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5D: Lessons Learned from a Manhattan Green Roof Retrofit, the Largest Green Roof in Halifax, and Four Green Roofs in Cincinnati

URBAN LEARNING LABORATORY FEATURES FOUR EDUCATIONAL, MONITORED GREEN ROOFS

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Abstract

The Civic Garden Center of Greater Cincinnati's Green Learning Station is home to an accessible flat roof comparing extensive, bio-tray and intensive vegetated roof systems and the city's first sloped green roof. The intensive roof section is a vegetable garden producing food year-round. Monitors embedded in the soil and downspouts measure soil moisture and temperature, runoff volume and rate. Additional data is being collected to compare runoff water quality between the green roofs and their traditional counterparts.

The Green Learning Station roof is open to the public (accessible via a prominent staircase) with signage explaining the systems and their benefits. Tours are given regularly to secondary science classes, college courses, the general public and building and design professionals. A self-guided tour uses QR codes linked to videos to prompt visitors to interact with the site.

The project is an example of a successful collaboration between a non-profit (Civic Garden Center), the private sector (in-kind donors Tremco Incorporated, Urbanalta, Green City Resources, Melink) and the public sector (University of Cincinnati professors and students, Metropolitan Sewer District of Greater Cincinnati, Cincinnati Park Board and US EPA).

In 2007, the Civic Garden Center (CGC) began dreaming about how it might convert its storage building, a former gas station, into a demonstration site for sustainable landscape practices, including a wide variety of green infrastructure for stormwater management. Since 1942 the organization had been educating Cincinnatians about best practices for urban gardening, which had long included environmentally safe methods of pest and weed control and responsible water use in the landscape. A new program and site focused on the application of the green movement to the landscape would enable the organization to demonstrate the best practices it had long championed and serve as a leader in sustainable site methods in the region. As the design visioning process moved forward, it became clear that the opportunity for education, research and up close comparisons of different systems were the main priority. Other factors that had to be met were the reuse of the existing building and affordability of the project to the non-profit organization.

Designing for Education and Accessibility

There were a number of green roofs in the Greater Cincinnati region when the Green Learning Station (GLS) was being designed, but only one of them was accessible to the public, and that only during guided tours. We wanted the roof of the GLS to be something that drew people onto it whether they were on site for a program or just passing by. The low stature of the former service station made exterior steps or ramps onto the roof a realistic option. Initial designs called for a large wooden ramp and a staircase leading to a wrap around walkway, as depicted in Figure 1.

Figure 1: 2007 design of GLS roof access via ramp and steps

Educators included in the design process quickly realized that the lack of wide gathering spaces on the roof would make it difficult to address groups larger than a few people while also viewing the vegetated roofs.

From the beginning, the CGC wanted to demonstrate a range of green roof styles, from sloped to flat and a spectrum of growing medium depths, in order to demonstrate to building decision makers the options on the market. Comparing the resilient plants growing in extensive systems with the palette of plants that can be grown in intensive systems provided an educational opportunity for teenagers attending field trips to the GLS with their science classes. Signs were planned for all educational features and major plants on the site, so visitors touring without a guide could get the most out of their trip. After the physical interpretive signage was complete, planning started for media linked to the site signs through QR codes. Plant identification signs were linked to audio narratives about the plants accompanying a slideshow of images of the plants in different settings and seasons. Green technology signs were linked to videos of a tour guide explaining key features about the site and prompting visitor interaction with them.

Designing for Reuse and Affordability

Once we started calculating costs on the original design, we realized the beautiful and functional ramp system was just not in the budget. Designs were modified to remove the ramp and better integrate the staircase into the overall campus design. The area that had to be enclosed with fall protection railings was decreased, substantially reducing that section of the budget.

Figure 2: Green Learning Station roof access staircase after construction

The biggest change that happened between design phases was the relocation of the vegetated roof systems from the roof of the existing building to the roof of the storage additions planned for the front of the building. Structural evaluations showed that the old gas station roof would need to be reinforced to support the added weight of the planned vegetated roofs. Since we were already designing additions, it made more sense to design and build those to support the necessary loads.

