GREEN ROOFING IN INDIANA: CASE STUDIES AND DESIGN NOTES

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INTRODUCTION

Green roof technology and implementation are taking root in North America at an accelerating pace. Growing recognition of the benefits of green roofs and increasing interest in green infrastructure are leading to expansion of green roof technologies that have been in use for decades in Europe and elsewhere. While some regions have adopted the use of green roofs on a large scale, other areas are warming up to the concept more slowly. Large-scale implementation of green roofs has not yet occurred in Indiana, but a number of exemplary projects have been constructed, and there are signs that interest in the technology is increasing in the state. The purpose of this article is to provide an overview of green roof technology, analyze selected green roofs in Indiana, explore trends in the state, and address issues for future development of green roof technology in the region. A variety of green roofs were investigated throughout the state. Discussions were held with individuals involved in each project to obtain technical and logistical details of green roof design, installation, and performance.

KEYWORDS

green roof technology, green roof design and installation, green roof maintenance and performance, stormwater management, modular versus loose laid systems, energy efficiency

BACKGROUND

Green Roof Technology and Design

Vegetated roofs have been employed for aesthetic and practical purposes since early civilization. Evidence of tree-covered temples in ancient Mesopotamia and the hanging gardens in Babylon indicate that green roofs were included in important architectural structures for millennia B.C.E. Rooftop gardens were enjoyed by the well-to-do in Europe and in present-day Mexico throughout the Middle Ages. Grass and sod roofs have been used for decades to insulate homes in cold European climates, and as a substitute for wood as a building material in North American prairie areas (Osmundson 1999). Germany has been at the forefront of modern green roof technology, and has produced internationally recognized standards for design, materials, construction, and maintenance (FLL 2002). Green roofs have been implemented on a large scale in Europe and Asia, in part due to government policies encouraging or requiring use of the technology (Lawlor et al. 2006). The construction of green roofs in North America has accelerated since the 1970s, and interest in this technology is increasing in the U.S. and Canada as its benefits become better known. These benefits have been well-documented and include: improved insulation of the building, which can reduce heating and cooling costs; noise insulation; reduction of the urban heat island effect; stormwater attenuation and filtration; habitat for pollinators, birds, and other small wildlife that is relatively protected from predators; aesthetic value and enhanced marketability of property; extended lifetime of the roof and improved air quality (Oberndorfer et al. 2007). Installation of a green roof can increase developable space, increase a building's marketability (Velazquez 2005), and decrease costs and infrastructure for stormwater management (Scholz-Barth 2001; Deutsch et al. 2007).

Green roofs can be installed on flat or pitched roofs. On flat roofs, a base layer of tapered, rigid insulation can be used to provide the minimal slope needed for drainage. Roofs with slopes in the range of 20° or greater require horizontal supports to prevent growing media and vegetation from sliding (Peck and Kuhn 2009). A variety of approaches to design and installation of green roofs are taken, from the use of self-contained modular systems, to customized layered systems ("loose-laid" or "built-

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in-place”). A common convention is used to describe green roofs as “extensive” or “intensive,” according to their depth. Extensive green roofs are shallow (<6 inches) and lightweight, and are often used to cover large areas. Intensive green roofs are deeper and can be planted with any type of vegetation, from turf to trees, depending on the composition and depth of the media. The terms “semi-intensive” or “semi-extensive” are sometimes used to describe roofs of intermediate depth or those that feature both shallow and deeper areas.

Regardless of their depth or surface area, all green roofs are comprised of a series of vertical layers, each of which serves a specific purpose. The foundation for any green roof is a structurally sound roof deck with an intact waterproofing membrane and root barrier. The green roof portion can consist of a simple porous growing medium with vegetation, or may be a complex, multi-layered system including insulation, water storage and drainage, filter fabric, growing media and vegetation (Dunnett and Kingsbury 2008). Irrigation systems are often included within intensive green roofs, and less frequently in extensive systems. Because of the unique environment of the rooftop, the structure of elevated green roofs differs from that of ground level or earth-based landscapes. Extensive green roofs are exposed to the erosive and drying forces of wind, but also need to be lightweight. Green roofs can be designed to store a specific volume of water and must be free-draining after their storage capacity is reached. The growing medium—the heaviest component of the green roof—must be relatively lightweight and porous, and free from silt or clay-sized particles that could clog the drainage system. In most modern green roofs, the growing medium consists mainly of inorganic materials that do not degrade over time, which would cause the roof to lose volume. A diverse range of inorganic materials can be used in the growing medium, such as recycled clay tile or brick, coarse sand, expanded slate or shale. If organic matter is included it generally consists of a small percentage of composted material (Snodgrass and Snodgrass 2006).

The selection of plant species for a green roof depends on the depth and composition of the growing medium; objectives for the roof (e.g., recreational amenity, ecological diversity, stormwater management); environment and climate, including microclimate; budget; and plant growth habit and propagation characteristics (Snodgrass and Snodgrass 2006). Plants may be established by seed, cuttings, or plugs, or pre-grown mats of vegetation can be rolled out over the roof or installed in trays. The plant species selected for shallow green roofs should generally be drought-resistant, fibrous-rooted, and tolerant of temperature extremes. Species selection for intensive green roofs depends on the desired use and objectives for the roof and the level of ongoing maintenance that can be provided. Roof height, exposure, aspect, and pitch influence the choice of plant species. If a green roof is established by seed, cuttings, or plugs, a protective covering is installed to prevent the exposed growing medium from eroding during the grow-in period. A green roof planted with cuttings or plugs typically takes about two years to attain full plant coverage, during which time the roof will occasionally be fertilized, weeded, and watered. Pre-grown trays or mats can be more costly than planted green roofs, but also provide the instant gratification of complete plant coverage and require less initial maintenance. Loose-laid green roofs can offer more flexibility in design, especially on irregularly shaped roofs and roofs with varied microclimates.

Succulents, including the *Sedum* and *Sempervivum* families, are often used in green roofs due to their drought-tolerance, semi-evergreen low-stature growth habit and proven success in Europe. *Sedum* species are generally easy to propagate and require minimal maintenance. Many of these species are not native to North America but only a small proportion is considered invasive. Many other species are suitable for planting on green roofs, depending on the goals for the green roof and the amount of maintenance available (Getter & Rowe 2008; Dunnett & Kingsbury 2008). Native plants are increasingly being used and experimented with on green roofs, to increase their ecological value and diversity (Park 2010; Martin 2007; Monterusso et al. 2005).

