the roof was left without

irrigation for 1 week in the hottest and driest part of the summer of 2009. At the end of the week, one variety had died (the *Santolina Chamaecyparissus*) and many were starting to go dormant. Further study is needed to determine a balance of ecological services such as the evapotranspiration required to mitigate the urban heat island effect with the imperative to save water. The Hydrotech system is very good at moisture retention and watering can probably be cut back considerably after the first few growing seasons. Regular watering does promote weeds where there is bare media and also promotes reseeding by desirable species while the roof is getting established. Additionally, a narrower plant palette can be selected from the plant trials that will require less frequent irrigation. The roof was occasionally hand watered the first summer during especially dry and hot weather to help the plants get off to a good start.

The Modular Roofing System

The modular roofing system selected for the trials is the 'GreenGrid' system by Westin Solutions (see http://www.greengridroofs.com/). This system consists of 2'x4' black plastic trays with a high percentage of recycled content. The trays have three components: the tray, filter fabric, and growing media. The trays have a series of depressions in the bottom for water storage and holes on the ridges for drainage. The proprietary growing media provided by Westin has a high percentage of fired clay replacing the expanded shale in the Hydrotech soil and comes with some fertilizer in it. The media arrives in 100lb bags on palettes. At the time of the UT-Arlington installation, Westin did not have agreements in place in the DFW to pre-grow the trays prior to installation as is normally done for tray systems. Therefore, we filled the trays with media by a loading dock and transported them six a time to the roof with media in place. The saturated weight of the media, plants, and trays is calculated by Westin at 18lb/sf. or less. The installation of the tray system is very fast and easy and took about 1/3 the time that the monolithic system required. Figures ? through ? show the installation of the Westin Green Grid modular green roof system at UT-Arlington.

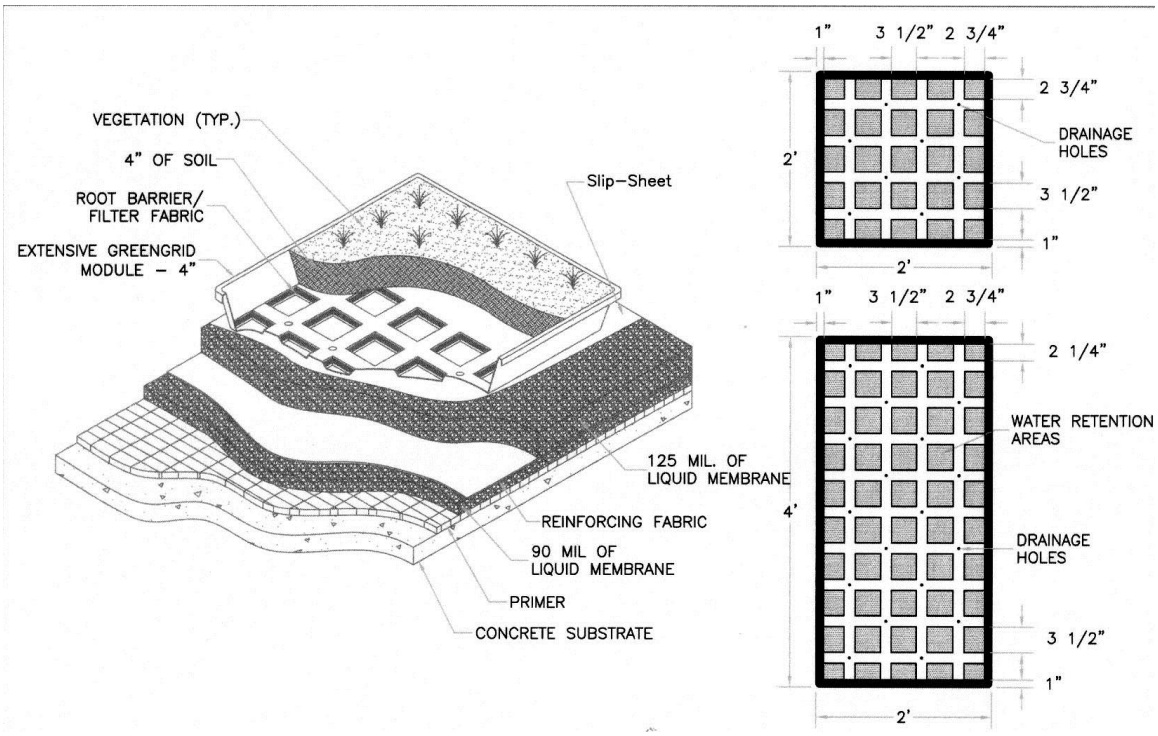


Figure 12: Westin Green Grid System

Figure 13: First row of pre-filled trays are placed on roof

Figure 14: installing plants in the GreenGrid System

Figure 15: GreenGrid Side—partially planted out—three weeks after installation

Irrigation for the Modular Side

The GreenGrid side used a Dramm irrigation system recommended by Westin Solutions. The system places headers between every other row of trays and connects a ring of emitters to the headers-two per tray. Each ring has six emitters that release a combined 8 liters per hour (four liters per hour is now available). This results in 16 liters per hour per 8 sf. tray. With the system running twice a week for 50 minutes, each tray is receiving 3.5 gallons of water per week or 1.66 gallons per sf. The system was easy to install and although it appeared rather flimsy at the time of installation, it has held up well through three growing seasons (see http://www.dramm.com/media/GREENROOFbooklet.pdf)

Comparing the modular and monolithic extensive green roof systems

Discussion

The observations that follow are necessarily preliminary as the roof at UT-Arlington has only been in place 27 months as of this writing. Both systems have performed well in the UT-Arlington trials. The first growing season, the modular side plants were growing somewhat faster due to the fertilizer in the soil mix. By the second season, this was no longer the case. It should be noted, that no fertilizer has been applied to either side after a liquid root stimulator was applied twice in the first few weeks after plant installations.

