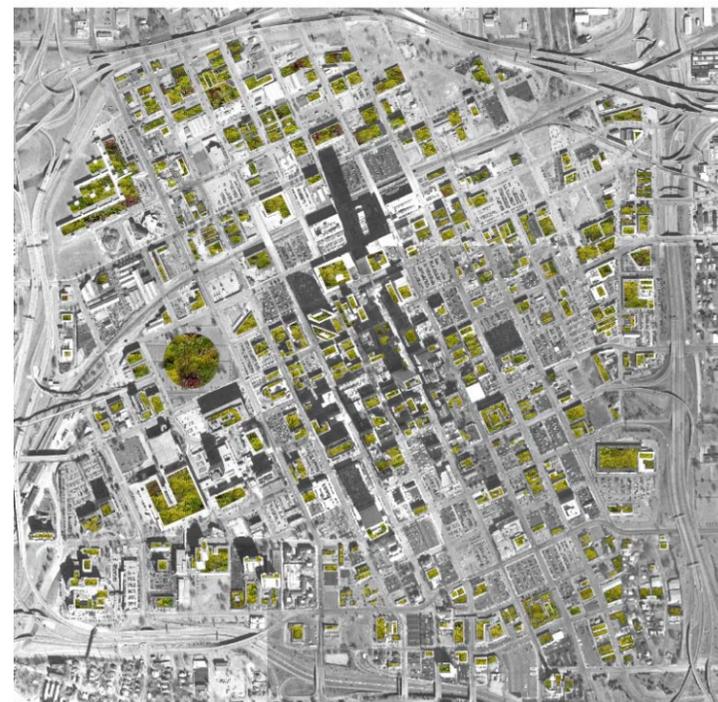




Green Roof Plant Trial Array

May 2009



The University of Oklahoma
Graduate College

Green Roof Plant Trial Array

A Professional Project
Submitted to the Graduate Faculty
in partial fulfillment of the requirements for the
degree of
Master of Science in Architectural Urban Studies

By

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2009

A Professional Project approved for the
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Acknowledgements

Nathan Diekelman would like to thank the following:

Reid Coffman MLA, Ph.D., ASLA, GRHC

Dr. Janet Cole, Professor Ornamental Horticulture

Shawn Michael Schaefer, AIA, NCARB, OUUDS Director

Matthew Hufft, AIA, LEED AP

Matthew O'Reilly, Owner and Developer of Green Circle Shopping Center

Jason Hainline, Vice President of Sustainable Design and Development Services- EMSI

Melissa Cox, MLA

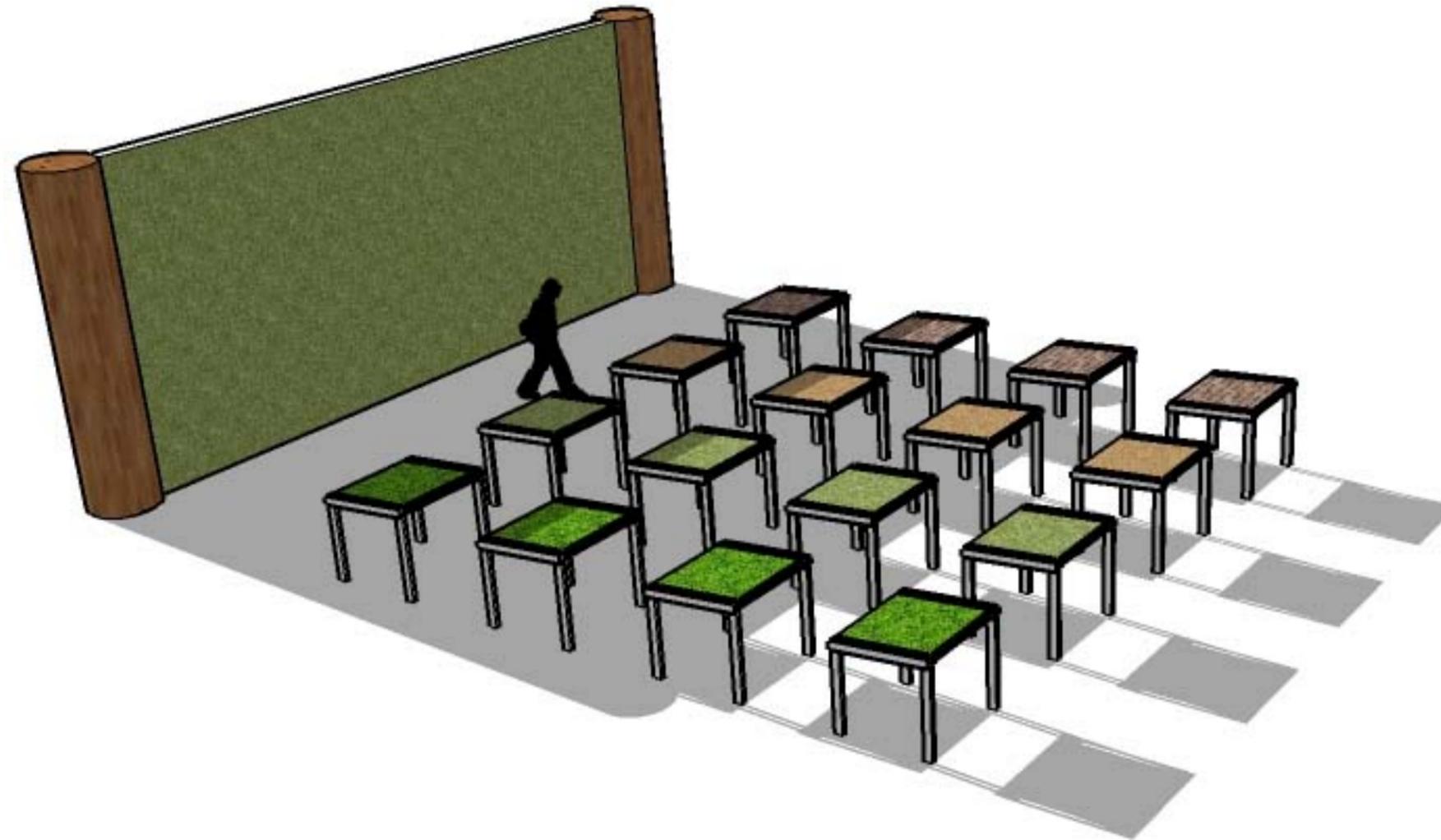
Alan Roark, Roark Landscaping

Empire Roofing

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Project Overview



This project explores green roofs, looking at the ways in which green roofs are constructed and the benefits that can be gained from installing green roofs. After a basic introduction to green roofs this project will explore two different components; the green roof plant trial array and then a green roof scenario for Tulsa.

The first part of the project is the green roof plant trial array. The research array is going to be built and operated as part of my future Doctoral program at Oklahoma State University. I will begin classwork in the Fall 2009 while I prepare the research trial array. This is a longterm project, plant trials take several years to conduct and planting is planned for the spring of 2010. Several funding bids are being prepared to send to private organizations and government agencies such as US Environmental Protection Agency.

The second part of this project is a scenario that estimates the potential benefits of widespread green roof installations in downtown Tulsa. These estimates can act as a starting point for development conversations in the downtown area. Understanding the impacts on the urban environment can help developers and citizens make sound decisions regarding the best use of our land. This scenario itself is split into two parts. The first is downtown Tulsa with 80% of the current rooftops converted to green roofs. The second scenario adds to the first by extending greening techniques to all of the parking lots and parking structures.

Introduction

What is a Green Roof?

A green roof is a roof surface that is covered in living plant material. Unlike roof gardens or intensive green roofs an extensive green roof restricts access and supports a more uniform plant covering. Roof gardens are often container gardens with heavy nutrient rich growing medium to produce flowers and vegetables for the pleasure of the garden guest. Green roofs are an opportunity to reclaim the footprint of a building. Replacing the hardscaped rooftop with a living layer of insulation can have economic and ecologic and social benefits.

There are many benefits to installing a green roof. In urban environments green roofs are said to help mitigate the Urban Heat Island Effect. They promote watershed health by absorbing the initial water of a rain event, and reducing exposure to typical petroleum based roofing materials. Providing thermal insulation and reducing UV exposure on rooftops is an additional benefit. Lastly, there are social and ecological effects as well. People have the potential to enjoy the green space as much as the birds, snakes and other wildlife do.

Extensive green roofs can vary greatly between installations. They can be vast rooftop meadows covering several thousand square feet or they can be simple monoculture turf installations on a small 10 ft x 10 ft roof. Design differences come from a myriad of factors; the building, the intended use of the roof, the cost of installation, and the cost of maintenance over time.

Cities like Chicago and New York have embraced green roofs. Private developers have begun to realize not only the environmental and economic benefits, but also the social rewards. Public and private research combined with the global knowledge of green roof development can greatly increase the awareness and utility of green roofs across the central US. dated within city limits?

*Below:
Rooftop meadow in Salt Lake City, Utah
Photo: Nathan Diekelman*



*Extensive green roof on the concession stand at
the Washington Nationals baseball stadium.
Photo: www.greenroofs.com*



*Photovoltaic cells mounted on an extensive green roof.
Photo: www.greenroofs.com*

Green Roofs

Construction and Materials

The term green roof actually denotes a system comprising several components, or layers, that work together to function as a single, combined unit (Snodgrass, 2006). Green roof technology has been largely developed in Germany by The Society for Landscape Development and Landscape Design, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau or, or FLL for short. In addition to a structurally sound deck there are seven additional components outlined by the FLL guidelines for green roofs. The materials and methods are fairly universal, the substrate and the plant materials will need to be selected for regional differences.

Deck Layer: Designed and engineered as part of the building. Live loads will add incredible amounts of weight to the structure, and the roof must be considered by a structural engineer to ensure building safety. Common deck materials are concrete, wood, metal or composite.

Waterproofing Membrane: Green or not, the most important part of any roof is the waterproof membrane. Any failure of the membrane will allow water and roots to penetrate to the deck layer, and may cause considerable damage. Water may migrate from its point of entry and be nearly impossible to trace, requiring the entire green roof installation to be removed in order to repair the problem. After the waterproofing membrane is applied a leak detection test must be performed.

Root Barrier: Plants undergoing full photosynthetic potential can grow very vigorously and aggressive roots can do serious damage to the waterproofing membrane and roof deck. A protective layer may be necessary if the waterproofing membrane has seams or contains organic materials, such as wood or asphalt. PVC is a common root barrier, which can be laid out in single sheets. Chemical compounds like copper, which is a natural root repellent, can also be integrated into root barriers.

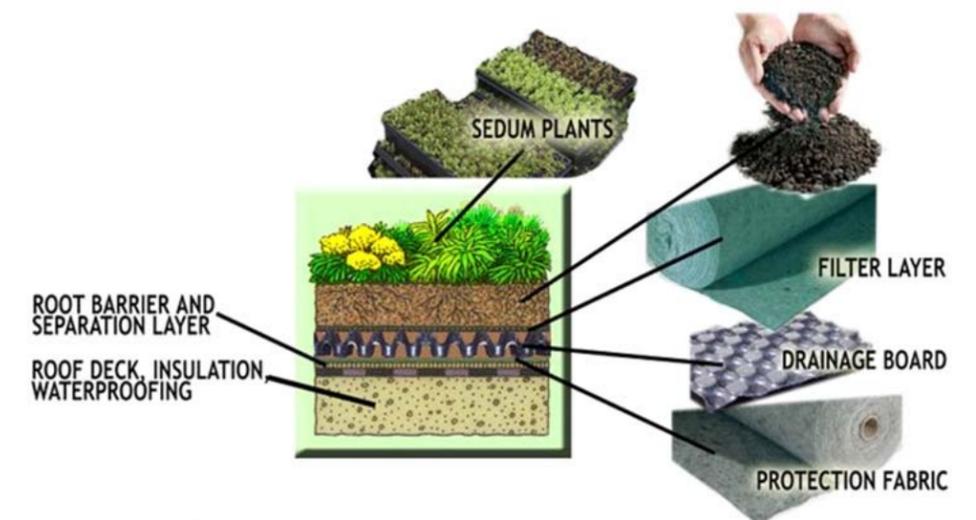
Insulation: To maximize the heating and air conditioning of the building, a rigid foam insulation layer is installed. The most common insulation method for a green roof is the Inverted Roof Membrane Assembly -IRMA, which places the insulation above the waterproofing membrane (Earth Pledge, 2005). On an IRMA roof this layer also doubles as an extra barrier to protect the waterproofing membrane from UV degradation and mechanical penetration.

Drainage and Capillary Layer: To prevent excess water from collecting in the growth media a good drainage system is required on all green roofs. Plant roots will begin to rot if they are in puddles of water. Engineered drainage systems are available and are often included as part of a complete green roof system. Ensuring that water drains away from the roots of the plants can be accomplished through the medium itself on most extensive roofs, especially on sloping roofs and where rainfall is limited (Snodgrass, 2006). A capillary storage layer is often included to help store water during dry periods.

Root Permeable Filter Layer: Filter fabric is placed on top of the drainage layer to help hold the growth media in place, otherwise loose media can float into the drains, clog the system and cause pooling.

Growing Media: Green roofs are distinct from ground gardens because of the difference in substrate composition compared to the dynamic natural properties of a native soil. The substrate provides the nutrients for plant growth and serves as an anchor for root growth. Ground gardens have high levels of humus, peat and other organic materials, with sand to increase porosity. Green roof substrates do not contain such high amounts of heavy organic materials and fillers. Low-weight, high-porosity aggregates like expanded shale and clay are particularly suited for rooftops and have stable grains that will not get windblown (Earth Pledge, 2005). New technology has recently introduced substrates that are engineered to retain water without increasing the load on a roof during dry periods, this substrate is used to supplement any capillary layer.

Plant Material: The plant species actually growing on a green roof may include intended species and weeds or other volunteer species if maintenance is lacking. Plant selection needs to be made based on the geographic location of a roof and the desired outcome of each roof. Elevation, light intensity and the regional water cycle are just a few of the important factors to consider during the plant selection process.



*Layers of standard green roofs.
Photo: Green Roof Service LLC
www.greenroofservice.com*

Green Roofs

Planting Intensity

Green roofs are as widely varied as the buildings that they cover. Some roofs offer building residents a place to sit and relax, while others are inaccessible except for maintenance. The wide variety of roof types and plant materials can be categorized as Extensive or Intensive.

“The simplest green roofs (extensive) are shallow; 3 or 4 inches of growing medium planted with drought tolerant succulents or grasses and requiring minimal maintenance. Deeper, more elaborate green roofs (intensive) can be landscaped with flower and vegetable gardens, or even trees.” (EarthPledge, 2005)

Extensive roof installations are cheaper than intensive roofs. The cost of installation and the maintenance costs over a roof's lifetime are lower with extensive green roofs. Intensive green roofs require more inputs for success; such as growth media rich with organic matter, irrigation systems, higher cost of structural engineering, and increased installation costs.

The difference in planting intensity affects human interaction with the roof. Extensive roofs offer limited access to the planted area. The inorganic substrate is sensitive and all efforts should be made to prevent collapsing its structure. Plant roots interact with water and atmospheric gases in the tiny compartments between soil particles, this process is restricted when the structure is compromised. Intensive green roofs allow more access to foot traffic and public viewing. A roof like the Church of Jesus Christ Ladder Day Saints Conference Center in Salt Lake City Utah was designed for public access, with full ADA compliance.



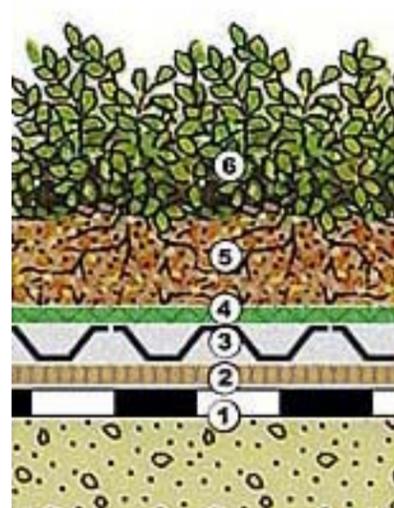
Extensive green roof on Chicago's City Hall
Photos: www.wikipedia.com



Intensive green roof in Manhattan

Extensive Roofs:

- Cover large areas of roof surface
- Plant material is small and shallow rooted
- Plant material is tolerant to water stress
- Restricted access
- Inorganic substrate
- Light weight



Extensive Roof Cross Section
Photo: www.greenroofservice.com/extens.html

Intensive Roofs:

- Have deep planting media
- Can support deep rooted plants; trees and shrubs
- May require an irrigation system
- Typically allow visitor access
- Organic substrate
- Heavy

Layers Legend

1. Roof deck, Insulation and Waterproofing
2. Protection and storage layer
3. Drainage and capillary layer
4. Root permeable filter layer
5. Growing media
6. Plant material



Intensive Roof Cross Section
Photo: www.greenroofservice.com/intens.html

Green Roofs

Storm Water Mitigation

Storm water mitigation is the largest recognizable public benefit of green roof installations. When rain falls on undeveloped land the water is absorbed into the soil and gravity pushes it down to recharge the aquifers and rivers. Some of the water will be intercepted by plant roots, be transported up to the leaves and transpired out into the atmosphere. However, when it rains in cities and built environments the water cannot penetrate the surface. Instead it will flow downhill across rooftops and paved areas and gather in lowlying areas, resulting in localized flash flooding. Creating dangerous conditions for property owners and area motorists. Typically the burden for repairing these situations often falls on the taxpayers of a community.

Increasing the amount of porous surface in urban environments will give rain water a place to go and provide storage for short periods of time. While stored in the roof substrate, water will have time to be absorbed by plant roots and used during the photosynthetic process. A green roof will have limited capacity to store water. When the roof reaches maximum capacity water will begin to flow down the drains and can either be stored on site for later use, or it will empty out onto the street and join the rest of the municipal stormwater system. Delaying the initial surge of runoff from rooftops can reduce local flooding, by extending the storm surge into a gradual discharge.

Governments are increasingly setting standards for both the reduction of stormwater runoff and the quality of any of that does occur, providing powerful reasons for green roofs to be taken seriously by policy makers at local government level (Dunnet and Kingsbury, 2008).

Green Roofs

Air Quality

High concentrations of automobile exhaust combined with industrial processes and the harsh conditions of large metropolitan environments have been suspected of increasing local temperatures and linked to chronic health problems. Vegetated rooftops can provide a platform for particulate matter to settle out and wash into the substrate during rain events. Once in the soil natural chemical and biological processes will break down the solid particles.

