Green Roofs: Restoring Urban Landscapes One Roof at a Time

Brian Taylor, P.E.
March 2010

WSU
LID Workshop, Puyallup
Overview

- Introduction
- Green Roof Benefits
- Types of Green Roofs
- Design & Installation
  - Components
  - Factors & Considerations
- Post-Installation
- Retrofits
- Stormwater Performance
Architecturally Focused Civil Engineering
Architecturally Focused Civil Engineering
Sites To Mimic Nature
Urban Green

Narrow Sidewalks
Better Tree Pits
More Street Trees
Better Lighting
No Tree Pits

On Site
Eco-Roof
Cistern
Better Detention
Open Space

Sustainable Infrastructure
Storm Drainage
Eco-Corridors
Better Streets

Wide Sidewalks
Green Streets
Eco-Streets
Green Roofs ....

Source: www.roofscapes.com
...aka...

“Living Roofs”

“Vegetated Roofs”

“Eco-roofs”

“Roof gardens”

Source: www.roofscapes.com
Green Roof Components - Overview

Image: www.lowimpactdevelopment.org
Benefits

- Ecology
- Social
- Noise Reduction
- Energy and Heat
- Economy
- Stormwater
Ecology: Habitat & Biodiversity

- Wildlife habitat
- Demonstrated success when targeted to species

Laban Dance Centre, London

Source: www.greenroofs.com

Black Redstart
Ecology: Habitat & Biodiversity

Killdeers
Source: www.roofscapes.com

Birdhouse with Green Roof
Source: Barry Taylor

Ladybug
Ecology: Air Quality

- Particulates trapped
- Secondary benefits from reduced temperature

Increased temperature = increased smog
Social

- Faster healing
- Happier, more content, less stressed
- Increased productivity
- Reduced sick days

Green roof at nursing home

Source: www.greenroofs.org
Energy & Heat

- Roofs have major role in building energy consumption

**Extensive Greened Roof**

Energy balance, daily mean

- Global Radiation: 5354 Wh
- Reflection: 803 Wh
- Evaporation (Latent Heat): 1185 Wh
- Sensible Heat: 872 Wh
- Increased Thermal Radiation: 2494 Wh
- Net Longwave (Thermal) Radiation: 7555 Wh
- Net Radiation: 2057 Wh

**Advantages**
- Improvement of the microclimate
- High durability of the sealing of the roof
- Reduction of the runoff by evapotranspiration

**Main Influencing Factors:**
- Field capacity of the soil
- Exposition
- Percentage of cover of the vegetation

**Fig. 4**

Extensive greened roofs transfer 58% of net radiation into evapotranspiration during the summer months, UFA Fabrik in Berlin, Germany

Source: Marco Schmidt
Energy & Heat

- Traditional roofs & pavements contribute to urban heat island
Energy & Heat

- Moderate roof temperature
- Thermal mass
- Evapotranspiration
- Reduce heat stress on roof membrane
- Reduce ambient air temperature

Source: Jeffrey K. Sonne, Florida Solar Energy Center
Energy & Heat

- Improve mechanical efficiency
- Improve solar efficiency
- Reduce greenhouse gases from heating/cooling

Source: www.roofscapes.com

Source: U.S. EPA Region 8
Economic

- Reduce size of HVAC equipment
- Extend roof membrane life
- Higher lease rates
- Higher productivity
- Incorporate function...
  - Water treatment
  - Food production

Source: www.greenroofs.com
Green Roof Hydrologic Processes

- Precipitation
- "Run-On"
- Evapotranspiration
- Depressions
- Interception
- Surface Runoff
- Subsurface Drainage and Retention
- Percolation
- Media Moisture/Retention
- Structure
- Drain
- Roof Runoff
Stormwater Control Factors

- Thickness of media
- Media hydraulic properties
- Type of drainage layer used
- Properties of drainage layer
- CLIMATE!
  - How much time is available to “recharge” media
  - Evapotranspiration rates driven by temperature, humidity, windspeed, and solar radiation
Green Roof Components – Growing Media

- Moisture retention & plant water availability

Source: www.bae.ncsu.edu
Green Roof Categories

- Intensive: 6” or thicker
- Semi-intensive: 25% above or below 6”
- Extensive: up to 6”

Source: Green Roofs for Healthy Cities
Green Roof Categories:  Intensive

- “Roof garden” with trees, shrubs, etc
- Often accessible
- 50+ psf
- Expanded planting palette
- Highest cost
- Highest maintenance