The grid side is consistently drier than the modular side despite receiving more irrigation water. This has helped some plants and hurt others. For example, the Salvia Greggii, native to much drier parts of Texas than Arlington, actually are growing better in the drier modular side. Stemodia tomentosa, native east of DFW, looks better in the Hydrotech side with its superior moisture holding capacity. A plant palette should be chosen for future roofs that takes into account both the roofing system and the growing media.

The expanded shale base for the growing media is gaining popularity over fired clay. It is much more cost effective and is produced locally. The one advantage of the clay based media is that some of the plants seem to reseed more successfully in it. The clay pieces are rougher than the shale and may afford small seeds a better opportunity to anchor in and germinate in windy rooftop conditions. This was especially noted in the reseeding of *Tetraneuris scaposa* and *Salvia Farinacea*.

Both irrigation systems have performed very well. The Netafim produces more even moisture due to the regular 12" grid spacing. The Dramm system permits some flexibility with specific grids getting more or less water or even no irrigation. Note that the Dramm ring emitters must be placed perfectly flat or watering results will be uneven.

Advantages of monolithic system

1. No barriers to root growth allows for free spread of plant roots, stolons, etc.
2. Built in insulation for turnkey systems may allow for less or no insulations for the roof of the building thereby allowing the building to be slightly shorter-saving some money.
3. Growing media is produced locally with local materials and is performing well
4. Moisture capture system is very efficient and permits very low water usage
5. Netafim drip is a very robust and proven irrigation system.
6. The company has a long track record with complete roofing systems throughout the United States

Disadvantages of monolithic system

1. Roof is more labor intensive to install
2. Roof is expensive to replace or to remove for repairs
3. Plants cannot be pre-grown and may take two or more growing seasons to achieve maximum coverage.

Advantages of Grid System

1. System is very quick and easy to install
2. Grids can be moved or removed relatively easily. Therefore, design is both flexible and adaptive
3. Plants can be pre-grown for instant green

4. May cost less than other systems
5. The company has a long track record with extensive roof systems throughout the United States

Disadvantages of Grid System

1. Plant roots get trapped in each eight sf. Container.
2. Water retention is not as robust, thereby necessitating more water usage.
3. The aesthetics of the seams in the grids may be an issue although most grid manufacturers are developing methods to hide the seams.

The decision of which type of roofing system to use will be determined by the goals and priorities of the owner and the designer of the roof as will all decisions related to construction of a green roof. One note of caution—results will vary if more or less media is used or if the roof drainage and slope are different than the UTA test roof. The UT-Arlington test roof has unimpeded drainage on a roof with a grade not exceeding 2% (1/2" per foot).

Climate in North Texas

The biggest unknown for the installation of the first extensive roof system is North Texas at UT-Arlington was the palette of plants suitable to four inches of media in the highly variable climatic conditions. The North Texas is subject to much greater extremes of temperature than are experienced in many other parts of The United States. The record temperature ranges from minus 8 degrees Fahrenheit, recorded in 1899, to 119 degrees Fahrenheit, recorded in the unusually hot summer of 1980 (Shinners, 1999).

More significant even than the extreme heat and cold are the wide swings in temperature that plants are subject to over a very short period of time. One celebrated example occurred in 1989. The hard winter freeze came very late that year. Many trees and shrubs were still in leaf on the second week of December and had very little time to adapt when the temperature hit 12 degree F. on December 12. The cold weather persisted and by December 23, 1989 a record low for that day of -1 degree F was achieved (http://www.srh.noaa.gov/fwd/CLIMO/dfw/normals/dfw12nrm.html).

A more common phenomenon is called false spring weather anomaly. This happens on a regular basis where plants break dormancy in response to extended warm spells in late winter and early spring. A subsequent late hard freeze will then severely damage the leaves on an evergreen or partially or even completely defoliate a deciduous tree or shrub. The plants are rarely killed but may be misshapen for a year or two until they have time to fill back in. Even some of the best native trees for the area are susceptible in rare extreme cases such as occurred on April 11-12 1987. Native Plants partially defoliated that year included: Bur Oak, Chinkapin Oak, Post Oak, and Red Oaks. The study of tree rings has determined that 44 severe examples of this phenomenon have occurred between 1650 and 1980 (Stahle and Cleveland 1995 quoted in Shinners, 1999)

Since 1989, there has been a noticeable increase in mean winter temperatures. It is very rare for the temperature to drop below 15 degrees F. and it usually bounces back to warmer temperatures very quickly. As a result, most of the DFW area is now firmly in zone 8a which used to be the USDA climate zone for Austin , Texas approximately 200 miles to the south of DFW. As a result, many native plants from the Texas Hill country and other warmer climes are making their way into the DFW nursery industry.