Adoption of Green Roof Technology in Indiana

A combination of positive experience, policy and incentives has led North American cities including Chicago, Washington, DC, Toronto, Vancouver, Philadelphia, Baltimore, Portland, and New York, to implement green roofs on a large scale (GRHC

2010; GRHC 2009; GRHC 2008; Taylor 2007), and thus to be in the forefront of industry development. A 2004 survey comparing attitudes and opinions of architects and building owners in Indianapolis and Chicago indicates that the slower adoption of green roof technology in Indiana is due to a lack of knowledge and available examples (Hendricks & Calkins 2006). Major concerns expressed by survey participants included fear of potential roof failure and leaks and high short-term costs. Lack of exposure to green roofs or information on their advantages can result in misconceptions or reluctance to consider the technology. The Indiana Business Journal (6 November 2006) proposes that a lack of economic incentives such as tax credits or permit facilitation has been a barrier to green roof installation in Indiana. Effective August 2010, rebates of up to 50% of permit fees are available for green building projects in Indianapolis, pursuant to an initiative by the Indianapolis Office of Sustainability in cooperation with the Department of Code Enforcement. While this initiative is a positive step, permitting is a relatively minor expense compared to the cost of many green roof projects, although for large projects the rebate might provide a more substantial incentive. The Office of Sustainability and United Water are providing competitive matching grants up to $20,000 annually for green infrastructure projects in Indianapolis, through 2012. A number of green roof projects in Indiana have found support by public or private grants, and volunteer labor.

Public and private interest in green roof technology is increasing in Indiana in conjunction with national attention to low impact development, and a focus on remediation of combined sewer overflow problems. A Green Roofs for Healthy Cities (GRHC) "Green Roof Market Symposium" was held in Indianapolis in 2007, and preliminary standards for implementation of green roofs have been provided by the Indianapolis Department of Public Works (Indianapolis DPW 2009). A variety of green roofs have been built across the state, including small residential roofs and large systems on public and commercial buildings, extensive and intensive green roofs, and using both modular and loose-laid designs. Indiana's initial green roof projects have raised regional awareness about the technology, and are helping to shape local markets for green roof products. The goal of this assessment of green roofs in Indiana is to provide practical information to facilitate the use of green roofs in and beyond the region.

APPROACH

Eleven green roofs installed by the end of 2009 in Indiana were investigated, and discussions were held with landscape architects, landscape companies, horticulturalists, project designers and managers, and roofing companies involved in the design or installation of the roofs. Information on the following topics was sought for each project:

- Design objectives for the green roof
- Structural loading capacity of the roof
- Roof slope and drainage system
- Structure of the roof assembly
- Plant species chosen, and planting methods used (seeds, cuttings, plugs)
- Roof slope and drainage system
- Membrane protection and leak detection procedures used
- Details of the installation process
- Costs
- Required maintenance
- Observations made of green roof performance

Eight of the green roofs that were investigated are presented here, representing a variety of designs and objectives. "Retrofit" refers to green roofs that were installed when an existing building's roof was replaced. "New" refers to green roofs installed on new building projects.

INDIANA GREEN ROOF PROFILES

Minnetrista Museum, Muncie: Retrofit, Extensive, Modular

Background and Design Objectives

The Minnetrista Cultural Center opened in late 1988. The original, 20-year-old roofs above the west and east arbor arms at the museum's entrance contained wooden sub-roofs under a concrete deck, bonded waterproofing membrane, and gravel ballast. When the arbor roofs began to leak and required repair or replacement, Minnetrista staff drafted a grant proposal for a 376 ft^2 green roof. The design objectives for the green roof over the west arm of the museum entrance were to 1) establish a demonstration system that would inform homeowners and businesses about the benefits of green roofs, 2) provide an example of one approach to green roof design, 3) collect data on temperature and runoff characteristics of the green roof and a ballasted control roof, and 4) provide information for the museum on options for re-roofing the main building. The east arbor arm would be repaired as a ballasted control, and instruments for automated data collection would be installed on both roofs.

Design and Installation

A structural assessment of the roof determined that the loading capacity was 30 pounds/ft^2. Modular and loose-laid green roof systems were considered. The project timeline was tight, and Minnetrista's horticulturalist, Cassie Banning, chose a LiveRoof® modular system to simplify the design and installation process. Plant species chosen for the roof included: *Sedum acre* "Aureum." *Sedum floriferum* "Weihenstephaner Gold," *Sedum reflxeum* "Green Spruce," *Sedum sexangulare, Sedum spurium* "Dragon's Blood," *Sedum spurium* "Voo Doo," *Sedum stefco, Sempervivum* "Silverine," and *Sempervivum* "Purple Beauty." The Minnetrista roof is minimally sloped; runoff is discharged to a single drain that connects to the museum's main drainage system, which outlets to the Muncie stormwater system.

The arbor arm roofs were replaced in 2008. Ballast removed from the west roof was reserved to create a walkway around the perimeter of the green roof plantings. Wool fleece was placed onto the concrete deck to protect the new waterproofing membrane, and two additional layers of 60-mil, non-adhered EPDM waterproofing membrane were placed over the fleece, in May 2008. The membrane was continued part way up the west limestone sidewall. Modules, buckets of gravel ballast, extra planting mix, and weed fabric were staged on the ground below the roof, and pallets were raised with a front-loader to deliver the 3′ × 1′ modules to the roof. The rectangular modules did not precisely fit the curved roof, so additional planting mix and *Sedum* were placed on top of weed fabric between gaps in modules. No leak test was performed on the membrane, but no leaking was observed in the months before the green roof was installed. Insulation was not included because the roof covers an outdoor walkway.

Maintenance and Performance

Weeding and watering are performed on the Minnetrista green roof as necessary. Temperature data have been recorded since June 2009 for the green roof and the ballasted control. In general, the two roofs have shown similar patterns of temperature change on a daily and monthly basis, with a greater amplitude of change on the control roof (Table 1).

The average monthly temperature values were comparable between the two roofs because nighttime temperatures were generally much lower, and daytime temperatures much higher over the ballasted roof. If it

FIGURE 1. Installing waterproofing membrane and flashing on west arbor arm for Minnetrista green roof, September 2008. Photo credit: Minnetrista.

FIGURE 2. Installing ballast and green roof modules on west arbor arm, Minnetrista, September 2008. Photo credit: Minnetrista.

TABLE 1. Average monthly temperature values for Minnetrista green and ballasted roofs (°F).

	June 2009	Aug. 2009	Sept. 2009	Oct. 2009	Nov. 2009	Dec. 2009	Feb. 2010	Mar. 2010	Apr. 2010	May 2010	June 2010
Green roof max	92.3	87.2	82.8	62.4	58.3	37.9	28.3	55.4	69.7	89.0	86.5
Ballast roof max	116.2	108.5	101.4	78.9	75.9	49.3	39.9	75.3	98.2	116.2	114.0
Green roof min	68.6	60.6	51.9	35.7	30.2	25.2	23.0	26.8	43.5	47.4	66.5
Ballast roof min	66.4	54.1	51.0	31.3	27.2	11.4	19.3	24.0	35.5	39.0	57.7
Green roof avg	78.5	75.4	70.6	50.0	45.0	28.4	26.4	41.0	58.5	66.2	77.5
Ballast roof avg	84.5	78.8	73.3	52.4	47.8	29.9	28.2	46.9	64.5	71.1	80.2

were over an occupied structure, the green roof would be expected to reduce the energy demanded by air conditioning equipment in warmer months, and to provide a minor insulation benefit in the winter.

