APPENDIX A. Case Studies

The following case studies are presented in this appendix:

Montgomery Park Business Center

Life Expression Chiropractic Center

Chicago City Hall

Ford Dearborn Truck Assembly Plant

Mountain Equipment Cooperative (MEC)

Jordan N. Carlos Middle School Art Building, Woodward Academy

20,000 SF green roof on the main building

Bioretention in parking lot at building entrance

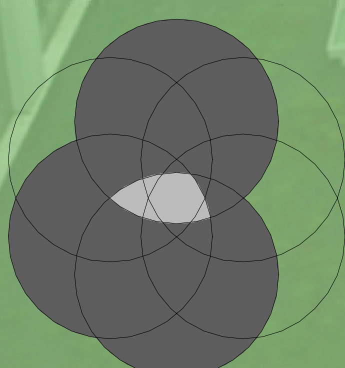
Bioretention after a day of steady rainfall

Location
Baltimore, Maryland
Green Roof Designer
Katrin Scholz-Barth Consulting
Year Completed
2001
System Type
Extensive
Project Area
30,000 sf (3,000 m^2) total

A. Storm Water

The two green roofs at Montgomery Park were designed primarily as storm water mitigation devices. Combined with bioretention areas in the building's parking lot, they reduce the impermeable footprint of the existing complex.

The Maryland Department of the Environment (MDE, 2004) encourages the use of nonstructural storm water management techniques like green roofs to reduce the need for structural controls. While some Maryland jurisdictions allow green roofs to be calculated as grassed areas, MDE advises assessing the hydrologic impact during the review process.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Maryland Department of the Environment. (2004). Maryland's stormwater management program. Baltimore, MD: MDE.

MONTGOMERY PARK BUSINESS CENTER

A+D+E

View from roof level

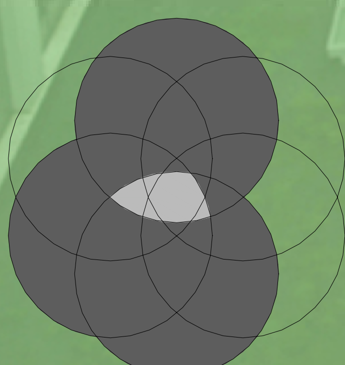
Gravity draws water filtering through the system down the 1:12 roof slope to the gutters at the roof edges. Filter fabric and vertical slots in the edge metal prevent loss of growing medium to the gutters.

Structural modifications beneath the 20,000 sf (2,000 m^2) green roof include steel sections welded to the underside of the existing roof purlins.

Location
Baltimore, Maryland
Green Roof Designer
Katrin Scholz-Barth Consulting
Year Completed
2001
System Type
Extensive
Project Area
30,000 sf (3,000 m^2) total

D. Structure

Because the 20,000 sf (2,000 m^2) green roof was installed over an existing train shed, weight considerations controlled the design of the green roof and required the existing steel roof framing to be structurally augmented. The green roof system comprises, from top to bottom: plants, 2-3” (50-75 mm) of growing medium made of 75-80% expanded slate and 20-25% organic mushroom compost, two textile root barrier layers, 2” (50 mm) of extruded polystyrene insulation, and a PVC single-ply roof membrane. The combined system has a saturated weight of only 18 psf (88 kg/m^2) (MDE, 2004).



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Maryland Department of the Environment. (2004). Green building features of Montgomery Park. Baltimore, MD: MDE.

MONTGOMERY PARK BUSINESS CENTER

A+D+E

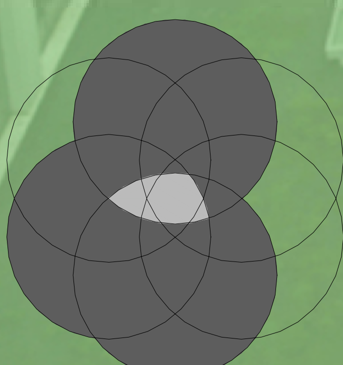
Montgomery Park Business Center

Adaptive re-use of the 1920s structure

Location
Baltimore, Maryland
Green Roof Designer
Katrin Scholz-Barth Consulting
Year Completed
2001
System Type
Extensive
Project Area
30,000 sf (3,000 m^2) total

E. Compliance

Winner of the U.S. Environmental Protection Agency's Phoenix award for excellence in brownfields redevelopment, the adaptive reuse of the historic Montgomery Wards Building incorporates numerous resource-conserving measures. The Code of Maryland Regulations stipulate that all redevelopment projects must reduce existing site imperviousness by 20%, provide water quality control for 20% of the site's impervious area, or employ combination of these strategies. Green roofs are a key method used to reduce a site's impervious area (MDE, 2004).



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Maryland Department of the Environment. (2004). Stormwater management & urban redevelopment. Baltimore: MDE.

MONTGOMERY PARK BUSINESS CENTER

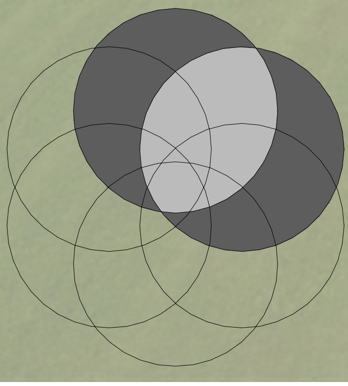
A+D+E

The green roof compensates for the displaced landscape.

Location
Hazleton, Pennsylvania
Architect
Van der Ryn Architects
Year Completed
2001
System Type
Extensive
Project Area
6,000 sf (600 m^2) total

A. Storm Water

The Life Expression Chiropractic Center was envisioned as a first step in the movement toward a more sustainable office facility. The green roof intercepts and delays the flow of incident rainfall, allowing it to flow through a gapped fascia at the edges. Although the green roof replaces some pervious surface displaced by the building footprint, building officials still required a full sized storm water retention basin behind the project. The green roof requires no additional irrigation thanks to its engineered lightweight growing media that simultaneously retains and drains water.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

LIFE EXPRESSION CHIROPRACTIC CENTER

A+B

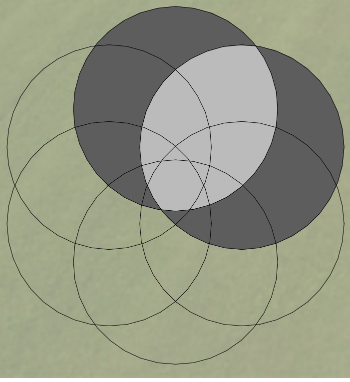
Clerestory windows permit light and air to enter the building.

