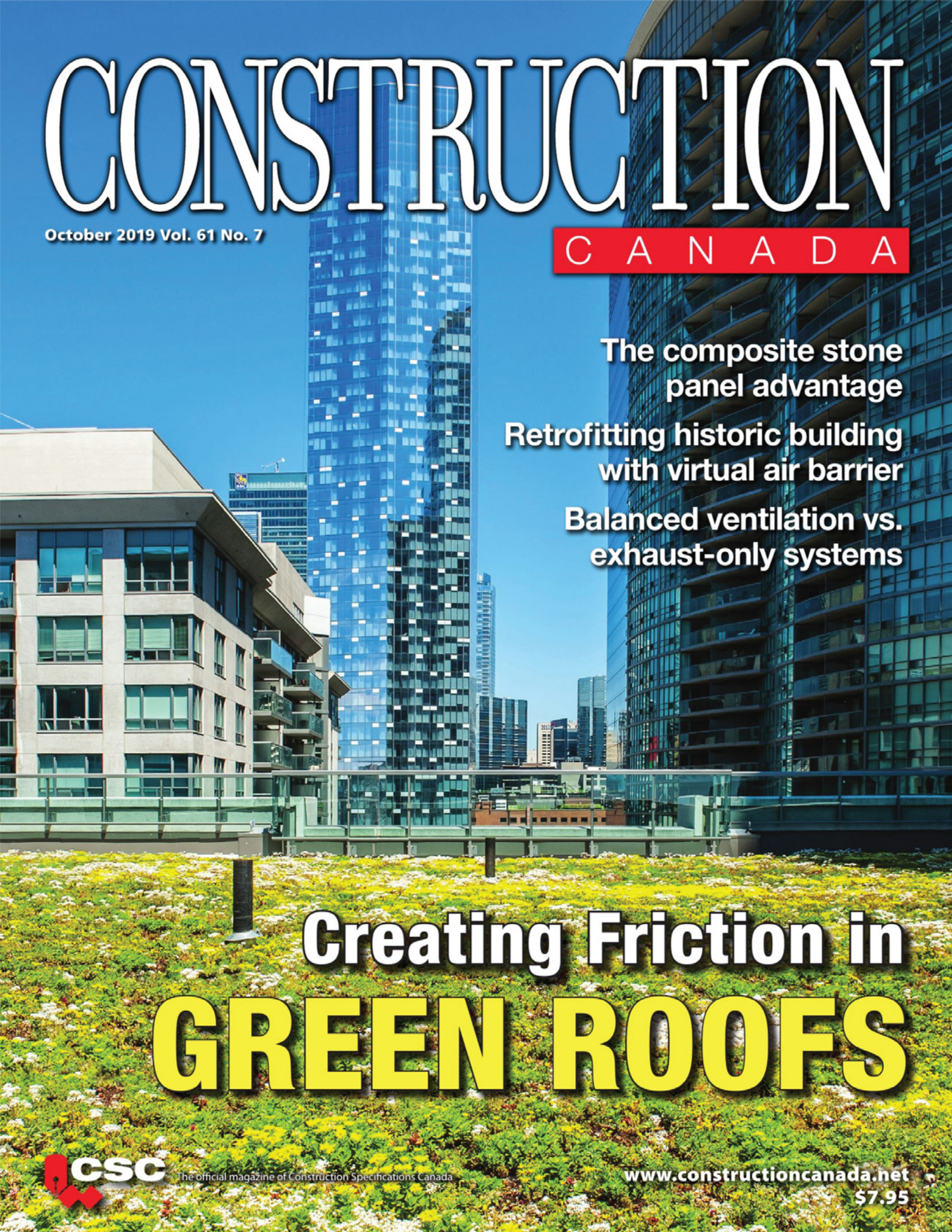

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Reinventing the Traditional Vegetated Roof for Detention

By Sasha Aguilera, B.Arch, GRP, and Brad Garner

Vegetated roofs, more commonly known as green or live roofs, are a sustainable solution emulating and echoing designs found in nature in response to modern human challenges. This nature-inspired innovation is known as biomimicry.[1]

One early example of biomimicry was Leonardo da Vinci's study of the bird's anatomy to enable human flight. Today, researchers continue to study nature to develop new technologies, such as the bullet train modelled after the kingfisher bird to reduce noise and increase speed and efficiency. The most ubiquitous example of biomimicry is the removable, re-useable, all-surface fastener inspired by the tiny hooks on bur fruits.[2]

As climate change presents an increased risk to urban stormwater management (SWM), watersheds, and public health overall, implementing green infrastructure has become a key tool to help manage rainwater where it falls, and thus increase community resiliency.[3]

Modern vegetated roofs bring nature back to the cities for a plethora of benefits, using available space on rooftops, mostly for SWM benefit.