With a reduced amount of space available for green roofing, we had to assess which roof systems made the most sense to include on the GLS roof. The sloped sections planned for a built out sloped structure in the original designs (see Figure 1) were eliminated. A small stone cottage adjacent to the Civic Garden Center's property, owned by the Cincinnati Park Board, was identified as a possible location for a sloped green roof and discussions began to permit the modification of that roof. Final selections in vegetated roof systems were made once the roofing vendor was secured. Tremco Incorporated agreed to donate all roofing materials for the job and the following roof systems were selected:

- 550 sf extensive sloped roof on stone cottage, 4" of growing medium with soil stabilization system, planted with pre-vegetated sedum mat;

- 150 sf extensive biodegradable tray system (trays made from coconut fiber), 3" deep tray with 1" additional growing medium below, planted with plugs one month prior to transfer to roof, located on eastern perimeter of former gas station roof;
- Two sections of extensive built in place systems: 94 sf planted with plugs, located on south addition to front of existing building, 150 sf seeded with short rooted prairie plants, located on existing built out storage room in back of former gas station;
- 210 sf intensive built in place system, 12" growing medium, planted with annual and perennial herbs and vegetables, located on north addition to front of existing building.

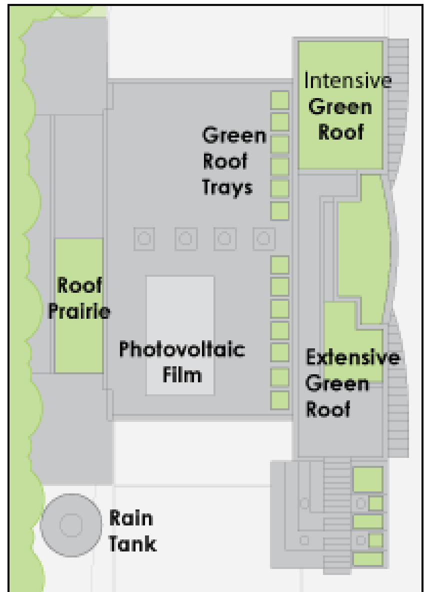

Figure 3: Overhead diagram of final roof design.

The final design allowed for comparison between four different styles of vegetated roof systems while minimizing costs related to the building structure. Figure 3 indicates final placement of the green roof systems on the flat roof of the Green Learning Station. In retrospect, it would have made more sense to have finalized the green roof vendor before finalizing design and construction documents as there were many factors, such as required root free zones and size of trays, which required us to modify designs during the construction process.

Designing for Research

Early in the design process, the Civic Garden Center engaged in conversation with representatives from the Metropolitan Sewer District of Greater Cincinnati and the EPA's Office of Research and Development based in Cincinnati. They indicated the need for local data on the performance of green infrastructure controls for stormwater management, to help make the case for their implementation in the region. Urbanalta came on board to design instrumentation and its required plumbing and electrical infrastructure to quantify stormwater flows through the site[i]. After the roofs were constructed, a team of professors and students from the University of Cincinnati (UC) started designing research experiments using the green roofs.

Research Context

Current work of the University of Cincinnati research team has focused on using information from local vegetated roofs and pilot-scale test plots to generate a coarse set of hydrology and water quality data and develop initial hypotheses (Buffam et al. 2011, 2012). The immediate goal is improving our understanding of the hydraulic and water quality performance of vegetated roofs for use within an integrated stormwater management system. Our long-term research goals are to develop a comprehensive understanding of green infrastructure technologies associated with engineering (e.g., hydraulic, water quality, urban heat island), economic (e.g., construction and maintenance, land value), and ecosystem service (e.g., nutrient cycles, recreation) objectives to inform an integrated urban planning, design and management framework.

Monitoring Infrastructure Design

There are two separate monitoring systems currently installed at the GLS. The first was designed by Urbanalta based on 1-Wire microchip technology; the second was designed by scientists from the University of Cincinnati using more traditional environmental sensors and involving manual water sample collection for water quality. The 1-Wire system uses high-resolution chip sensors that continuously stream data with minimal onsite resources to cloud computing. The sensors become complete instruments when connected to the cloud using public communication infrastructure. Urbanalta's Chip-to-Cloud™ instrumentation lowers the installation and life cycle cost, improves scalability and renders data into actionable metrics online. Precipitation at the GLS is measured by dual 8-inch diameter rain gauges with 1/100" resolution and a visual sight glass as back-up verification. The rain gauges quantify the rainfall and define the beginning and end of a rain event.