Plants grow and reproduce using carbon from the atmosphere. Sequestering carbon has recently been seen as a major advantage in the fight against global warming. As for quantifying the benefits of green roofs to absorbing air pollutants, the precise work has yet to be published on the value of different roof types in carbon sequestration (Dunnett and Kingsbury, 2008).

Individual green roofs are not likely to impact the macroconditions of any city in any climate, however if large areas can be massed together and regreened the potential benefits can be achieved and possibly exceeded with advances in technology. City planners typically offer economic incentives to developers in the hopes that one day large cities can accumulate vast areas of green roof.

Economic Benefits

Building developers and owners will often ask “What’s in it for me?” Financial incentives and savings can be a great stimulus to the expansion and implementation of green roofs in the central United States. The upfront costs of an extensive green roof is about times the cost of a conventional roof, but economic savings are realized over time through a few avenues with green roof installations; reduced utility costs, extended roof life and the potential for on-site water detention.

Utility costs are impacted by the living plant material and the insulation capacity of the growth substrate. Leaves shade the roof surface eliminating the daily increase in roof temperature. Green roof plant material also actively cools the air immediately adjacent to a rooftop. By reducing the heat load on the surface of a building, less power is required to cool the buildings interior during the hot summer months. In climates where air conditioning is regarded as essential for creating decent indoor working conditions, this could be a major reason for considering roof greening: every reduction in internal air temperatures of 1° F can reduce electricity use for air conditioning by up to 8% (Dunnett and Kingsbury, 2008).

Conventional roofs are exposed to very rough climatic conditions and this exerts a lot of force on roofing materials. Ultraviolet (UV) light can break down the structural integrity of materials over time, and the annual freeze/ thaw cycle can cause cracking and other material failures. Living plant material can physically intercept the UV light and have a big impact on roof longevity and performance. During the spring and summer, temperatures on a neighboring black tar roof varied by as much as 90°F, while the variation under the 2.74-inch vegetated cover was only 18°F (USEPA, 2000). Reducing the external roof temperature lowers the energy demand on a building

by eliminating conduction of the cool inside air out into the hotter atmosphere.

Developers are responsible for managing the water regime on any new development project. This is typically done by constructing an on-site detention pond or by paying In-lieu Fees to the city. Green roofs provide a unique opportunity to integrate stormwater management into the building design process.

Green Roofs

Urban Heat Island Effect- UHIE

When dark impermeable surfaces are warmed by the radiant energy of the sun the energy is absorbed and then released back into the surrounding environment. The amount of energy that a surface reflects, which determines how hot it will become, is called albedo, measured on a scale of from 0 to 1 (hottest to coolest). The albedo of a tar or gravel roof is about 0.08, as compared to 0.25 for grass and 0.6 for reflective roofing (EarthPledge, 2005). Living plant material not only absorbs the sun's radiant energy, but they also actively cool the air through the process of evapotranspiration. Water is constantly being drawn in through the roots and lost through the leaves, plants also add fresh oxygen to the atmosphere.

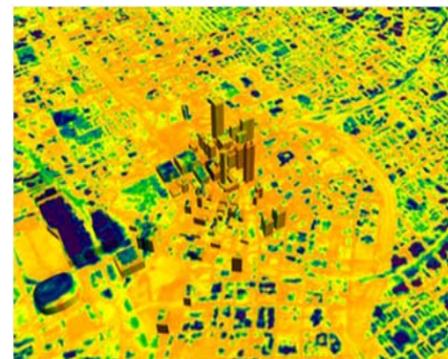
One green roof will not affect the UHIE, however several acres of reclaimed roofs may start to make a difference. The benefits gained by green roofs can be magnified by adding more strategies to the reduction of UHIE; limiting automobile exhaust primarily diesel emissions and increasing green space at street level.



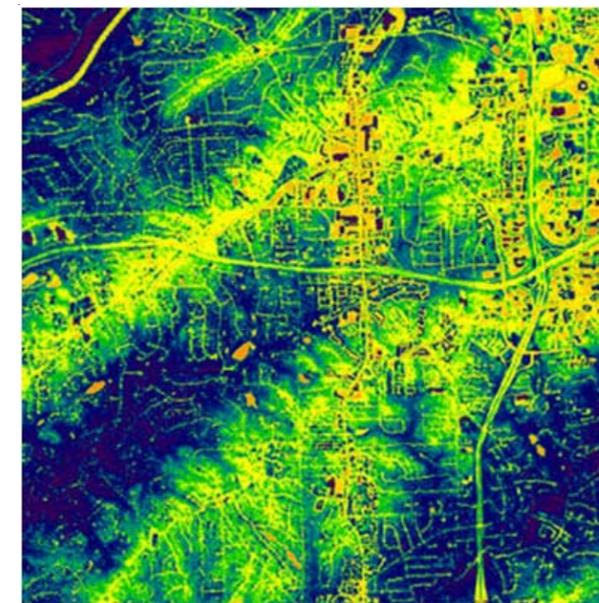
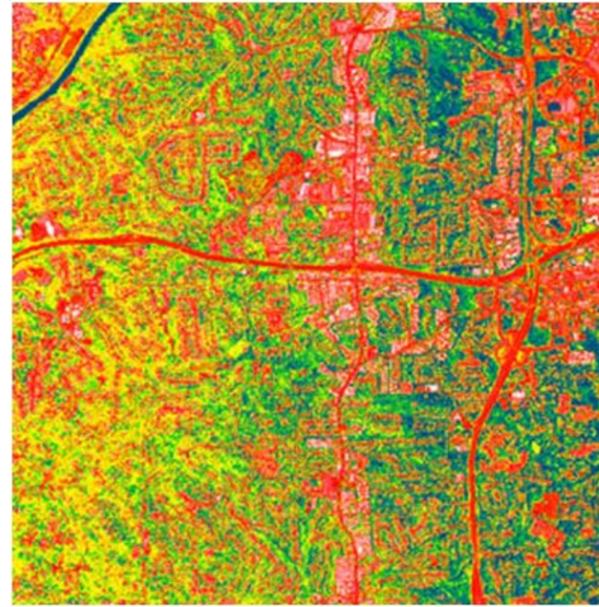
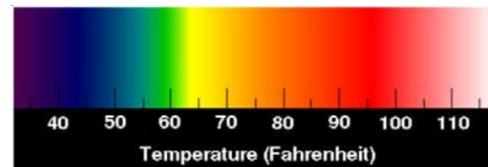
Downtown Atlanta, Georgia under normal conditions.



Downtown Atlanta during a summer day in 2004.



Downtown Atlanta at night in the summer of 2004.



Top: Suburban Atlanta during the day.

Bottom: Suburban Atlanta at night.

NASA conducted an Urban Heat Island Effect survey of Atlanta, Georgia. Thermal images were captured during the summer of 2004. The daytime images of both downtown and the surrounding area show that a majority of the land area can reach temperatures approaching 100° F. Downtown can get to 110° F or higher. At night when the earth has a chance to cool down the large paved areas of metropolitan Atlanta radiate the stored energy and can be seen in the mid-60's. In the night time images downtown Atlanta demonstrate a temperature around 85° F. A large suburban area can be seen near the center of the images on the right. Urban sprawl like this can be seen in communities across the country.

Green Roofs

Urban Ecology

Our built environments are often composed of rough, impervious man-made materials. Wildlife and natural habitats are pushed further away from our cities' cores every day. Green roofs are commonly inhabited by various insects including beetles, ants, bugs, flies, bees, spiders, and leafhoppers (Coffman and Davis, 2005). Providing lower order animals along the food chain will begin to attract higher order predators; birds, bats, mammals, and reptiles; increasing the overall biodiversity in a community. Extensive green roofs, which are not designed to be walked on and are therefore isolated from people, can be potentially very good undisturbed habitat for plants, birds, and insects (Dunnett and Kingsbury, 2006).

The thin composition of an extensive green roof nearly replicates some of the rocky outcroppings found across the Oklahoma plains. By creating a similar environment it may turn out that entire plant communities volunteer and colonize green roof installations in the area.

A green roof designed for wildlife benefit has a growth substrate of varying depths to provide protection to soil dwelling animals and increase the diversity of plant material. Other elements of habitat creation include providing dead wood and rocky areas. Swiss green roof developer Dr Stephan Brenneisen has developed specific habitats including river banks and floodplains to the spontaneous communities along railroad rights of way. Dr Brenneisen works with local soils and subsoils and common urban rubble materials, like crushed concrete or brick. His intention is to use local materials to directly connect the ground level environments with reclaimed urban surfaces.



*Goose nest on a green roof in Toronto.
Photo credit: www.toronto.ca/greenroofs*



*The depth of this tree pit will provide several inches of protection to insect communities that may colonize in the substrate.
Photo: Nathan Diekelman*

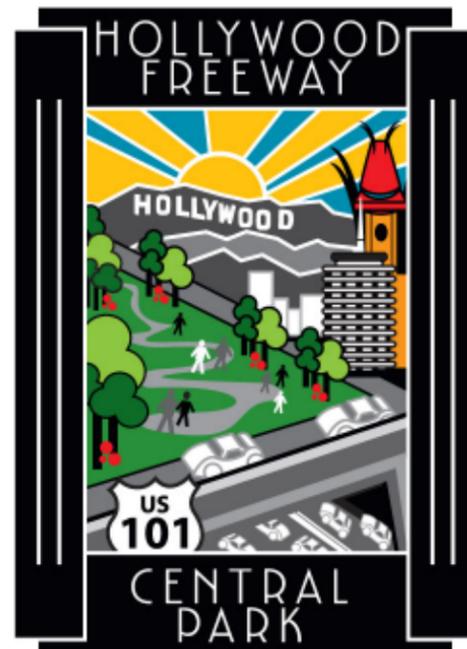
Green Roofs

Recreation Space

Rooftops represent the open space lost to building footprints, and green roofs are an opportunity to give the roofs back to building residents and local citizens. Recreational space at roof level has the advantage that access can be controlled, thereby making an environment safer from vandalism, assault, and the other social problems which tend to plague public green space at ground level (Dunnett and Kingsbury, 2008).

Access to green space for gardening is an amenity that developers are offering in dense urban areas, like New York city. Residents live in restricted conditions and hand grown herbs or tomatoes can bring a personal touch to meals. Installations that include food production need to be engineered for increased load due to biomass accumulation and for human access, raising the overall cost of the green roof. The substrate of these roofs will need regular maintenance to keep mineral and nutrient levels high enough to support production roofs. An alternative to this is to use a native soil on a roof, instead of a designed growth substrate. Native soil performs well because it has a specific structure developed over hundreds of years. Soil structure is easily destroyed and compacted making widespread use on extensive green roofs impractical.

Any roof with public access should always address the edge danger. There is little data available on the values associated with having access to green roofs, leaving room for social researchers to add valuable information to the subject.



The Hollywood Freeway Central Park is a 27 acre green roof park proposed to cover a section of the submerged highway running through the middle of Los Angeles, CA. The installation will be at ground level and will provide residents both a park and a safe way to cross over the busy roadway.

Photo credit: www.hollywoodfreewaycentralpark.org

This intensive green roof demonstrates an opportunity for low impact human use along with wide spread greening.

Photo credit: www.digigreen.com



The Clinton Park building proposed for Manhattan. This building will feature large public green roofs provided for the commercial development on the lower floors and private or semi-private green roofs for some of the apartments on the upper floors.

Photo credit: www.digigreen.com





Vegetated Mats

- Pregrown plants set in geotextile fabric and a thin layer of growth substrate.
- Can be produced in long strips to be rolled out on site, or cut into square and rectangular pieces for precise edges.
- Mats are heavy and difficult to transport long distances without drying out, especially on hot summer days.
- With irrigation, establishment can be immediate.

Mats being installed

Photo: www.greenroof.co.uk/naturemat.htm

Volunteer Communities

- Can be seen on old conventional roofs as a result of neglect.
- Invasive species may outcompete intended plant material.
- May be composed of native plants suited to the environment.



Pot- Grown Nursery Plants and Plugs

- Utilize fully formed individual plants.
- Can be used to achieve specific design patterns and artistic effects.
- Pot-Grown plants can be sized and purchased for specific locations and will not provide rapid roof cover and plant spread.
- The best option is to propagate plants in plug trays, the cellular units widely used in the nursery trade to grow large numbers of small plants (Dunnett and Kingsbury, 2008).
- The most commonly specified rate for planting plugs is two plugs per square foot, which will provide coverage of the roof in 12 to 18 months (Snodgrass,2006).

Potted plants after installation

Photo: www.nihrecord.od.nih.gov



Cuttings

- Quicker to establish than seeds.
- Cuttings are a viable and increasingly popular method for establishing *Sedum* on green roofs and are the most commonly used method of installation in Germany (Snodgrass, 2006).
- Cutting should be evenly distributed across a roof at a rate of 25 to 50 pounds per 1,000 ft² (Snodgrass, 2006).
- Cuttings require 12 to 18 months of growth to establish.

Cuttings being installed on a sloped roof

Photo: www.hubcoop.org



Direct Seeding

- Useful and cost-effective technique for establishing plants on roofs larger than 215 ft² (Dunnett and Kingsbury, 2008).
- Generally take 2 to 3 years to mature.
- Seeds are best sown in spring or fall, depending on the climate, using a propagation specialist with experience in hand sowing or hydroseeding technology (Snodgrass, 2006).

Direct Seeding a green roof

Photo: www.roofmeadow.com

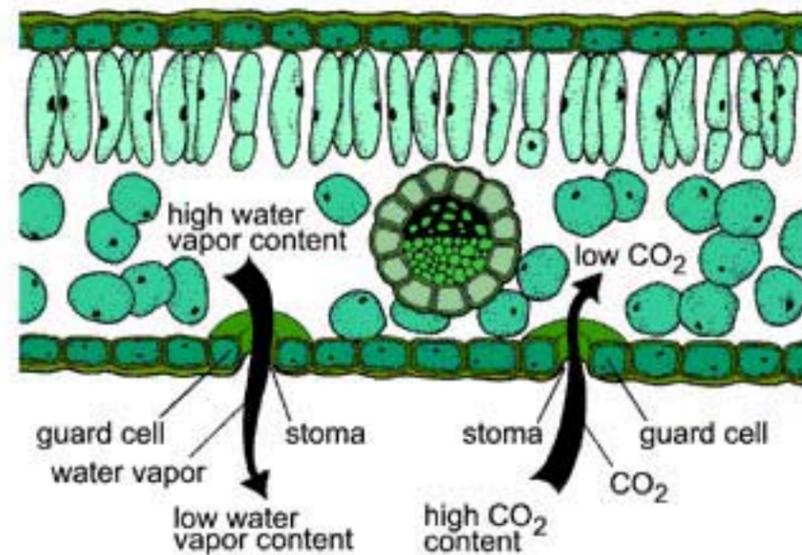
Plant Mechanics

What is a plant?

Plants are earth's primary producers, they collect and store radiant energy from the sun. Every food chain depends on plants to convert the sun's energy into sugars and starches. No matter what your dietary preferences are, you are ultimately dependent on plants to fuel yourself. As a culture we are dependent on ancient plants which have become fossil fuels, to drive our economies and lifestyles.

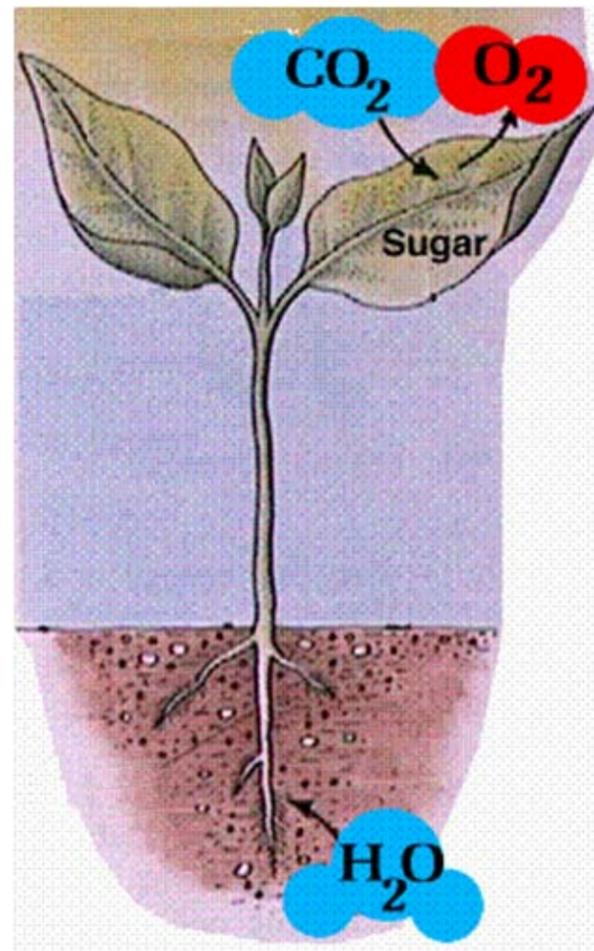
Plants lack mobility. Since they are stationary they have to grow towards water and nutrients, the essential elements of life. Another fundamental difference between plants and animals is that plant cells are surrounded by a rigid cell wall. This rigid cell wall adds fundamental structural integrity against the pull of gravity as the plant grows upward toward the sun. Plants also contain specialized structures to move water and mineral nutrients from the soil upward into the leaves. Water is steadily being lost through evaporation, it is drawn from the soil and siphoned out through the leaves.

Plants consist of several specialized cells, tissues and biochemicals. All of these special features work together to harness sunlight and atmospheric gases to store energy as carbohydrates. Leaves house the mechanisms that perform these functions. They provide the interface between the environment and the internal chemistry of the plant. Roots are as essential for water uptake, as leaves are for gas exchange. Plant reproductive cells are highly individualized and result in beautiful splashes of color, floral displays and delicious fruits and vegetables. A plant stores energy to perform its reproductive function. Flowers and fruits become sinks for the carbohydrates produced during photosynthesis, all efforts are put into protecting the precious seed.