Source: Green Roofs for Healthy Cities
Green Roof Categories: Intensive

- Millennium Park, Chicago

Source: www.greenroofs.com
Green Roof Categories: Semi-Intensive

- May be turf/lawn
- May be accessible/partially accessible
- 35-50 psf
- Moderate planting palette
- Take advantage of roof capacity
- Moderate cost/maintenance

Source: Green Roofs for Healthy Cities
Green Roof Categories: Semi-Intensive

- Vancouver Public Library

Source: www.greenroofs.com
Green Roof Categories: Semi-Intensive

- Seattle Art Museum/WAMU
Green Roof Categories: Extensive

- Lightweight
- Larger areas
- 12-35 psf
- Somewhat limited planting palette
- Typically inaccessible
- Lowest maintenance & cost
- Amenable for retrofits

Source: Green Roofs for Healthy Cities
Green Roof Categories: Extensive

- Whistler Daycare Centre, B.C.

Source: BCIT
Green Roof Categories: Extensive

- MKA Green Roof Evaluation Test Plot
Green Roof System (Modular)
Green Roof Systems

- Modular
  - Trays or “bags”
  - Can pre-plant off-site
  - Quick installation, simpler coordination
  - Easier roof repairs
Green Roof Systems

- Modular (cons)
  - Expense of modules
  - Gaps & exposed membrane
  - Weight of loaded trays
  - Irrigation constraints
Green Roof System (Multi-course)

Figure 3: Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual
Green Roof System

- Loose-laid or Built-Up
  - Established practice
  - Amenable for new construction
  - Likely to provide enhanced benefits
  - Horticultural benefit
Green Roof System (Multi-course)

Image: www.roofscapes.com

Granular Drainage
Green Roof System (Single-Layer)

Image: www.roofscapes.com
“What kind of roof can be vegetated?”

......just about any!
“Flat” roofs

Chicago Wal-mart
Source: www.roofscapes.com

Ford Rouge River Plant
Source: www.greenroofs.com
Sloped roofs

California Academy of Sciences
Source: www.calacademy.org

Source: www.roofscapes.com
High-rises

Chicago
- 111 S. Wacker
- 51-story bldg
- High wind
Wood frames

Zoomazium, Seattle
- New construction
- Native plantings
Bridges/structures
Green Roof Standards

- U.S.
  - ASTM tests for media properties
  - The National Roofing Contractors Association (NRCA) Green Roof Systems Manual

- International (Germany)
  - F.L.L. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau)
  - “Guideline for the Planning, Execution and Upkeep of Green-Roof Sites”
Green Roof Guidance & Resources

- Green Roofs for Healthy Cities
  - Conference
  - Training workshops
  - Designer certification
- Experienced practitioners
  - Vendors
  - Consultants
- Greenroofs.com website
- Conservation Technology, Inc.
Green Roof Design Teams

- Architect
  - Roofing & flashing details
  - Building integration
- Green roof/landscape designer
  - Green roof components & plants
- Growing media consultant
- Roofing consultant/building envelope specialist
  - Waterproofing design
- Engineers
  - Structural, Mechanical, Civil
- Leak Detection Specialist
- Irrigation Specialist
Green Roof Components

Figure 3: Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual
Green Roof Components

- **Roof Deck**
  - Concrete, Steel, or Wood, typ.
Green Roof Components

- Roof Deck
  - Structural -
  - Extensive green roofs 10-50 psf
  - 6-inch extensive say 40 psf typ.
  - Structural Engineering Analysis critical
# Green Roof Weight

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Weight (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-in (vegetated mat)</td>
<td>8-15</td>
</tr>
<tr>
<td>2-in</td>
<td>10-22</td>
</tr>
<tr>
<td>4-in</td>
<td>22-34</td>
</tr>
<tr>
<td>6-in</td>
<td>33-51</td>
</tr>
<tr>
<td>8-in</td>
<td>47-65</td>
</tr>
</tbody>
</table>
Green Roof Components

- **Roof Deck**
  - Insulation above or below waterproofing membrane
  - Coordinate architectural details with green roof assembly (insulation, vapor barrier locations, and venting)
  - Building Envelope consultant
Green Roof Components

- Waterproofing membrane
  - Loose laid (ballasted)
  - Bonded (adhered)
  - Mechanically attached
Green Roof Components