The industry has a big gap in its understanding of what is really going on given the dynamics of rainfalls. Moreover, the measurement of water flows driven by gravity over wide areas has been technically challenging and expensive. Urbanalta flow instrumentation is designed for affordable, retrofit installation with 10% accuracy from a trickle flow to 100-year rain flow using downspouts between 2 and 4 inches in diameter. Once fully installed, the roof will include continuous flow instruments using MEMS (micro electrical mechanical sensor) and image sensors, as well as soil moisture instruments based on Time Domain Reflectometry.

Validation of the value proposition for green roofs requires accounting for all the flow in and out as well as the instantaneous change in storage. The storage can be calculated from field measurements using the equation: *precipitation flow = runoff flow + change in storage + evaporation flow*. During the rain event, evaporation can be set to zero with negligible error. The equation can then be solved for change in storage instant by instant.

Using opportunistic events, the total storage capacity can be calculated and the evaporation can be characterized. A large rain event that ends a long dry spell allows the storage capacity to be calculated as the storage changes from 0 to 100%. Assuming storage is near zero at the end of a long dry spell and a heavy precipitation saturates the storage at 100%. The amount of precipitation minus the run off equals the storage capacity. Knowing that the storage is at 100% going into a long dry spell allows calculation of the evaporative flow as a subsequent rain event tops off the storage 100%. The characteristic evapotranspiration can be allocated between surfaces and plants using additional sensors—temperature, soil moisture, humidity and wind.

There are additional opportunities to use the same networked information infrastructure to automate irrigation using soil moisture as a criteria, measure of plant vigor to improve selection, detect roof leaks and meter heat transfer to and from the building.

Specifics of Monitoring Design on the Sloped Green Roof

The sloped roof consists of an eastwardly facing extensive green roof and a westward facing traditional asphalt shingle roof. Runoff water samples have been collected from the downspouts of both roofs during every rain event since April 2011 and analyzed for a range of water quality parameters. To determine water balance and mass flow rates of water quality contaminants, sensing equipment was installed in June 2012 (specifically light meters, flow meters, soil moisture, temperature probes, and a rain gauge) at various locations on and around the roof. Because half of the roof is shaded by an overhanging tree, particular care was taken to place multiple sensors in both the shaded (northern) and exposed (southern) portions of the green roof for comparison, as well as install an additional rain gauge to capture throughfall (obstructed rainfall) rate. Below is a detailed list of equipment by location detailed in Figure 4. All equipment is connected to a Campbell Scientific CR-1000 datalogger, except ONSET loggers which are self-contained.

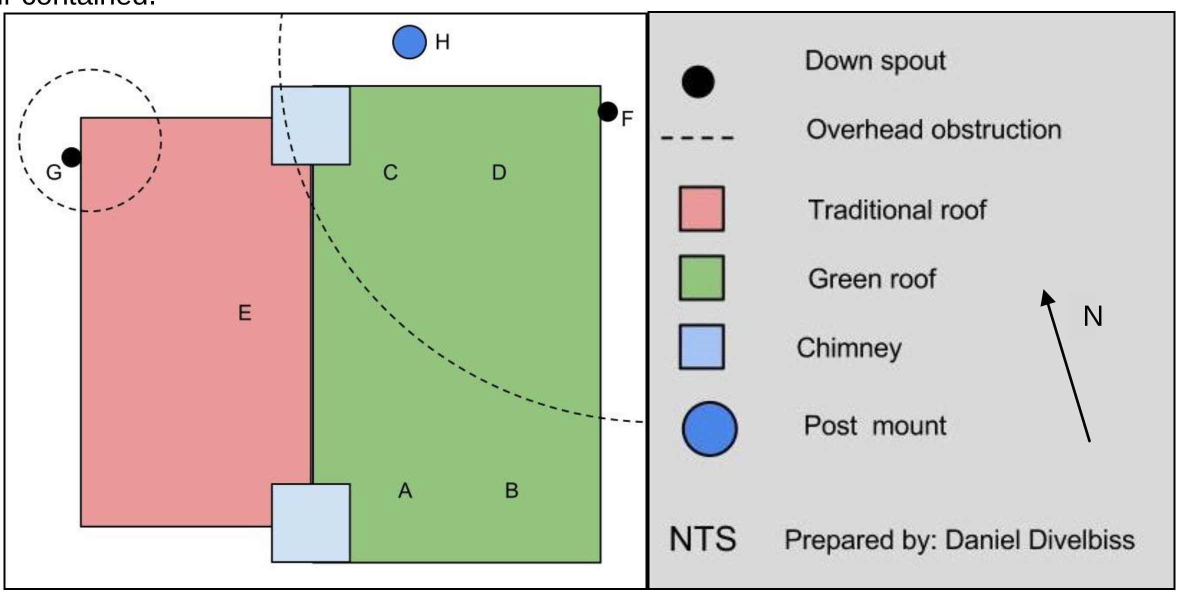

Figure 4: Diagram of sloped roof monitoring infrastructure. Letters correspond to listed instruments below. Overhead obstructions are trees.