The extreme summer temperatures are equally problematic for many plants in the DFW area. The area is in AHS heat zone 9. For more information see http://www.ahs.org/publications/heat_zone_map.htm#1and http://www.ahs.org/pdfs/05_heat_map.pdf. One of the effects not seen in other parts of the country occurs when evening temperatures remain above 80 degrees F. Some exotic plants decline with these extreme high daily lows and some natives go dormant and reemerge in the fall or winter (such as the native Calylophus).

Precipitation in North Texas varies tremendously. Periods of months with virtually no rain are not uncommon (both summer and winter) and extended rainy spells can also occur at any time. These rainy periods, when they occur during hot summer months, can lead to fungal growths and dieback on plants such as Sedums and Delosperma. In the winter of 2009-2010, the area received a one

day snowfall of over 12 inches though this is rare. Small snowfalls and occasional ice and sleet are more common. All of these climatic conditions have occurred during the three growing seasons of the UT-Arlington green roof. The wet summer periods are particularly instructive since they cannot be controlled. Rain often comes in great torrents over a short time frame. Therefore, unimpeded drainage of the roof is imperative. Test at the LBJWC have indicated that a green roof will capture 100% of rain events at or below .4 inch. Retention of amounts above this vary widely depending on the roofing system and plant materials.
The UT-Arlington Green roof irrigation system is turned on and off manually and does not have a weather station or moisture sensors to help make determinations on irrigation usage. These automated systems would make the roof much easier to maintain efficiently over the long term.

Plants

There is a large universe of plants that are possible candidates for trials on the UT-Arlington test roof. Each year more plants are added as other species prove unable to survive adequately in the harsh conditions of an extensive green roof. Criteria for selection of species and varieties include:

1. Availability of the plant in large quantities in the nursery trade,
2. Suggestions from recognized experts at the LBJWC, Texas A&M, and elsewhere,
3. Experience with specifying plants and research by David Hopman, and
4. Donations and suggestions from vendors and growers.

Detailed information on plant trials is provided below. The plants have been divided into three categories based on their success in the green roof trials. Since the roof is not being carefully monitored for environmental services, the definition of success is primarily horticultural and aesthetic. The three broad categories are:

1. Highly recommended
2. Recommended with limitations
3. Not recommended based on the UT-Arlington plant trials

The detailed information on each plant will explain the placement in the category. Much more information and photographs are provided for the recommended species than for less successful plants. A number of plants were very carefully documented before it was known that they would not work out well. This documentation was used to make the determinations on the most appropriate category for these plants.

A thorough plant census has been undertaken twice each year since the inception of the project. Figure 16 shows the results of the plant census comparing the fall of 2008 and the fall of 2009. This census will be updated each fall. Plants that do not appear on the census have not survived through the fall of 2009. They are briefly discussed in the not recommended section.