Interiors illuminated with natural light

Location
Hazleton, Pennsylvania
Architect
Van der Ryn Architects
Year Completed
2001
System Type
Extensive
Project Area
6,000 sf (600 m^2) total

B. Energy

Clerestory windows along the three wings of the building permit the introduction of daylighting and natural ventilation into the spaces, providing restful interiors and reducing the demand for electricity. The green roof itself lowers temperatures at the roof surface as compared with traditional roofing, reducing heat flow into the building on warm days. The system also provides some degree of roof insulation with its 2-3" (50-75 mm) of growing media and plant layer, though this effect is difficult to quantify at present.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

LIFE EXPRESSION CHIROPRACTIC CENTER

A+B

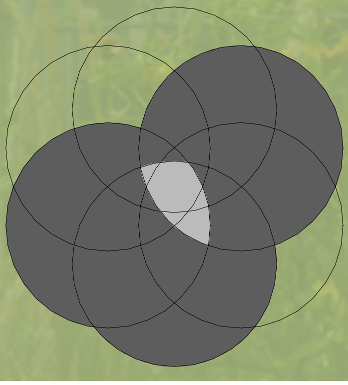
The green roof trims the load off traditional HVAC systems.

Test plots at the Chicago Center for Green Technology

Location
Chicago, Illinois
Green Roof Designer
William McDonough + Partners
Year Completed
2001
System Type
Mixed
Project Area
20,300 sf (1,890 m^2) total

B. Energy

Funded by a settlement with electrical utility Commonwealth Edison, the City Hall Green roof is projected to save $3,600 in heating and cooling per year. Ambient air and surface temperatures were monitored at the City Hall roof and the adjacent Cook County black roof. On August 9, 2001 at 1:45 pm, there was a 50°F (28°C) difference between the surface of the green roof and the surface of the black roof. After three years of summer data collection at City Hall, monitoring continues at test plots at the Chicago Center for Green Technology.



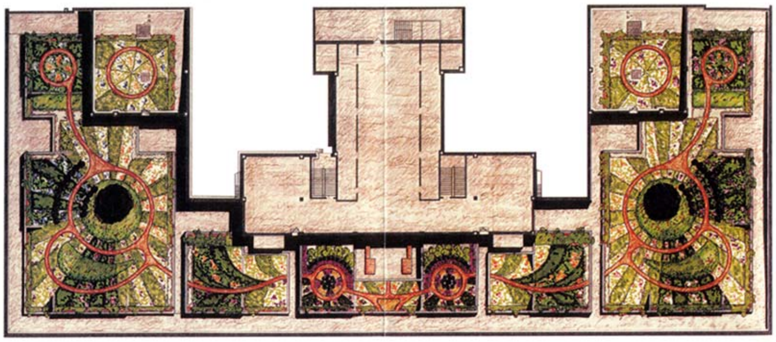
A Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

City of Chicago Department of Environment. (2004). Monitoring the rooftop garden’s benefits. http://egov.cityofchicago.org (25 July 2004).

CHICAGO CITY HALL

B+D+E

Location
Chicago, Illinois
Green Roof Designer
William McDonough + Partners
Year Completed
2001
System Type
Mixed
Project Area
20,300 sf (1,890 m^2) total



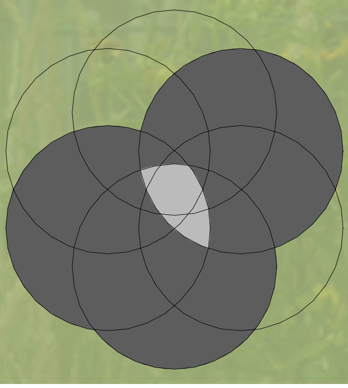
Starburst patterns of initial design are now obscured.

Insulation creates contours.

Beds at former skylights

D. Structure

The design of the roof garden echoes the structure of the existing roof deck. The trees in intensive planting areas (18" (450 mm) deep) are centered over columns, while semi-intensive planting areas (4-8" (100-200 mm) deep) are in raised beds that coincide with former skylights. The remainder of the roof is extensive (3-4" (75-100 mm) deep). To avoid overloading the structure, polystyrene insulation above the roof membrane was used to create the contours of the garden. Two 150-gallon (570-L) cisterns were secured to the structural steel of the renovated penthouse walls.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Drawing: "Chicago's Green Rooftops, A Guide to Rooftop Gardening.
Insulation: Photo © 2003, Roofscapes, Inc. Used by permission; all rights reserved.

CHICAGO CITY HALL

B+D+E

Chicago City Hall's gardens are visible from adjacent towers.

Flowering annuals

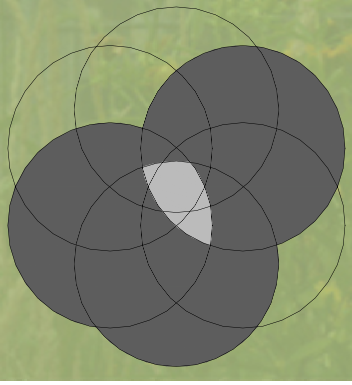
Beehives

A home for wrens

Location
Chicago, Illinois
Green Roof Designer
William McDonough + Partners
Year Completed
2001
System Type
Mixed
Project Area
20,300 sf (1,890 m^2) total

E. Compliance

The City Hall green roof was the initial demonstration project of the Chicago Department of Environment's Urban Heat Island Initiative. The gardens were initially planted with 156 species, and now sustain plants ranging from prairie grasses to traditional green roof sedums to flowering annuals. The gardens are frequently maintained and replanted for aesthetic reasons. Results of the project include guidelines for future green roof projects in Chicago, a performance specification for green roofs, and data demonstrating environmental benefits.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Weston. (1999). Urban heat island initiative pilot project, city hall green roof final report. Roy F. Weston, Inc.

CHICAGO CITY HALL

B+D+E

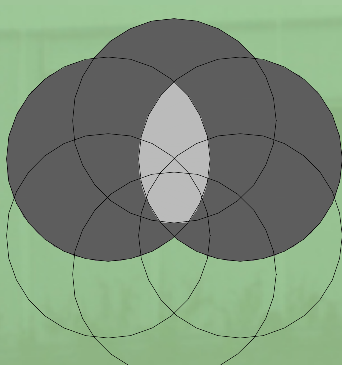
The green roof atop the new truck plant retains approximately 50% of incident rainfall.

Porous paving and drainage swales mitigate site storm water.