A, B, C, D: Campbell Scientific 107-L Temperature Sensor in growing medium
Campbell Scientific CS616-L Water Content Reflectometer in growing medium
ONSET UA-002-64 HOBO Pendant Temp/Light logger at surface

E: Campbell Scientific 107-L Temperature Sensor on roof surface
ONSET UA-002-64 HOBO Pendant Temp/Light logger at surface

F, G: Campbell Scientific CS450-L Pressure Transducer in modified down spout
Weir (thel-mar volumetric weir in horizontal section of 6-inch PVC pipe)

H: Campbell Scientific 107-L Temperature Sensor for ambient air temperature
Texas Electronic TE-525 Tipping Bucket Rain Gauge for obstructed rainfall

Research Results to Date

University of Cincinnati research scientists collaborating with the GLS have measured concentrations of nutrients and metals in runoff from the sloped green roof at the Civic Garden Center during every rain event for over a year (Nichting and Buffam 2011). As a control, the concentrations were also measured in the incoming precipitation and in runoff from the adjacent, traditional shingled roof. Results were mixed: for example, nitrate changed little, zinc and copper concentrations were reduced in green roof runoff relative to the traditional roof runoff (Figure 5), but phosphate was substantially enriched in green roof runoff, and is a contaminant known to contribute to surface water eutrophication. These results clearly show that vegetated roofs can substantially change the runoff water quality passing through the roofs.

Monitoring of this roof continues with measurement of water quality in runoff during every rain event, and the newly installed environmental sensor infrastructure (Figure 4) now enable us to measure water balance and to generate input-output budgets of nutrients and metals for the roofs. The results from this project have inspired questions for many ongoing research projects involving both graduate and undergraduate student researchers at the University of Cincinnati and Northern Kentucky University. For example, students are pursuing questions regarding the source of phosphate in green roof runoff, and the impact of plant species on nutrient retention in green roofs.

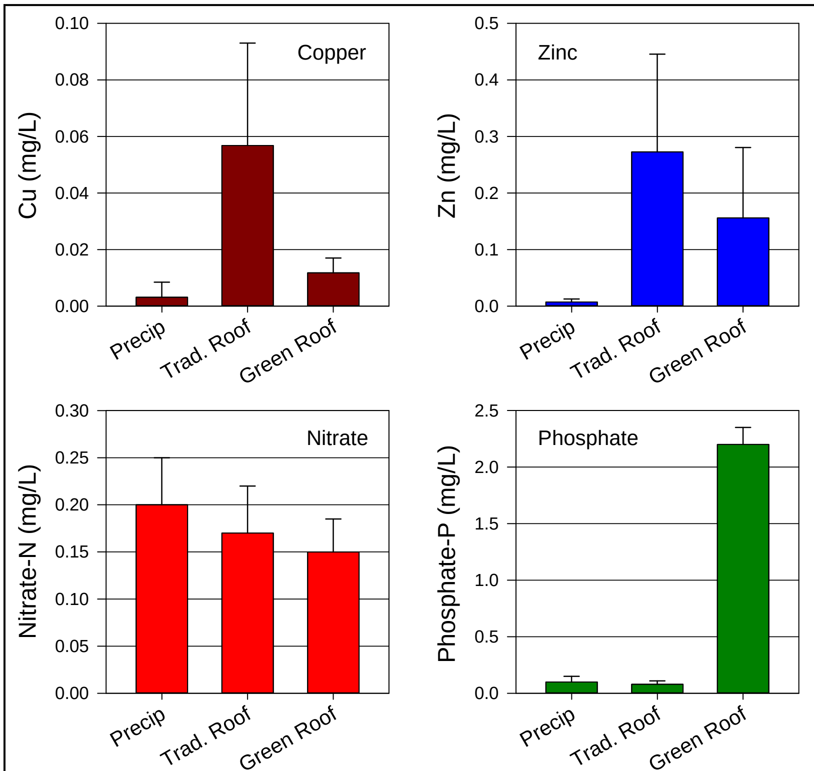

Figure 5: Metal and nutrient concentrations in precipitation and runoff from a sloped green roof and a shingled roof.