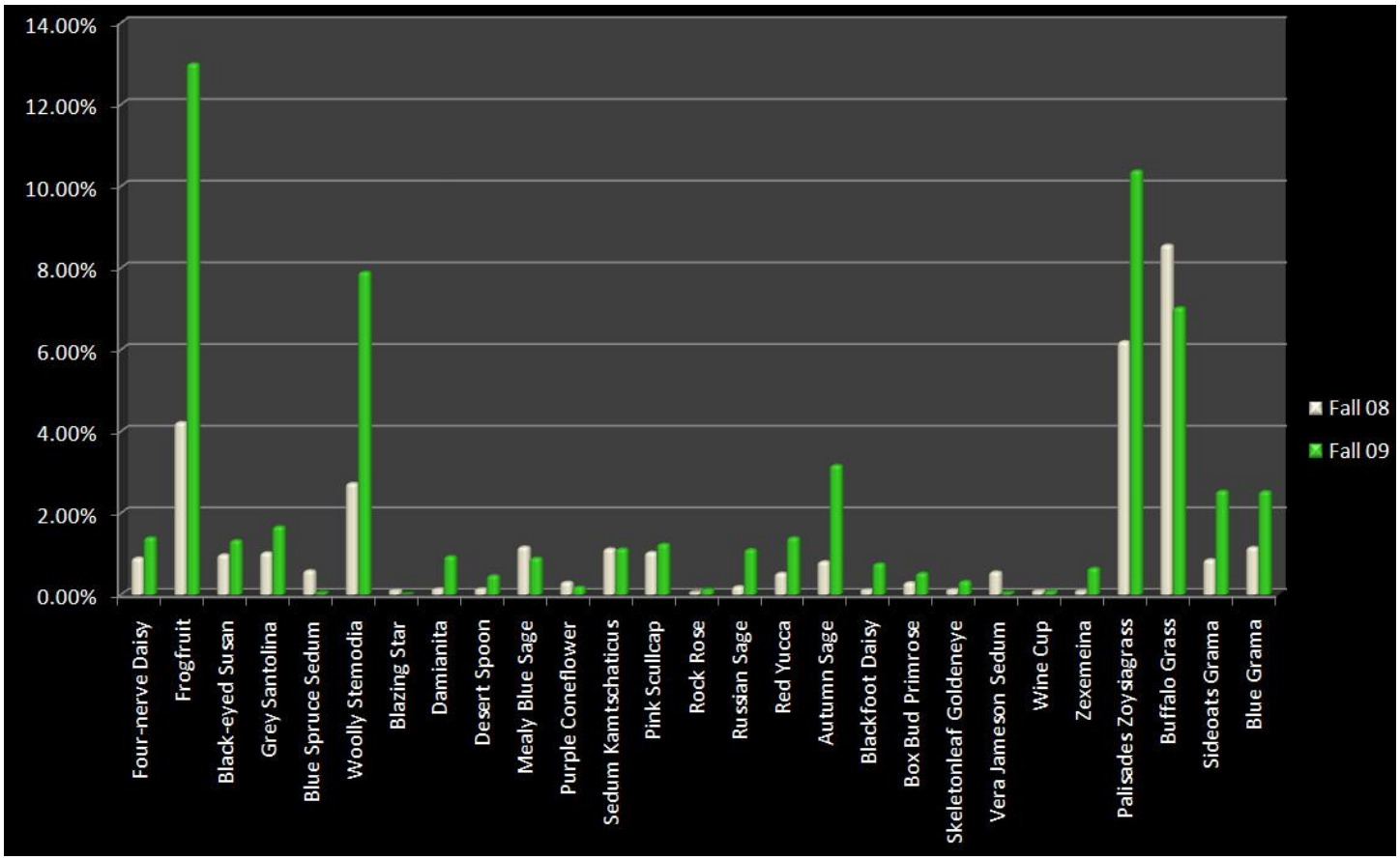


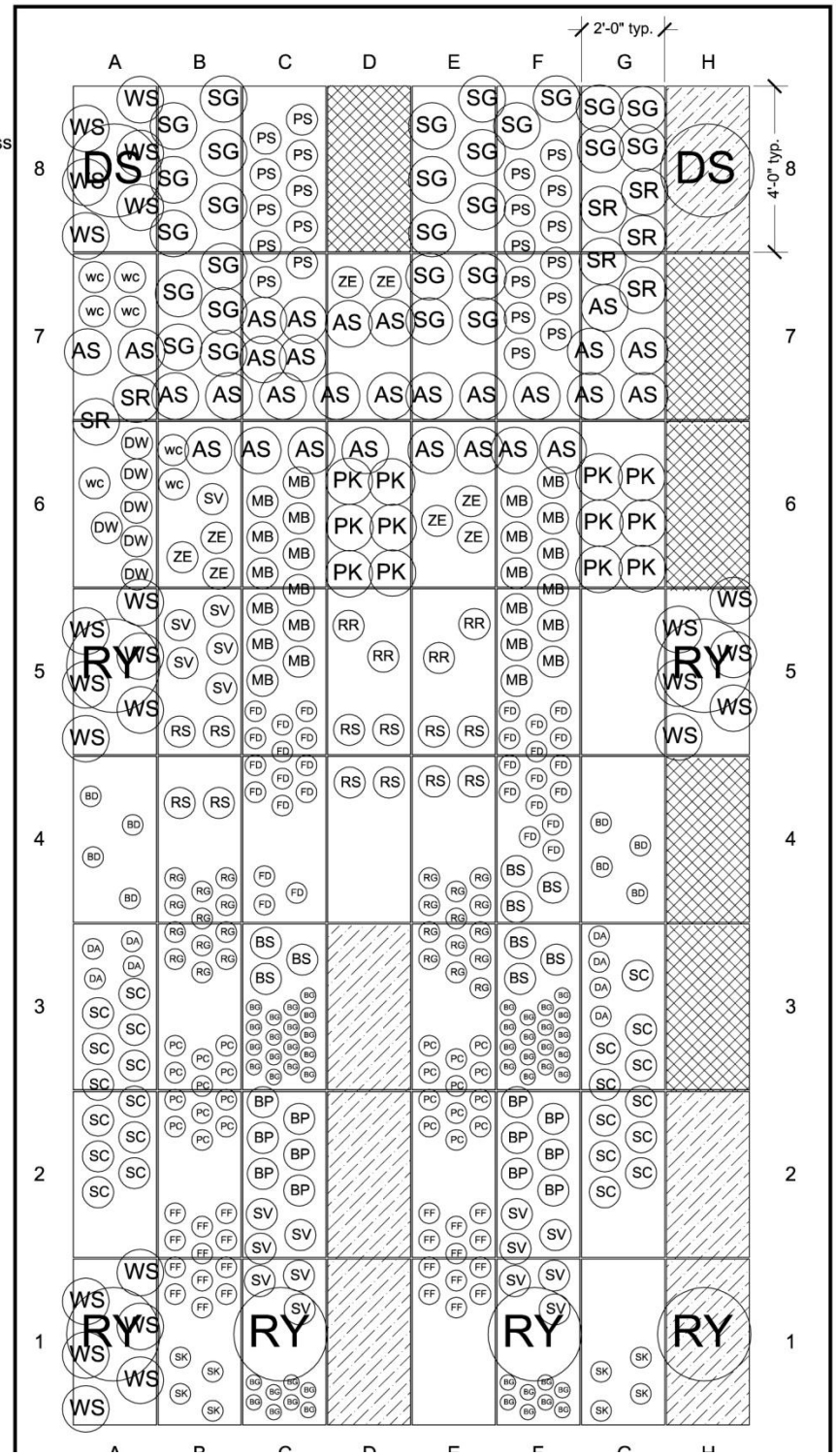
Figure 16: Plant census comparing fall 2008 with fall 2009