Location
Dearborn, Michigan
Green Roof Designer
William McDonough + Partners
Year Completed
2002
System Type
Extensive
Project Area
475,000 sf (44,100 m^2)

A. Storm Water

The green roof on the new truck assembly plant forms part of a comprehensive plan to mitigate storm water at the Ford Rouge complex. The roof is expected to prevent 447,000 gallons (1,690,000 L) per year, or 50% of the rainfall incident on the roof, from entering the storm sewer (GRHC, 2003). Porous paving and drainage swales on site also reduce and filter runoff.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Green Roofs for Healthy Cities. (2003). *Green roof awards of excellence: profile of award winners.* Chicago: The City of Chicago and Green Roofs for Healthy Cities.

FORD DEARBORN TRUCK ASSEMBLY PLANT

A+B+F

Roof monitors bring natural light to factory space.

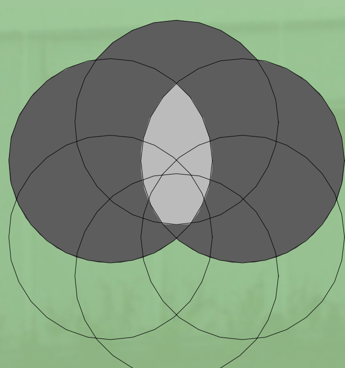
Solar shading using vines on building facades

Solar thermal panels above sedum mats at grade are another experimental energy-saving strategy on site.

Location
Dearborn, Michigan
Green Roof Designer
William McDonough + Partners
Year Completed
2002
System Type
Extensive
Project Area
475,000 sf (44,100 m^2)

B. Energy

Vegetative solar shading at the roof and walls of the new truck plant minimizes heat gain. According to Green Roofs for Healthy Cities, the project's engineers expect the green roof to reduce energy use by 7% (2003). The Ford Motor Company's green roof tour placards claim that the green roof's insulation properties "save millions of dollars in energy costs" and that it "lowers temperatures inside by up to 10[°F (6°C)]." While these benefits are currently difficult to demonstrate, researchers will monitor the building to determine compliance with design goals (Litt, 2004).



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Litt, Steven. (2004, May). Some sustainability required. *Architecture*, pp. 52-59.

FORD DEARBORN TRUCK ASSEMBLY PLANT

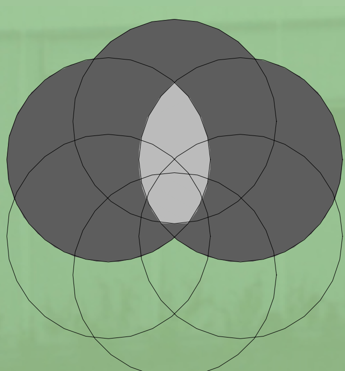
A+B+F

Visitors view the green roof from an observation level as part of a tour of the truck assembly plant.

Location
Dearborn, Michigan
Green Roof Designer
William McDonough + Partners
Year Completed
2002
System Type
Extensive
Project Area
475,000 sf (44,100 m^2)

F. Cost

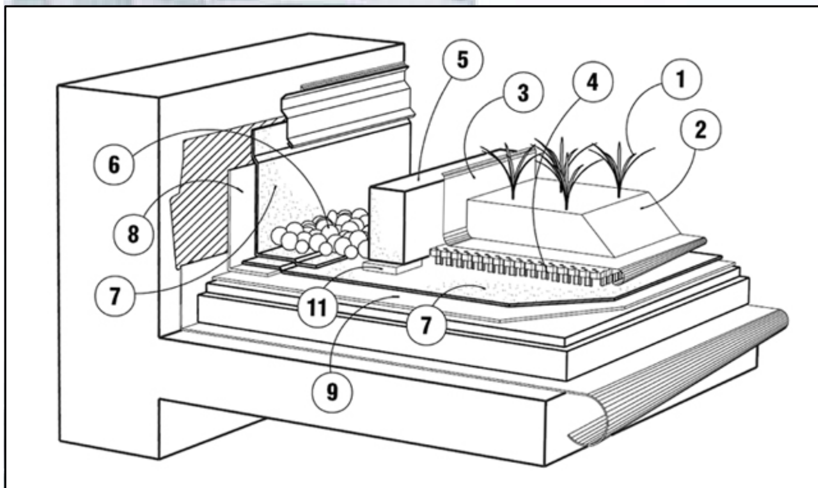
The Ford Motor Company hired William McDonough + Partners to assist in the revitalization of the Ford Rouge complex, a project slated to take 20 years and $2 billion. McDonough estimates that the green roof alone saved the company $5 million by avoiding the construction of a new storm water treatment plant (Litt, 2004). BRC Imagination Arts, a firm whose resume also includes Disney attractions, made “the World’s Largest Living Roof” a feature of the new Ford Rouge Factory Tour, which opened in May 2004. Visitors view the roof from an observation deck overlooking the truck plant.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

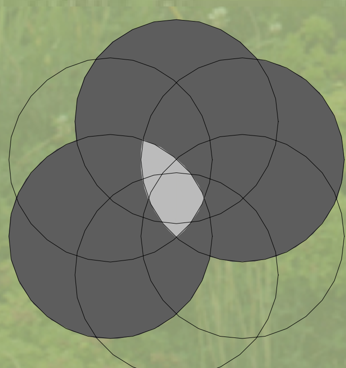
FORD DEARBORN TRUCK ASSEMBLY PLANT

A+B+F



The Sopranature System:
1) Vegetation
2) Sopraflor growing medium
3) Soprafiltre
4) Sopradrain
5) Cement curb
6) Gravel (omitted at MEC)
7) Sopralene Flam Jardin
8) Sopralene Flam 180
9) Base sheet with primer
11) Rubber spacer (Sopramat)
(Soprema, 1998)

The installed system shown below:
Vegetation
Lightweight growing medium
Root barrier
Expanded polystyrene drain board
Modified bitumen roofing



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Soprema. (1998). Perimeter protection detail. http://download.soprema.ca/fichier/sna02-e.pdf (6 Sept. 2004).

Location
Toronto, Ontario
Architect
Stone Kohn McQuire Vogt Architects
Year Completed
1998
System Type
Extensive
Project Area
10,000 sf (900 m^2)

A. Storm Water

The Toronto MEC store is equipped with a sophisticated multi-layer green roof system called SopraNature, manufactured by Soprema. The layers both reduce and slow storm water, though no monitoring equipment is in place to quantify this benefit. The system provides a delicate balance between retaining too much water (which would lead to ponding and drowning of plant roots) and too little water (which would require excessive irrigation and compromise the storm water retention benefits of the roof). Occasional irrigation with sprinklers is necessary to maintain the roof during dry weather.

TORONTO MOUNTAIN EQUIPMENT COOPERATIVE

A+B+E

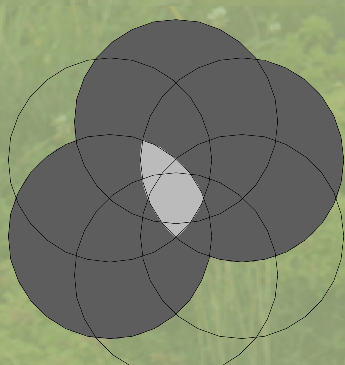
The green roof reduces temperatures at the roof surface.