Moonblock Building, Indianapolis: Modular and Loose-laid

Background and Design Objectives

The Englewood Community Development Corporation (CDC), a non-profit organization focused on urban renewal in Indianapolis, initiated the installation of Indianapolis's first green roof above ground level. The site chosen for the "green renovation" was an abandoned commercial structure called the Moonblock Building located north of downtown Indianapolis at 2807 East 10th Street. Four objectives for the community's green roof were outlined by Joe Bowling of the Englewood CDC:

1. Serve as a pilot project and catalyst for implementation of green roofs in Indianapolis.
2. Enhance the Eastside community aesthetically and socially.
3. Demonstrate energy efficiency and water conservation, while reducing stormwater runoff from the site.
4. Integrate into the overall goal of community development and neighborhood rejuvenation.

The Moonblock green roof evolved as a collaboration between the Englewood CDC and three Indianapolis businesses. Firestone Building Products was interested in testing green roof materials for compatibility with their roofing products; Landscape Architect Craig Flandermeyer of Schmidt Associates had been experimenting with growing media and plant growth in green roof test plots on the firm's roof; and AAA Roofing Company was interested in exploring this potential new market.

Design and Installation Structural analysis of the abandoned building found the load-bearing capacity to be inadequate to support a green roof. A second truss system was designed to increase the capacity to 80 pounds per ft^2, to accommodate the green roof and a planned patio. The roof assembly consisted of a wooden deck covered with four-inch Polyiso insulation and a Firestone fully-adhered 60-mil thermoplastic olefin (TPO) membrane. An ethylene propylene diene monomer (EPDM) slipsheet was placed over the TPO membrane to provide additional separation of the green roof from the waterproofing membrane. Firestone chose two distinct green roof systems for the project: 1) a 550-ft^2 LiveRoof® modular system, fully grown in with LiveRoof's "Spring Mix" plant community, and 2) a 1200-ft^2 loose-laid Advanced

FIGURE 3. Replacement of roof deck, Moonblock Building, May 2007. Photo credit: John H. Boner Community Center.

Vegetative Roof System (AVRS) from Columbia Green Roof Technologies, planted with *Sedum* plugs. The materials for the AVRS area were placed into 100-mil 2′ × 2′ × 4-5/8″ recycled polypropylene trays laid out on the roof, which were the same size as the LiveRoof® modules.

A crew of volunteers including professional trades and members of the Englewood CDC removed the old roofing materials down to the deck, and installed the second interior truss system. The new roof assembly was then installed on top of the original deck. The AVRS green roof was installed in June 2007. Trays were arranged on the roof and a drip-irrigation system was installed through all the trays. Growing media was brought up by cranes in "Supersacks," and the trays were filled by hand-raking the media across the roof. *Sedum* plugs were planted by hand 6″ on center. The LiveRoof® modules were installed in September 2007, with pavers separating green roof areas.

Maintenance and Performance

Very few maintenance activities were carried out on the Moonblock green roof over the first few years. The LiveRoof® modules have maintained approximately 75% plant cover. Vegetation has been slow to develop in the AVRS area, with substantial bare patches remaining three years after installation. However, the maintenance procedures recommended for successful development of the AVRS green roof, including fertilization and watering, were not performed. The drip irrigation system implanted in the AVRS system did not function properly from the beginning, and constraints of time and labor prevented a regular maintenance schedule from being kept up. In August 2010, AAA Roofing donated additional planting media, 1′ × 2′ sedum mats and plugs that were surplus from a recent company project. The AVRS area was weeded and watered, extra media was placed in areas where it had eroded, and the new plugs and mats were planted. A plan for regular maintenance is currently being developed. The Moonblock Building has been showcased frequently to introduce community groups and prospective clients to the concept of green roofing.

FIGURE 4. Moonblock AVRS (top) and LiveRoof (bottom) green roof areas, April 2008. Photo credit: John H. Boner Community Center.

Indianapolis Museum of Art: New, Intensive, Loose-laid

Background and Design Objectives

The Indianapolis Museum of Art (IMA) features one of the largest green roofs in the state, occupying 57,300 ft^2 (approximately 1.3 acres) on top of a belowground parking garage. Master planning for expansion of the IMA took place from 1997–2000, led by Browning Day Mullins Dierdorf Architects of Indianapolis. Gardens and other green space are an integral part of the 152-acre IMA site. Accommodating additional parking spaces without sacrificing garden areas presented one of the biggest challenges for the expansion, according to landscape architect Barth Hendrickson. IMA horticulture manager Chad Franer also expressed the museum's desire to avoid the heat-island effect that would be created by a large parking lot. A 250-space underground parking garage with the museum's main entrance lawn on top was designed as a solution.

Design and Installation

Construction of the IMA green roof was completed in 2005. Performance characteristics demanded of the roof included 1) good aeration for plant roots; 2) resistance to compaction from foot traffic and poured concrete walkways; and 3) unrestricted drainage while maintaining adequate moisture content. The ground-level green roof varies in depth from 14 to 42 inches, with the majority at 42 inches deep. The parking garage roof is a concrete structural slab that slopes at a 2% grade to the west. A 60-mil Carlisle 860 self-adhering rubberized asphalt membrane was heat-welded onto the slab. Two inches of polystyrene insulation were placed on top of the membrane, followed by a Carlisle 6200 polystyrene drainage mat bonded with non-woven filter fabric. The waterproofing, insulation, and drainage mat were installed by Jarnagin Enterprises Inc. of Indianapolis. A six-inch drainage layer of washed pea gravel was placed on top of the filter fabric, followed by an additional layer of filter fabric. The planting medium consists of 55% Haydite (rotary kiln expanded shale), 30% sand, and a maximum of 15% pine bark, pre-mixed with a pH of 7.0–7.2.

FIGURE 5. Installation of IMA green roof growing medium, March 2004. Photo credit: Indianapolis Museum of Art.

FIGURE 6. Red maples to be installed on IMA green roof. Photo credit: Indianapolis Museum of Art.

This soil mixture was derived using information on structural soils for street tree plantings developed by Nina Bassuk at Cornell University, and was tested to ASTM standards for prevention of clogging. The green roof vegetation consists of turf lawn bordered with 56 red maple trees (6-in diameter at planting), shrubs, and herbaceous flowerbeds. Sidewalks, benches, and a large sculpture are included on the roof. The sidewalks are supported by a base of crushed limestone, which was installed before the other components of the green roof. The roof drains to a separator that filters suspended solids and discharges to an existing wetland below the west side of the museum. The green roof's irrigation system is tied into an existing well-house pump system.