Figure 17: UTA extensive green roof test roof in the summer of 2010

UTA LIFE SCIENCES BUILDING
EXTENSIVE GREEN ROOF

HYDROTECH SIDE ARLINGTON ■ TEXAS

Key	Latin Name	Common Name
	Grasses	
BG	Bouteloua gracilis	Blue Grama
SG	Bouteloua curtipendula	Sideoats Grama
	Buchloe dactyloides	Buffalo Grass
	Zoysia japonica 'Palisades'	Palisades Zoysiagrass
	Forbs	
AS	Salvia greggii	Autumn Sage
BD	Melampodium leucanthum	Blackfoot Daisy
BP	Calylophus hartwegii	Box Bud Primrose
BS	Liatris spicata kobold	Blazing Star
DA	Chrysactinia mexican	Damianitaa
DS	Dasylirion Wheeleri	Desert Spoon
FD	Tetraneuris scaposa	Four-nerve Daisy
FF	Phyla nodiflora	Frogfruit
GS	Santolina virens	Green Santolina
LA	Artemesia ludoviciana	Louisiana Artemisia
MB	Salvia farinacea	Mealy Blue Sage
MP	Orbexilum pendunculatum	Mountain Pea
PC	Echinacea purpurea	Purple Coneflower
PK	Phedimus kamtschaticus	Sedum Kamtschaticus
PS	Scutellaria suffrutescens	Pink Scullcap
RG	Rudbeckia fulgida 'goldstrum'	Black-eyed Susan
RR	Pavonia lasiopetala	Rock Rose
RS	Perovskia atripliplicifolia	Russian Sage
RY	Hesperaloe parviflora	Red Yucca
SA	Sedum Acre	Gold Moss
SC	Santolina chamaecyparissus	Grey Santolina
SK	Viguiera stenoloba	Skeletonleaf Goldeneye
SR	S. Reflexum 'Blue Spruce'	Blue Spruce Sedum
SV	Sedum Vera Jameson	Vera Jameson Sedum
WC	Calirhoe involucrata	Wine cup
WS	Stemodia lanata	Woolly Stemodia
ZE	Wedelia hispida	Zexmenia



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NOTE:

THIS PLAN COVERS ½ OF THE ROOF. THE OTHER 500 SF. IS AN EXACT COPY

PLANTING PLAN

Figure 18: original UTA green roof plan

Highly Recommended Plants (Alphabetical)

Bouteloua curtipendula Side Oats Grama

Side-oats Grama is a Texas native bunch grass that has grown to about 12 inches tall and wide on our roof with a seed spike of about 24 inches. This mid-successional grass is the state grass of Texas and is widely distributed, particularly in disturbed sites such as roadsides and grazed areas. The grass has grown slowly from 4" pots. Each year, the clumps increase and by the third growing season, they are almost growing together from their original 15" spacing. A spacing of 12" would probably be ideal and other plants could be placed in the gaps for the first year or two such as *Salvia farinacea.* Side-oats Grama has good winter character and greens up quickly in the spring. It will go dormant in summer if not watered regularly.

Figure 19: Side-oats at installation in July of 2008

Figure 20: Side-oats in September of 2009

Figure 21: Side-oats winter character in January of 2010

Bouteloua Gracilis **Blue Grama**

Only 12-14 in. in full flower, Blue Grama is among the shortest of the native ornamental grasses. Blue Grama has been an outstanding performer on both sides of the green roof. It looks good all year—turning tan in winter, produces attractive eyebrow shaped horizontal seed heads in fall, and has not been invaded by any other species other than the Frogfruit planted adjacent to it. It is a bunch grass that is easy to control and tends to stay where it is placed. This grass never goes completely dormant in winter and greens up quickly in the spring. The plants were planted from 4" pots and spaced about 7 inches on center. Blue Grama is an important, drought-resistant, short grass in the mixed prairies and throughout the Great Plains and the Southwest US.

Figure 22: Blue Grama one month after installation in July 2008

Figure 23: Seed heads in September, 2009

Figure 24: winter character January, 2010

Calylophus hartwegii Box Bud Primrose, Sundrops

This Calylophus variety is very useful for an extensive green roof. It thrives in hot gravely conditions with reflected heat and is native to the Dallas Fort Worth area. The plant can go dormant in the summer. It will then green up in the fall and into winter, a time when very few other plants on a green roof are green. A good color show follows in the spring for about 6 weeks with bright yellow, conspicuous flowers. For best effect, it should be used with companions that bloom later in the season and can fill in during the summer such as Zexmenia.

Figure 25: Calylophus in April, 2009

Figure 26: Calylophus winter character in January of 2010 after a hard freeze of 12 degrees

Chrysactinia mexicana *Damianita*

Damianita has performed very successfully in all seasons. This small shrub, native to the Edwards Plateau & Trans-Pecos in Texas, New Mexico and Mexico, has slowly grown from plugs to about 7 inches wide and tall. The small densely packed leaves create a dramatic contrast to the small yellow when the plant is bloom in spring and fall. It is one of the very few reliably evergreen plants on the UT-Arlington green roof. It has not shown any signs of stress from heat, cold, or any other weather condition on the roof. If planted from plugs, care should be taken to hand water for the first few weeks as the drip irrigation may not make it to all the small plants. The small plants can also very easily blow out of the media in the first few weeks if not planted at the correct depth.