The green roof surrounds the roof monitor.

Location
Toronto, Ontario
Architect
Stone Kohn McQuire Vogt Architects
Year Completed
1998
System Type
Extensive
Project Area
10,000 sf (900 m^2)

B. Energy

The green roof at MEC surrounds a central roof monitor that provides natural light to the retail floor below. Windows linked to a temperature sensor open automatically to vent hot air from the space using the stack effect. The green roof's main energy benefit is the reduction of air temperature at the roof surface, which translates to reduced temperatures at the roof membrane. Unfortunately, no instrumentation is presently installed to record these reduced temperatures.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

TORONTO MOUNTAIN EQUIPMENT COOPERATIVE

A+B+E

TORONTO MOUNTAIN EQUIPMENT COOPERATIVE

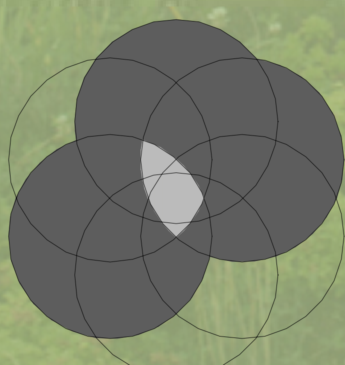
Façade and naturally illuminated interior of the store

A roof meadow in downtown Toronto's theater district

Location
Toronto, Ontario
Architect
Stone Kohn McQuire Vogt Architects
Year Completed
1998
System Type
Extensive
Project Area
10,000 sf (900 m^2)

E. Compliance

In accordance with MEC's philosophy, the design of the Toronto store endeavored to "Reduce, Reuse, Recycle and Rethink" the ways in which a building is built. The façade was constructed from logs recovered from the bottom of the Ottawa River, while the supports of the roof monitor were salvaged from the demolished Marconi Radio Building in Montreal. Where possible, interior finishes were eliminated or made of recycled materials. The green roof was envisioned as an urban meadow to host migratory birds, butterflies and other insects (MEC, 2004).



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

Mountain Equipment Co-op. (2004). Green facilities, Toronto store. *Social and environmental responsibility*. http://www.mec.ca/ (6 Sept. 2004).

A+B+E

GreenTech modular green roof atop the Tucker-Brand Middle School Art Building

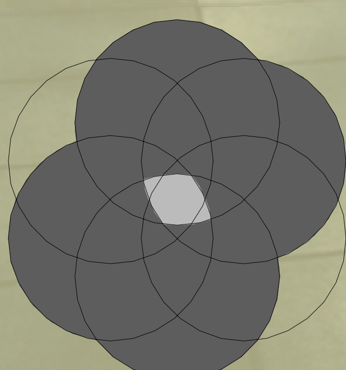
Rain garden

Bioretention swale at perimeter of Middle School Campus

Location
Atlanta, Georgia
Green Roof Designer
Ecos Environmental Design, Inc.
Year Completed
2004
System Type
Semi-intensive
Project Area
4,000 sf (400 m^2)

A. Storm Water

The GreenTech modular green roof installed atop the art building at the Woodward Academy's Jordan N. Carlos Middle School Campus contributes to storm water management on the site. Along with other non-structural strategies including rain gardens at building downspouts and bioretention swales at the perimeter of the project, the green roof slows the rate and reduces the volume of runoff to be held in a concrete tank located beneath the Middle School's parking lot. The tank slowly releases storm water to the city's storm sewer system.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

WOODWARD ACADEMY

A+B+D+E

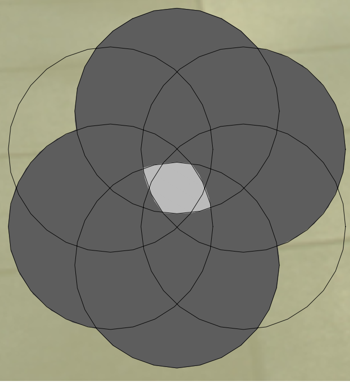
View of the Art Building from a science classroom

Clerestory windows bathe the art studio below with natural light. Tall plants will be visible through the windows as they grow to maturity.

Location
Atlanta, Georgia
Green Roof Designer
Ecos Environmental Design, Inc.
Year Completed
2004
System Type
Semi-intensive
Project Area
4,000 sf (400 m^2)

B. Energy

The Middle School Campus, designed by Perkins + Will, incorporates numerous energy-saving building strategies, from geothermal wells for heating and cooling to daylighting of classrooms and common areas, to a sophisticated energy management system. Woodward Academy expects the thermal benefits of the green roof on the Art Building to offset, at least in part, the higher cost of green power purchased in the form of renewable energy certificates. These certificates support the use of wind, landfill natural gas, and solar energy sources.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

WOODWARD ACADEMY

A+B+D+E

Modules are clearly visible on roof surface

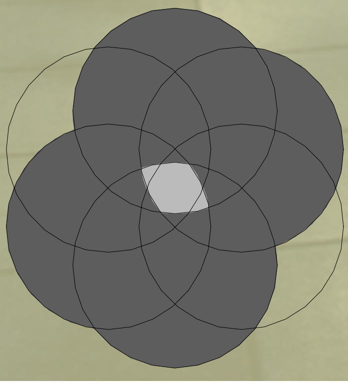
GreenTech module above gravel ballast

Underside of roof deck in Art Building

Location
Atlanta, Georgia
Green Roof Designer
Ecos Environmental Design, Inc.
Year Completed
2004
System Type
Semi-intensive
Project Area
4,000 sf (400 m^2)

D. Structure

Load constraints on the roof structure limited the green roof load to 35 pounds per square foot. The growing medium was saturated with water and subjected to a load test to determine the maximum allowable depth of 6½" (160 mm). Because the modules are 8" (200 mm) deep, the grid of modules is clearly visible on the surface of the roof. The modules were installed above 3" (75 mm) of gravel ballast to prevent roof membrane uplift, which is especially critical in the absence of a parapet wall at the roof perimeter. Without a parapet or railing at the roof edge, the roof is accessible only to maintenance personnel.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

WOODWARD ACADEMY

A+B+D+E

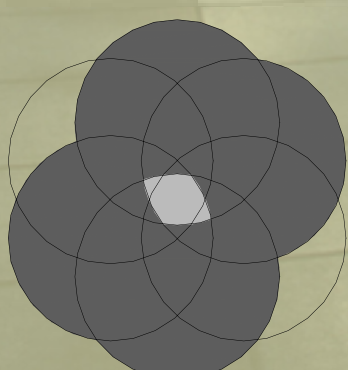
Side view of modules atop Art Building


Middle school students in an outdoor science class

Location
Atlanta, Georgia
Green Roof Designer
Ecos Environmental Design, Inc.
Year Completed
2004
System Type
Semi-intensive
Project Area
4,000 sf (400 m^2)

E. Compliance

The modular green roof system on the Art Building exemplifies the architectural approach used throughout the Middle School Campus to expose building systems to view where possible. With this approach, the students are made aware of the technology necessary to support their educational environment on a daily basis. Though originally planned for concealment behind a fascia, the crenellated profiles of the modules are exposed to view. They serve as visual evidence of the plants' drainage system and hint at the method by which the modules were installed on the roof.