From a researcher's perspective, the cottage green roof design has both advantages and disadvantages. The roof is well constructed for runoff water flow and water quality monitoring, because the green roof covers the entire roof side and drains to a single downspout easily accessible for water sampling and installation of sensors. The green roof is accompanied by a control (shingled) roof of similar size and with a single, similarly accessible downspout. However, research and monitoring were not integrated into the original design of this roof, thus all sensors and monitoring efforts have had to be installed post-construction (retrofit). As a result, sensor cables are exposed rather than buried, flow monitoring required the addition of extra lengths of exposed PVC drain pipe, and this part of the sensor network isn't well integrated into the overall site sensor network.

The sloped green roof is half-shaded by a tree resulting in visibly patchy vegetation. The tree intercepts some rain/snow and the exact amount of precipitation that makes it through the canopy as throughfall is spatially variable and more difficult to quantify than precipitation in an open space. The tree's presence thus increases the uncertainty in the sloped roof's water balance, although in an effort to lower uncertainty the site has been equipped with both open air rain gauges and obstructed throughfall rain gauges for comparison. The research team has taken advantage of this unplanned shading experiment by establishing a monitoring system to compare variation in surface light, temperature, soil moisture and plant species coverage between the sunny and shaded portions of the green roof. Since the roof was established with the same substrate and vegetation throughout, any observed differences can be attributed to variation in microclimate.

Implementation of Green Roof Systems and Educational Outreach

The construction of the green roofs was conducted in two stages. The cottage roof was modified in April 2010 and the flat roofs installed throughout the summer of 2011. The cottage roof installation went smoothly and quickly, being completed in slightly over a week, and that long because of the amount of time needed for the Tremco cold adhesive to set prior to continuing work. The crew and crane were able to access the roof easily from a driveway, preventing damage to planting areas directly below the green roof. The sedum mat arrived well covered in the following plants: approximately 50% of the sedums are Sedum Album, Sedum Sexangulare, and Sedum Acre, with the remainder consisting of a mixture of the following: Spurium (several varieties), Rupestre (several varieties), Floriferum, Kamtschaticum, Immergrunchen and Hispanicum.

The installation of the flat roof sections on the Green Learning Station were delayed a number of times due to timing of construction on the rest of the site and coordination of trades working on the job. We realized the importance of having a green roof specialist on site during each phase of installation when a Civic Garden Center staff member noticed the roofers were installing the drain board upside down. Fortunately, the problem was identified before it was buried with tons of growing medium. Because the roof was to be used for educational purposes, we expected an attention to finish details that may not normally be a concern on a roof, and our expectations were not always met. The uncertain timing of vegetated roof installation made it difficult to determine when to plant the biotrays, which was being done on-site. They ended up being planted about one month prior to installation, which gave the plants a head start over the plugs in the other extensive system, but did not provide the dramatic coverage you would expect in a tray system. Plants started as plugs in the two extensive systems include: Sedum takesimense, Sedum 'Autumn Delight,' Sedum spurium 'John Creech,' Sedum rupestre 'Angelina,' Sedum reflexum 'Blue Spruce,' Sedum album f. murale, Allium cernuum, Talinum calycinum and Dianthus deltoids. The intensive roof section was first planted by the owner with vegetable seeds and transplants in August 2011 and is maintained as a rooftop vegetable garden. Its railings were designed to be trellises for climbing plants, maximizing what can be grown in the space using vertical growing techniques.

Every day visitors climb the steps to the Green Learning Station's roof. Upon it they find a palette of unique plants with signage explaining and illustrating the different roofing systems and why green roofs make environmental and economic sense. They compare the plants growing in extensive and intensive systems and learn how green roofs can regulate building temperature and keep rain out of combined sewer overflows. Teenagers attending field trips experiment with 18" x 24" bins containing different roof types (white TPO, tray, extensive and intensive). They hypothesize, design a procedure, conduct an experiment and collect data to answer the question "Which green roof type will keep the most rain out of the sewer system?" Through the course of their experiment they gain an appreciation for timing of rain fall events and roof runoff and the ability of plants and soil to act like a sponge. Students return to school with the inspiration to advocate for a green roof on their school and the skills to conduct a stormwater audit of their campus.