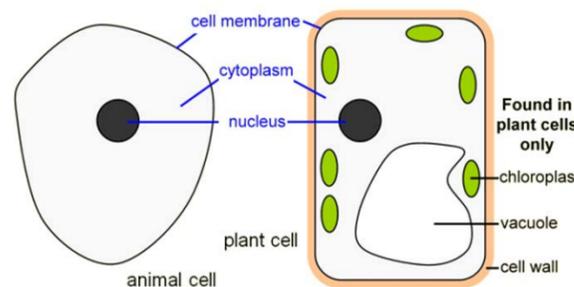


Top:
Cross section of a leaf displaying the air space between the epidermal layers. This space is used for gas exchange, bringing in CO₂ and exporting H₂O.
Photo credit: www.progressivegardens.com

Bottom:
Photograph of closed stomata with guard cells surrounding the small stomatal openings.
Photo credit: www.progressivegardens.com



What plants do. Plants convert the sun's energy and carbon dioxide and water into sugars and starches.
Photo credit: <http://www.cartage.org.lb/en/themes/sciences/BotanicalSciences/Photosynthesis/Photosynthesis/Photosynthesis.htm>



Comparison of an animal and plant cell. The structures in blue type are shared among cell types. Plant cells have a few special structures, labeled in black.
Photo credit: <http://www.bbc.co.uk/schools/gcsebitesize/science/images/aq>

Plant Selection

Photosynthesis

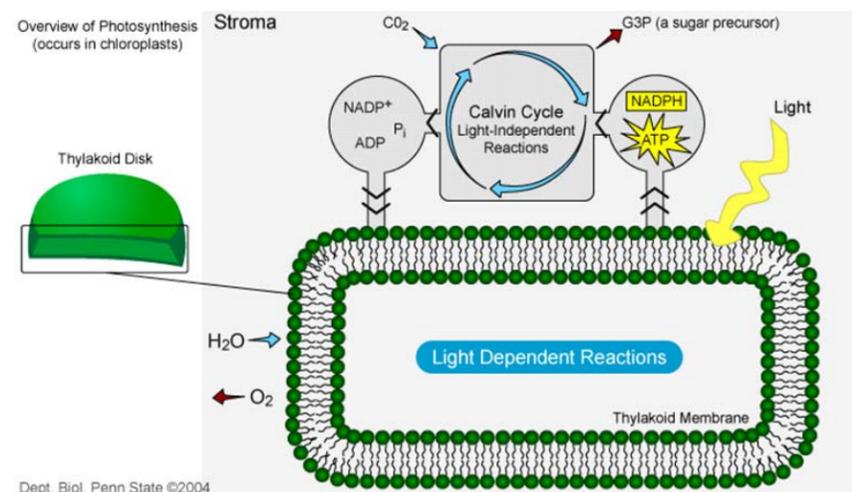
Energy from the sun is the source of all life on earth. Photosynthesis is the only known process for capturing the sun's radiant energy and converting it into chemical energy. Plants store energy as carbohydrates built out of carbon dioxide, CO_2 , and water, H_2O . Several chemical and physiological reactions combine to form the process of photosynthesis. These reactions are split into two major categories: light reactions and carbon reactions. The light reactions generate energy phytochemically in the form of ATP and NADPH. The carbon reactions consume the ATP and NADPH, in the Calvin Cycle to reduce CO_2 into carbohydrates and regenerate the starting materials. Chemically speaking the process of reduction adds electrons to a molecule reducing its charge. Oxidation is the process of removing an electron and positively charging the molecule. Plants use solar energy to oxidize water, thereby releasing oxygen reducing carbon dioxide, forming large carbon compounds, primarily sugars (Class notes, 2006).

Balanced Equation of Photosynthesis:



Photophosphorylation

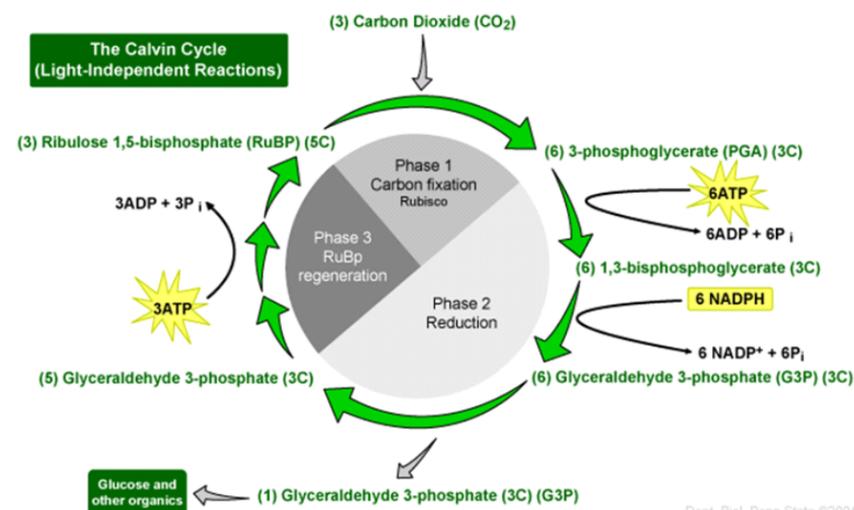
The light reactions utilize the radiant energy from the sun to create stored energy to drive the carbon reactions. Pigment molecules known as chlorophylls and carotenoids become excited, meaning they move to a higher state of potential energy, when exposed to the sun's radiant energy. A molecule of H_2O is split into O_2 and a positive Hydrogen atom. The other hydrogen atom becomes increasingly positive until it enters the redox chain. The electron cascades down the chain, and the energy is used to generate ATP and NADPH.



Photosynthesis occurs into two phases: the light reactions, photophosphorylation and dark reactions, the Calvin cycle.
Photo Credit: Department of Biology, Penn State University, 2004

The Calvin Cycle

The Calvin cycle operates in three stages. Carboxylation, during which atmospheric CO_2 and water are linked to a carbon skeleton. Reduction is the next stage, carbohydrates are formed at the expense of the ATP and NADPH produced during the light reactions. The final step of the Calvin cycle is to regenerate its startup chemicals to perpetuate the cycle.



The dark reactions or the Calvin Cycle
Photo Credit: Department of Biology, Penn State University, 2004

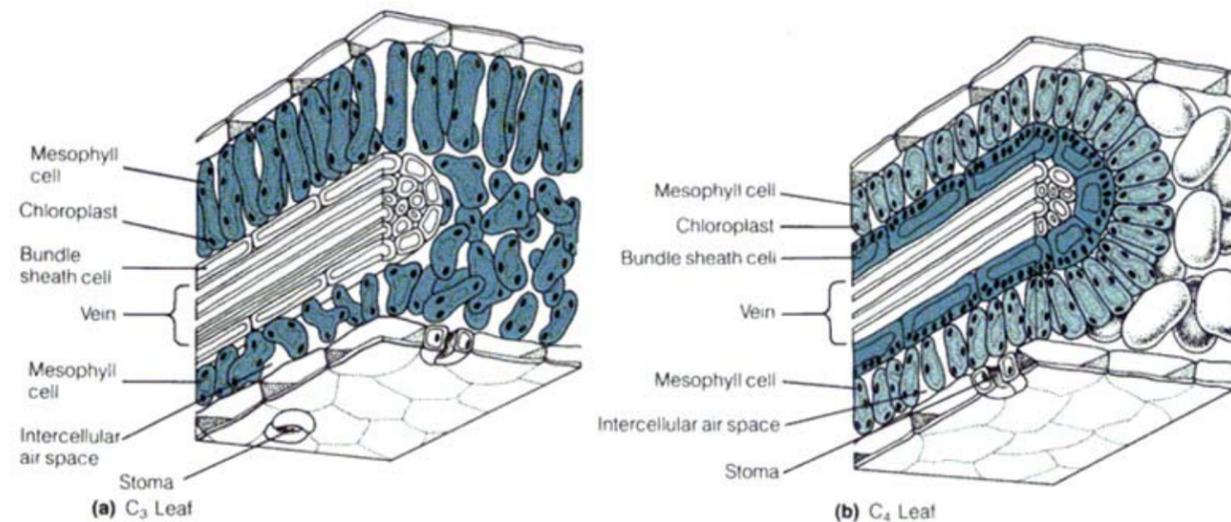
Plant Mechanics

Types of Photosynthesis

There are three types of photosynthesis in the plant kingdom: C₃, C₄ and CAM. Most plants use C₃ photosynthesis, the other two types are adaptations to arid growing conditions. All three types utilize the Calvin Cycle to reduce CO₂ into carbohydrates. C₃ plants rely on the Calvin Cycle alone for metabolism. C₄ and CAM plants have adaptive values increasing their Water Use Efficiency. Some plants like the Ice Plant undergo Facilitative CAM, meaning under normal conditions they operate as C₃ plants. When stressed they transition into CAM metabolism.

All three mechanisms of photosynthesis have to outweigh other environmental factors to thrive and successfully compete. C₄ plants tolerate higher temperatures and drier conditions than C₃ species, but may not compete successfully at temperatures below 25 C. CAM plants conserve water by closing their stomata during the day, a practice that severely reduces their ability to take in and fix CO₂ (Raven, 1999).

Horticulturalists have a saying “the right plant in the right place”, a saying that is very true in relation to green roofs. Proper plant selection is essential to the success of any green roof. It is always advised to consult a local horticulturalist or other plant expert for recommendations for green roofs. CAM plants are the usual suspects because of their ability to survive in very dry conditions. In addition to considering USDA Hardiness Zone, designers need to factor in all other elements of the green roof, a synthetic microenvironment.



3D sectional model of C₃ and C₄ plant leaves

(a) In the C₃ plant the mesophyll cells are loosely arranged within the leaf.

(b) The mesophyll cells are tightly packed around large bundle sheath cells. Each mesophyll cell is within two or three cells of the bundle sheath cells.

Diagram: Botany Department, The University of Hawaii from www.botany.hawaii.edu

C₃ plants

- Called C₃ because the CO₂ is first incorporated into a 3-carbon compound.
- Stomata open during the day.
- RUBISCO is the enzyme used in photosynthesis, but it is also involved in photorespiration resulting in a decrease in productivity.
- Rely on Calvin Cycle to fix CO₂.
- Photosynthesis takes place throughout the leaf.
- Strong competitor in cool, moist environments.
- C₃ plants have a water use efficiency of 0.002 (Taiz, 2004).
- Most plants are C₃.

C₄ Plants

- Called C₄ because the CO₂ is first incorporated into a 4-carbon compound.
- Stomata are open during the day
- Photosynthesis takes place in the mesophyll and bundle sheath cells.
- PEP Carboxylase is the enzyme used in the uptake of CO₂ which is converted into the acid, Malate, in the mesophyll.
- Malate is transported from the mesophyll to the bundle sheath where it is broken back to CO₂ and enters the Calvin Cycle.
- C₄ plants have a water use efficiency of 0.004 (Taiz, 2004).

CAM Plants

- CAM is short for Crassulacean Acid Metabolism, because it was first discovered in the Crassulaceae family.
- Stomata open at night and closed during the day.
- CO₂ is converted into the acid Malate and stored in the vacuole during the night. When the stomata close the acid is transported to the chloroplast where it is broken back into CO₂, is delivered to RUBISCO and enters the Calvin Cycle.
- May CAM-idle. During extremely arid times the stomata may be left closed all the time. CO₂ given off during respiration can be captured and used for photosynthesis. The oxygen given off during photosynthesis is in turn used for respiration. This is a temporary process, plants can't sustain this forever.

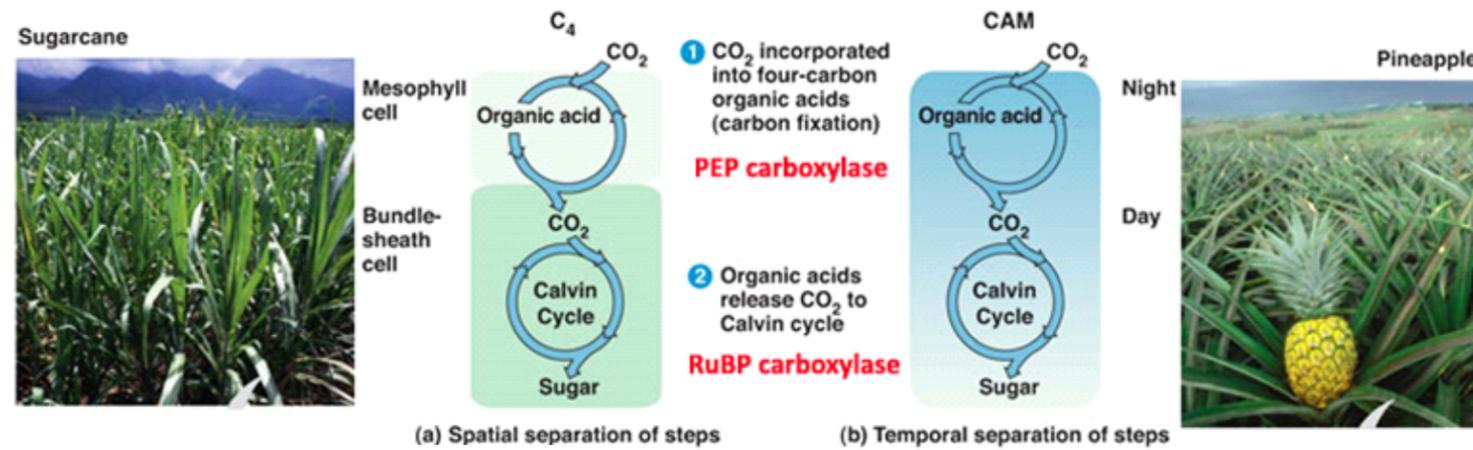
Plant Mechanics

CAM Plants

C4 and CAM plants can outperform C3 plants under hot arid conditions. CAM plants physically separate photosynthetic operations to conserve energy. To conserve water CAM plants close their stomata during the heat of the day, opening them at night when air temperatures are lower. These simple differences make CAM plants good choices for green roof installations. CAM plants are typically found in tropical regions.

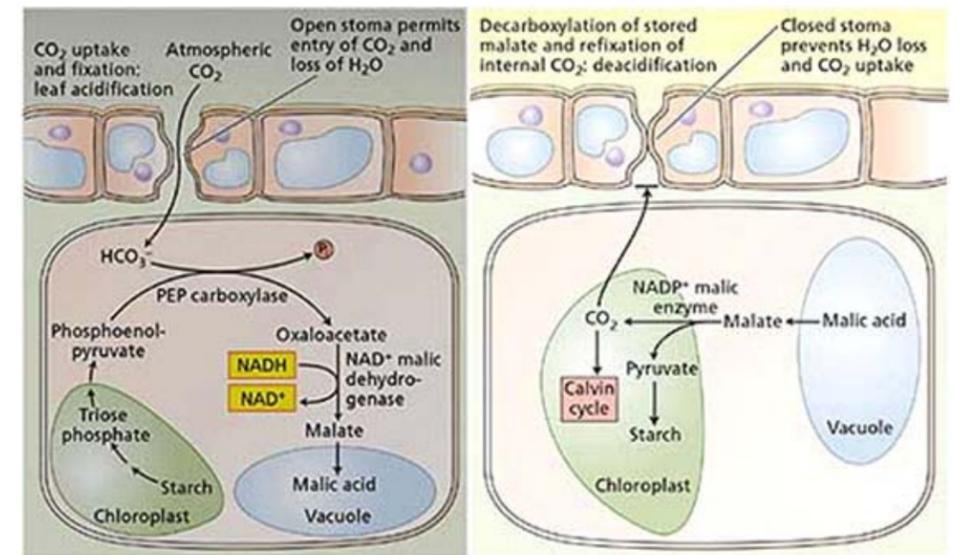
C4 and CAM Plants

- Carry out photosynthesis more efficiently than C3 plants in hot and dry environments.
- Rely on adaptations to the Calvin Cycle known as the C4 Cycle.
- Utilize unique methods of separating the photosynthetic processes.
- Have efficient water use ratings.



This picture shows the spatial separation of the two photosynthetic processes in C4 plants and both the spatial and temporal separation in CAM plants.

Photo credit: University of Michigan biology website www.eeb.lsa.umich.edu



CAM photosynthesis

Special adaptations make these plants very efficient in hot and dry climates.

Photo credit: Taiz & Zeiger

Research Review

Michigan State University

The green roof research program at MSU was initiated in collaboration with Ford Motor Company during 2000 in an effort to advise them on the installation of a 10.4 acre extensive green roof on a new assembly plant in Dearborn, Mich.

Principal Researchers:

Bradley Rowe, Associate Professor of Horticulture

Jeff Andersen, Associate Professor of Geography

John Lloyd, Professor of Mechanical Engineering

Joanne Westphal, Professor of Landscape Architecture

Tim Mrozowski, Professor of Planning, Design and Construction

Objectives

1. Conduct a performance evaluation of specific plant species for rate of establishment, nutrient requirements, environmental tolerances, plant competition, ability to exclude invasive weeds, and survival and persistence
2. Evaluate mixed plant communities and succession over time
3. Examine differences in evapotranspiration rates, substrate moisture levels, and plant performance among species exposed to several substrate depths and various levels of drought
4. Utilize chlorophyll fluorescence measurements to quantify plant stress before its evident from visual observations
5. Determine effect of rooftop microclimate on winter damage and subsequent growth
6. Determine the carbon sequestration potential of green roofs
7. Quantify the differences in water retention among roof vegetation types
8. Quantify the differences in water retention among combinations of green roof slopes and substrate depths
9. Evaluate the influence of roof vegetation on roof membrane temperature

Experiment Types:

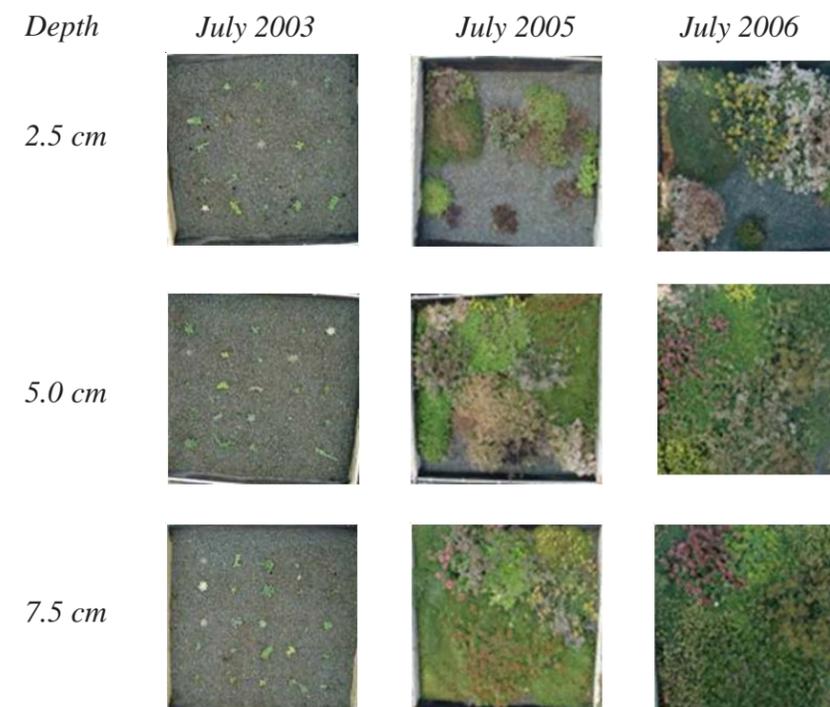
Roof Platforms

A plant establishment, competition, and survival study is currently being conducted on 24, 4' x 4' platforms. 25 species of *Sedum* plants were planted on the platforms with varying substrate depths of 2.5cm, 5.0 cm, and 7.5 cm (0.98 in, 1.97 in, and 2.96 in). Each species is replicated eight times with each substrate depth for a total of 600 plants.