Maintenance and Performance

The root systems of the red maples have demonstrated robust, shallow growth in the porous growing media. Fertilizer was initially added to the irrigation water but was found to quickly percolate below the root zone in the deep media, so nutrient addition was discontinued. Excessive alkalinity has been an issue, with pH reaching 8.0 across the top six inches of the roof. The alkalinity is generated from the limestone supporting the sidewalks and from the irrigation water, which comes from a limestone aquifer. Red maples prefer acidic soils, and some of the trees on the IMA green roof have demonstrated chlorosis (leaf yellowing) that is typical for this species when pH is too high. Some of the perennials on the green roof have also shown stunted growth.

The alkalinity has been addressed by adding an acid-injection system into the green roof irrigation system. A timed dosing system injects hydrochloric acid into the irrigation water before it is pumped to the roof. The acid injection has helped to stabilize the pH, but it must be continued indefinitely unless more alkaline-tolerant species are substituted for the red maples. The IMA is considering alternative perennial species for some of the flower beds. Because the green roof soil drains more quickly than other landscaped areas, it requires irrigation earlier in the spring and later into the fall. After observing plant growth on the green roof, IMA horticulturalists consider pine bark to be an inadequate organic component for growing media because it does not retain water and it appears to provide a poor substrate for root growth. Perennial beds containing plant species that are less tolerant of the green roof growing medium have been amended with composted horse manure. IMA staff have observed a significant insulating effect on the garage below the green roof and report that very little stormwater runoff is discharged from the roof.

Oaklyn Branch Library, Evansville: New, Intensive, Loose-laid

Background and Design Objectives

At 17,250 ft^2, the Oaklyn Branch Library building green roof was the first green roof to be installed in Indiana, in September 2002, and won a Green Roofs for Healthy Cities North American Green Roofs of Excellence Award in 2004. The objectives of the Oaklyn Library green roof were to 1) create a "mesic meadow" prairie that blended into the landscape on the new building's earth-sheltered, upslope side; 2) contribute to restoration of regional prairie landscapes; 3) provide irrigation in a way that minimized evaporation; 4) conserve energy; and 5) require little maintenance.

FIGURE 7. Oaklyn Library green roof around LightBridge Clerestory, and adjacent native meadow, June 2010. Photo credit: Pam Locker, Oaklyn Branch Library.

Design and Installation

The Oaklyn Library green roof is a 14-inch deep intensive system. The design represented a collaborative effort between the Evansville Vanderburgh Public Library, architecture firm Veazey Parrott Durkin & Shoulders, landscape architect Storrow Kinsella Assoc., and Roofscapes, Inc. Architect William Brown is credited with developing the overall concept for the site, and Charlie Miller with conceiving the green roof design. The roof deck consists of a lightweight composite of steel and concrete. The roof's waterproofing membrane is hot air welded fiber-reinforced 80-mil PVC (Sarnafil G-476), on top of which was placed an additional protective PVC membrane. The waterproofing membranes were extended up and over the parapet walls to minimize the potential for leaking, and "containment strips" were used to compartmentalize the roof for flood tests and to facilitate finding and repairing any future leaks. The green roof was designed as a two-layer system that mimics shallow soil (eight inches of growing medium) over bedrock (six inches of granular drainage media). The media making

FIGURE 8. Another view of Oaklyn Library green roof, LightBridge Clerestory and adjacent native meadow, July 2010. Photo credit: Pam Locker, Oaklyn Branch Library.

up both layers were tested according to FLL (1995) standards, and provide approximately 4.75 inches of stormwater storage under fully drained conditions.

The Oaklyn Library green roof was planted with prairie species including Little bluestem (*Andropogon scoparious*), Sideoats grama (*Bouteloua curitpendula*), Cornflower (*Centaurea cyanus*), Bluebell blueflower (*Campanula rotundifolia*), Yellowfruit sedge (*Carex annectens*), Bicknell's sedge (*Carex bicknellii*), Golden tickseed (*Coreopsis tinctoria*), Canada wild rye (*Elymus canadensis*), Dense blazing star (*Liatris spicata*), Annual phlox (*Phlox drummondii*), Downy phlox (*Phlox pilosa*), Scarlet globemallow (*Sphaeralcea coccinea*), and Prairie dropseed (*Sporobolus heterolepis*). Plants were established from hand-sown plugs and by hydroseeding, and a mulch cap was applied to protect the green roof from erosion during the grow-in period. Mesic prairie conditions were simulated by creating ponding ridges below the protection membrane. These ridges extend along the length of the roof and are spaced approximately 20 feet apart. Water collects behind the ridges, and when the water level exceeds the height of a ridge it flows down slope to the next ridge. Perforated rectangular drain pipes were installed level with the upper portion of the ponding ridges to enable gradual drainage.

Installation of the Oaklyn Library waterproofing system and green roof were conducted by Midland Engineering (South Bend, IN) and Enviroscapes (Madison, IN), respectively, in fall 2002. The ponding ridges were created by hot-welding 2-inch pipe to the bottom of the protection membrane. The drainage layer and growing media were dispersed across the membrane with pneumatic blowers. A base trickle irrigation system designed by Optigrün International AG® was installed at the bottom of the green roof system. A float mechanism in a chamber at the bottom edge of the slope triggers a pump when the water level drops to a specified elevation, and water is pumped to the base of the green roof at the top of the slope. The roof deck slopes at a 3% grade, and runoff is discharged to a grass swale that contains a perforated storm sewer pipe.

Maintenance and Performance

Target plant cover was achieved in approximately two years. Each spring, a corn-based herbicide/fertilizer is applied to the green roof by the library's maintenance department, to minimize growth of unwanted plants. During the rest of the year, undesirable vegetation is weeded by hand. The Oaklyn green roof is mowed once per year in late fall. The irrigation system is inspected regularly and adjusted as necessary to ensure the correct amount of water is being pumped to the roof. The green roof and adjacent prairie are used as educational tools, and public tours of the site are conducted frequently.

Clarian Cancer Center, Indianapolis: New and Retrofit, Extensive/Intensive, Loose-laid

Background and Design Objectives

The Clarian Cancer Center contains five extensive and intensive green roof areas on three different levels of the building, covering approximately one acre in total. The green roofs were designed by CBA, Inc. (Indianapolis) to meet the following aesthetic, economic, and environmental objectives: 1) provide relaxing and aesthetically pleasing healing spaces; 2) insulate the building; 3) extend the lifetime of the roofs; and 4) manage stormwater. The green roofs were considered pervious surfaces for stormwater runoff calculations, which enabled the project to be permitted without an underground stormwater storage system. The underground storage would have required approximately a quarter acre.