A. Storm Water
B. Energy
C. Acoustics
D. Structure
E. Compliance
F. Cost

WOODWARD ACADEMY

A+B+D+E

APPENDIX B. IRB Documents

Initial Research Protocol: Approved by IRB May 12, 2005

Informed Consent for Participants: April 12, 2007

Revised Research Protocol: Approved by IRB May 12, 2006

INITIAL RESEARCH PROTOCOL (Approved by IRB May 12, 2005)

Investigator: Elizabeth J. Grant

Advisor: Dr. James R. Jones

Title: A Decision-Making Framework for Vegetated Roofing System Design

Justification of Project

The project comprises the creation of a framework describing the decision process involved in the design of vegetated (green) roofing systems. Through a series of expert interviews and case studies, the available knowledge will be captured and organized in order to determine the critical factors affecting design decisions. The study will begin with a mapping of the factors and interactions that determine the design of vegetated roofs, followed by a validation of this framework through correlation with available quantitative data and experts' methodologies.

The expected benefit of the framework lies in its collection and organization of a set of interacting factors affecting green roof design in order to provide a navigable path through the decision-making process. The best source of information regarding the process of designing vegetated roofs can be derived from green roof designers themselves. An important component of this research will be interviews conducted with individuals responsible for the design of green roofs in North America.

Procedures

A group of between five and twenty interviewees will be selected from a pool of designers, policy makers and researchers involved in the design of green roof projects. Interviewees will be asked to participate through phone, letter or e-mail contact. There will be no limit or restriction on the age or gender of the participants, except that no participants will be under 18 years of age.

Unstructured (open ended) interviews will be conducted by the investigator in person or over the telephone, either at Virginia Tech's College of Architecture and Urban Studies or in the office of the interviewee at a mutually agreeable time. These interviews will be recorded using a digital voice recorder. Interviews will last between one-half and one hour. Follow-up interviews may be requested of the interviewee. The interviewee has complete power to grant or deny this request. No more than three (3) one-hour sessions will be requested from any individual.

An outline of the open-ended interview questions is found on the last page of this research protocol. Interviewees will be asked to rank the importance of various factors in the design of green roofing, to describe the steps taken in the design process, and in some cases, to verify the credibility of various performance scales used to evaluate different green roof types.

Risks and Benefits

There is a minimal risk that in the process of relating their design experiences, some interviewees may be reminded of unpleasant or adversarial project conditions that may lead to difficult emotions or reactions. The type of risk possible in this study is generally assumed and expected by participants in the design fields, and is no greater, considering the probability and magnitude, than that encountered during the routine performance of their tasks. Further, interviewees will be made aware of this risk in the Informed Consent Document. The investigator agrees to refrain from asking any leading questions that seek to deliberately evoke a potentially damaging negative reaction, and will remind the participant of his or her complete freedom to stop the interview or withdraw from the study at any point. Each participant will have full access to the transcript of his or her interview as well as the opportunity to provide feedback to the investigator.

No promise or guarantees of benefits are offered from the research group to any of the participants. However, the framework generated in part from the outcome of these interviews is expected to be of benefit to the larger design community, and to be of particular and significant interest to the class of persons of which the interviewees are a part: green roof designers. Participants will likely gain a sense of satisfaction from the contribution they will be making to their chosen profession. These benefits will likely outweigh the minimal risk to the project participants.

Confidentiality/Anonymity

All information collected from all participants will be confidential. All interviews will be recorded with a digital voice recorder. Transcriptions of voice data will be performed by the investigator. Voice data and transcriptions of interviews will be stored in secure locations by the investigator. A coding system will be used to label the interviews. These materials will only be accessible to the investigator and her advisor.

Voice data and transcriptions will be destroyed when research involving these items is deemed complete by the research group. The investigator will be forced to break confidentiality if any abuse incidents are known or strongly suspected or if the participant is believed to be a threat to himself or herself or others.

In certain cases, due to the relatively small size of the green roof design community, it may be possible for the reader of the final dissertation to deduce the identity of the interviewee based on his or her responses to questions. This is an unavoidable outcome of research in the design field, where the identity of the designers of buildings is generally considered public knowledge. The Informed Consent Form will include a description of this possibility in order to assure that interviewees agree to accept the risk of this possibility. The investigator agrees to not divulge the identity of the interviewee without his or her express prior written consent.

Informed Consent

The informed consent form to be given to and signed by interviewees prior to interviews is attached. Subjects will be given ample time to review and return this form before the interview takes place.

OUTLINE OF INTERVIEW QUESTIONS (Approved by IRB 12 May 2005)

I. Purpose: To establish a methodology for determining weight factors in the selection of green roofing systems.
   A. Determine the order in which green roof designers have ranked the six identified categories of Storm Water, Energy, Acoustics, Structure, Cost and Compliance in their own green roof designs.
   B. Determine the reasons for the rankings listed in question A.
      1. How does geographic location impact these rankings?
         a. How do climate, code, and utility constraints impact these rankings?
      2. How does urban density (e.g. urban, suburban, or rural site) impact these rankings?
      3. How do project-specific factors affect these rankings?
      4. How do roof-specific factors affect these rankings?

II. Purpose: To discover the steps taken by designers when approached with a vegetated roofing project.
   A. Determine the process of design as described by the designer.
   B. Get critical feedback from designers regarding the influence diagram of the vegetated roofing design process proposed by the investigator.
      1. Is the diagram comprehensive? Should any elements be added?
      2. Is the diagram overly complicated? Should any elements be deleted?
      3. Is the diagram accurate? Should any elements be modified?

III. Purpose: Verify the credibility of attribute scales for green roof performance parameters.
   A. Propose attribute scales to the interviewee for review based on his or her area of expertise.
      1. Is the attribute scale an accurate reflection of the value that should be assigned to particular green roof characteristics?
      2. Should any levels or values be added, deleted or modified?