A second study is underway to evaluate an additional 12 *Sedum* species planted on 8' x 8' platforms. This study replicates the first experiment, except each species is replicated 12 times within each of the three substrate depths for a total of 432 plants.

In both experiments, species are being evaluated at the three substrate depths for propagation success, establishment rate, growth, survival, density, and water stress.

Roof platforms are also equipped to measure stormwater runoff volumes and rates. Initial results show that vegetated roofs retained 60% of the rainfall compared to the substrate-only and conventional roofs with values of 50% and 27% respectively.



Above:
Representative growth at three substrate depths over three years.

Photo credits: MSU Horticulture Department
www.hrt.msu.edu/greenroof/

Research Review

Michigan State University

Experiment Types:

Effect of Planting Season on Establishment

Plugs of nine *Sedum* species were planted at depths of 4.0 cm, 7.0 cm, and 10.0 cm on green roof platforms in autumn (September 2004) and spring (June 2005) and the evaluated for survival on June 1, 2005 and again on June 1, 2006. Plants planted in the spring had a better survival rate of 81% compared to the fall at 23%.

Greenhouse Studies on Drought Tolerance

Native perennials, a native grass, and a mixture of seven *Sedum* species were planted in trays and a control with no plants were subjected to five different watering regimes. Irrigations schedules consisted of watering every other day, once a week, once every two weeks, once every four weeks, and never.

To measure the rate of evapotranspiration the weight of each tray was recorded and tracked over time.

This study is replicated except that it is expanded to test three different substrate depths.

One of the most interesting results of this study is that when *Sedum* was watered after 28 days of drought, its photosynthetic potential recovered to values characteristic of the 2 days between watering treatment.

Carbon Sequestration

The object is to quantify the carbon storage potential of extensive green roofs. 20 plots were covered with a single species of either *S. acre*, *S. album*, *S. kamtschaticum* var *ellacombianum*, or *S. spurium* 'Summer Glory'. Carbon analysis will be performed by measure the above ground biomass (leaves and stems), below ground biomass (roots), and soil carbon content. Sampling is ongoing and results will be available over the course of a few more years.

Plant Evaluation Trial Roofs

Several campus buildings have extensive roofs installed and are being studied for plant performance and the impact of green roofs on heat flow and energy consumption. Thermocouples are located inside the building, on top of the waterproof membrane, above the insulation layer, on top of the gravel ballast, and 1 meter above the roof. Local weather conditions are also recorded at each roofing site. All data is recorded every five minutes 24 hours a day with a datalogger and storage module.



Above:
8' x 8' test platforms, featuring enclosed gutters and tipping bucket rain gauges that log data every 5 minutes.

Photo credits: MSU Horticulture Department
www.hrt.msu.edu/greenroof/



A camera mounting frame was constructed to document plant growth during this study.



This point frame transect was constructed to measure leaf area index at three different canopy heights across test roof platforms.

Research Review

Penn State

Mission Statement

To demonstrate and promote green roof research, education, and technology transfer in the Northeastern US.

Objectives

1. Build a green roof research test facility
2. Gather data on how efficiently green roofs mitigate the volume of stormwater runoff
3. To compare green with non greened roofs for purposes of gathering information on energy savings during the winter heating and the summer air conditioning seasons
4. To sample rainfall from greened and non greened roofs to determine the capacity of a green roof to cleanse rainwater, especially related to nitrogen, neutralize acid rain, and particulate pollution
5. Determine how effectively green roofs buffer acid rain
6. To evaluate the efficacy of porous expanded polypropylene (PEPP) as a green roof growing matrix
7. To evaluate research data so architects and engineers can develop design tools related to green roofs
8. Select plants adapted to green roofs
9. To evaluate green roof growing media and plant growth characteristics
10. To develop light weight modular green roof growing systems
11. To evaluate the economic advantages of green roofs
12. To evaluate the social impacts of green roofs
13. To calculate the aesthetic benefits of green roofs in the urban environment

Test Building Facility

The Penn State Center for Green Roof Research Test Building facility is comprised of six buildings. Three buildings have conventional, non-green roofs and the remaining three buildings have green roofs. Each of the six buildings is equipped with weather monitoring equipment to record rainfall, wind speed and direction, solar radiation, and temperature. This data gives a clear idea of the ambient environment at each building unit.

Green roofs are planted in a modified layer system. A drainage layer overlain with 4-inch of expanded clay based substrate covered with Porous Expanded Polypropylene (PEPP). One-inch diameter holes are drilled in the sheet of PEPP on three-inch centers; cuttings of *Sedum spurium* are planted in the holes.

Heat Flux

All of the buildings are insulated with three inches of household grade fiberglass and fitted with thermister sensors in the roof, walls, and floor. Green roof buildings are equipped with a total of 39 sensors while the conventional roofs have 14 sensors. To get a continuous idea of roof performance the sensors log data every 30 minutes.

Energy Use

Each building has a 3kW air conditioner and a 1kW space heater and a standard household watt-hour meter to record energy consumption.

Stormwater Management

Enclosed gutters are connected to rain barrels fitted with pressure transducers to measure runoff. Data is collected every minute and averaged over every five minutes. Initial results indicate that green roofs may retain as much as 47% of the rain that falls on a roof's surface.

Other Research

Plant Growth and Spread

Ten plant varieties are planted in 14"x5" circular pots, originally designed as hanging baskets. The substrate is a highly porous expanded clay. At planting each pot received 10 g of Osmocote 14-14-14 applied to the surface and watered in. Each plant variety is planted in triplicate and the 30 pots are arranged randomly in a 6 by 5 grid. Plant growth performance is monitored every 2 weeks by photographing the plants and transferring the photos into Photoshop. Once in Photoshop the images are sized, printed and the outline of each plant is cut out and measured.

Evapotranspiration Model Development

This is being done in partnership with the USEPA. Green roof modules, 4.5 s.f., are hung in a greenhouse. Half of the modules are planted with *Sedum* and *Delosperma* and the other half contain only the green roof substrate. The object is to evaluate how plant material impacts a green roof's ability to absorb and transpire water.

Media Analysis

German FLL procedures are being duplicated to test green roof substrate.

Specific topics include:

- Interaction of medium depth and drought stress on the establishment of succulents.
- How can *Sedum* cuttings survive on a roof without irrigation yet root when irrigated?
- Media analysis on the effect of organic matter on plant growth.
- Do green roofs remove pollutants from rainfall?



Nathan Diekelman
Academic Year 2008-2009

Research Review

Penn State



Left:
Test building plot located at the Russel Larson Agricultural Research Center. The control roofs and green roofs can be distinguished by their distinct colors.

Right:
The rain barrel and kilowatt meter are mounted on the exterior of the building, the air conditioner can be seen under the deck holding the rain barrel.

Photo credits: <http://horticulture.psu.edu/greenroofcenter/research.html>



Individual potted plant trials at Penn State University

Ground Level Field Research Site

Modular roof panels are 2' x 2' wooden frames sealed with EPDM roofing membrane and planted with either 2, 4, 6, or 8 inches of substrate. Stormwater is collected using covered gutters that drain into sealed canisters that are measured by hand after rain events. Thermocouples are placed on the EPDM membrane and connected to a data logger to track thermal trends. There are 16 test and control models for a total of 32 roof panels. Four of each of the test models are planted with the four substrate depths (2, 4, 6, or 8 in). Four of the control panels are only covered with roofing membrane, and the remaining 12 panels are split into four groups of three and filled with the varying levels of growth media without plants.



Field Research site at SIUE. Test models and control models are randomly assorted on the benches.



Installing the gutter on a test panel.



Thermocouple adhered to the roof membrane before adding the drainage layer.



Data logger to record measurements from the thermocouple.



Measuring the rainfall amounts by weight.

Photo credits: www.green-siue.com

Research Review

Southern Illinois University

The Green Roof Environmental Evaluation Network or G.R.E.E.N. is housed at Southern Illinois University's Edwardsville campus. G.R.E.E.N is the closest full scale green roof research facility to Tulsa.

Principal Researchers:

Dr. Bill Retzlaff, SIUE Environmental Sciences Program

Dr. Susan Morgan, P.E., SIUE Department of Civil Engineering

Dr. Serdar Celik, SIUE Department of Mechanical Engineering

Objectives

1. Evaluate the thermal benefits of green roof systems
2. Evaluate storm water runoff quality and quantity from a Midwest green roof system
3. Evaluate the performance of green roof plants and growth media for the Midwest
4. Evaluate storm water runoff from Green Roof Blocks™ and Green Paks Green Roof Systems
5. Evaluate the performance of the Ecoworks living wall system

Research Array

Introduction

Why focus on the performance of Native *Sedums*?

Sedum species are the most common groundcovers used on extensive green roof sites, and since I am trying to promote extensive green roofs in Oklahoma, I need to start my research efforts by focusing on the plant material that is most likely to be chosen. Landscape Architects and horticulturalists typically try to use native plants, because they are adapted to specific regions or microclimates and tend to provide more suitable forage and habitat opportunities local to wildlife populations.

Green roof sites are highly synthetic. Waterproof membranes and the other layers that combine to form the foundation green roofs and keep plants within their designated space. Growth substrate is a mixture of highly processed materials that are engineered to hold water, increase pore space, and deliver chemical agents. Do these conditions really favor native species?

Why investigate mixed communities instead of individual species?

Extensive green roofs should be planted with a diverse selection of species. In the unlikely event that a species is vulnerable to a pest population, an entire green roof could be lost overnight if it does not have a variety of plant material. For the interest of my research I will be looking at mixed communities of *Sedum*, in real installations it would be wise to diversify beyond the sedum species.

Detailed planting records will allow individual plants and each of the separate species to be tracked and evaluated over the course of the research array.

Questions

Given Oklahoma's capricious climate:

- Primarily looking at thermal fluctuation and stormwater mitigation what are the performance differences between traditional roofs, established green roofs and unplanted green roofs?
- How will variations in light intensity affect plant establishment performance, both vegetative and reproductive growth?
- What is the survivability of *Sedum* in the trial?
- What combinations of *Sedum* plants performs best?
- How will substrate moisture content be affected by both the hot summer sun and the dry windy winter conditions?
- Will green roofs withstand torrential rain and hail storms associated with storm season each spring?
- Which insect species choose to locate on or in any of the green roof modules? Which module; native, adapted or unplanted?
- Are there other animal species that utilize green roofs for food or shelter?
- Do any roof panels grow volunteer plant species?
- Do green roofs provide safe habitat for disease and viral pathogens? If so, what impacts could be expected; financial losses to food and commodity agriculture, threats to mammalian avian and insect populations, or increased range and distribution of pathogens?

Outcomes

- Plant recommendations, with regional considerations for Oklahoma.
- Detailed schedules for maintenance and inputs; irrigation, fertilization, pest control.
- Problem solving techniques for dead sections, wind blown sections, or other failures.
- Regional suppliers for plant material.

Statement of Purpose

I am studying establishment, performance and lifespan of *Sedum* species on green roof installations in the central United States, specifically Oklahoma, because there is currently no plant performance data available for the region, in order to determine which species are best suited for extensive green roof installations so that I can publish plant recommendations and Best Management Practices (BMPs) for extensive roofing sites.

Green roofs are dynamic, living architectural features and to achieve the maximum benefits plant material needs to succeed. The costs of failure are extensive. All of the benefits that owners hoped to receive will never be realized. Owners make an initial capital investment with the hopes of seeing a return on their money in energy savings, only to be faced with a decision to reinvest. Plant material is expensive, and replacing plants is labor intensive and sometimes involves the extra step of replacing substrate. In this situation green roofs may not always remain a viable economic option.

Hypothesis

Native species of *Sedum* will perform better than non-native adapted species of *Sedum* on extensive green roof installations in Oklahoma.

Research Array

Goals and Objectives

This research trial will determine specific values for the performance and functions of green roof plants and methods for the plains of the central United States. There are many possible research questions and methods for testing green roofs. This trial is first and foremost about the establishment and performance of the plant material and its impact on the regional environment, secondary efforts will be directed to the social and cultural benefits.

The objective of this research is to evaluate plant material and substrate performance on green roofs, to quantify the environmental and economic costs and benefits. A research site of this kind at ground level is a great opportunity to interact with the public, and provide an educational platform for green roofs and other urban issues.

A Plant Material

Evaluate 2 native and 3 adapted *Sedum* species
Develop relationships with local nurseries

B Vegetative Support

Growing media
Roof membranes and materials

C Environment

Local microclimate data
Light Intensity

D Stewardship

Inform general audiences about green roofs
Promote local green roof installations
Create regional markets for goods and services

Plant Material

- A.1- Establish 5 species of *Sedum* on 4 ft. x 4 ft. (16 s.f.) roof panels.
- A.2 - Document the growth and development stages of each *Sedum* species; vegetative growth, flowering, reproduction, and senescence.
- A.3 - Monitor plant nutrition.
- A.4- Evaluate plant material for its tolerance to water stress; both drought and flood conditions.
- A.5- Estimate evapotranspiration rates for plant species based on the microclimate water cycle.
- A.6 - Measure photosynthetic potential on the surface of selected roof panels.
- A.7- Estimate plant productivity and efficiency based on carbohydrate storage and biomass production.
- A.8- Monitor every roof panel for pests: insects, disease pathogens, weeds, and other unintended species.

Vegetative Support

- B.1 - Develop media in accordance with the FLL.
- B.2 - Monitor media for nutrition content weekly.
- B.3- Monitor the Electrical Conductivity (EC) and pH of growth media.
- B.4- Measure moisture content of growing media.
- B.5- Evaluate the durability of construction materials at the end of the trial

Environment

- C.1- Measure surface temperature and light intensity throughout the test facility.
- C.2- Track daily climate conditions including wind speed, relative humidity, and barometric pressure.
- C.3- Measure precipitation amounts on the research plot.

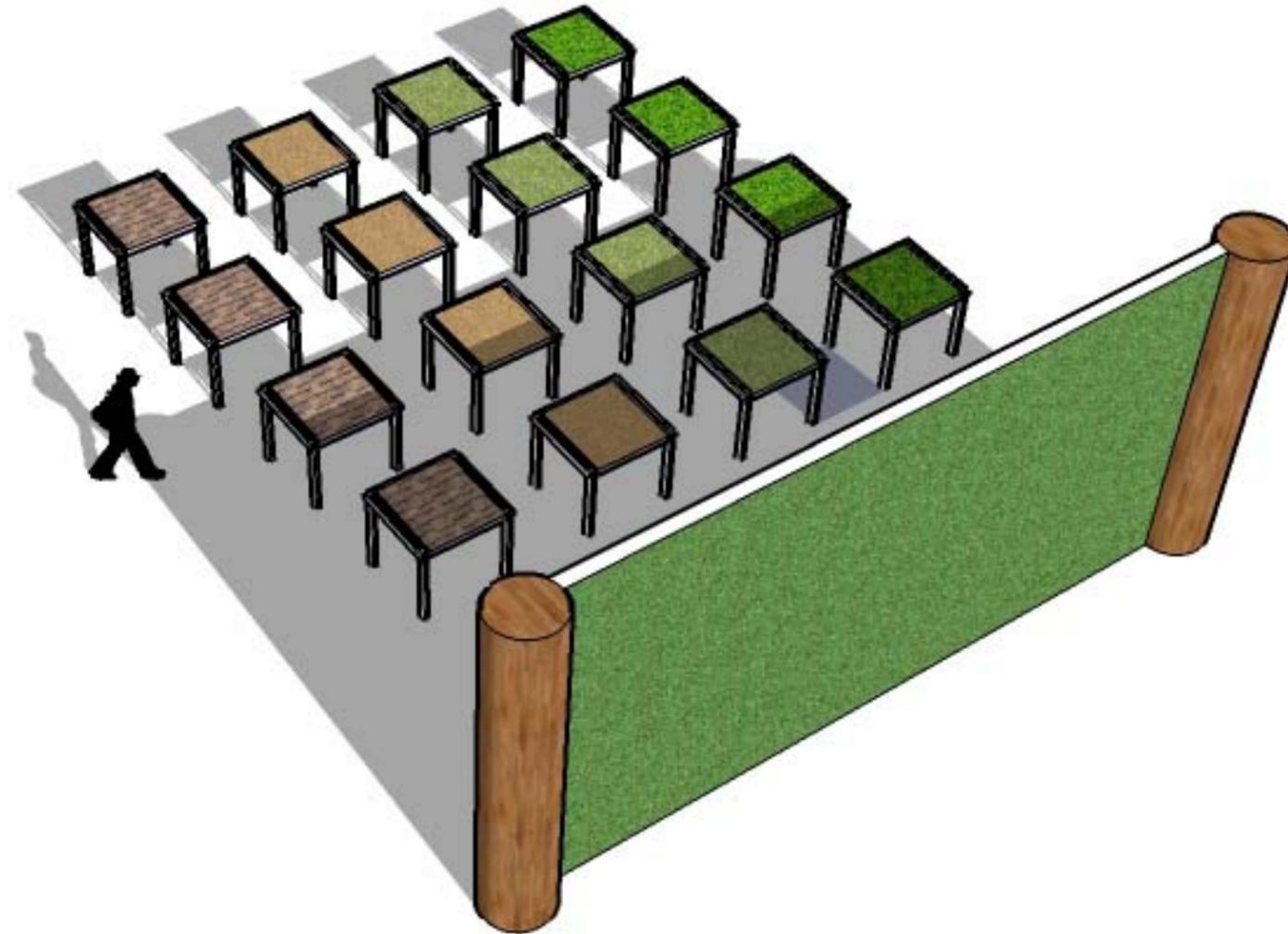
Stewardship

- D.1- Develop printed materials for botanical garden guests and visitors.
- D.2- Create educational curricula for school tours.
- D.3- Promote and encourage local green roof development.
- D.4- Evaluate the potential benefits of green roofs for health and social benefits

Research Array

Methods

Four roof panels measuring, 4ft by 4ft will be constructed to ASTM standards for commercial roofs using traditional roofing materials, and these will serve as the constants in the research trial. Twelve additional 4ft by 4ft panels will be constructed to ASTM standards for green roofs. Four panels will be planted with a mix of native Sedum plants, *Sedum pulchellum* and *Sedum sarmentosum*. Four panels will be planted with a mix of plants that are non-native to Oklahoma, *Sedum spurium* and *Sedum album* and *Sedum reflexum*. The remaining four panels will be built as green roofs, including media but remain unplanted. The sixteen panels will be arranged in a 4 by 4 array, each column representing one of the four panel types; conventional, native, non-native, unplanted. At the southern edge of the array will be a shade casting wall (or screen). Each of the sixteen roof panels will be outfitted with thermistors on both the membrane layer and the underside of the panel to measure temperature fluctuations. Panels will also have light meters to track daily light intensities and fluctuations. Individual panels will also measure the amount and timing of rain runoff, to do this roofs will have gutters that empty into tipping buckets that have small cups that empty with every 4 oz of water and log when water is dumped. The array as a whole will be equipped with weather stations throughout to monitor temperature, humidity, wind, precipitation and atmospheric pressure. Data loggers will record and track all environmental changes and climatic factors at the trial site and on each of the roof modules.