Design and Installation

Intensive green roofs at Clarian Cancer Center are approximately eight inches deep and contain patios and deeper bermed pockets with perennials, ornamental grasses, turfgrass, shrubs, and trees. The berms were created by building up layers of rigid Styrofoam insulation. The extensive green roofs contain mainly *Sedum* species. Extensive green roofs were installed over existing protected membrane roof assemblies with composite metal decks. Green roofs are located on sloped areas visible from adjacent streets, on a courtyard inside the main hospital entrance, on the first floor where they provide a "healing garden," in an inaccessible but visible area on the second level, and over an operating room. A Carlisle Hot Fluid Applied waterproofing system was chosen to replace the existing membranes. The

FIGURE 9. Clarian Cancer Center south green roof after planting, May 2008. Photo credit: Becker Landscape Contractors, Inc.

FIGURE 10. Clarian Cancer Center west green roof after planting, June 2008. Photo credit: Becker Landscape Contractors, Inc.

green roof growing medium consists of a locally-sourced mixture of composted pine needles, sand, and expanded aggregate. The intensive green roofs are supported by new concrete roof decks with high loading capacity. The roof drains connect to the city stormwater system.

New waterproofing systems were installed on the Cancer Center by Roberts Roofing & Siding, Inc. (Wisconsin) in 2007. Becker Landscape Contractors, Inc. of Indianapolis completed installation of the green roofs in 2008. Materials were delivered to the roof site as needed by crane or through the interior of the hospital, rather than staging large quantities of materials on the roof. The green roofs were installed last in the construction sequence to avoid destroying the vegetation. All waterproofing membranes were subjected to a 24-hour flood test prior to installing green roof materials. The green roofs were planted with plugs and cuttings six inches on center.

Maintenance and Performance

Maintenance of the green roofs is performed by Clarian Health. After two growing seasons, the extensive sloped roof and courtyards have attained complete plant cover. Less accessible green roofs on the upper levels of the hospital are reported to have received less maintenance, and plant cover is not as complete in those areas. Responses of patients and hospital staff to the green roof landscapes are reported to be very positive.

Ball Memorial Hospital, Muncie: New, Extensive, Modular

Background and Design Objectives

The 'South Tower', a new, five-story wing, was added to the Ball Memorial Hospital (BMH) in 2009. The 30,000-ft^2 South Tower roof was designed with a structural loading capacity of 100 pounds/ft^2 to allow for vertical expansion; the original intention was not for the tower to include a green roof. However, BMH's Senior Administrative Director of Engineering Services, Richard Shelton, initiated efforts to green the new roof. Design objectives for the BMH green roof were to aid in stormwater management, extend the lifetime of the roof, and reduce heating and cooling costs.

Design and Installation

The BMH green roof covers approximately 23,170 ft^2. The roof assembly consists of a flat concrete deck covered by insulation that is tapered to create slope to the roof drains. A single-ply Carlisle EPDM membrane is fully adhered to the insulation and continued up the parapet walls beneath metal coping. Project designer Ann Clevenger, Administrative Assistant in the Engineering Administration, chose a "Standard Extensive" 4-inch deep Weston GreenGrid® modular system. Her choice of GreenGrid® was attributed to the relatively low cost of the modules, and the belief that a modular

FIGURE 11. BMH green roof and walkways, January 2010. Areas not covered by snow are located near heat vents. Photo credit: Anne Altor.

system would simplify finding and repairing leaks. The GreenGrid® system consists of 150-mil, 2′ × 2′ polyethylene trays filled with a proprietary growing medium pre-planted to approximately 50% cover with *Sedum album, Sedum floriferum* "Weihenstephaner Gold," *Sedum kamtschaticum, Sedum sexangular, Sedum spurium* 'Fuldaglut', and *Sedum spurium* "White Form."

Foot traffic by various trades occurred on the waterproofing membrane in the months before the green roof was installed, and a third-party roofing contractor was hired to inspect the membrane for damage. Some seam patches were missing, and numerous holes were found and repaired with adhesive patches. No leak test was performed because of the expense of the test and the presumed thoroughness of the inspection and repair. The South Tower roof was completed in January 2009, and Jay Crew Landscaping installed the green roof over a two-week period in October 2009. Cranes were used to lift skids containing the green roof modules to the roof. Roofing felt was placed over the waterproofing membrane in the staging area, and plywood platforms were laid on the felt to distribute the load of the skids. From the skids, modules were loaded onto a balloon-tire cart and wheeled to the locations where they were to be placed. Espoma Plant Tone organic fertilizer was applied to the green roof after installation.

Walkways covered with rubber mats are located around the perimeter of the green roof area, and at approaches to ventilation stacks and maintenance points. The waterproofing membrane remains exposed in areas that are not covered by green roof modules or rubber mats. Two 2.5′ hydrants were installed on the roof to provide irrigation as necessary. Roof drains on the South Tower discharge directly to the Muncie sanitary sewer.

Maintenance and Performance

Upkeep of the green roof is provided by the hospital's maintenance department. During the first growing season, little weeding was required and abundant rain made irrigation unnecessary. Plant growth in the modules was reported to have been rapid. Thermal temperature scans used on the roof in summer 2010 recorded a 70°F difference between areas covered with green roof vs. areas above black roof (86° vs. 156°F respectively). Separate electricity metering is currently not available for the South Tower, so energy savings have not been measured to date. The location of BMH is convenient to Ball State students and faculty, some of whom have proposed research projects for the green roof.

3Mass Condominiums, Indianapolis: New, Extensive and Intensive; Loose-laid

Background and Design Objectives

The 3Mass condominiums are located in downtown Indianapolis, on a site that was previously a parking lot. The objectives for installing a green roof on the 10-story building were to accommodate required stormwater storage and provide the added value of an amenity space. Without the green roof, an underground storage system would have been needed to contain stormwater runoff from the site; in addition to the expense of the stormwater system, parking spaces would have been lost to accommodate the storage tanks. Landscape Architect Craig Flandermeyer of Schmidt Associates estimates installing the 3,500-ft^2 green roof saved developers Halakar Properties and Pillar Investment approximately $150,000 in stormwater management costs. According to Dana Larsen of AAA Roofing (Indianapolis), incorporation of the green roof facilitated approval of the building's stormwater permit.

Design and Installation

The condominium building was designed to incorporate an extensive green roof, with several inten-

FIGURE 12. 3Mass waterproofing installation: bitumen membrane carried up parapet wall, with extra layer of EPDM before finishing with coping. April 2009. Photo credit: AAA Roofing.

sive planting areas located over structural members, and a rooftop patio area. The inverted roof assembly consists of a concrete deck, a heat-welded, 2-ply Soprema Sopralene Flam 250 modified bitumen waterproofing membrane carried up over the roof's parapet walls, and four inches of Styrofoam insulation on top of the membrane. An additional EPDM membrane was placed over the parapet walls, which were then capped with aluminum coping. Disposable insulation was placed on the membrane to protect it during the months before the green roof was installed. Before the permanent insulation and green roof were installed, a 24-hour flood test was performed by the waterproofing installer (AAA Roofing).