VIRGINIA POLYTECHNIC AND STATE UNIVERSITY

Informed Consent for Participants

in Research Projects Involving Human Subjects

Title of Project: A Decision-Making Framework for Vegetated Roofing System Design

Investigator: Elizabeth J. Grant

Advisor: Dr. James R. Jones

I. Purpose of this Research

The demand for vegetated roofs in North America is growing. Many practitioners are now being called upon to include green roofs in their project designs. A decision support system is needed to assist these designers in comparing the efficacy of various vegetated roofing systems in the context of specific projects.

The creation of a framework for vegetated roof system selection, which comprises the work of this research, constitutes the first step in the effort to collect, organize and present the available knowledge on green roofing in North America in a form that is readily usable by designers of green roofing systems. The framework will address many of the possible benefits as well as potential pitfalls of green roofing in the effort to provide a holistic view of the possibilities and limitations inherent to these systems.

A group of between five (5) and twenty (20) green roof designers will be interviewed to determine the importance of various factors in the design of green roofing, to describe the steps taken in the design process, and in some cases, to verify the credibility of various performance scales used to evaluate different green roof types.

II. Procedures

Unstructured (open ended) interviews will be conducted by the investigator in person or over the phone, either at Virginia Tech's College of Architecture and Urban Studies or in the office of the interviewee at a mutually agreeable time. These interviews will be prefaced by web-based survey tools accessed by interviewees at Survey.vt.edu, which will give interviewees the opportunity to review the questions and prepare responses. The interviews will be recorded using a digital voice recorder. Interviews will last between one-half and one hour. A follow-up interview or interviews may be requested of the interviewee. The interviewee has complete power to grant or deny this request. No more than three (3) one-hour interview sessions will be requested from any individual.

III. Risks

There is a minimal risk that in the process of relating their design experiences, some interviewees may be reminded of unpleasant or adversarial project conditions that may lead to difficult emotions or reactions. The investigator agrees to refrain from asking any leading questions that seek to deliberately evoke a potentially damaging negative reaction. The participant has complete freedom to stop the interview or withdraw from the study at any point. Each participant will have full access to the transcript of his or her interview as well as the opportunity to provide feedback to the investigator.

IV. Benefits

No promise or guarantees of benefits are offered from the research group to any of the participants. However, the framework generated in part from the outcome of these interviews is expected to be of benefit to the larger design community, and to be of particular and significant interest to green roof designers.

V. Extent of Anonymity and Confidentiality

All information collected from all participants will be confidential. All interviews will be recorded with a digital voice recorder. Transcriptions of voice data will be performed by the investigator. Voice data and transcriptions of interviews, and responses to web-based survey tools, will be stored in a secure location by the investigator. A coding system will be used to label web-based surveys and interviews. These materials will only be accessible to the investigator and her advisor.

Voice data, transcriptions and web-based survey responses will be destroyed when research involving these items is deemed complete by the research group. The investigator will be forced to break confidentiality if any abuse incidents are known or strongly suspected or if the participant is believed to be a threat to himself or herself or others.

In certain cases, due to the relatively small size of the green roof design community, it may be possible for the reader of the final dissertation or papers generated therefrom to deduce the identity of the interviewee based on his or her responses to questions. This is an unavoidable outcome of research in the design field, where the identity of the designers of buildings is generally considered to be public knowledge. By agreeing to participate in this study, the interviewee consents to accept the risk of this possibility. The investigator agrees to not deliberately divulge the identity of the interviewee without his or her express prior written consent.

VI. Compensation

The participants will receive no compensation for their participation in this study.

If members of the research group determine that the participant should seek counseling or medical treatment, a list of local services will be provided.

VII. Freedom to Withdraw

Participants will have full freedom to stop the interview or withdraw from the study at any point. Participants are free not to answer any interview questions that they choose.

There may be situations where the investigator may determine that a participant should not continue to be involved in the study.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IRB Approval Date: May 12, 2005

IRB Approval Expiration Date: May 11, 2008

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. To access web-based survey tools and participate in a one-half to one hour recorded interview, either in person or over the telephone.
2. To provide feedback to the research group as needed.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date ____________
Subject Signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Elizabeth J. Grant Investigator	(540)392-7718/elgrant2@vt.edu Telephone/e-mail
Dr. James R. Jones Faculty Advisor	(540)231-7647/wolverine@vt.edu Telephone/e-mail
Robert P. Schubert Departmental Reviewer/ Department Head	(540)231-5607/silver@vt.edu Telephone/e-mail
David M. Moore Chair, Virginia Tech Institutional Review Board for the Protection of Human Subjects Office of Research Compliance - CVM Phase II (0442) Research Division	(540)231-4991/moored@vt.edu Telephone/e-mail

RESEARCH PROTOCOL (Approved by IRB May 12, 2007)

Investigator: Elizabeth J. Grant

Advisor: Dr. James R. Jones

Title: A Decision-Making Framework for Vegetated Roofing System Design

Justification of Project

The project comprises the creation of a framework describing the decision process involved in the design of vegetated (green) roofing systems. Through a series of expert interviews and case studies, the available knowledge will be captured and organized in order to determine the critical factors affecting design decisions. The study will begin with a mapping of the factors and interactions that determine the design of vegetated roofs, followed by a validation of this framework through correlation with available quantitative data and experts' methodologies.

The expected benefit of the framework lies in its collection and organization of a set of interacting factors affecting green roof design in order to provide a navigable path through the decision-making process. The best source of information regarding the process of designing vegetated roofs can be derived from green roof designers themselves. An important component of this research will be interviews conducted with individuals responsible for the design of green roofs in North America.

Procedures

A group of between five and twenty interviewees will be selected from a pool of designers, policy makers and researchers involved in the design of green roof projects. Interviewees will be asked to participate through phone, letter or e-mail contact. There will be no limit or restriction on the age or gender of the participants, except that no participants will be under 18 years of age.

Unstructured (open ended) interviews will be conducted by the investigator in person or over the telephone, either at Virginia Tech's College of Architecture and Urban Studies or in the office of the interviewee at a mutually agreeable time. These interviews will be prefaced by web-based survey tools accessed by interviewees as Survey.vt.edu, which will give interviewees the opportunity to review the questions and prepare responses. The interviews will be recorded using a digital voice recorder. Interviews will last between one-half and one hour. Follow-up interviews may be requested of the interviewee. The interviewee has complete power to grant or deny this request. No more than three (3) one-hour sessions will be requested from any individual.

Two questionnaires, to be delivered via web survey and orally in interviews, are attached to this protocol. Interviewees will be asked to rank the importance of various factors in the design of green roofing, to describe the steps taken in the design process, and in some cases, to verify the credibility of various performance scales used to evaluate different green roof types.