Sketch Up model of the Green Roof Plant Trial Array. The column on the far left is the conventional roof control, next is the green roof substrate control, the third and fourth columns are the mixed communities of native and non-native Sedum species respectively. The shadow cast by the wall serves to evaluate plant species for their performance with seasonal light changes.

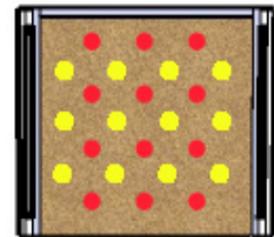
Research Array

Planting

Plant material will be evaluated as communities of mixed species. *Sedum pulchellum* and *Sedum sarmentosum* will be planted together on the native roof panels. *Sedum spurium* and *Sedum album* and *Sedum reflexum* are the non-native adapted plants being evaluated in the research array. Each 4ft x 4ft roof panel will be planted with 49 individual plants, on 6in centers. In addition there will also be a series of panels that contain only the growth substrate, to try and determine the value of a green roof installation without established plant material.

Plants will be sourced from a local distributor. Prior to transplanting to the roof panels, all plants will need to be hardened off to prepare for life outside of the production nursery. While at the nursery, plants may receive daily water and nutrient supplements in addition to a highly regimented light schedule. Upon delivery to the research site, each plant will need to be inspected for physiological defects, mechanical damage, and the presence of pests before they can be planted and evaluated for performance.

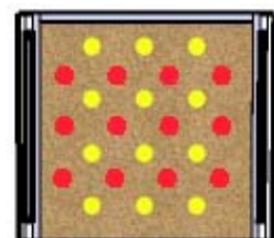
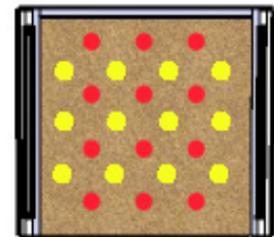
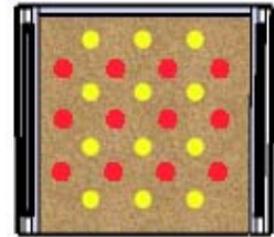
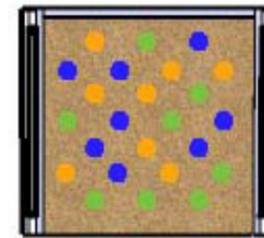
To retain hardiness to water stress the minimum amount of water will be used during the establishment process, and once plants are established no additional irrigation will be provided. Mineral nutrients will be provided in the original substrate recipe and no additional fertilizer will be used in the course of the research trial. The objective of the research array is to better understand how these plants will perform under typical green roof conditions. Owners do not want to pay high maintenance fees to keep a roof bountiful, so it is best to design the research to evaluate plants in the natural green roof state.



Sedum pulchellum



Sedum sarmentosum



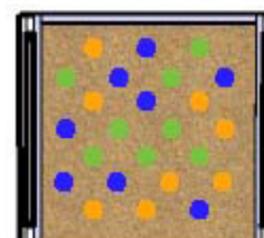
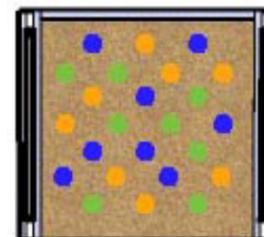
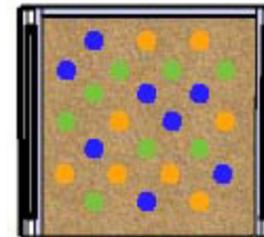
Sedum spurium



Sedum album



Sedum reflexum



● *Sedum pulchellum*

● *Sedum sarmentosum*

● *Sedum spurium*

● *Sedum album*

● *Sedum reflexum*

Plant Photos:
Elevated Landscape Technology
www.elgreenroofs.com



Nathan Diekelman
Academic Year 2008-2009

Plant Material

Native *Sedum*



Flowering Sedum pulchellum.

Sedum pulchellum

Native to Virginia through Kansas south to Texas and Georgia
USDA Hardiness zone: 6- 10

Habitat:

Full sun to partial shade, tolerates moisture, easy groundcover

Other notes:

Short lived

Reproduce best by seed

- Sowing dates: Anytime
- Sowing to germination: 3-4 weeks
- Germination to transplant: 6-8 weeks
- Transplant to establishment: 8- 10 weeks



Vegetative growth of Sedum sarmentosum.

Sedum sarmentosum in full flower.

Sedum sarmentosum

Native from Georgia to Kansas south to Louisiana
USDA Hardiness zone: 3- 9

Habitat:

Full sun, prefers arid conditions, rapidly growing groundcover

Other notes:

Highly Invasive

Reproduces through root division or by taking cuttings

Planting Schedule

- Planting dates: Anytime
- Sowing to germination: 3-4 weeks
- Germination to transplant: 3-4 weeks
- Transplant to establishment: 5-6 weeks

Plant Material

Adapted *Sedum*



Sedum album displaying its namesake white flowers.

Sedum album

Native to Europe and Northern Africa
USDA Hardiness zone: 4-8

Habitat:
Sunny sites and can tolerate a wide variety of soil conditions

Other notes:
Reproduce by seed
Flowering response may be increased by lower temperatures

Planting Schedule

- Sowing dates: October- November
- Sowing to germination: 2-3 weeks
- Germination to transplant: 4-6 weeks
- Transplant to establishment: 6-10 weeks

Photo credits: Elevated Landscape Technologies
<http://www.eltgreenroofs.com>



Sedum spurium in vegetative growth.

Sedum spurium

Native to Virginia through Kansas south to Texas and Georgia
USDA Hardiness zone: 6- 10
Native to Iran and the Caucasus
USDA Hardiness zone: 5-9

Habitat:
Full sun, well drained soils

Other notes:
Reproduce by seed
May need exposure to cold to germinate

Planting Schedule

- Planting dates: Anytime
- Sowing to germination: 2-3 weeks
- Germination to transplant: 4-6 weeks
- Transplant to establishment: 6-10 weeks



Sedum reflexum

Sedum reflexum

Native to Europe
USDA Hardiness zone: 3-9

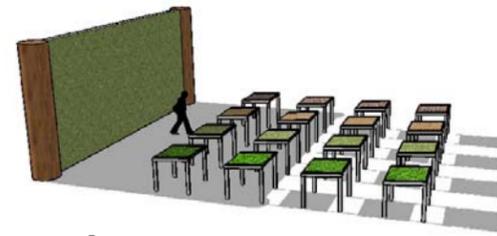
Habitat:
Full sun or partial shade and well drained soils

Other notes:
Reproduce by seed or cutting

Research Array

Shadow Model

The constant changing light conditions found in the urban environment are directly being evaluated in the research trial. Day length and time of year affect the length and timing of shadows in the urban environment, plant systems have compensatory mechanisms for these ever changing conditions. Performance and efficiency may or may not be affected the light conditions, only years of data collection will be able to determine how plants in urban settings will survive.



January



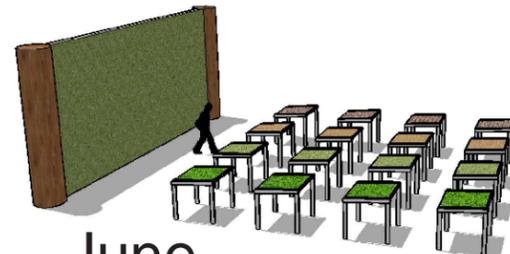
May



September



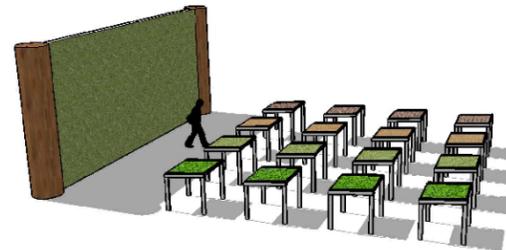
February



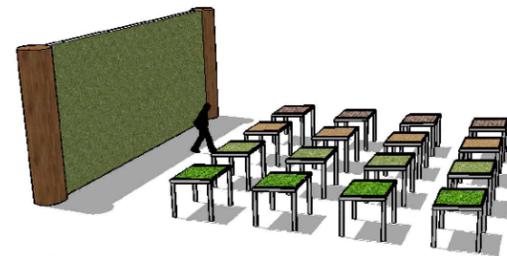
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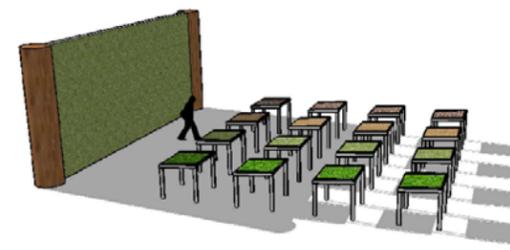
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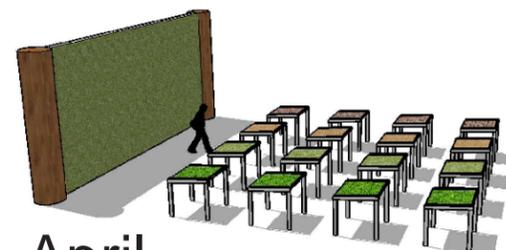
March



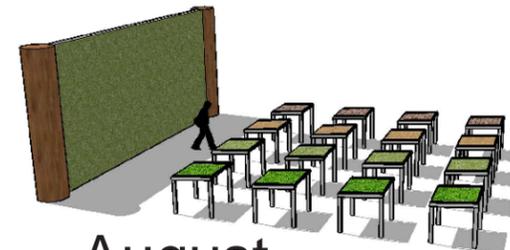
July



November



April



August



December

Research Array

Budget

Materials for Research Plot

Roof Panels	Quantity	Cost
2 x 4 x 8	80	\$190
2 x 4 x 12	20	\$60
Plywood 8' x 4'	8 sheets	\$240
4 in Flashing	200 ft	\$175
EPDM Self-Adhesive Gasket	250 ft	\$400
Aluminum Edging	80 ft	\$200
Waterproofing Membrane	250 ft ²	\$700
Protection Fabric	20 ft ²	\$200
Root Barrier	250 ft ²	\$350
Drainage Board	250 ft ²	\$500
Retention Fabric	250 ft ²	\$160
Gutter	64ft	\$140
Vinyl Tubing	80 ft	\$120
Sealable containers	16	\$240
Gravel	20 ft ³	\$200
Growing Media	96 ft ³	\$800
Plant Material	200 plants	\$560
Asphalt Shingles	64 ft ²	\$75
Total		\$5,310

Shade Wall	Quantity	Cost
Class 1 poles	3	\$800
Aircraft Cable	100 ft	\$300
Shade Cloth	450 ft ²	\$340
Pole Setting	3	\$600
Total		\$2,040

TOTAL COST **\$7,350**

Materials in Kind

Materials in kind that will be provided by Oklahoma State University, Department of Horticulture and the Oklahoma State Botanical Garden.

- ¼ Acre of land at the Oklahoma State Botanical Garden in Stillwater
- 4 Greenhouse benches- 6' x 20' (480 ft²)
- Fertilizer- Osmocote during establishment phase
- Media additives- crushed brick, expanded slate, sand
- Weather sensors and data loggers
- Thermocouples and data loggers
- Light Meters
- Fluorometers
- EC Meters
- pH Meters
- Forage Analysis Laboratory
- Media Analysis Laboratory
- Oklahoma Plant Disease and Pathology Laboratory
- Entomology Diagnostics Laboratory

With an estimated cost \$7,350 for all 16 roof panels and the shade wall this project is well within economic means. The average cost for each roof panel is around \$460. To guard against any unexpected costs a safer estimate of expenses should be made around \$8000, or \$500 per panel.

Average Cost per Roof Panel

$$\frac{\$7,350}{16} = \$459.38$$

Efforts are currently underway to secure funding from public groups like the US EPA and the Federal Wildlife Fund. In Oklahoma support is being sought from The Kerr Center for Sustainability, The Noble Foundation, and Greenleaf Nursery. Special assistance is available from personal friends, Emily Oakley and Mike Appel at Three Springs Farm, organic vegetable farmers in Oakes, OK and vendors at The Cherry Street Farmers Market in Tulsa. Large corporate research partners are interested, but have expressed hesitation about participating in an inaugural project. Even one growing season would be enough to demonstrate the scientific foundation of the program.



Greening Tulsa

A Scenario

A visual survey of Tulsa within the Inter-Dispersal Loop (IDL) was completed by field visits and referencing maps and photographs, to determine the distribution of land use in downtown Tulsa. The foundation of this scenario is a mapbase created by Professor Shawn Schaefer and students of the OU Urban Design Studio.

Methodology

The map base was split into feature layers: Streets, parking areas, building footprints, dedicated urban space, railroad right-of-way, and undeveloped open lots. Each layer was color coded in photoshop and the number of pixels in every layer was recorded. The pixel count can be converted into a number that can be represented as, city blocks, square feet, acres or square miles. Nine complete city blocks were identified on the parking layer and a single complete block was found on the buildings layer, these whole blocks were duplicated into individual layers and pixel counts were obtained for each. Knowing the pixel count for an individual city block, 300ft by 300ft, it is possible to determine values for the distribution of land in downtown Tulsa.

To begin the scenario we will examine the current condition of downtown Tulsa. Next, Scenario 1 will look at what Tulsa would be like if green roofs were installed on 80% of the building footprints. Beyond that Scenario 2 goes to the extreme and assumes not only the green roof installations of scenario 1, but also the greening of all surface parking lots and multistory parking structures. A third scenario will show the possibility for green roofing in the Greenwood neighborhood, adjacent to the Tulsa Drillers baseball stadium.

Each scenario will be accompanied by estimated values for benefits such as; a roofs capacity to hold storm water or reduce energy loss from a building. Understanding the upfront costs and materials required will help developers and the public decide for themselves about the value of green roofs and broader planning efforts in the new sustainable climate.



Photoshop rendering of downtown Tulsa showing what it could look like if green roofs were embraced and installed.

Greening Tulsa

Current Conditions

Automobile and railroad transportation occupy 184 acres, nearly 22% of the land within the IDL. The intense network of surface streets is required to move the large number of employees that work in downtown. Limited residential and cultural development means that most of the activity in downtown occurs during standard business hours. That is likely to change in the near future with the construction of the BOK Center and the relocation of the Drillers Stadium from 21st and Yale to the Greenwood neighborhood.

The railroad supports several industries in downtown Tulsa, more importantly it connects Tulsa to the refineries on the other side of the Arkansas River. Tulsa is currently involved in a discussion to develop a LightRail train centered in downtown with initial service to Broken Arrow, eventually expanding to other communities. An additional of this magnitude would greatly increase the capacity of the transportation network. Regular commuter service would increase appeal to prospective residents and encourage local citizens to come and spend the day downtown.

Streets make-up 169 acres paved for motorized transportation mostly used to move people to places of employment. Delivery of goods and service, and small personal vehicles add to the diversity of the traffic flow. Railroad right of way is 15 acres currently used for heavy industrial transportation.



- Streets and Highways
- Railroad Right-of-Way

Surface Streets

$$\frac{724,049 \text{ pixels}}{8,835 \text{ pixels}} = 81.9 \text{ City Blocks}$$

$$81.9 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 7,380,000 \text{ ft}^2$$

$$\frac{7,380,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 169.4 \text{ acres}$$

$$\frac{7,380,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.26 \text{ mi}^2$$

Railroad

$$\frac{64,552 \text{ pixels}}{8,835 \text{ pixels}} = 7.3 \text{ City Blocks}$$

$$7.3 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 657,000 \text{ ft}^2$$

$$\frac{657,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 15.08 \text{ acres}$$

$$\frac{657,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.02 \text{ mi}^2$$

Greening Tulsa

Current Conditions

Certain land is already dedicated to urban functions and will need to maintain its function as Tulsa develops. Municipal projects, like a new central library, present a special opportunity to create ecologically sensitive outdoor public spaces.