The green roof was installed by Enviroscape (Madison, IN) in July 2009. The roof is a loose-laid system containing the following layers above the insulation: Soprema Sopradrain 650 drainage mat; Soprema root barrier; two inches of granular drainage media (minimum 80% ≥ 3/8″); root-permeable polypropylene separation fabric; three inches of growing media; photo-degradable coconut-based wind erosion fabric; and *Sedum* plugs planted 8" on center. The expected grow-in period for the vegetation is about two years. The majority of the green roof area is located on the top of the building; in addition, 4-ft wide green roof strips, from 10–50 ft long were installed adjacent to some of the condominium units. Intensive areas (18–24″ deep) were planted with *Pennisetum alopecuroides* (dwarf fountain grass), *Calamagrostis acutiflora* (feather reed grass), *Nepeta sp.* (catmint), *Amelanchier sp.* (serviceberry), and *Juniperus sp.* (juniper). Cranes were used to deliver the drainage and growing media to the roof in 2-yd^3 bags, and the media was hand-raked into place. Plugs were brought up in trays via a freight elevator. The wind erosion fabric was anchored to the separation fabric with zip-ties attached to both layers, and plugs were installed through small cuts in the fabric. The 3Mass green roof drains to the city stormwater system.

Maintenance and Performance

P-trap roof drains were chosen by the project owner to prevent emission of odors, because the drains tie in to sanitary lines. According to John Bruns of Enviroscape, the P-trap drains did not contain the access chamber and gravel that would normally be specified for a green roof. Shortly after installation, these drains clogged with construction debris and fines from the growing medium. The drains were cleaned out, and access chambers with aluminum mesh, filter fabric, and gravel were installed around them to correct the issue. Maintenance will have been performed approximately six times during the 3Mass green roof's first year. This maintenance includes cutting back dead ornamental grasses and removing the clippings, weeding and spot-spraying with pre-emergent herbicide, inspecting drains, applying fertilizer (spring), and testing the growing medium for nutrient content (fall). The fertilizer used is Osmocote slow-release 14-14-14, applied at

FIGURE 13. 3Mass green roof after planting, August 2009. Photo credit: AAA Roofing.

approximately 1-lb N/1000 ft^2. Soil testing is performed at Penn State University, and amendments will be applied if recommended.

The Maxwell Courtyards, Indianapolis: New, Extensive/Intensive, Modular, and Planters

Background and Design Objectives

The Maxwell is a 5-story building containing 105 residential units in downtown Indianapolis. The Maxwell's 2,000-ft^2 green roof is located in a ~4,000-ft^2 interior courtyard on the 2nd story, above the building's parking garage. Indianapolis fire code occupancy limits could have been easily exceeded if the entire courtyard were accessible to foot traffic, so the owner/developer (Constructa, Inc.) needed to limit the amount of space that could be occupied in the residential courtyard. A central fountain and green roof were chosen as amenities that would provide aesthetic value while limiting the number of people that could use the courtyard at one time. The developer was also interested in gaining green building experience that could be transferred to projects in which LEED certification was sought or required.

Design and Installation

The Maxwell courtyard was designed by architect Robert Finger of Weaver Sherman Design (Indianapolis) to accommodate an 18-inch green roof profile. The landscaping contractor, Mike Rian of LederPro Consulting (Indianapolis), explored green roof options at a Greenbuild Indianapolis tradeshow and selected LiveRoof® modules based on horticultural standards and a tight project timeline. The Maxwell roof deck consists of composite concrete, reinforced in the parking garage below with floor to ceiling columns. A profile of light concrete was installed over the flat deck to contour the roof toward the drains. Two drains in each quarter of the courtyard receive runoff from the green roof, which flows through the building to the city sewer. A Tremco Tremproof 25 fluid-applied elastomeric waterproofing membrane was installed on top of the slab followed by a Rootshield fabric, a multi-composite Tremco drainage and protection board, and a root/weed barrier slip sheet. LiveRoof® modules planted with *Sedum spurium* 'Royal Pink', *S. spurium* "Tricolor," *S. sexangulare*, *S. stefco*, *S. album* "Coral Carpet," *S. daglut*, *S. ellacombianum*, variegated *S. ellacombianum*, *S. floriferum* "Weihenstephaner Gold," and *S. takesimense* "Gold Carpet" were installed on top of the root barrier. Additional media was applied in areas where modules did not fit together seamlessly. This additional media was sourced and mixed by the landscaper, and included sand, Haydite, pine bark, and a small amount of potting mix.

The project owner wanted more visual relief on the roof, so 52 2′ × 2′ × 18″ deep planters were added to the design and placed at even intervals throughout the roof. The planters were filled with the same media that was used to fill spaces between modules, and were covered with hardwood bark. *Astilbe x Arendsii* "Erica" was installed in each planter. Rainbird sprinkler heads were installed around the perimeter of the green roof. A pea gravel perimeter borders the green roof adjacent to the building and around the fountain, to minimize oversplash of organic material or media onto the fountain or sliding doors. Hanover pavers were installed in four small patio areas outside each entrance to the courtyard.

LiveRoof® installation protocol was not followed for The Maxwell green roof. The project timeline was not sufficient for the modules to be pre-grown to 95% plant cover, so modules were obtained with approximately 75% cover on an 'as-is' basis with no performance warranty. There was no space for

FIGURE 14. Support posts for green roof and fountain, Maxwell Courtyards parking garage, August 2010. Photo credit: LederPro Consulting.

a crane in the building's confined urban area, and all green roof materials were carried by hand to the second floor where they were placed on rollers and moved to the courtyard. The green roof was watered and slow-release Osmocote fertilizer was applied after installation. The landscaper provided a 1-year warranty and maintenance agreement, guaranteeing 95% plant cover within the first year.

FIGURE 15. Maxwell Courtyards green roof and fountain, August 2010. Photo credit: LederPro Consulting.

FIGURE 16. Maxwell Courtyards green roof and fountain, June 2009. Photo credit: LederPro Consulting.

Maintenance and Performance

Maintenance visits were made approximately once per week during the first growing season, to water and pull weeds as necessary. The plants grew quickly and reached full coverage by early summer; *Sedums* began to spread over the pea gravel and required regular trimming to keep them within the defined green roof area. The Maxwell residences were designed to be sold as condos, but the downturn in the real estate market resulted in the units being offered as rental property. Some tenants have used the green roof as a convenient alternative to walking their dogs, and as a place to dispose of cigarette butts. The Maxwell's management is addressing these issues, and signs have been installed requesting that people keep themselves and their pets off the green roof. These problems illustrate potential maintenance challenges that can be encountered when an accessible green roof is located in a confined urban area.