Figure 6: Signage explaining intensive green roof system

Maintenance of the Green Learning Station's Roof Systems

The GLS's green roofs are in an ideal environment for careful maintenance: they are all easily visible and accessible and are sited at the headquarters of a gardening non-profit. Unfortunately, that does not necessarily mean that they receive an ideal level of maintenance. Staff schedules are tightly packed and in the middle of a drought, there are 8 acres of gardens to water so the drought-tolerant sedums are not high on the priority list. The surrounding gardens provide plentiful sources of weed seeds, which easily blow onto the low roofs with short parapet walls. The biggest problem in the extensive roof systems has been the shade conditions on the north half of the cottage roof. While some of the sedum varieties planted in the sedum mat have survived in the part shade, enough of them have faded out that sizeable gaps appear, making room for weeds to take hold and out-compete the struggling sedums. We have noticed substantially more weeds germinating on the shady half of the roof and have started filling in with shade loving plants that can tolerate shallow soils such as sweet woodruff and dwarf solomon's seal. The owner insisted on removing the root free zone at the bottom of the sloped roof to give the feel of an edge-to-edge planting. As a result, many sedums are hanging over the flashing edge and are periodically trimmed back to prevent their migration into the gutters. While this edge treatment choice does not look crisp, it does provide a ready source of cuttings for the green roof experiment trays and filling gaps.

The intensive vegetable garden receives the most attention given its constantly changing plantings and water demands. A mini-sprinkler head system was installed in June 2012 to provide even watering throughout the fast-draining soil. The garden is watered 5 days a week for about ½ hour, occasionally twice a day in high temperatures and drought conditions. The roof section is planted in the square foot style of vegetable gardening, with seeds planted closely together to maximize plant coverage and production. A number of plants survived the mild winter of 2011-2012 with zero maintenance: carrots, swiss chard, cabbage, broccoli, lettuce and kohlrabi. February plantings of peas yielded substantial harvests. Early plantings of lettuce and spinach produced no edible yield: the plants looked stunted compared to plants started at the same time in an in-ground garden, and the leaves turned bitter even before bolting. Two theories for the failure of the cool-weather leaf crops are reduced levels of water-soluble nitrogen and phosphorous in the green roof growing medium and soil temperatures rising early in the season given the relatively shallow depth and lack of insulating sub-soil. Our new sensors will help us quantify this effect.

Plants that have thrived in the intensive green roof include a variety of legumes: soybeans, peas, pole beans, fava beans (their ability to fix their own nitrogen from the air may have something to do with their success), brassicas like cabbage and kohlrabi, tropical climate plants such as eggplant, pepper, tomato, luffa and cucumbers. When replanting sections of the garden, we do add a mild, organic, slow-release fertilizer to keep nutrient levels at appropriate levels. We hope to start measuring nutrient runoff from the roof in the near future and to integrate the irrigation system with the moisture sensors to create an efficient feedback loop.

Conclusion

The Green Learning Station has succeeded in its goal of installing a wide variety of green roof systems for the public to view and touch. Through tours, field trips and educational signage, we are reaching a diverse cross section of Cincinnatians, who take away from our site an understanding of how green roofs perform, factors that influence suitability of a building for a green roof, and their impact on the region's environmental quality. We field calls frequently from individuals who have learned of our roofs and are interested in pursuing green roofing (and even rooftop vegetable gardening) on their home or office.

The Civic Garden Center has built strong relationships with researchers interested in using our rooftops and tapping into the monitoring network that was designed for the site as a whole. As new environmental sensors start collecting data on water and heat moving through the roof systems, we hope to generate additional interest in the project as we communicate our findings, especially to the design and construction, academic and government communities.

Designers and owners of future green roofs would benefit from planning for monitoring and accessibility while they are still in design stages. Incorporating monitoring infrastructure allows the roof to prove its value by telling a concrete story of stormwater absorption, temperature regulation, greenhouse gas exchange and other tangible benefits. Green roof systems become more compelling when they can be touched or at least seen at close range rather than through a distant window or video feed. We hope to see accessible, educational green roofs popping up in every city so they can inspire more people to green their own roofs.

Footnotes

[i] The Green Learning Station also contains six pervious pavement test areas, rain water harvesting tanks and rain gardens. The monitoring system was initially designed for the pervious paving infrastructure, with the green roof instrumentation included in the Phase 2 of sensor network design, allowing it to benefit from lessons learned in the other systems.

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