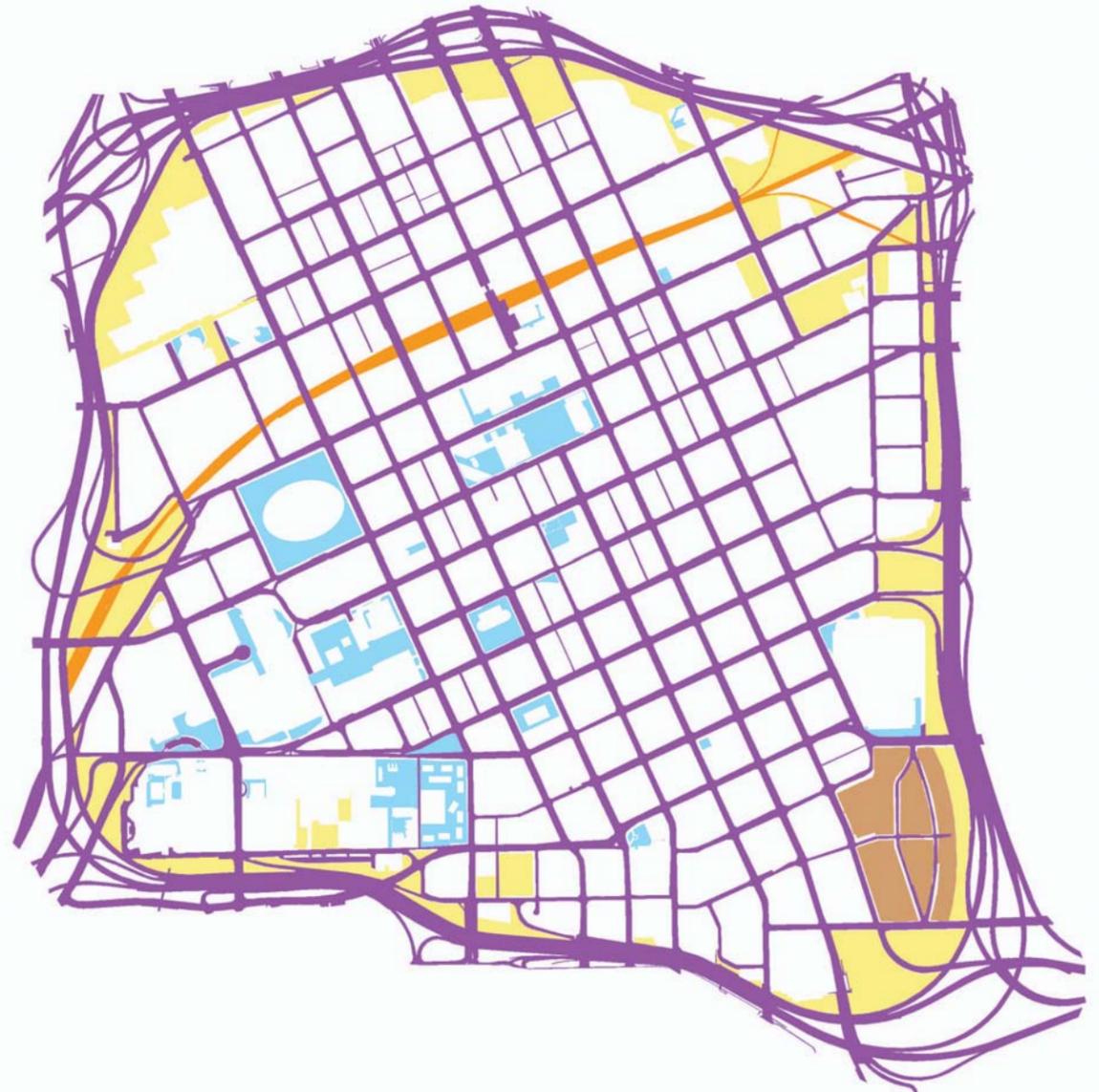
Urban space is 34 acres of dedicated urban hardscaping, some for gathering and public assembly, some building plazas and still some around the perimeter of parking lots or even urban recreation. This category can be supplemented with intense vegetation efforts. Portions of this category could be renovated to create a water permeable interface between the built and natural environments.

Open land is defined for this project as the 80 acre buffer separating the hardscaping of the highways from the city developments. This land is considered green but it might experience limited development.

Gunboat Park Neighborhood is about 16 acres tucked in the southeast corner of downtown Tulsa. This area has historic influence in the area and should be developed respectfully. About half of the land here is built on or developed to some extent, the rest is open space with room between lots.

111 acres of surface area within downtown are left over after all the other feature layers are separated and calculated. Most of this area is city sidewalk, but it also includes several small building egresses and large areas at the perimeter of parking lots. This land is considered dedicated to the urban texture of Tulsa and not capable of being greened as part of this scenario.

- Streets and Highways
- Railroad Right-of-Way
- Urban Space
- Gunboat Park
- Open Space



Urban Space

$$\frac{144,141 \text{ pixels}}{8,835 \text{ pixels}} = 16.3 \text{ City Blocks}$$

$$16.3 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 1,467,000 \text{ ft}^2$$

$$\frac{1,467,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 33.7 \text{ acres}$$

$$\frac{1,467,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.05 \text{ mi}^2$$

Open Lots

$$\frac{349,381 \text{ pixels}}{8,835 \text{ pixels}} = 39.5 \text{ City Blocks}$$

$$39.5 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 3,555,000 \text{ ft}^2$$

$$\frac{3,555,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 81.6 \text{ acres}$$

$$\frac{3,555,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.13 \text{ mi}^2$$

Gunboat Park

$$\frac{34,717 \text{ pixels}}{8,835 \text{ pixels}} = 3.9 \text{ City Blocks}$$

$$3.9 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 351,000 \text{ ft}^2$$

$$\frac{351,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 8 \text{ acres}$$

$$\frac{351,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.01 \text{ mi}^2$$

Sidewalks and Entryways

$$\frac{476,356 \text{ pixels}}{8,835 \text{ pixels}} = 53.9 \text{ City Blocks}$$

$$53.9 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 4,851,000 \text{ ft}^2$$

$$\frac{4,851,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 111.4 \text{ acres}$$

$$\frac{4,851,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.17 \text{ mi}^2$$



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Greening Tulsa

Single City Block

Tulsa is laid out in traditional grid fashion comprised of evenly divided city blocks. The benefits of green roofs in Tulsa can be broken down in a similar fashion. A single city block of green roof will not make a big difference in the harsh environment of downtown, but if several blocks can be greened the real value of green roof installations can be realized in Tulsa. Greening efforts can remain manageable when approached at the block level.

A single block is the measuring stick for all of the scenarios.



1 square mile = 27,878,400 ft²
 1 square mile = 310 city blocks
 1 square mile = 640 acres

1 city block = 90,000 ft²
 1 city block = 2.07 acres

1 acre = 43,560 ft²

Greening Tulsa

Current Conditions

Building footprints occupy 22% of the available surface area in downtown Tulsa, roughly 186 acres. The dense core consists of multistory office buildings surrounded by several blocks of low industrial and warehouse buildings mixed with churches, hotels, and small municipal offices. The largest land use is 241 acres of surface area designated for parking cars. Most of this space is in the form of surface lots, but there are a few multi-story parking structures that increase the amount of actual space available for parking. Street parking is not considered as part of this figure, that space is represented in the streets category. Out of the 844 acres of land available within the IDL, building footprints and parking lots combine for a total of 427 acres, just over half of the land. Dunnett and Kingsbury report in their book *Planting Green Roofs and Living Walls* that the most effective targeted application for hydrological benefit is to retrofit industrial areas. Considering this, it is easy to see how the distribution of land in downtown Tulsa is particularly suited to green roof development. Several acres of Tulsa can be quickly greened with a simple and effective extensive green roof applications.



Building Footprints

$$\frac{794,668 \text{ pixels}}{8,835 \text{ pixels}} = 89.9 \text{ City Blocks}$$

$$89.9 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 8,091,000 \text{ ft}^2$$

$$\frac{8,091,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 185.7 \text{ acres}$$

$$\frac{8,091,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.29 \text{ mi}^2$$

Parking Lots

$$\frac{1,030,336 \text{ pixels}}{8,835 \text{ pixels}} = 116.6 \text{ City Blocks}$$

$$116.6 \text{ City Blocks} \times 90,000 \text{ ft}^2 = 10,494,000 \text{ ft}^2$$

$$\frac{10,494,000 \text{ ft}^2}{43,560 \text{ ft}^2} = 240.9 \text{ acres}$$

$$\frac{10,494,000 \text{ ft}^2}{27,878,400 \text{ ft}^2} = 0.38 \text{ mi}^2$$

Greening Tulsa

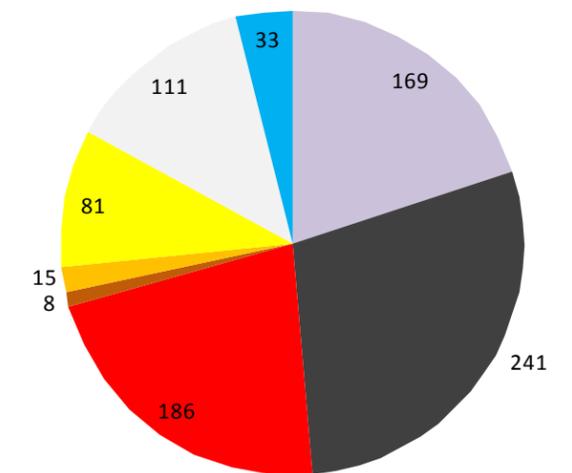
Current Conditions

This is a look at the current distribution of land within downtown Tulsa, the layout of the city is clearly visible. Several municipal buildings with large flat roofs stand out along the left side of the image. The convention center, central library, and county jail are ideally suited for extensive green roofs. High profile projects like these would compliment the roof being planted on the Tulsa Community College Center for Creativity and help increase public awareness of green roofs.

- Streets and Highways
- Railroad Right-of-Way
- Urban Space
- Gunboat Park
- Open Space
- Sidewalks and Entrances
- Building Footprints
- Parking Lots



Disribution of Land



Values reported in acres

Greening Tulsa

Retrofitting Roofs



Downtown Tulsa showing the dispersion of buildings and parking facilities. Many of the office buildings have flat roofs and are potential candidates for light weight extensive green roof installations.

Photo Credit: www.visitngdc.com/airports/tulsa-airport-address.asp

Lightweight extensive systems with substrate depths of 2-6 in increase the loading on the roof by between approximately 14 and 35 lb/ft² (Dunnett and Kingsbury, 2008). The load of a green roof system is a dynamic measurement and will reflect the moisture content of the external environment. During the design phase there are several factors to consider; will people have access to the roof, what is the roof slope, and what type of drainage network is installed to remove water from the roof? This first scenario will consider the roofs in downtown Tulsa that can be reasonably be retrofitted with extensive green roofs. A high percentage of the buildings are flat roofed, but even some of the sloped roofs can be included. A structural engineer will need to be consulted on each project to inspect a building's condition considering the specified load for the roof project. Landscape Architects should be able to provide an accurate estimate of substrate weight based on the composition, structure (pore space), and water holding capacity. Performance standards and weights of waterproofing, filter and drainage layers will be provided by the manufacturer.

This base weight doesn't factor in the saturated load that will develop during rain events. Germany has a standard test to determine the saturated weight. The test involves moistening a sample of the substrate, pressing it into a mould, soaking for 24 hours, draining for one hour, and then weighing. This will give a clear indication of the maximum weight possible for the substrate. The volume of water weighed will exceed normal field capacity, and will rarely be realized on a real installation. Currently, no standard test to quantify green roof installation weight exists in North America.

The actual load on a green roof should be expected to increase overtime. Developing plant material will create biomass by growing new tissues and storing the by-products of photosynthesis.

Greening Tulsa

Scenario 1

If Tulsa installed green roofs on 80% of the current building footprint value an area of 149 acres would be reclaimed from the urban landscape. This is an arbitrary value, selected to show the potential of widespread green roof coverage. Green roofing to this magnitude would require both time and financial resources, but the estimated gains demonstrate that real ecological, economic and social benefits are possible for Tulsa.

Benefits

- Particulate matter captured by plant material: 3 tons/year
- Stormwater retention: 133 million gallons annually, about 14% of the stormwater
- Energy savings: \$234,654 annually
- Potential recreation space: 16 acres (697,458 ft²)

Inputs

- Plant material: 13 million nursery grown plugs
- Growth substrate: 3.2 million ft³

- Streets and Highways
- Railroad Right-of-Way
- Urban Space
- Gunboat Park
- Open Space
- Sidewalks and Entrances
- Building Footprints
- Parking Lots
- Green Roofs



Stormwater Retention

$$6,476,400 \text{ ft}^2 \times \frac{112.3 \text{ in}^3}{\text{ft}^2} = 727,429,248 \text{ in}^3$$

$$727,429,248 \text{ in}^3 \times \frac{42 \text{ in/year}}{12 \text{ in/ft}} = 30,552,028,416 \text{ in}^3/\text{year} = 132,259,863 \text{ gallons/year}$$



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Greening Tulsa

Scenario 2

As Tulsa develops and green roof efforts succeed, new construction projects should try to achieve the maximum greening of the site including rooftops. As the pressure for land increases and surface parking lots will be ideal targets for development. This second scenario looks at how Tulsa would be affected if all of the parking surface in town was developed green. Green roofs would be installed on new buildings and all multistory parking garages. Parking won't be eliminated, surface lots can be covered with green roofs and paved with a variety of pervious pavement technologies and systems, including grass buffers and bioswales around the perimeter of lots. For this simulation it is assumed that all of the current area for parking can be efficiently and wholly greened.

The area of green coverage for the simulation is 381 acres, nearly half of the land available in downtown Tulsa.

Benefits

- Particulate matter captured by plant material: 7.5 tons/year
- Stormwater retention: 338 million gallons annually, about 35% of the rain falling in the area
- Energy Savings: \$601,504 annually
- Potential recreation space: 41 acres (1,787,843 ft²)

Inputs

- Plant material: 33 million nursery grown plugs
- Growth substrate: 8.3 million ft³

- Streets and Highways
- Railroad Right-of-Way
- Urban Space
- Gunboat Park
- Open Space
- Sidewalks and Entrances
- Building Footprints
- Parking Lots
- Green Roofs
- Greened Parking



Stormwater Retention

$$\begin{aligned}
 &16,601,400 \text{ ft}^2 \\
 &\times \frac{112.3 \text{ in}^3}{1 \text{ ft}^2} \\
 &= 1,864,337,220 \text{ in}^3 \\
 \\
 &1,864,337,220 \text{ in}^3 \\
 &\times \frac{42 \text{ in/year}}{1 \text{ ft}^2} \\
 &= 78,302,163,240 \text{ in}^3/\text{year} = 338,970,404 \text{ gallons/year}
 \end{aligned}$$



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Greening Tulsa

Greenwood

The relocation of the Tulsa Drillers stadium to downtown is likely to bring a wave of new development in the Greenwood neighborhood. This presents a fundamental opportunity to begin the green roofing of Tulsa. Over the next few years I anticipate that several of the open lots in the area will be developed with mixed commercial and residential properties, buildings that are likely to have low flat roofs ideally suited for extensive green roofs.

Serious market potential exists with the Greenwood neighborhood going 'green', and green roofs can serve as a highly visible connection to the built environment. Proximity to the Oklahoma State University Tulsa campus adds incentive to develop this neighborhood, sustainable development is likely to appeal to future generations of students considering the housing options in downtown. I don't see any need to increase the amount of parking in the area, several large lots are located within walking distance to the ballpark, especially on the other side of the highway at OSU Tulsa.

The estimated area of green roof coverage for this scenario is 22 acres.

Benefits

- Particulate matter captured by plant material: 0.40 tons/ year
- Stormwater retention: 20 million gallons annually
- Energy savings: \$36,098 annually
- Potential recreation space: 2.18 acres (94,985 ft²)

Inputs

- Plant material: 1.7 million nursery grown plugs
- Growth substrate: 441,000 ft³



Greening Tulsa

Scenario Benefits

Once values have been determined for the amount of green area gained in each of the scenarios it will be possible to estimate the potential benefits to be gained for Tulsa. Dunnett and Kingsbury have found that as of this writing there have been limited attempts to translate benefits into monetary equivalents and that there have been relatively few attempts at identifying how these multiple benefits may play out at a city scale.

The estimates for Tulsa will be far from perfect, but it will serve as a starting point to convince planners, developers and the general public that green roofs will have a valuable impact in Tulsa. As green roofs gain in popularity more resources will be put into technology and development, hopefully lowering costs while increasing efficiency. Over time the estimates made for Tulsa will need to be updated based on the best available technologies and current data.



Research green roof installation during the establishment phase at the Toronto Zoo.
Photo credit: http://www.toronto.ca/greenroofs/incentive_applicants07

Stormwater Retention:

- The average rainfall for Tulsa is 42 inches per year
- Extensive green roofs planted to a depth of 6 inches
- Assume 13% of the substrate volume is available to hold and store water during any 1 inch rain event

Rainfall

$$\begin{aligned} 844 \text{ Acres} &= 5,281,562,880 \text{ in}^2 \\ &\times \frac{1 \text{ in Rain}}{1} \\ &= 5,281,562,880 \text{ in}^3 \text{ of surface water downtown per 1'' rain event} \\ &= 3,056,460 \text{ ft}^3 \end{aligned}$$

Annual surface water in Tulsa

$$\begin{aligned} 3,056,460 \text{ ft}^3 \times 42 \text{ in rain} &= 128,371,320 \text{ ft}^3 \text{ surface water in Tulsa/ yr} \\ &= 2,218,256,409,960 \text{ in}^3 \end{aligned}$$

Capacity to hold water

One square foot of extensive green roof

One Square Foot of Green Roof

$$12'' \times 12'' \times 6'' = 864 \text{ in}^3$$

$$864 \text{ in}^3 = 478.75 \text{ oz}$$

$$864 \text{ in}^3 \times 0.13 = 112.32 \text{ in}^3$$

$$112.32 \text{ in}^3 = 62 \text{ oz}$$

One square foot of 6'' deep extensive green roof can hold 62oz of water during a 1 inch rain.

Energy Savings

- The R-Value of a conventional commercial roof is about 18
- The R-Value of a 6'' multilayer extensive green roof is about 36
- 3,685 Average Heating Degree Days ($^{\circ}\text{F}$) for Tulsa
- 2,014 Average Cooling Degree Days ($^{\circ}\text{F}$) for Tulsa
- Consider 1 square meter of extensive green roof planted 6 inches deep
- Assume that 1 watt hour costs \$5

Heating degree days

$$3685 \text{ }^{\circ}\text{F} = 2302 \text{ }^{\circ}\text{K}$$

$$2302 \text{ }^{\circ}\text{K} / 365 \text{ days/yr} = 6.3 \text{ Heating Days}$$

$$E = \text{Change in Temperature} / \text{R-Value}$$

$$= 6.3\text{kJ}/36$$

$$= 0.175 \text{ Joules/meter}^2/\text{sec}$$

$$= 0.0486 \text{ Watts/ hour}$$

Under these conditions a square meter of green roof allows 0.0486 Watts of energy to escape each hour, costing \$0.24 an hour or \$2102 a year.