DISCUSSION AND CONCLUSIONS

Individuals from a wide variety of backgrounds are involved in green roof design and installation, including roofing companies and suppliers, landscape architects, landscaping companies, horticulturalists, public service professionals, office managers, engineers, and green roofing professionals. Design choices made by individuals involved in the Indiana green roof projects profiled here were influenced by professional background, horticultural knowledge, project objectives, timelines and budgets, previous experience with green roofs, exposure to marketing materials, client preferences, and site constraints and opportunities.

Loose-laid green roof designs in Indiana tended to be chosen on projects in which architects, landscape architects, and green roof professionals played a central role. Reported advantages of loose-laid green roofs over modular systems include: 1) greater potential to customize materials, shape, depth, and vegetation; 2) seamless accommodation of irregularly-shaped roofs; 3) better stormwater retention during large storm events; 4) unrestricted lateral movement for water and plant roots; and 5) no visible grids over the green roof's lifetime (DDC 2007; Roofscapes, Inc.). Modular green roof systems generally do not contain a water-storage reservoir, whereas loose-laid systems may, depending on the design objectives. The stormwater benefits of a green roof are substantially enhanced by providing water storage reservoirs, which retain as well as slow the release of stormwater (Wingfield 2005). Reported advantages of modular green roof systems over loose-laid systems include: 1) modules can be moved if changes are desired in the layout of the green roof; 2) modules provide a predesigned system, which can make green roof technology accessible to individuals and businesses that don't have the background to design a green roof; 3) fully grown-in modules provide the instant gratification of complete plant cover (note: vegetated mats are an option for complete plant coverage on loose-laid green roofs); 4) fully grown in modules can require less maintenance than a loose-laid green roof without full initial coverage; and 5) installation time can be decreased due to the "all in one" nature of modular systems (Markham & Walles 2003; Velasquez 2003).

A number of individuals interviewed for this report felt that green roof modules would simplify repairing the roof because modules could be easily removed to access the waterproofing membrane, if necessary. Suppliers of modular systems promote their products with such claims. The same suppliers also acknowledge that a typical 2′ × 2′ × 4″ green roof module weighs approximately 100 pounds when saturated. Proponents of loose-laid roofs maintain that localized areas of green roof can be rolled back to expose the membrane if necessary. While there may be merits to both perspectives, focusing on this issue could fuel the misconception that leaks are a major concern for green roofs. Prevention of leaks by careful and proficient design and installation is the critical foundation of any successful green roof project. Thermal scans and electro vector field mapping enable leaks to be located if they do occur. Given the importance of preventing leaks, testing the membrane before installation of the green roof is essential. Three of the case studies described here included flood tests, one performed close visual scrutiny of the waterproofing membrane, and others were satisfied that rain events prior to green roof installation proved the integrity of the membrane. The entire waterproofing membrane should be covered even if only a portion of the roof is greened, to prevent weathering or other damage that typically occurs on a conventional roof. Ballast, pavers, or other materials can be used to cover areas that don't include vegetation.

In summary, when planning a green roof a number of steps must be followed to ensure a successful project. These steps include:

1. Define the objectives for the green roof.
The green roof design will emerge from the objectives desired for the roof. For example, a different set of plant species will be chosen for a green roof designed primarily for stormwater management or improved energy efficiency, compared to a green roof designed as a garden, habitat, or recreational landscape. A single site might have multiple objectives that are achieved with one or more green roof areas, as was the case for the Clarian Cancer Center. Whatever the objectives, the planning process should insure that the size and materials of the green roof are compatible with the existing roof and are integrated to meet those goals. Plans should be included for monitoring the green roof's performance whenever possible. Monitoring can include automated data collection, surveys of plant species, water quality testing, measurement of stormwater runoff, and use of the roof by wildlife, to name just a few possibilities. In retrofit projects, before and after energy usage data can be collected to quantify savings and help estimate the financial pay-back period for the green roof. Such data will contribute to quantifying performance aspects of green roofs. In terms of budget, shallow green roofs planted with plugs or cuttings are generally less expensive than fully vegetated or deeper green roofs.

2. Evaluate the structural capacity of the roof.
The roof assembly must be capable of supporting the calculated dead and live loads of the green roof. Dead loads include the weight of all roofing materials when fully saturated with water; live loads refer to weight added by people and equipment during maintenance or recreation, as well as snow and flowing water (Luckett 2009). If documentation of load-bearing capacity is not available for the building, a structural assessment is required. A licensed struc-

tural engineer generally performs the assessment, which involves evaluating the roof materials, slab, beams, columns, trusses, or other reinforcements. If the existing loading capacity is inadequate to support a green roof, reinforcement of the roof may be an option. Reinforcement can include addition of truss systems or other supports to reduce span, addition of reinforced composites or bonded steel to concrete roof decks, and post-tensioning (Alkhrdaji 2004; Cuono and Bates 2010). New buildings incorporating green roofs are designed at the outset to support the extra weight. Approximate increases in dead load contributed by green roofs range from 14–35 lb/ft^2 for extensive roofs, and between 60–200 lb/ft^2 for intensive green roofs (Dunnett and Kingsbury 2008). Intensive green roof areas or other landscape features on the roof are often located over structural members where the loading capacity is highest. For example, the fountain in the middle of the Maxwell green roof is located over pillar supports in the parking garage below.

3. Consider regional and microclimates.

The regional climate defines the range of potential plant species for the green roof, and the microclimates on the roof will impact species selection. Questions to address include: is any part of the roof shaded, and for what proportion of the day? What are the height, slope, and exposure of the roof? Is there a heat-island effect on the roof, created by surrounding hardscapes or reflective surfaces? What depth and composition of growing media are available for the green roof? What level of maintenance will be available long-term? How can the green roof be integrated into the surrounding landscape to provide visual and ecological continuity? The Oaklyn Library provides a fine example of how even on challenging sites a green roof can help to minimize a building's impact and tie it in to its surroundings.

Geographical regions that experience temperature extremes require vegetation that can adapt to heat or cold, and to significant changes in temperature from day to night. Consider growth habit when selecting plant species. Plants that produce fibrous root networks will effectively anchor the growing media while species that produce taproots will not be suitable for an extensive green roof. The shallower the growing media, the more the temperature and moisture conditions will fluctuate. High points on the roof will dry out more quickly than low areas, and sheltered areas will be less prone to wind stress. In temperate climates, shallow green roofs can benefit from a layer of insulation below the growing medium that helps to protect roots from damaging freeze/thaw cycles (Weiler & Scholz-Barth 2009). When selecting plant species for the green roof, consider the hardiness zone in which the project is located and utilize plants that are adapted to that zone. Regional growers that specialize in green roof plants can be consulted (links to a variety of growers can be found at greenroofs.com).