Figure 27: Damianita two weeks after installation

Figure 28: Damianita one year after planting

Croton monanthogynus Dove Weed, Prairie Tea

Dove Weed is the only true annual in our trials. This plant provides food for both birds and butterflies and is native to the DFW area and throughout Texas, except the panhandle. Dove Weed actively reseeds each year and fills in any bare media not covered by other plants. It has shown few signs of stress and grows slowly each year to about 8" tall and 12" wide. This plant is not available in the nursery trade but is easy to find for transplanting and is currently in trials at The Texas A&M Dallas Urban Solutions Center. The leaves have a very characteristic aroma that makes identification easy. Special thanks to Dr. Pat Taylor for suggesting it and for donating the plants.

Figure 29: Dove Weed, September, 2009

Hesperaloe parvifolia Red Yucca

Red Yucca has been one of the most reliable plants in three growing seasons of the green roof. It is evergreen, turning slightly purple in winter, blooms irregularly but consistently and is less dwarfed by the tough conditions on the roof than other plants. It was planted from 1 gallon pots and anchored in and started growing rapidly. We have spaced these plants far apart as accents and have underplanted them with low growing groundcovers as Red Yucca will not cover the bare growing media. A spacing of three feet or more would be ideal. Red Yucca is a near native found mostly in the Texas Hill country south of Dallas.

Figure 30: Red Yucca July 2008 three months after planting

Figure 31: Red Yucca in bloom September, 2009

Figure 32: Red Yucca seeds early spring 2010

Melampodium leucanthum Blackfoot Daisy

Blackfoot daisy has been very reliable in our green roof trials. It blooms from March to November with showy small white daisy flowers, is semi-evergreen, and in two seasons, each plant has grown to about 8 inches tall by 12 inches wide. The plant shows great promise as a filler/accent plant or as a plant for large massing on a green roof. It is native to gravely thin soils in Texas. The plants were planted in the fall of 2008 from about 1 inch plugs. A small amount of seeding out has been observed.

Figure 33: Black foot daisy at installation from plugs, October, 2008

Figure 34: same plant one year later

Figure 35: August 2010 after 14 straight days over 100 degrees

Perovskia atriplicifolia Russian Sage

Russian sage has been a very showy perennial since we planted it from plugs in October of 2008. Now in its second full growing season, it has increased in size to about 12" wide and 18" tall as of early July. Like all the plants on the roof, this one will be smaller than you would see in a typical landscape setting. The plant is a perennial that comes back slowly in the spring. Therefore it should be used in conjunction with evergreens or plants that green up earlier. It can take the hottest weather and is currently one of the tallest plants on the roof. Russian Sage is native to the mountains of Pakistan and Afghanistan and is not a true sage.

Figure 36: Russian Sage at end of first growing season in September of 2009

Figure 37: Russian Sage in July of 2010 after two growing seasons

Phyla nodiflora Texas Frogfruit

Frogfruit has been a very interesting test subject with big pluses and some minuses as well. On the plus side, this relative of the Verbenas spreads very quickly (over 6' the first year from 4" pots) at a time when most of the media is bare. It is ornamental when in flower and attracts a never ending parade of bees and moths. It has a deciduous habit in the DFW area on a roof so the runners green up quickly and do not need to re-grow from the ground. The final plus is that Frogfruit is native to DFW area. On the negative side, Frogfruit can be hard to control due to its rapid spreading and can outcompete some other plants such as Calylophus and Sedum Vera Jameson. The first year it bloomed all spring and summer and into the fall. The second year it bloomed much less and was not as showy. The plant has limited interest when not in bloom as it is less than one inch tall with very inconspicuous leaves. The third growing season we cut it back severely and it bloomed again and was very attractive. This is in keeping with Sally Wasawski's description that Frogfruit looks better when it is abused such as being walked on. This plant may be very useful on an extensive green roof as long as these limitations are taken into account.

Figure 38: Frogfruit in bloom, July 2008, 3 months after planting

Figure 39: Frogfruit out of bloom one year later

Figure 40: Frogfruit filling in and blooming, July 2010

Stemodia lanata (*tomentosa*) Wooly Stemodia

Wooly Stemodia is native to sandy soils along the coast of Texas and into South Texas and Mexico. This has been one of the outstanding performers for our extensive green roof trials. It has very attractive silver foliage with occasional small lavender blooms, fills in rapidly but not overly aggressively, can take both extreme heat and prolonged wet weather, is reliably perennial, has an interesting presence in winter, and comes back quickly in the spring. This plant is a good candidate for a mass planting or as a filler with other less reliable species interspersed. It spreads slowly by stolons—no seeding has been observed yet. The Stemodia was planted from 4" pots and placed about 9" on center.

Figure 41: Stemodia three months after planting

Figure 42: Stemodia winter character-January 2010

Figure 43: Stemodia second growing season-8/09

Figure 44: Stemodia in August of 2010-third growing season

Tetraneuris scaposa var. scaposa, (Hymenoxys scaposa) Four Nerve Daisy

Four Nerve Daisy has been one of our best performers. It is evergreen and blooms yellow 12 months of the year with the biggest shows in spring and fall. This small wiry plant, native across wide areas of Texas, including the DFW area, does not fill in to completely cover the roof and should be interplanted with other low spreading plants. It looks good both widely dispersed throughout the roof and in more dense spacing. Plants are typically 4 inches wide and tall with the yellow daisy like flowers poking about 10 inches above the ground. Four Nerve Daisy has been the most active reseeder of any plant in our trials. We have planted them successfully from both plugs and 4 inch pots.