A conventional commercial roof with an R-value of 18 will allow twice as much energy to be lost, costing \$0.48 an hour.

Cooling Degree Days

$$2014 \text{ }^{\circ}\text{F} = 1374 \text{ }^{\circ}\text{K}$$

$$1374 \text{ }^{\circ}\text{K} / 365 \text{ days/yr} = 3.8 \text{ Cooling Days}$$

$$E = \text{Change in Temperature} / \text{R-Value}$$

$$= 3.8\text{kJ}/36$$

$$= 0.106 \text{ Joules/meter}^2/\text{sec}$$

$$= 0.0294 \text{ Watts/ hour}$$

Under these conditions a square meter of green roof allows 0.0294 Watts of energy to escape each hour, costing \$0.15 an hour or \$1314 a year.

A conventional commercial roof with an R-value of 18 will allow twice as much energy to be lost, costing \$0.30 an hour.

Greening Tulsa

Conclusion

A significant effort to install green roofs in Tulsa can lead to widespread benefits. With these benefits in mind, developers and owners can begin to make decisions that will have an impact both environmentally and economically. Benefits can be separated into two categories, public and private.

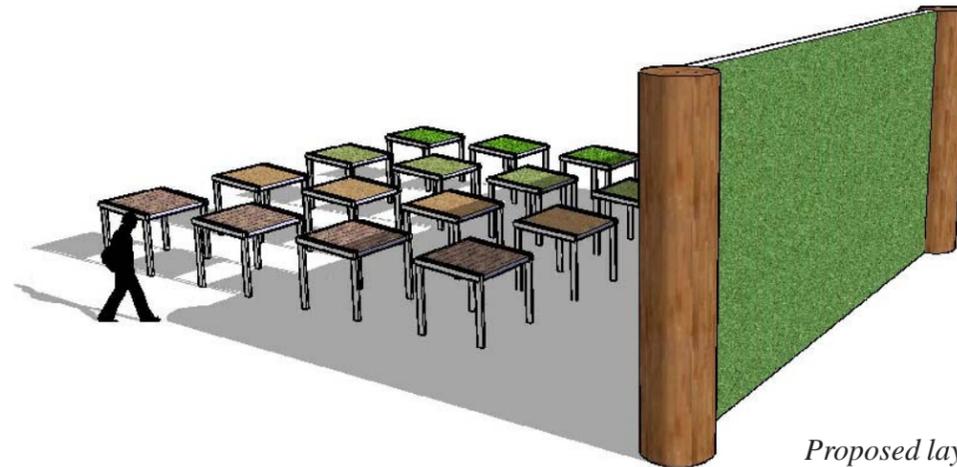
The community benefits range from environmental solutions, personal satisfaction, and beautification. Private benefits also include environmental stewardship efforts but these are often directly coupled with economic savings over time.

New construction in Tulsa is subject to regulation for water management on a development site. Water must be detained on site, unless the master plan is exempt or the developer is allowed to pay a fee in lieu of on-site detention. Green roofs offer an alternative to compensatory excavation if a development is determined to have a negative impact on floodplain valley storage. Consider that one city block extensively green roofed has the potential to retain almost 1 million gallons a year. In Scenario 1 nearly 94 million gallons of water can be captured annually. This translates directly into savings of real dollars for developers and a cleaner healthier city, especially for the possibility to reduce flooding events.

Creating a wildlife corridor through the heart of downtown Tulsa connecting the Arkansas River to the Osage Hills and grasslands beyond is perhaps the greatest environmental gain. Increased biodiversity and species preservation are two fundamental ecologic gains for green country and the Tulsa metropolitan area.

The contribution of a healthy dynamic green roof ecosystem in Tulsa is really unknown, but the estimates generated in this scenario are a starting point for the citizens and owners involved in downtown Tulsa. Time will reveal the real values and shortcomings of green roofs. Tulsa Community College has taken the first step in the campaign for green roofs in northeast Oklahoma. With TCC as a role model Tulsa has begun the process, hopefully others will follow their lead.

Closing Thoughts



Proposed layout of plant research trial.

The average American city is an ocean of concrete and the disappearance of native soil structure has had a profound impact on the local environment. The top 6 inches of the earth's crust is the interface between geology, water, plant material, and atmosphere. Green roofs provide an opportunity to recreate this essential layer in our built environments. Once roof tops have been reclaimed by plants they will attract more human activity, adding a layer to the texture of the city.

Green roofs have been popular in central Europe for more than a decade. North America is just beginning to embark on major green roofing efforts. All the major horticultural research in the field is being done in the upper midwest and mid-atlantic regions of the country. Climate and topography make Oklahoma distinctly different from these areas and require that green roof research needs to be conducted on a regional level. Construction methods and materials will basically be the same the around the world, depending on availability, but the plant material is likely to vary.

Oklahoma's harsh climate is a constant threat to plant life. Violent spring storms and heavy summer rains are likely to risk flooding and drowning plant material. On the other hand, the steady low relative humidity and cold winds of winter will have just the opposite affect and threaten to dessicate plant roots, and impact the next seasons growth and reproduction. Plant recommendations based on effective research trials should ease the maintenance burden overtime for green roof installations in Oklahoma.

A significant factor in this green roof plant evaluation is the ever changing light intensity. The wall to cast the shadow is intended to mimic the adjacent buildings that would be found around any green roof in a metropolitan area. Urban environments are hard places and plants have proven their ability to thrive in brutal places, the green roof is an intentional manifestation of these two elements.



*Green roof on the Hilton Hotel in Baltimore, Maryland.
Photo: www.greenroofs.com*



*Green roof patio recently constructed on the headquarters
of the American Society of Landscape Architects.
Photo: www.asla.org*

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- Personal correspondence and discussion with Dr. Reid Coffman, Assistant Professor of Landscape Architecture at The University of Oklahoma
- Personal meetings and discussions with Dr. Janet Cole, Professor of Ornamental Horticulture at Oklahoma State University
- Email correspondence with Matthew Hufft, AIA, LEED AP
- Presentation by Clifford Johnson of Empire Roofing & Insulation and Alan Roark of Roark Landscaping, contractors for the Tulsa Community College Center for Creativity.

Appendix A

Green Circle Shopping Center

I am looking to get an overall idea of the design process for The Green Circle Shopping Center and the evolution of its green roof. This roof was an important part of this project since the beginning and I want to explore how the needs of the roof were met during the design process. 2,000 s.f. of rooftop is planted with native adapted plants mixed with prairie grasses and an iconic dogwood tree make the ecoroof at the Green Circle Shopping Center in Springfield, MO one the largest and well established green roofs in the central United States.

Through exploration I hope to determine obstacles to plant selection during the design process. Clearer details about design expectations and procedures can make the plant recommendation process more convenient and effective. How does time affect perceived obstacles to the design process? Does the success of the roof quite any doubts during design and construction or are there major lessons to learn that can be implemented on other projects to save time and resources. The Green Circle Shopping Center was designed to educate as much as it was designed to thrive as a business setting. The green roof is a feature element of the shopping center. Green Circle Shopping Center was designed by Hufft Projects of Kansas City, Missouri. The green roof was designed by EMSI-International, based in Springfield, Missouri.

The karst topography of the region has pushed native plants to adapt to perpetual dry conditions. The porous rock allows water to fall away from the surface very rapidly, forcing plants to act quickly during wet conditions or adapt special features to survive. The Springfield area is where the plains of south central Missouri meet the foothills of the Ozark Mountains. Deep lush valleys run full of water during the wet season connecting a network of natural springs and seasonal streambeds into the greater waterway systems of the Mississippi River. Currently the land in the area is dedicated to agriculture, but the native meadow thrived for thousands of years before the area was settled. The Green Circle ecoroof is an opportunity to reestablish the native meadow and use native plant material featuring a Flowering Dogwood, the state tree of Missouri.

The Green Circle Shopping Center was conceived out of a need for space for two of Springfield's wellness focused businesses, Dynamic Earth Equipment Company and Dynamic Body a Pilates and yoga studio, owned by siblings Matt O'Reilly and Lindsay French respectively. Faced with the decision to take a risk and build green or just choose a conventional building and store front for their businesses they stepped out and took a chance. Their business models and missions fit well with the goals and objectives of building green. Based on the concept of sustainability and building green the shopping center was able to find two other locally owned tenants that shared the same passion for environmental stewardship, MaMa Jean's natural food store and San Francisco Oven restaurant.



Frontside parking lot of the Green Circle Shopping Center.

Note the tree branches rising from the roof

Photo: www.springfieldgo.com

During the development of the shopping center, Matt O'Reilly paid close attention to the core elements of sustainability; devotion to economic, environmental, and social responsibility. Under this general framework of sustainability specific targets for energy savings, creating a productive environment, and sharing space and services were identified as opportunities to create a competitive advantage in the current marketplace of Springfield. Green Circle is a purpose driven development with synergy between its tenants and an affirmative attitude toward the community and the environment. Working with LEED architect Matthew Hufft the Green Circle Shopping Center went from concept to design to building. Similar to some of his other projects the Green Circle was an opportunity to create a singularly significant building that enhances its natural setting and brings personal satisfaction to the buildings occupants and their customers. The Green Circle is the only development in Springfield to receive the LEED Platinum rating from the U.S. Green Building Council.

Matt O'Reilly and architect Matthew Hufft enter into this project with several shared characteristics, but each brings unique issues and perspectives to the project. O'Reilly comes as a capitalist, entrepreneur, and landlord while Hufft comes as architect and designer. Both have exhibited a sincere commitment to better utilization of resources, promoting social wellness, and innovation. The common threads connecting these two men as individuals are displayed throughout the building they created together. The design reveals several parallel issues throughout the project, not a surprising consideration when you remember that the overall objective was to demonstrate an unwavering devotion to economic, environmental, and social responsibility.

Appendix A

Green Circle Shopping Center

The Green Circle project provides a stable economic platform for business tenants. Fixed rent and lowering operating costs are estimated to provide a competitive advantage over time as the market for energy is put under pressure and rates increase. The high density, multiuse retail center delivers occupants an abundance of resources in common. Shared facilities and services eliminate resource duplication and result in a more efficient use of utility services. For example, the mass of air cooled by the air conditioning utility is shared between Dynamic Earth, Dynamic Body and MaMa Jean's by eliminating interior walls. The design decision to use this open floor plan is magnified by the multiplier effect realized with increased light dispersion, cleaner air, and an improved sense of place resulting in more productive environment for employees. O'Reilly considers his employees as his biggest investment and expects them to become valuable assets to his business and providing an enhanced work environment is an investment in employee buy-in and dedication.

Environmental dedication is a fundamental element behind the creation of Green Circle. Several building elements presenting positive environmental benefit have already been mentioned. The commercial appeal of eco-awareness and responsible corporate policy continues to grow as consumers themselves become more aware and educated on the issues. On-site water storage, pervious pavement, leaving undeveloped land on the site, and creating a green buffer before the street are all tools used to manage the water regime on the site, a key environmental concept. Several building elements presenting positive environmental benefit have already been mentioned.

Social benefits are realized by many people at very different levels and are often tricky to identify. The spectrum of social benefits realized by the public includes supporting the local economy by purchasing building materials from regional markets to providing a LEED certified building as a platform for the public to explore and learn about sustainable development efforts. Social sustainability rewards employees for consistent high-quality work while still maintaining an affordable retail environment for the customer base. Categorically the benefits of sustainable development start to run together when compared to the core concepts of sustainability. Economic benefits are seen when an environmental benefit was intended and each of these benefits in turn stimulates social gains.

Design concepts to promote environmental stewardship

- Shared space with building neighbors
- Reduced energy consumption
- Less water use
- Reduced rain water runoff from the site
- Active greening efforts to have living mature plant material on site
- Use of recycled materials throughout the building such as using reclaimed local barn boards as shelving, cabinetry and countertops
- Active recycling efforts by tenants and their customers
- Use of locally sourced and/or sustainable materials
- Providing a multiple-use commercial retail center

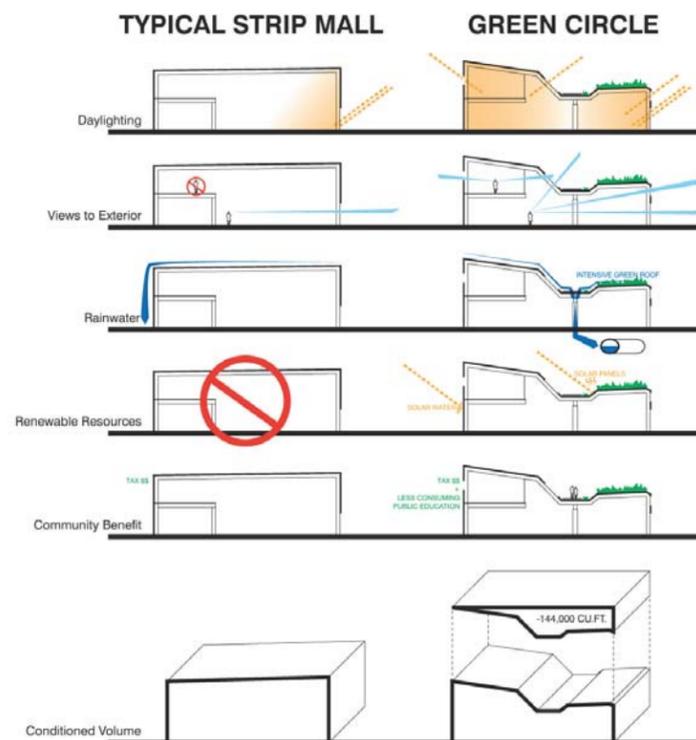


Diagram displaying design concepts and demonstrating building systems.

Photo: Hufft Projects

Design concepts to reduce water consumption

- 14,000 gallon on site storage tank for rain water harvest and storage for use in toilets
- Shared facilities between tenants requiring fewer fixtures

Design concepts to retain rainwater on-site

- Pervious parking lot pavement to eliminate runoff
- 14,000 gallon rainwater storage tank
- Green Roof to intercept and hold rain
- Conservation of 22,000 ft² of land to remain undeveloped and uncompacted during the construction phase

Design concepts to reduce energy use

- Building orientation
- Reduced building volume
- Reflective Roof on the upper level to reflect the sun's light and reduce the absorption of solar radiation keeping the building cool
- Green roof at mezzanine level to reduce energy leaks and intercept solar radiation as a driver for photosynthesis
- Angle of mezzanine windows to increase reflectivity
- Photovoltaic cells to produce energy

Design concepts to enhance space

- Shared parking with adjacent buildings
- Green space in the setback from the road
- Ground level plantings at entryways
- Green roof walkway and deck
- Rooftop patio dining for San Francisco Oven
- Open layout

Appendix A

Green Circle Shopping Center

The Green Circle Shopping Center is comprised of a series of feature elements that come together to create an efficient building machinery with a stunning physical presentation. Dissecting the site reveals several different elements akin to the organs and tissues of any living organism. Mechanical systems drive daily function and maintain the core conditions, much like the nervous and respiratory systems of mammals. The structural beams act as the skeleton holding the system together, providing support where the body needs it the most. Like the hips and pelvis of a human are designed to support the incredible loads exerted by an active human body, the internal structure of the building is reinforced to support the green roof above. Best considered a dynamic organism The Green Circle depends on each of its components to perform its function to maintain a high quality of life and even be replicated; entering into a sort of architectural reproduction cycle. Considering other biological processes buildings of this sort are destined to adapt and evolve over time and with dispersion from the population core. Matt O'Reilly sees this as the part of the learning curve for developing green buildings and writing sustainable business plans to occupy such buildings.

Functioning similar to a layer of skin a green roof acts as an interface between the external and internal environments. The green roof is a major design element of this project featuring a plant palette of native grasses, flowers, shrubbery and an iconic mature dogwood tree. Several perennial species of Sedum are also found on the roof and serve as an extensive groundcover across the surface of the roof. The layout of the green roof is a striking component to The Green Circle Shopping Center. The design of the green roof was entrusted to locally based EMSI-International. Specifically, the roof is designed to establish a replica of the native Missouri meadow that once dominated the landscape utilizing a wide variety of indigenous plant material. The imbalance created between planting natives to recreate the flowering prairie and establishing an extensive Sedum groundcover presents an interesting design dichotomy.

As the green roof enters its second growing season Melissa Cox, the principle designer of the roof layout and substrate, is excited to see the plant material reemerge. Cox had to keep the core concepts of the building in mind with her plant material prescriptions. The challenge was developing a diverse plant schedule that could be maintained by one growth substrate. The planting depth for the perennials is about 8 inches and the tree pit is about 3 feet deep, about 4 times deeper than the rest of the roof. In addition to the changes in substrate depth the green roof has a slope at either end of the installation. These two factors will have a big impact on how falling rain water performs with the green roof. A larger substrate volume leads to an increase in a substrates water holding capacity. Water on the sloped edges of the green roof will travel through and under the growth substrate gaining momentum as it moves downhill, creating a certain risk of washing out the growth substrate. Only with a clearer understanding of the physical layout that had been designated for the green roof was Cox able to begin the diligent task of laying out the planting design. The drainage capacity of the inclined edges of the green roof reinforces the building systems by moving water away from the roofs surface, either into the storage tank or out onto the parking lot to absorb into the soil. Eliminating water buildup reduces the load exerted on the roof during wet periods.

This mixed intensity roof truly attempts to reestablish native plant material introducing habitat and specialized food sources into the highly developed suburban Springfield. To begin with, the Kousa Dogwood anchors the planting and helps establish a sense of permanence on the site. The structural design of the building specifically accommodates the tree pit on the west end of the roof. The ecosystem associated with this singular tree extends from the edge of the root ball to the tips of the leaves and encompasses the plant material growing under its branches and in its shadow. Plant material beneath the tree is woody shrubbery mixed with herbaceous perennials. This planting bleeds out into herbaceous perennials and grasses planted in with native flowering perennials. To support the physical layout of the green roof and protect the integrity of the substrate layer the roots of the native grasses should grow together forming an interlocked web hold substrate particles in place. The inherent relationship between adjacent plants cannot be overlooked on a green roof, with finite mineral resources and such a drastic water table these plants will take every advantage they can over their neighbors.



Green roof on the Green Circle Shopping Center facing east.