- Waterproof membranes
  - Waterproof vs. water-shedding
  - Use a quality membrane
  - Proven track record
  - Durability, UV resistance
  - Root resistance varies
  - Puncture resistance
  - Retrofit compatibility
Green Roof Components

- Types of membranes
  - Built-up (layers of felt/fabric & bitumen)
  - Fluid applied
  - Elastomeric – EPDM (sheets of rubber-like material)
  - PVC/TPO
  - Others

American Hydrotech MM6125® monolithic fluid applied rubberized asphalt membrane
Green Roof Components

- Protection Course
  - Protects membrane from damage
  - Boards, sheets, mats
  - Sometimes insulation used
Green Roof Components

- Root Barrier
  - Polyethylene sheets (10 mil min.)
  - HPDE boards
  - Some EPDM, PVC, TPO membranes
  - Root inhibitors

Figure 2: Extensive (vegetative) green roof system
Green Roof Components

- **Drainage layer (Roofing perspective)**
  - Relieves hydrostatic pressure
  - Allows insulation to breathe
Green Roof Components

- Drainage layer (vegetated roof perspective)
  - Prevents over-saturation of growing media
  - Detains storm runoff
Green Roof Components – Drain Layer

- Two Basic Options: Granular and Non-Granular
  - Non-granular: mats, boards, & modules
- Factors
  - Slope
  - Weight
  - Compressive strength
  - Site conditions
Green Roof Components – Drain Layer

- Properties
  - Porous to permit water movement
  - Transmissivity - related to catchment area
  - Permeability - 425+ in/hr for granular media
  - Continuous coverage
  - Compressive strength for overburden and traffic

Source: Green Roofs for Healthy Cities
Green Roof Components – Drain Layer

- Non-Granular “Open” Drain Layer Products
  - Transmissivity & strength
  - Moisture retention

Source: www.optigreen.com
Green Roof Components – Drain Layer

- **Granular Drainage**
  - Light weight aggregate (e.g. pumice)
  - Open graded (highly porous)
  - Refer to FLL for info

Source: © www.conservationtechnology.com
Green Roof Components – Drain Layer

- Internal drains and retention edges
- Refer to NRCA for flashing and retention edge placement details
- See Conservation Technology, Inc.'s Green Roof Manual for additional information

Source: Conservation Technology, Inc.

Source: www.optigreen.com
Green Roof Components

- Moisture Retention Layer
  - Waffle boards or mats
  - Similar benefit can be achieved by using more growing media
  - Often integrated with drainage or protection layers
Green Roof Components

- Moisture Retention Layer

Source: American Hydrotech
Green Roof Components

- **Filter Fabric**
  - Geotextile fabric placed beneath growing media to retain fine particles
  - Resistant to weathering and puncture
Green Roof Components

- Growing Media
  - Light-weight mineral components
  - FLL guidelines: low organic
  - Sustains vegetation
  - Retains moisture
Green Roof Components - Growing Media

- **Requirements**
  - Permeable (to prevent over-saturation)
  - Light-weight (to reduce roof load)
  - Fire-resistant
  - Stable versus sliding & slumping
  - Frost-resistant
  - Compression resistant
  - Nutrient and chemical properties **proven** compatible with horticultural growth (ph 6.5-8.0, etc)
  - Free of foreign substances

Source: FLL
Green Roof Components - Growing Media

- Moisture retention & plant water availability

Source: www.bae.ncsu.edu
Green Roof Components

- Why not use topsoil?
  - Light-weight mineral components
  - Permeable (to prevent over-saturation)
  - Stable versus sliding & slumping
  - Free of foreign substances
  - Sustains vegetation

![Diagram of green roof system]

Fine particles can seal filter material
Specifying Growing Media

- Example of an Extensive Growing Media Blend
  - Coarse lightweight aggregate: 40-80%
  - Organic material: 0-25%
  - Sand or fine lightweight aggregate: 0-35%
  - Air content at max. water capacity: 15% at 45%

- Example of an Intensive Growing Media Blend
  - Coarse lightweight aggregate: 35-60%
  - Organic material: 5-20%
  - Sand or fine lightweight aggregate: 25-50%
  - Air content at max. water capacity: 10% at 35%

Source: Green Roofs for Healthy Cities, as adapted from Friedrich 2005
Green Roof Components - Growing Media

- Organic Content (FLL Guidelines)
  - Depends on the weight of materials and type of roof
  - Intensive lightweight <12% by mass
  - Extensive lightweight <8% by mass
  - Extensive single course <4% by mass