Traditional vegetated roofs achieve retention by holding a certain amount of rainfall onsite. After they are fully saturated and retention is maximized, additional rainfall drains through as quickly as it falls. Detention technology takes over where retention capacity ends. Detention helps manage the excess rainfall onsite by slowly releasing it to prepare for the next event, within a matter of hours or days. Now, a detention layer in vegetated roof systems helps manage the excess stormwater runoff onsite by mimicking friction found in watersheds and aquifers. Friction in nature includes tall grasses in meadows, dense masses of reeds in wetlands, or layers of leaves on a forest floor. Friction-detention in vegetated roofs is a technological innovation inspired by nature to achieve rooftop SWM in dense urban areas.

Traditional vegetated roof systems

There are many types of vegetated roofs, and generally fall under two classifications: intensive or extensive.

Intensive roofs feature a variety of plants in a heavy and deep substrate layer of 250 mm (10 in.) or more. Extensive roof systems, on the other hand, are lighter in weight because of a shallow substrate of 20 to 150 mm (¾ to 6 in.) and they typically feature vigorous, low-growing, drought-tolerant plant species such as sedums and mosses. Extensive systems are economical, easier to remove and repair, and require less maintenance than the intensive ones. Extensive systems may also be retrofitted on existing buildings. This article focuses on extensive vegetated systems.

How do vegetated roofs work?

The main principle components of a green roof are explained below.

Vegetation

Most extensive vegetated roofs include succulent plants such as sedums.[4] Sedums have thick leaves in which they store water, making them more heat- and drought-tolerant and better suited for rooftop survival.[5] When it is not raining, the vegetation uses the water stored in the growing medium and the leaves and releases it to the atmosphere through evapotranspiration (explained later). The water that is released to the atmosphere and never becomes runoff is retained water contrary to detained water, which eventually becomes runoff.

Engineered growing medium

Typical vegetated roof media are higher in mineral aggregates and lower in organic matters, allowing for good drainage and rainfall retention.[6]

Water-retention layer

Recycled synthetic fleece or natural rock mineral wool increase the water holding capacity of a vegetated system.

Drainage

The three-dimensional composite layer provides drainage and a water reservoir, designed to permit excess rain to flow through to the roof drains. The drainage layer can be manufactured from looped nylon filaments or fabricated from modular cups. The latter also offers some retention capability.

A traditional vegetated roof has the five layers of vegetation, engineered growing, retention, drainage, and root barrier.

Root barrier
A flexible and impermeable sheet made of low-density polyethylene (LDPE) protects the roofing membrane from root penetration.

Good retention but limited by weather

Vegetated roofs retain water well when they are mostly dry. Retention is good at managing small rainfall events as they hold a certain quantity of water and never allow it to flow into the roof drain. This water only leaves as vapour, slowly, taking about one to two weeks for 25 mm (1 in.) of water to fully dry out through evaporation and transpiration, collectively referred to as evapotranspiration.[7] Evaporation is the process of the sun and wind converting liquid water to vapour. Transpiration is the process of plants drawing water from the soil and releasing the water through pores in their leaves. Transpiration is faster than evaporation, which is why green infrastructure can efficiently convert water to vapour. However, the rate of transpiration and evaporation are weather dependent, so little can be done to speed them up. The effectiveness of a traditional vegetated roof in managing stormwater through retention depends on many factors, mostly the amount and frequency of rainfall.