Photo by: Nathan Diekelman, 24 Feb 2009

Appendix A

Green Circle Shopping Center

Life on this green roof is designed and formatted to be much like life on the open prairie for these plants. They will not receive any supplemental fertilizer or irrigation. They only inputs anticipated over time are from natural events. Rain and snow events in the case of the water regime and supplemental nutritional elements and minerals will be deposited by an active ecosystem. Debris and by-products of supporting various bird species, insect populations, other active animal communities, and decaying plant material will generate future nutritional components. Unlike life on the open range, the substrate depth here becomes a limiting factor. Similar to hardpan conditions one might find on old agricultural land in the area, the metal decking of the roof is intended to limit root development and stunt plant growth. Relying on this passive pruning method is an intriguing approach on roof featuring a mature dogwood tree which has the potential to grow from 20 to 30 feet tall (Dirr, 1998) in a natural environment. The relentless indifference of nature and the pursuit of life are bound to twist the roots horizontally where they will continue to grow with unknown end results. The potential risks don't seem as severe with the herbaceous perennials or flowering shrubs, but plant material should never be underestimated. The mechanical forces generated by woody plant roots have the potential to cause serious damage the integrity of the metal deck and the concrete structure beneath.



Kousa Dogwood planted in the three foot deep tree pit on the Green Circle Shopping Center.

Photo by: Nathan Diekelman, 24 Feb 2009

The harsh conditions of long, hot dry periods will challenge plants to survive with full exposure to the sun, driving the surface temperature up forcing substrate moisture into the atmosphere. However, in the central Midwest severe thunderstorm cells can develop rapidly changing a relentless drought into a flash flood in a matter of hours. The design of the green roof will actively contribute to flood prevention on the roof. With each edge of the linear roof plan inclined, water will not have a chance to pool in the main body of the green roof. Standing water poses a real threat to the indigenous plant material, the native soils don't hold water for long because it is always headed downstream and fast. The plant community as a whole needs to develop a structural network of roots within the first few growing season to protect the investment and resources put into the green roof system.

The design of the Green Circle Shopping Center focuses on creating a commercial development that is equipped to respond to its environment. With the ability to react, the building has the capacity to give its occupants more than just a place to do business. With a high performance building, occupants can expect to receive financial savings, increased satisfaction and sense of place, and in the current market a stable rate of occupancy. Green Circle is an excellent project to demonstrate how the singular components of a building come together to support and complement one another. Categorizing the individual components into the distinct systems they support is a helpful way to consider green buildings. Systems can be identified that focus on reducing consumption and conserving resources, systems exist to help integrate the building into its natural setting, other systems work towards engaging the general public in the discussion and debate about sustainable development. Singular components like the green roof contribute to multiple systems mentioned above. Green roofs should derive economic benefits by protecting the thermal mass inside the building and they also add to site integration by including plant material from the area on the actual development. The green roof on Green Circle is specifically intended to be an educational tool and outreach device with the community. Unrestricted access to the rooftop patio and deck adjacent to the green roof provides the population of Springfield with an excellent exposure to the advancing topic of sustainable architecture, more specifically at green roof construction and implementation. Granted that developments like Green Circle require more initial capital expenditure Matt O'Reilly believes the cost benefit analysis favors the business owner who in exchange shares the same benefit with her customer base. The sustainable business model is a recent endeavor in the United States, communal projects tend lose support in our capitalist market system. Combining sustainable practices from the business model to the physical facilities down to the actual

products or services offered can create a corporate culture that extends beyond the walls of your store. The Green Circle stands as its own advertisement for environmental and social awareness in Springfield. Located at a major intersection and sited on a hill the development stands out when compared to its neighbors; shared parking, muted color scheme, and lots of onsite green space are distinguishing elements. As the roof enters its second growing season hopes are high for appropriate weather conditions to stimulate and promote even growth upon the roof.

Appendix B

Oklahoma Nursery Industry

During the design phase of The Green Circle Shopping Center it was determined that the objective for the green roof was to recreate the native flowering plains of Missouri in conjunction with establishing an extensive groundcover comprised of naturalized Sedum species. The mixed intensity roof can support a wide variety of plant types and sizes; the difficulty in this is to create a combination of plants that can coexist and thrive in the same substrate. With professional services from EMSI-International the plant selection process for the Green Circle green roof resulted in a mixed plant community ranging from small native flowers and grasses through perennial Sedums to small shrubs and a single tree. The regional nursery industry was able to provide all of the necessary plant material to the project. Native plants were sourced from a nursery in Jefferson City, Missouri that deals mostly with regional plants. The Sedum plants were obtained from small very local nurseries; only a few hundred plants were required. The nursery industry in Oklahoma seems prepared to outfit an emerging green roof market.

According to the most current membership listings for the Oklahoma Nursery and Landscapers Association (ONLA) I was able to identify over 25 individual nurseries in Oklahoma. It is important to realize that this membership list is limited to growers interested in the professional organization and willing to pay the annual membership dues. Other nurseries and growers surely produce plant material here in Oklahoma; they have simply chosen not to join the professional organization for one reason or another. With the list of plant growers and nurseries in hand I contacted each one to try and ascertain their green roof plant production values. Many were contacted, but only a few replied. In such a labor intensive industry as the nursery industry owners and operators of small scale growing operations often perform most of the physical labor required of their business. I am not surprised by the lack of response, especially in anticipation of the spring growing season. This is actually an encouraging sign that growers have a demand to fill in the current market, and hopefully we can start to understand the ways in which the market can expand to satisfy the looming green roof market. Two principle nurseries were able to spend some time talking with me about their operations and plant material, Kerbo Nursery in Choctaw and Greenleaf Nursery in Tahlequah.

The nursery industry relies on consistent high quality growth among its plant material. With a wide range of potential customers, even here in the Oklahoma market, growers need their plant materials to survive in a variety of soil types and growing conditions. Plants are typically produced in a greenhouse, with a controlled climate and bountiful moisture; before these plants can be shipped to customers they will need to be hardened. Hardening off is the process of preparing a plant or plants for the environment outside of the greenhouse. The humidity is reduced until it reaches the ambient relative humidity, and the temperature is allowed to increase to match that of the external environment. Fertilizers and supplemental light should be eliminated several weeks prior to shipping. Plants should be weaned off of their high water ration in the greenhouse to prepare for life in the planted environment of a green roof. The high intensity, high exposure rooftop installations threaten tender plants in so many ways. Root tissues are fragile, and essential to interface with the soil. Developing shoots are tender and considering they even survive the move and the transplant they will face incredible exposure to the sun's radiation. Whether they were grown in a greenhouse or in a field environment all plants need to be hardened off. Growers rely on their reputations for providing well-bred well-groomed plants to customers, and the dramatic needs of a green roof environment create another consideration when preparing plants for shipment.

Rick Kerbo, owner and head grower of Kerbo Nursery is currently growing 14 species of sedum. As indicated by the selection of cultivars, sedum is his primary crop with several acres in production. Kerbo Nursery doesn't have the ability to hire a large permanent staff, but they seem interested in the potential to expand the operation, even just enough to relieve some of the work load.

I also had the chance to speak with Jay Baker, regional representative for Greenleaf Nursery. Sedum is one of the several dozen fundamental crops grown at Greenleaf. With major market clients like Wal-Mart and three satellite operations (North Carolina, Texas, and Park Hill, Oklahoma) in addition to the production site just outside of Tahlequah on the shore of Lake Tenkiller. Greenleaf Nursery employs about 800 people and they generate more than 32 million dollars in annual sales in Oklahoma. Their primary crops are potted plants and shrubs for the commercial retail industry. Woody plants, featuring 5 to 7 year old mature specimen trees are another featured item of the nursery. A large portion of the Tahlequah facility is dedicated to producing and storing trees before delivery to customers. The seasonal variety of plant processes allows Greenleaf to operate year round, maybe not at full scale, but they can continue to provide economic vitality throughout the year. Trees are harvested during the dormant season in the middle of winter (Nov- Feb) and stored bare root in cold storage until they can be delivered for planting in the spring (Mar-Apr). By the end of winter the annuals and perennials will need to be started in the greenhouses, and the fields will need to be prepared for plants. They start potted plants in a greenhouse, and transition them outside to bring them to maturity. Moving these plants requires an incredible invest in manpower and transportation services. Spread over more than 600 acres mechanized transportation isn't optional, especially when moving heavy and often delicate living plant material.

Appendix B

Oklahoma Nursery Industry

Neither Kerbo Nursery nor Greenleaf Nursery offers any type of installation or long-term maintenance services. These are simply production facilities and will assume responsibility for all plant material until it is delivered on the job site, or to the wholesale distributor to the retail chains. To acquire installation and maintenance services it is best advised to seek the professional assistance of a landscape architect. This industry is full of individuals presenting themselves in various ways, and consumers should pay attention to hire only licensed professionals with a long-standing reputation. The Tulsa Community College is currently installing a green roof on their new building in downtown Tulsa, The TCC Center for Creativity. They hired Tulsa area landscape architect Alan Roark to design and install the green roof substrate and plant material. Over time Roark will provide maintenance, but aside from a periodic walkthrough he doesn't anticipate a large workload with this roof. The Green Circle project hired the Springfield based group EMSI-International to design and maintain the green roof. Choosing a licensed landscape architect or designer for a project provides some piece of mind to customers because they should be able to expect a certain degree quality. Professional organizations like Green Roofs for Healthy Cities are starting to compile lists of service providers, contractors, and materials manufacturers. Consulting a digital resource such as this one can lead consumers and developers toward regional resources with a minimum amount of effort required. Connecting the fragmented network of services and providers will hopefully lead to an increase in green roof installations around the country.

In addition to the standard production of sedum and Ice Plant (Species *Delosperma*), the Kerbo and Greenleaf nurseries will produce large quantities of plant material specified for a particular installation. I found another nursery, Guthrie Greenhouse that would be willing to grow a large volume of sedum as a contract order. Typically, sedum species can be ready to plant about 8 weeks after sowing the seed. Orders can be filled with 3 or 4 months headway, as long as growers have the bench space available in their greenhouses. If green roofs gain widespread acceptance and the plant production markets demonstrate viability and stability these growers may choose to dedicate more resources and priority to the green roof industry. There is a lot of potential to develop a new service industry and expand a small but current market to supply green roof construction materials. The ONLA lists dozens of retailers and service providers for the nursery and landscape industry. In addition to these professionals, the roofing industry can provide a variety of standardized waterproofing materials and services. Creating these new markets for goods and services would develop new economic drivers for state and regional markets.

In addition to these local nurseries which can provide traditionally grown plugs or containerized plants for green roof installations, national green roof provider Xeroflor will start providing services in the south central United States beginning in 2009. Xeroflor offers clients a textile-based precultivated Sedum mat. Installed on top of a custom layer system the pre-vegetated mats create an instant green roof. The textile based mat offers multiple green roof system benefits including a natural resistance to wind and water erosion, resistance to weed infestation, and easier installation. With a production field expected to open soon near Little Rock, Arkansas to provide service to an area including eastern Oklahoma. Projects within a 500 mile radius of the production site are eligible to qualify for LEED points for using locally sourced plant material. With the predictable nature of a product like Xeroflor vegetated roof mats a roof can be structurally engineered based on well known values. Ranging from 12 to 18 pounds when saturated this extensive green roof system provides a flexible and instant green roofing option. Xeroflor has a longstanding and well earned reputation in the green roof industry, based on who they are and what they offer to their clients. A tradition based on cooperating with major research efforts with partners such as, Michigan State University and the Ford Motor Company. They have also earned many accolades for their projects in the private sector.

Depending on the design and layout specified for a green roof there may be an additional plant material production industry to consider. The community of Bixby, just down the Arkansas River from Tulsa, is known for its vast sod farms. Special considerations need to be made when designing roof installations with sod, the vigorous roof systems will desire a heavier substrate. Sod is typically used at ground level on new development sites with heavily compacted soils. The substrate for a sodden roof needs to be substantial enough to support such an intense growth pattern. A thicker richer substrate will increase the overall load exerted on the supporting structure, this often eliminates sod from potential plant palette due to the economics of construction costs and materials. Sod is sometimes hardened off to tolerate water stress, but it is grown in such a nutrient rich environment that it requires substantial maintenance inputs after installation. Some of the downsides to choosing sod are that it needs copious water to take root and get full coverage, it will also require fertilizer treatments during the establishment phase, and the shipping range is drastically reduced. On the other hand some of the benefits of sod are that it is easy to harvest and transport, it installs with ease by hand or mechanically, and it reproduces in the production site rapidly.



Map showing the current and anticipated range for Xeroflor installations

Photo: www.xeroflor.com

Appendix B

Oklahoma Nursery Industry

The nursery professionals I talked to during this project were able to identify some barriers or threats to their industry. Rising energy costs are affecting growers on many levels across the board. Transportation expenses alone are hard enough for growers to manage, but then factor in that a lot of the nursery trade materials are developed out of petroleum by-products. Greenleaf nursery is exploring cheaper transportation options. They produce and handle so much plant material by volume that they depend on machines to do the work. The number one cost to nursery operations is labor, and on sprawling production sites like Greenleaf most of an employee's time is spent walking from activity site to activity site throughout the day. Innovative transportation options can add a lot of value to a nursery operation by lowering the overall operating cost through wage savings. That is, if transportation costs can be maintained. Transportation concerns don't end there. The expense of delivering plant material is passed on to the client. As cheaper transportation evolves these costs will come down, until then producers will need to demonstrate diligence in how they package material for shipment. Plant material needs to retain a certain amount of moisture but water is heavy so a balance needs to be reached. Too wet means that the estimated delivery expense will be too low and you lose money, and if it is too dry you lose your delivery and possibly your contract and client. Transporting plant material can be delicate work. If they are just loaded up on the back of a truck there is a real risk of drying out the substrate, desiccating the plants causing death. Young delicate plant materials can be easily damaged if they are handled roughly or battered. Proper packing will prevent mechanical damage to sensitive plant tissues. If, for example, the growing point (apical meristem) is damaged that plant will not experience normal vegetative growth. All of these losses cost the grower valuable dollars.

Another limiting factor to the regional green roof industry is that there is very little storage capacity for harvested plant material before it can be planted on a roof installation. Producers may be able to hold harvested plant material for a short time, but they need to clear their greenhouses and production sites to prepare for the next crop. In theory plants will be scheduled for harvest, delivery and installation all within a few days of each other. The reality is that sometimes things happen; thunderstorms develop or a rare ice storm will hit in the end of April. Being able to provide a moist, cool environment would be helpful in these situations. Care must be taken to prevent exposure to disease vectors, viruses, or other pathogens. Infection at this point in the project will surely result in plant failure upon planting, failing to establish and take hold.

To further stimulate the green roof industry in Oklahoma I think that state or regional law makers should offer property developers and plant producers a variety of economic incentives to continue their work in the field. The incentives should be structured as tax credits based on either the square footage of green building developed or the square footage of plant material produced for the construction industry. Plant material produced for other purposes, such as resale, would not be eligible for the tax credit. Hopefully, the benefit of the tax credit will be enough to offset the capital investments needed to enter into more dedicated production. The two industries of green roof development and green roof plant production will need to develop simultaneously; one cannot thrive without the other.

The Oklahoma nursery industry seems very well prepared to handle green roof installations at the current rate of development. As green roof technology is embraced and adopted with widespread enthusiasm, the service industries will grow to support the trade. The economic potential for green roof markets includes materials, labor, and various professional services not just the plant materials produced in a nursery. Currently the nursery industry in Oklahoma supports regional plant requirements producing a wide variety of trees, shrubs, flowers, grasses, and more. The majority of this plant material is planted at ground level, in an amended natural soil. Compost with high organic matter content is a likely soil additive at ground level, in addition to the many synthetic fertilizers available in the commercial market. Expanding an emerging market for the nursery industry, such as green roof installation and services, can lead to vibrant and robust economic trade. Regional nurseries should be able to provide plant material that will survive in Oklahoma's rigorous growing conditions. Addressing the rising cost of petroleum products ranging from fuel to fertilizer additives should help encourage the long term establishment of green roof plant production systems in the area. Growers are faced with uncertain expenses and rising costs every growing season, coupled with the uncertain nature of local weather patterns make the nursery business a risky endeavor without long-term clients like Greenleaf Nursery. The volume of their production system makes them able to absorb for market fluctuations. Small scale operations operate on thin cost estimates, and market instability can disrupt small nurseries to the point of failure. Green roof installation services and maintenance over time can boost the economic standing of individuals dedicated to the field. Establishing green roof construction and installation standards on a state level will help protect customers and producers at the time. Knowing how to identify high-quality plants and proper installation methods will save both time and money on a green roof project. Although I only mentioned three or four specific producers in the Oklahoma nursery business, there are dozens of very small growing operations across the state. Check with your local plant provider before ordering from a distant grower. Most local plant producers would be willing to grow a special order for a customer if they have the time and space.

Appendix A and B

Resources

Resources:

Dirr, Michael A. Manual of Woody Landscape Plants. Champaign, IL: Stipes Publishing LLC, 1998.

Baker, Jay. Personal interview with Nathan Diekelman. 9 March 2009. Regional representative for Greenleaf Nursery based out of Tahlequah, OK.

Cox, Melissa. Email correspondence with Nathan Diekelman. February and March 2009. Project manager with EMSI Sustainable Design and Development Services for the Green Circle green roof plant layout and design.

Hainline, Jason. Email correspondence with Nathan Diekelman. August 2008, February and March 2009. Vice-President of EMSI Sustainable Design and Development Services.

Hufft, Matthew. Email correspondence with Nathan Diekelman. February and March 2009. AIA, LEED AP, Principle architect at Hufft Architects of Kansas City.

Kerbo, Rick. Email correspondence with Nathan Diekelman. March and April 2009. Owner and operator of Kerbo Nursery in Choctaw, OK.

Kirchmer, Kendra. Email correspondence with Nathan Diekelman. March and April 2009. LEED AP, Project manager of the Green Circle Shopping Center for Hufft Architects.

O'Reilly, Matthew. Email correspondence with Nathan Diekelman. December 2008- April 2009. Owner and Developer of Green Circle Shopping Center in Springfield, MO.

Oklahoma Nursery and Landscape Association

Roark, Alan. Attended a presentation he did on the TCC roof and personal email correspondence with Nathan Diekelman. Owner of Roark Landscaping Corp in Tulsa, contractors for the TCC green roof.

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