Source: FLL
Green Roof Components - Growing Media

- Granular Distribution
  - FLL is common standard for inorganic component of media blend
  - Different blends for intensive, multi-course extensive, & single-course extensive
  - Sand & gravel size, typ.
  - Refer to FLL or media supplier (Roof-lite, Roofscapes, American Hydrotech, etc)

Source: FLL
Specifying Growing Media

FLL$^1$ Particle Size Distribution Graph for Single Course Extensive Systems

FLL Guidelines:
Single Course Extensive

**Green Roof Components - Growing Media**

- **Water Holding Capacity**
  - Field capacity, “Maximum Water Capacity” (ASTM test): moisture retained by saturated media after free-draining, 40-60% typ.
  - Wilt point: moisture retained by media that cannot be removed (aka wilt point), 12-18% typ.
  - Available moisture for plants is the difference

- **Pore volume**: allows movement and temporary storage of moisture, 10% min.

- **Permeability**: 3+ in/hr
Green Roof Components - Growing Media

- Other Properties
  - Void Space
  - Cation Exchange Capacity
  - Carbonate Content
  - pH
  - Nutrients
  - Salts

Source: Green Roofs for Healthy Cities
Key Media Parameters for Storm Control

- Media composition (% organic)
- Maximum water content (field capacity)
  - 35 – 50% typ.
- Saturated/dry weights
- Saturated Hydraulic Conductivity (permeability)
  - 0.001 to >1.0 cm/s (!)
Specifying Growing Media

- Quality Assurance
  - Test growing media delivered to site
  - Spot checks on roof for uniformity
  - Avoid separation of components during handling

Source: Green Roofs for Healthy Cities
Green Roof Components

- **Plants:** Planting conditions
  - **Extensive:** harsh environment for plants; wind, exposure; often not irrigated
  - **Intensive:** deeper soil enables large plants; typically irrigated
Green Roof Components

- Common Plants
  - Succulents
  - Grasses
  - Herbaceous
Green Roof Plants

- Succulents use crassulacean acid metabolism (CAM) to minimize water loss
- Sedums
Green Roof Plants

- Succulents also have fewer stomata
  - Sempervium
  - Delosperma
Green Roof Components

- Proven Pacific Northwest Plants (unirrigated)
  - Sedum
  - Sempervium
  - Delosperma
  - Coastal Strawberry
Green Roof Components

- Planting Methods
  - Vegetated mats
  - Pre-planted modules
  - Seeding
  - Cuttings
  - Plugs
  - Container Plants (small!)

Source: www.optigreen.com
GREP Plant Progression

May

June

July

Sept
Green Roof Components

- **Plant Irrigation**
  - Required until establishment (3 yrs)
  - Drip or sub-surface recommended
  - Capillary systems available
Green Roof Costs

- Always use a quality waterproofing membrane (est. $5-$10/sf)
- Allow $7-$20/sf additional for the green roof
- Economy of scale
- Warranty likely to increase cost
- Leak detection system extra $5-10K
Green Roof Factors

- Layout
  - Gravel border
  - Take advantage of structural capacity
  - Window-washing
  - Wind & micro-climate
Green Roof Factors

- Sloped roofs
  - Greater than 2:12 requires analysis
  - Engineer media for steeper condition
  - Use structural restraining system
  - Terrace the roof
  - Consider soil moisture & plants
Green Roof Factors

- Sloped roofs: specialty geotextiles
  - Example: “EnkaRetain”
  - Consider geotextiles for slopes 2:12 to 3:12
Green Roof Factors

- Sloped roofs: Slippage restraint

Image: www.optigreen.com

SLOPETAME2

Image: www.hydrotechusa.com
Green Roof Factors

- Sloped roofs engineering
  - Avoid slip-plane failures:
    *Be careful what kind of drainage is used*
  - Where is the slippage being resisted structurally?
Green Roof Factors

- Sloped roofs: Cellular confinement
Green Roof Factors

- Sloped roofs: Cellular confinement.
Green Roof Factors

- Sloped roofs: Cellular confinement

MKA, 2009
Green Roof Factors

- Sloped roofs: Cellular confinement
Sloped Green Roof Case Study
Green Roof Factors

- Sloped roofs: Slippage restraint

Image: www.hydrotechusa.com
Green Roof Factors

- Warranty
  - Dialogue with waterproofing contractor/supplier
  - May affect choice of system
Green Roof Costs