When saturated, a traditional vegetated roof requires ideal weather conditions to dry and to have the capacity to absorb the next rain event.[8] This may take weeks. Also, when it rains back-to-back for several consecutive days or when monsoons last months, traditional vegetated roofs provide little SWM benefit. Further, there are also the local climatic minimums and maximums—all cities are subject to one-in-100-storm events that building professionals must plan for. Large storms are, of course, the most destructive, and this is where detention technology is implemented in the form of cisterns, ponds, or rain gardens as more reliable tools to meet municipal stormwater regulations.

Unpredictable, extreme downpours continue to flood communities

In most climates, approximately half the rainfall volume occurs in small, and less intense rain events, such as brief gentle showers or misting rain. The other half occurs in larger or intense storms.[9]

For example, in 2018, Toronto received a total of 885 mm (35 in.) of rainfall. Of that/total, 75 mm (3 in.) poured down on August 7 in an intense storm causing power outages, disrupting public transport, and flooding parts of the city.[10]

Less than 10 days later, another volatile storm brought 50 mm (2 in.) of intense rainfall, flooding Toronto's Union Station and causing commuter chaos downtown.

Within two days in August, Toronto received almost 14 per cent of its annual rainfall, causing great damage and more than $80 million in insurance claims. Heavy rain events have and continue to hit communities across Canada. The National Capital Region of Ottawa, Gatineau, and Montréal have flooded three years in a row with a state of emergency declared, and the army deployed most recently in April 2019. In 2013, Calgary and environs were deluged with 325 mm (13 in.) of rain, the city's entire average annual rainfall, in just 48 hours. This storm resulted in five deaths, the displacement of more than 100,000 people, and made it one of the costliest disasters in Canadian history at $1.7 billion.[11]

Detention technology mitigates floods

When implemented on a large scale, a vegetated system with detention technology can help mitigate the impact of extreme storms, lessen the strain on storm sewers, and decrease combined sewer overflow (CSO) due to the following key features:

- can manage large and repeat storms and is not dependent on weather to provide a repeat performance;
- stores water temporarily and limits the rate at which water flows from the roof drain; and
- can recharge in as little as a few hours.

Flood Risk across Canada

Recent flooding in communities across Canada have caused great property damage, loss of personal belongings, substantial increases to insurance premiums as well as impacted the physical and mental health of residents. Since the 1990s, cities such as Edmonton, Winnipeg, Hamilton, Toronto, Ottawa, and Montréal, and the Greater Vancouver Regional District implemented a variety of urban stormwater best management practices (BMPs), including use of vegetation, to help manage stormwater quantity and quality.* Since the turn of the century, new paradigms emphasize the importance of flood control. Some jurisdictions in Canada, such as the Province of British Columbia, have set runoff volume control targets and prescribe methods for runoff retention and detention onsite.**

* Read "Weathering the storm: Developing a Canadian standard for flood-resilient existing communities" by N. Moudrak and B. Feltmate, 2019.

** Consult "LID Implementation: From an international Perspective to a Canadian One: Synthesis of the SOCOMA (Source Control Management) Activities Specific Needs for Successful Projects in Canada" by G. Rivard for the fourth annual TRIECA conference in 2015.

Engineering a vegetated roof for detention increases ROI

Not only are detention-based vegetated roofs a good investment for Canada's long-term infrastructure plan, but also offer building owners a return on investment (ROI) with more efficient use of valuable real estate.

If detention is required onsite, it is achieved in the form of tanks, ponds, rain gardens, etc. All those solutions take up space that could possibly be used for other things. For example, tanks often take up space in parking garages. Though rain gardens or ponds can be attractive landscape features, they can require significant amounts of space that can constrain the site and/or building design.

Vegetated roofs, on the other hand, occupy under-utilized space. Instead of putting a tank in a parking garage, a detention vegetated roof could allow extra parking spaces to generate revenue. Instead of a sizable rain garden at street level, a more modest rain garden could be built, allowing for optimized use of valuable street-level retail space. It should be noted parking demands in Canada have significantly increased the last number of years and a single additional parking space in Toronto can cost more than $50,000 on average or bring in $7000/year in parking revenue.[12]

This benefit is compounded when a vegetated roof is a requirement. For example, if a vegetated roof is needed by ordinance, or for retention purposes, it will be installed regardless. A vegetated roof providing detention benefits can also lower the cost of other SWM devices. Outside of water retention for management of SWM, the two physical attributes of the roofing system being evaporation and transpiration also help to passively cool the building and moderate local urban heating (*i.e.* heat island effect).