Figure 45: Four Nerve Daisy in April one year after installation

Figure 46: Winter character (December)

Figure 47: Four Nerve Daisy (yellow flowers) increasing by seed (all the yellow in the photograph is *Tetraneuris*)

Wedelia texana Zexmenia

Anybody who has tried Zexmenia in the DFW area will find it no surprise that not only is it one of the best xeric adapted perennials for the DFW area, but that it is also performing very well on the UT-Arlington extensive green roof. The Zexmenia was planted from plugs in October of 2008 and has had no trouble getting established. It is reliably perennial and freezes completely to the ground for about three months in the DFW area. The first year, the plants stayed small, under 8 inches tall and wide. The second full growing season they are considerably larger to 18" tall and wide. Some seeding out has been observed. It is very easy to tell a Zexmenia seedling from a weed due to the rough texture of the leaf. This plant has not shown any signs of heat stress in the very hottest weather and blooms with small yellow ray flowers from April until frost. It is native to fields & wood borders, abundant on the Edwards Plateau, Rio Grande Plains, and less frequent in the Trans-Pecos and Southeast and North Central Texas.

Figure 48: Zexmenia in September of 2009 after first growing season

Zoysia japonica 'Palisades' Palisades Zoysiagrass

This plant was tested in order to potentially provide a turf path in future green roofs for access. This is a patented variety developed by and donated by Dr. Milt Engelke and Texas A&M University. This Zoysia anchored in very quickly and has been surprisingly durable. It stays green in the hottest weather, stays very dense and weed free, stays very low (around 2") without any trimming or mowing, and has held up under the small amount of foot traffic on the UTA roof. More testing is required to determine the maximum traffic it can bear without signs of wear. The only negative of this plant is that it has very aggressive stolons and rhizomes and has invaded nearby plants. Therefore, it should be used with a root barrier in monolithic roof systems.

Figure 49: Zoysia three weeks after planting

Figure 50: Zoysia at end of second season spreading into Sideoats

Dasylirion wheeleri Wheeler's Sotol, Desert Spoon

Anyone who has seen Wheeler's Sotol growing beautifully in the Chihuahua or Sonoran Desert, or the Texas Hill country, will understand why it was worth a try on the UTA extensive green roof. This is one of only a few plants being tested that have some height and structure. As such, the plant can help provide some shade, mitigate the very strong winds on a roof, particularly in spring, and afford some aesthetic appeal from a distance. The Sotols are doing satisfactorily as figure?? shows. However, they are growing very slowly from 1 gallon plants and as of the third growing season, it is still too soon to tell their final form or rate of success. Therefore they are in this section and not among the highly recommended varieties.

Figure 51: Sotol in Buffalo Grass-third growing season

Echinacea purpurea Purple Coneflower

Purple coneflower has been a sporadic presence since the first season. Like Salvia farinacea, this north Texas native develops quickly and then thins out considerably. It is worth planting into a mixed mass but should not be used as a primary cover plant. As with most of the plants on the roof, the blooms are smaller and the overall plant is dwarfed. It shows some signs of stress from very hot weather and dies back completely to the ground in winter. The flowers are showy when they appear in late spring and early summer and some reseeding has been observed.

Figure 52: Echinacea with butterfly-second growing season

Pavonia lasiopetala Rock Rose

Rock Rose is a Hill Country native that took a long time to get established on our roof. By the second growing season, it was about 14 inches tall and starting to be a presence in the mix of plants. It dies back to the ground in winter and blooms from early summer until frost. It was planted from plugs in the fall of 2008. 4" or larger plants would help make more of an impact sooner. Long term viability is still a question as of this writing.

Figure 53: Rock Rose-July 2010, second full growing season

Rudbeckia fulgida 'Goldsturm' **Black-Eyed Susan**

This popular Rudbeckia variety was found over 50 years ago in Czechoslovakia and selected for introduction into the horticulture industry. It is related to the native species in the United States but is not native to Texas. It has performed reasonably well in our trials and returned reliably each spring. The bloom period is a little shorter than when it is planted locally in the ground and the plant is much shorter and generally smaller. It also has not spread as actively by rhizome as it would under normal growing conditions. The yellow/orange ray flowers are very showy from June to the beginning of August and then more sporadic. The leaves show signs of stress in the summer and die back completely in the winter months. We have planted out test plants from 4" pots 9 inches on center as monocultures. This plant may look better with companions that help mitigate the harsh conditions on an extensive roof.

Figure 54: Rudbeckia in July, third growing season

Salvia farinacea **Mealy Blue Sage**

Mealy Blue Sage is native throughout North Texas and is one of the very few true area native perennials that has become an integral part of the local horticulture industry. This plant was very successful on the roof early on when the growing media had a higher percentage of compost. As the soil has become less fertile, the plant has become much less robust and showy. The plant has reseeded very actively (but not aggressively). It is very useful as an accent in the spring and fall, particularly the first year when other plants are just getting going. It should not be counted on, however, to provide cover over the long term. Additionally, its leggy character makes it a good candidate for filler companions lower to the ground such as four-nerve daisy or Blue Grama.