The depth and composition of the growing medium and availability of irrigation constrain plant selection, as illustrated by the Indianapolis Museum of Art and Oaklyn Library green roofs. Irrigation water for the IMA green roof came from a limestone aquifer, and additional limestone substrate adjacent to some planting areas caused the growing medium to become alkaline. Plant species that prefer more acidic conditions developed stunted growth or chlorosis, while those with higher tolerance of alkalinity performed well on the green roof. In this case it was a challenge to reconcile the planting plan with the growing media chemistry because few tree species were available locally at the desired caliper. In contrast to the dry conditions found on many green roofs, an intensive growing medium, ponding elements, and customized irrigation system enable mesic prairie species to thrive on the Oaklyn Library green roof.

4. Determine accessibility and installation protocols.

Consider how the roof will be accessed, how materials will be brought up to the roof, and how workers will be protected from potential falls. Is space available on the ground for a crane or other equipment if transporting materials up stairs or ladders is not feasible? At the Maxwell Courtyards, city alleys on either side of the building and the interior courtyard setting made the green roof site inaccessible by crane. In addition, the building's freight elevator was not operable at the time the green roof was installed. The most feasible way to transport green roof materials to the courtyard was up the stairs and onto a conveyor belt. Installation protocol required by the materials supplier (LiveRoof®) included a crane or lift truck and Hoppit® system for moving green roof modules. In this case, the landscaper provided the performance warranty.

Some roofing/waterproofing companies will require a contract to supply and install a specific green roof system in order to issue a performance warranty. Project managers for the BMH green roof achieved a significant price reduction by purchasing GreenGrid modules directly from the manufacturer, rather than through the roofer. However, doing so resulted in the roofer voiding his typical two-year installation warranty. Building owners, green roof designers, and installers should understand the procedures and protocols required to obtain materials warranties, and have a strategy for meeting them or an alternative form of insurance in place. Trade-offs among costs and warranties must be factored into purchasing decisions.

5. Determine the levels of short and long-term maintenance that are available and required for the green roof, and plan accordingly.

Extensive green roofs should require minimal routine maintenance after they are established. In the short term, extensive roofs installed without full plant cover must be regularly inspected, weeded, and watered as needed while the plants are growing in. Routine long-term maintenance of all green roofs includes inspecting roof drains and gutters for clogging; inspecting flashing for damage; monitoring the growing medium and vegetation for nutrient or irrigation needs and erosion; and adding plant materials to replace dead vegetation. Intensive green roofs require ongoing attention similar to other managed landscapes but with the additional details specific to the roof environment (Weiler & Scholz-Barth 2009). Maintenance should be a budgeted item and considered in the green roof design process. Personnel responsible for maintaining the green roof should be trained; the owner of the green roof can request a maintenance manual from the designer or materials providers.

6. Ensure that the roof's waterproofing system is flawless.

Green roofs are generally installed on top of a new waterproofing system to maximize the benefits and lifetime of the whole system. Green roof designers and materials suppliers may be reluctant to provide warranties for a green roof installed over an existing membrane because the membrane will have been subjected to degradation, at a minimum by weather. It is not uncommon for the waterproofing system to be completed for some time before the green roof is installed, due to construction sequencing or availability of plant materials. In this case it is critical to ensure the membrane is protected from exposure to foot traffic, equipment, materials, and weather. Foam insulation board is often used to protect the membrane until the green roof is installed. The integrity of the waterproofing membrane must be tested before the green roof is installed. A number of methods are used to inspect the membrane, including flood testing, infrared thermography, and electric field vector mapping. The precision with which each technique can locate flaws in the membrane varies greatly.

Flood testing is a straightforward procedure to determine whether a leak exists for relatively flat roofs. Depending on the size of the roof, the flood test will be done in one or more increments. On large roofs, the membrane can be partitioned into sections that are tested separately, as seen in the Oaklyn Library case study. During a flood test, a minimum of one inch of water is staged on the membrane for at least 24 hours to reveal leaking if the membrane is damaged (Crowe 2006). If leaks are present, they must be located, and the membrane must be repaired, re-tested, and approved by the manufacturer of the waterproofing system (Weiler & Scholz-Barth 2009). Alternative testing methods exploit the electrical conductance or heat retention properties of water to identify holes or tears in the membrane. Infrared scanners illuminate areas where water has intruded below the membrane, which retain more heat than surrounding dry areas. Infrared tests are often conducted around dusk because of the rapid temperature differential created between wet and dry areas after sunset.

One of the more precise methods for locating leaks in waterproofing systems is "Electric Field Vector Mapping," (EFVM). EFVM introduces a charge across the surfaces above and below the membrane. The top of the membrane must be wet in order to conduct the charge, and the surface below the membrane must be conductive, or be imbedded with a conductive grid. Potentiometer probes placed on the surface of the membrane register any electric connections that have been made through the membrane, which indicate a hole or tear. The potentiometer dial points the surveyor to the precise location of the leak (Eichhorn 2002).

7. Schedule installation of the green roof to optimize the project's success.

The green roof is often part of a larger construction project involving numerous trades. The coordination of trades influences what actions are required to insure the waterproofing system or green roof are not damaged by other work that requires use of the roof. The Ball Memorial Hospital and Clarian Cancer Center green roof projects illustrate different outcomes to similar situations. In both cases, the waterproofing membrane was installed before work by other trades was finished. At Clarian, layers of plywood and protective insulation board were placed over the membrane and flood tests were performed before the green roofs were installed. At BMH, the membrane was not protected and was exposed to foot traffic and construction materials. Inspection of the BMH membrane revealed a number of damaged areas that were repaired before the green roof was installed. Sometimes green roof materials themselves can be used to protect the membrane while work is being done on the roof. Materials were staged on the Indianapolis Museum of Art's 4-foot-deep growing medium before plants were installed.

In conclusion, momentum for the construction of green roofs is rapidly increasing in Indiana and across North America. Technologies that have been proven around the world are being exploited and enhanced, and there is an increasing focus on using green roofs for stormwater management and ecological restoration. Public and private property owners can benefit from including green roofs on new and retrofit building projects. The benefits of green roofs extend to society and the environment at large, and municipalities that provide incentives for using green roof technology are leading development of the industry. Specific green roof incentives aren't yet in place in Indiana, but property owners have realized short-term cost savings by eliminating the need for conventional stormwater infrastructure. While green roof technologies present significant benefits, careful attention to detail is critical throughout the design and installation process to ensure a successful project. The case studies and principles presented above illustrate key considerations for green roof design. Experiences gained to date in Indiana green roofing are shaping the industry in the state and can inform future projects in and beyond the region.

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