Evolution of roof systems with detention

Since the development of the modern vegetated roof in Germany 40 years ago and introduction of vegetated roofs to North America about two decades ago, nearly all of them have had extremely high drainage rates with minimal resistance to flow. The German Landscape Research, Development and Construction Society (FLL) green roof guidelines instruct the water permeability (K_f mod.) to be within the range 0.6-70 mm/min.

Put simply: the modern vegetated roof is designed to drain extremely fast. That is not to say no one has considered alternatives. Slowing down water to create detention has been tried in vegetated roofs, albeit with mixed success. There are a few examples of great success, but replicability and widespread adoption have been difficult to achieve. This is unsurprising, since creating detention in a thin vegetated system is challenging. However, innovations are changing that equation.

Different roof systems with detention technology

There are different types of detention-based roofing systems on the market. All solutions have their merits, and often a single project may benefit from multiple approaches.

Blue roofs

Often the most economical, blue roof simply store water on the roof. This was a building practice that was fading out of existence 40 years ago, and is coming back as a potential to moderate building heating and cooling, as well as retaining water on roofs. While effective at storing water, some considerations are:

- no vegetation;
- add substantial weight to the roof;
- require a flat deck;
- need specific roofing membranes and installation techniques for warranties to hold;

Photo © BigStockPhoto.com

Within two days in August 2018, Toronto received almost 14 per cent of its annual rainfall, causing great damage and more than $80 million in insurance claims.

Determining Suitable Projects

While friction detention technology can be added to almost any structure designed with vegetated roofs, the most suitable buildings have large footprint, space constraints, and require cisterns. Such buildings have larger podiums as opposed to a small tower roof and could use the space made available by reducing the water storage tank.

Determination of suitable projects is made by running calculations based on:

- roof plan with dimensions showing drain locations in relation to building's parapet and roof slope to each drain on either side of the cricket;
- site development plan; and
- regulatory site requirements.

- the roofing membrane is exposed to ultraviolet (UV) degradation;
- require controlled release such as an orifice restrictor, holes in an elevated drainpipe, or a mechanical valve that can be opened and closed using smart technology;
- impractical for small roof areas due to the fixed cost per drain; and
- standing water may pose risk of disease and safety issues to maintenance personnel.

Blue-green roofs on stilts

Also known as ponding-detention blue-green roofs, it allows for water to be stored underneath the vegetated roof. It is often the detention option adding the most weight to the roof because of the water detained through ponding and the water retained in the vegetative system. Aspects to consider include:

- require a flat deck and controlled release;
- an option for larger roof areas that can support a lot of weight; and
- plants used for blue-green roofs have a high tolerance for moisture and thus can be high-maintenance.

Friction-detention blue-green roofs

These roofs are inspired by nature and emulate friction found in watersheds to delay stormwater runoff and peak reduction. Water is stored throughout the vegetated roof profile instead of in an isolated pool beneath. Detention layer provides uniform friction and distributes water evenly throughout the surface and the green roof profile. The lightweight system can temporarily store 75 to 100 mm (3 to 4 in.). It is the only vegetated roof detention option that also works for sloped decks and is good for plants as water is more evenly distributed, increasing evapotranspiration and retention.

How friction-detention technology emulates nature

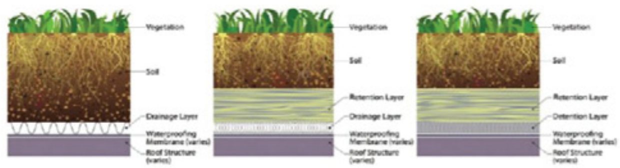
Detention in nature is caused by distance, slope, and friction. Water takes longer to drain if there is a greater distance to travel, a low slope, or flat surface and encounters some resistance en route. For example, when a drop of water lands in a meadow 1 km (0.6 mi) from the nearest stream, it must travel the long distance, across the flat surface, weaving through all the plant stems and blades, which cause friction, before it reaches the stream.