Figure 55: Salvia farinacea, second spring

Santolina chamaecyparissus Grey Santolina

This Mediterranean native is well known as a drought tolerant and durable sub shrub in Texas. It was tested for its potential to provide some geometric structure or a solid border for the green roof plantings. The Gray Santolina performed very well, particularly on the monolithic side with the more consistent moisture. 4 inch plants were spaced 12" on center and by the third growing season had almost filled in. However, the plant has one very significant drawback. If there is any break in the regular irrigation during extreme hot weather, the plant will not go dormant. Instead, it will die. All the plants were lost on one side of the roof after an experiment to not water for 7 days during extremely hot weather. Other plants simply turned brown and revived after watering was resumed. Nevertheless, this plant is the best candidate in our trials for a short border or hedge pattern. With consistent irrigation, it can perform very well as an evergreen low border or accent.

Figure 56: Grey Santolina 3 months after planting

Figure 57: Grey Santolina in July of third growing season

Sedum 'Vera Jameson' Vera Jameson Sedum

Sedum 'Vera Jameson' is a cross between Sedum telephium maximum 'Atropurpureum' and Sedum 'Ruby Glow'. It was tried due to its drought tolerance in area landscapes and its very showy purple foliage and bloom. This is the only Sedum that has preformed reasonably well in our trials. It is has survived in the grid side and slowly declined and died out in the monolithic side. It may have been overwatered there or it may have been crowded out by the Frogfruit. This plant is worth a try for the dramatic color accent it provides when in bloom. The plant has an evergreen rosette in our area.

Figure 58: Vera Jameson rosette-June of third growing season

Figure 59: Vera Jameson in Bloom-September of second season

Salvia Greggii Autumn Sage

Salvia Greggii has not performed as well as we had hoped. It is very open and leggy and growing extremely slowly. This may turn out to be a good plant over the long term but as of the time of this writing—half way through the third growing season—it has not filled out sufficiently to cover the media. Therefore, it should be used in conjunction with lower and faster growing plants. The Salvia Greggii have performed better on the grid side than on the monolithic side which may actually hold too much moisture for them. Salvia Greggii may be most useful with a green roof plant palette designed for minimal irrigation.

Figure 60: Salvia greggii in July of third growing season

Sedum mexicanum Mexican Sedum

This Sedum was planted from plugs in the fall of 2009. The plants that survived the relatively cold winter have slowly grown to about fist size and show some promise. Experience with other Sedums dictates caution until at least three growing seasons of trials.

Figure 61: Sedum mexicanum in July of first full growing season

Viguiera stenoloba **Skeleton-Leaf Goldeneye**

This viguiera is in the "too soon to tell" category. It was planted from plugs in October of 2008 and as of August 2010 was holding its own but had not bloomed and was at best 6-8 inches tall. Based in its provenance in near desert conditions, the plant should do well over time. It is evergreen on the roof.

Figure 62: viguiera July of second full growing season from plugs

Volunteers

In addition to the plants placed on purpose and the undesirable non-native invaders, there have been a few plants that have come in as welcome guests.

Asclepias verticillata L. Whorled milkweed

This plant is a larval food and nectar source for Monarch Butterflies and thrives and reproduces well in green roof conditions. It has spread throughout the green roof. We have thinned it but not eliminated it.

Plants not Recommended Based on the UT-Arlington Plant Trials

Bouteloua dactyloides Buffalo Grass

Buffalo Grass, although a native of the area, suffers from many of the same problems on an extensive green roof as it does in the landscape. It is regularly invaded by weeds, goes dormant if under even a moderate amount of stress, and is the only plant on the roof that has been invaded by fire ants on a regular basis. This is probably due to the clay soil in the sod.

Callirhoe involucrata Wine Cup

This native Winecup makes a brief appearance each spring as a very small plant. It has not spread on the roof the way it would in a ground level landscape planting in soil.

Delosperma nubigerum Yellow Ice Plant

The Ice Plant developed a white mold right in center the first year during warm rainy weather and was removed

Liatris spicata kobold Blazing Star, Gayfeather

The very few surviving Liatris plants are very showy. The 90% loss rate indicates that this is not a good variety for extensive roofs. It was planted as a compromise when the supplier could not provide the local native species (L. mucronata)

Phedimus kamtschaticus. Sedum Kamtschaticus.

This Sedum variety was proposed and donated by a green roof vendor. It looked very promising for the first year and then rapidly declined in a moist summer spell. The sedums, in general, do not do well during occasional extended warm rainy periods during summer months. They tend to either rot with warm humid weather or die back in hot dry weather.

Scutellaria suffrutescens Pink Skullcap

Pink Skullcap has proven to be too slow a grower to make an impact on the vegetation of the roof. In January of 2010, several of the specimens died back to the ground, further exacerbating the slow growth. Other skullcap species will be tested in the future and may be more durable.

Sedum Acre Gold Moss Sedum

This sedum dies down in the summer when it is needed most and never really recovers in cooler weather. It has not died out completely but will never fill in and cover the bare soil.

Sedum reflexum 'Blue Spruce' Blue Spruce sedum

This sedum dies down in hot summer weather. It does not die out completely but appears only sporadically and does not come close to covering the ground

[i] For a thorough discussion of extensive, semi-extensive, and intensive green roofs, see Cantor, 2008.