Risks and Benefits

There is a minimal risk that in the process of relating their design experiences, some interviewees may be reminded of unpleasant or adversarial project conditions that may lead to difficult emotions or reactions. The type of risk possible in this study is generally assumed and expected by participants in the design fields, and is no greater, considering the probability and magnitude, than that encountered during the routine performance of their tasks. Further, interviewees will be made aware of this risk in the Informed Consent Document. The investigator agrees to refrain from asking any leading questions that seek to deliberately evoke a potentially damaging negative reaction, and will remind the participant of his or her complete freedom to stop the interview or withdraw from the study at any point. Each participant will have full access to the transcript of his or her interview as well as the opportunity to provide feedback to the investigator.

No promise or guarantees of benefits are offered from the research group to any of the participants. However, the framework generated in part from the outcome of these interviews is expected to be of benefit to the larger design community, and to be of particular and significant interest to the class of persons of which the interviewees are a part: green roof designers. Participants will likely gain a sense of satisfaction from the contribution they will be making to their chosen profession. These benefits will likely outweigh the minimal risk to the project participants.

Confidentiality/Anonymity

All information collected from all participants will be confidential. All interviews will be recorded with a digital voice recorder. Transcriptions of voice data will be performed by the investigator. Voice data and transcriptions of interviews, and responses to web-based survey tools, will be stored in secure locations by the investigator. A coding system will be used to label the interviews. These materials will only be accessible to the investigator and her advisor.

Voice data, transcriptions, and web-based survey responses will be destroyed when research involving these items is deemed complete by the research group. The investigator will be forced to break confidentiality if any abuse incidents are known or strongly suspected or if the participant is believed to be a threat to himself or herself or others.

In certain cases, due to the relatively small size of the green roof design community, it may be possible for the reader of the final dissertation to deduce the identity of the interviewee based on his or her responses to questions. This is an unavoidable outcome of research in the design field, where the identity of the designers of buildings is generally considered public knowledge. The Informed Consent Form will include a description of this possibility in order to assure that interviewees agree to accept the risk of this possibility. The investigator agrees to not divulge the identity of the interviewee without his or her express prior written consent.

Informed Consent

The informed consent form to be given to and signed by interviewees prior to web surveys and interviews is attached. Subjects will be given ample time to review and return this form before the web surveys and interviews take place.

APPENDIX C1. Test Interview Questions

Introductory Questions

1. What is the nature of your experience with green roofing design?
   Cues:
   How many green roof projects have you been involved with?
   What were your responsibilities on the green roof projects you have worked on?

Design Process Questions (II.A.)

1. How do you make the initial decision to use a green roof on a project?

2. How do you decide what type of green roof(s) systems to use?

3. Please describe the process you go through in designing a green roof.
   Cues:
   What is the first step in the process of designing a green roof?
   After you have determined this, what do you do next?

4. Architects frequently use rules-of-thumb or guidelines in the design of buildings. One example in roofing is using charts to determine gutter and downspout sizing. Do you use any such rules-of-thumb or guidelines when designing green roofs?

   A. Can you think of any tools you would like to have to assist you in designing green roofs?

5. What, if any, obstacles do you face in the design of green roof(s)?

Design Factors Questions (I.A.)

1. I will now list six factors that can impact the design of green roofs. How important is each factor to the design of green roofs in general?
   4 - very important, 3 - somewhat important, 2 - not very important, 1 - not important:
   Ability to mitigate **Storm Water**
   Ability to minimize **Energy** use
   Ability to provide **Acoustical** benefits
   Impact on the **Structure** of a building
   Cost of the system (both initial and life cycle)
   Ability of the system to **Comply** with regulatory guidelines and governmental incentives (such as LEED)

2. Besides those that I have mentioned, what other factors impact your green roof design decisions?

Next, please consider a recent green roof project with which you have been involved, particularly one on which you spent a considerable amount of design effort. Please answer these next questions with this project in mind:

Design Factors Rationale Questions (I.B.3.)

1. At what stage was the green roof option introduced in this project?

A. In your opinion, was this timing too early, appropriate, or too late in the project?

2. For this project, how did you decide what type of green roof(s) system to use?

3 I will now ask you to rank the importance of the following factors from 4 to 1 for this green roof project in particular:
4 - very important, 3 - somewhat important, 2 - not very important, 1 - not important:
Ability to mitigate **Storm Water**
Ability to minimize **Energy** use
Ability to provide **Acoustical** benefits
Impact on the **Structure** of a building
Cost of the system (both initial and life cycle)
Ability of the system to **Comply** with regulatory guidelines and governmental incentives (such as LEED)

Design Factors Rationale Questions (I.B.1.)

1. Climate affects the way we design buildings in general. How did climate affect the design of the green roof specifically on this project?

2. How did code requirements affect the design of the green roof?

3. How did utility constraints affect the design of the green roof?

Design Factors Rationale Questions (I.B.2.)

1. How did the density (in terms of urban, suburban or rural) of the project site impact the design of the green roof?

Design Factors Rationale Questions (I.B.4.)

1. What plant types are planned for the green roof(s)?

   A. How was this decision made?

2. What type of growing medium is planned for the green roof(s)?

   A. How was this decision made?

3. What other green roof system components are used (other than growing medium and plants)?

   A. How was this decision made?

4. What is the waterproofing assembly?

   A. How was this decision made?

Wrap-up

1. Based on your design experience, do you have any recommendations for architects designing green roofs?

APPENDIX C2. Introductory, Process and Rationale Questionnaire

A DECISION-MAKING FRAMEWORK FOR GREEN ROOF SYSTEM SELECTION: INTRODUCTORY, PROCESS AND RATIONALE QUESTIONNAIRE

Please answer all questions to the best of your knowledge, indicating "don't know" or "N/A" where applicable.

Please enter your name. This information will only be accessible to the researcher and will remain confidential.

What is the nature of your experience with green roofing design?

How many green roof projects have you been involved with?

What were your responsibilities on the green roof projects you have worked on?

The next set of questions involves the process and rationale used to design green roofs. For these questions, please consider a green roof project with which you have been involved, particularly one on which you spent a considerable amount of design effort. Please answer all questions with the same green roof project in mind.

Project name:

Project city (give closest):

Project state or province:

How did you make the initial decision to use a green roof (as opposed to a non-vegetated roof) on this project?

Briefly describe the green roof system type or types used in the project (i.e. extensive, semi-intensive, or intensive, with approximate depth(s)).

Please describe the process you went through in selecting this green roof system. Was there anything specific to this project that affected your choice?