- Always use a quality waterproofing membrane (est. $5-$10/sf)
- Allow $7-$20/sf additional for the green roof
- Economy of scale
Installation Considerations

- Coordination of trades is critical
  - Waterproofing installer
  - Landscape crew
  - Mechanical equipment
  - Access to cranes/elevators
Installation Considerations

- Coordination of trades is critical
  - Waterproofing installer
  - Landscape crew
  - Mechanical equipment
  - Access to cranes/elevators
  - Mandatory Pre-Bid conference

- Pre-qualifying & bonding
Installation Considerations

- Allow time for test plots and material testing
- Pre-construction meeting
  - Address sequence & coordination needs
  - Identify when flood-testing to occur
  - Mechanical equipment
  - Access to cranes/elevators
Installation Considerations

- Safety
  - Trained crew / personnel
  - Fall protection systems (temporary & permanent)
Installation Considerations

- Material Handling
  - On- vs. off-site media blending
  - On- vs. off-site planting
  - Staging/stockpiling (do not exceed roof capacity)
  - Control moisture of media
  - Protect installed materials
Installation Considerations

- Media Conveyance & Handling
  - Prevent contamination
  - Prevent separation
  - Super-sacks (1.5 CY)
  - Small sacks
  - Blown
  - Evaluate media after placed, before planting
Installation Considerations

- Mulch/matting
  - Prevent wind erosion
  - Discourage weed germination
  - Reduce soil moisture loss
- Bird netting
Challenges – Birds
Maintenance

- 2- to 3-yr establishment period (80-90% coverage)
  - Irrigation
  - Watch for over-/under-compacted areas
- Monitor & repair steep slope sloughing
- Weeding
- Temporary mulch/matting
- Fertilization
  - Slow-release
  - May not be needed after first 5-yrs
“What types of existing buildings are suitable for green roof retrofits?”
Structural Considerations

- Building type overview
- Capacity per design load validation
- Building height
- Green roof placement
- Seismic
Capacity for Additional Roof Load (per typical design methods & procedures)

- Wood: worst
- Masonry: poor, maybe if seismically upgraded
- Steel: fair (newer) to best (older)
- Concrete: best
“How much green roof could be put onto an existing roof?”
Design Load Verification

- Snow load
- Load Swapping
- Plaza/Decks
Design Load Verification (cont.)

- Snow load
  - Drifting
  - True ground load: 20 ± vs. 25 psf design
Design Load Verification (cont.)

- **Load Swapping**
  - Ballast typically 10 psf ±
  - Concrete Sloping Slabs say 10 to 50 psf ±
  - Tiles
Design Load Verification (cont.)

- Plaza/Decks
  - Live (e.g. 100 psf)
  - vs. dead load

Image: www.greengridroofs.com
Building Height

- Steel & Concrete...
  - Higher buildings (6 stories +) more likely to have capacity for extra load
- Designed for extra floors
  - Very likely to have spare capacity
- Wind
  - Over 10 stories - GR design modifications
Seismic

- 2006 Seattle Bldg Code
  - Increase base shear >10% triggers seismic analysis
  - Expect to trigger seismic upgrade when adding green roof to URM
Seismic (cont.)

- Seismic upgrade
  - Improve roof-wall connections
  - Parapet bracing
  - Additional expense
Structural Screening Criteria

- Favorable
  - Steel / concrete framed
  - 6 to 10 stories
  - Large roof
  - Design for extra stories (e.g. cardeck)
  - Exist., removable topping (e.g. ballast, tiles)
  - Existing plazas
Structural Screening Criteria (cont.)

- Unfavorable
  - URM, wood frame
  - Less than 6 stories
  - Small roofs, parapets
  - No previous seismic upgrade
Target Weight

- CASE-BY-CASE
- Likely 5-20 psf
- Assume 2-4 inch green roof thickness
Example: Park Place Building, Seattle

- **Structural system**
  - Concrete moment frame
  - Reinforced conc. slab roof
  - 10-ft beam spacing

- **Design capacity**
  - 60 psf live load (exist per design)
  - 25 psf snow load

- **Safety**
  - Exist parapets
Example: Park Place Building, Seattle

- Green roof
  - 4-inch extensive; 9,656 sf

- Proposed Loads
  - Mechanical: 30,000 lbs
  - Green roof: 40 psf
  - Live load: 20 psf
  - Snow load: 25 psf

- Overlay existing
Questions?

Brian Taylor, P.E.
bttaylor@mka.com
www.mka.com