Did the system used possess certain advantages over other systems? If so, please list.

If you answered yes to the previous question, which of these advantages was the most important?

Architects frequently use rules-of-thumb or guidelines in the design of buildings. One example in roofing is using charts to determine gutter and downspout sizing. Did you use any such rules-of-thumb or guidelines when selecting this green roof system?

What tools would you like to have in the future to assist you in selecting green roof systems?

What, if any, obstacles or limitations did you face in the selection of this green roof system?

Climate affects the way we design buildings in general. How did climate affect the selection of the green roof system for this project?

How did the cost of local utilities affect the selection of the green roof system?

How did acoustical considerations affect the selection of the green roof system?

How did structural considerations affect the selection of the green roof system?

How did code requirements affect the selection of the green roof system?

How did the density (in terms of urban, suburban or rural) of the project site impact the selection of the green roof system?

How did financial considerations impact the selection of the green roof system?

Based on your design experience, do you have any recommendations for architects selecting green roof systems?

If you would like to add additional information, comments or clarification on any of the above questions, please do so here.

APPENDIX C3. Framework Input Questionnaire

A DECISION-MAKING FRAMEWORK FOR VEGETATED ROOF SYSTEM SELECTION: FRAMEWORK INPUT QUESTIONNAIRE

Please consider a green roof project with which you have been involved, particularly one on which you spent a considerable amount of design effort.

For questions mentioning a reference roof (to which a green roof's potential performance will be compared), please answer with information about the roof type that would most likely have been used if a green roof were not implemented on the project.

Please answer all questions to the best of your knowledge, indicating "don't know" or "N/A" where applicable. If you are estimating, please type "approx." next to your response. Please answer all questions with the same green roof and reference roof in mind.

These data will be input into the framework, and you will be contacted when the next phase (the weighting of the importance of advantages) is ready for your input. Thank you very much for your time and support.

Please enter your name. This information will only be accessible to the researcher and will remain confidential.

General project information:
Project name:

Project city (give closest):

Project state or province:

What is the slope of the GREEN roof?

Energy questions:
What is the R value of the REFERENCE roof in h•ft²•°F/Btu? If not known, please estimate using these R values: (HIGH=20; AVG=10; LOW=5).

What is the solar reflectance of the REFERENCE roof as a percentage? If not known, please estimate using these percentages: (HIGH=80; AVG=50; LOW=10), or answer with a generic description of the roof, e.g. white single-ply membrane, black single-ply

membrane, metal roof, BUR, etc.

What is the infrared emittance of the REFERENCE roof as a percentage? If not known, please estimate using these percentages: (HIGH=80; AVG=50; LOW=10), or answer with a generic description of the roof, e.g. white single-ply membrane, black single-ply membrane, metal roof, BUR, etc.

What is the R-value of the GREEN roof in h•ft²•°F/Btu? (Give the general R value based on insulation used in roof assembly, if any). If not known, please estimate using these R values: (HIGH=20; AVG=10; LOW=5).

What is the summertime cost of electricity for the building (or portion thereof) beneath the green roof in $/KWh? If not known, please estimate using these values (HIGH=0.20; AVG=0.10; LOW=0.05).

What is the air conditioner efficiency (Coefficient of Performance) of the building (or portion thereof) beneath the green roof? If not known, please estimate using these values (HIGH=2.5; AVG=2.0; LOW=1.5).

What is the energy source for heating the building (or portion thereof) beneath the green roof: electricity or fuel (choose one)?

If electricity, wintertime cost in $/KWh? If not known, please estimate using these values (HIGH=0.20; AVG=0.10; LOW=0.05).

If fuel, cost in $/Therm? If not known, please estimate using these values: (Natural gas: HIGH=1.00; AVG=0.70; LOW=0.50), (Fuel oil: 2002 East coast=0.85; 2002 Midwest=0.70).

What is the heating system efficiency? If not known, please estimate using these values: (Furnace or boiler: HIGH=0.8; AVG=0.7; LOW=0.5), (Electric heat pump: HIGH=2.0; AVG=1.5), (Electric resistance: 1.0).

Roof assembly questions:

Generally describe the roof deck construction of the REFERENCE roof including any insulation or cover board (e.g., metal deck, lightweight concrete, reinforced concrete, gypsum, etc.), giving approximate thicknesses where possible.

Generally describe the roof deck construction of the GREEN roof including any insulation or cover board (e.g., metal deck, lightweight concrete, reinforced concrete, gypsum, etc.), giving approximate thicknesses where possible.

Structural questions:

What was the available structural capacity for the green roof in pounds per square foot (i.e. how much weight allowance was given for the green roof)?

What is the approximate saturated weight of the green roof system used in pounds per square foot?

What is the approximate weight of the reference roof? If not known, please generically describe the reference roof system (e.g. fully adhered, mechanically fastened, gravel ballast, paver ballast, metal, slate, clay tile, etc.)

LEED questions:

Did the project as a whole receive (or has it been submitted in an attempt to receive) LEED certification?

Yes

No

Don't know

If the project received or has been submitted for LEED certification, does the project as a whole meet the requirements of Sustainable Sites Credit 2: Development Density and Community Connectivity? (This question uses the terminology of LEED-NC Version 2.2.)

Yes

No

Don't Know

If you would like to add additional information, comments or clarification on any of the above questions, please do so here.

APPENDIX D. CBA Tabular Format

Project No.

FACTORS	ALTERNATIVES																	
	R (REF. ROOF)		1		2		3		4		5		6		7		8	
A1 SW FLOW REDUCTION																		
Attributes:																		
Advantages:																		
B1 POT. ENERGY SAVINGS																		
Attributes:																		
Advantages:																		
C1 APPROXIMATE STC																		
Attributes:																		
Advantages:																		
D1 SURPLUS DL OF ROOF SYS.																		
Attributes:																		
Advantages:																		
E1 POT. CONTR. TO LEED CERT.																		
Attributes:																		
Advantages:																		
TOTAL IMPORTANCE:																		
TOTAL COST:																		

VITA

Elizabeth Joyce Grant was born in 1973 in Baltimore, Maryland. She received her undergraduate Bachelor of Architecture degree at Virginia Tech in 1995. After graduation she began work as an architectural intern in Gainesville, Florida, and became licensed as an architect in 1998. In 2000 she relocated to Blacksburg, Virginia and practiced architecture while earning a Master of Science in Architecture at Virginia Tech, awarded in 2003. Subsequently she entered the doctoral program and graduated in December 2007.

She currently resides in Blacksburg with her husband and daughter and works as an adjunct instructor at the College of Architecture and Urban Studies at Virginia Tech. She is involved in architectural, consulting, and research activities and plans an academic career.