Now consider a roof with drains spaced relatively close together, slopes at two per cent ($^{2}/_{100}$ m [$^{6}/_{330}$ ft]) toward drains, and a slick surface allowing water to flow across rapidly. Limited distance and efficient slope toward the drain, along with minimal friction create 'instant' runoff. From street level to rooftop, this situation is ubiquitous in urban areas, which is the root of urban stormwater problems.

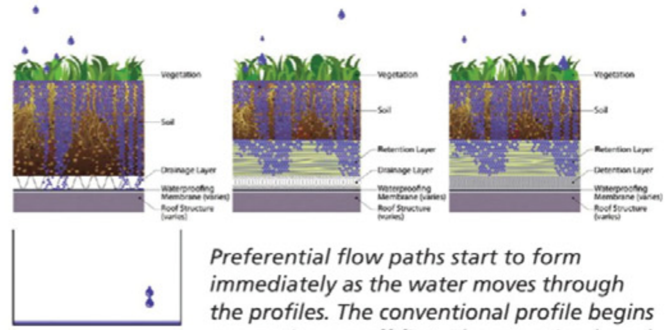
Now imagine a traditional vegetated roof of customary design. The vegetated roof acts like a sponge. However, when the sponge is wet, the entire system is designed to drain rapidly. As mentioned earlier, the rapid drainage is written into most common green roof guidelines, by requiring a high permeability of the growing media mix (engineered soil), and quick draining drainage layers. The 'sponge' (*i.e.* vegetated roof) is only able to absorb a predefined amount of rainfall until saturated, and then behaves exactly like a non-vegetated roof facilitating instant runoff. This is because the distance to drain, slope,

Figure 1

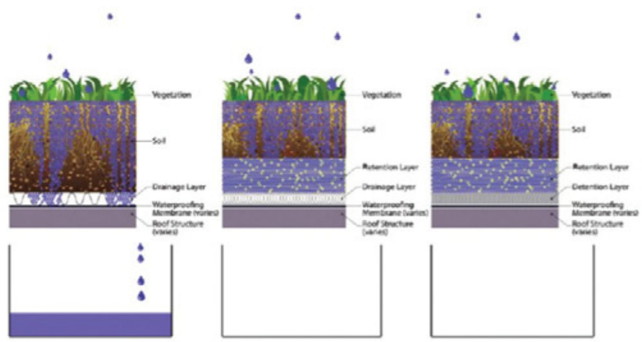
Images courtesy NLSM



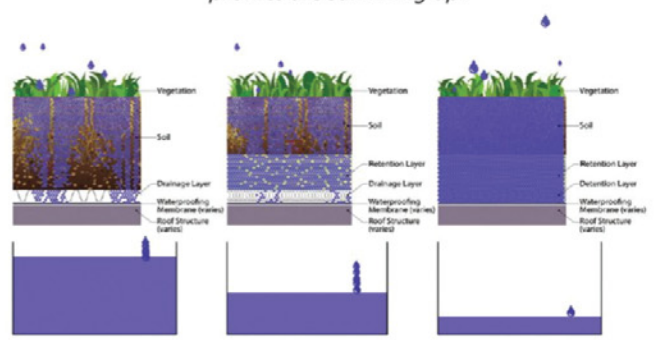
The far-left shows the conventional vegetated roof, the middle depicts a vegetated roof with an added retention layer, and the right shows a vegetated roof with added retention and detention layers.



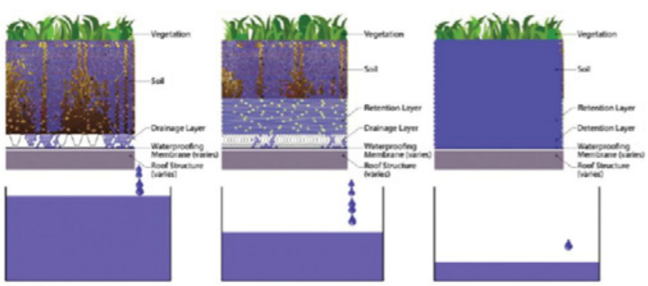
Preferential flow paths start to form immediately as the water moves through the profiles. The conventional profile begins generating runoff first. The retention-based and detention along with retention-based profiles are still filling up.



The conventional profile reaches a breakpoint in which rainfall and runoff rates occur at the same rate. The retention-based and detention along with retention-based profiles are still filling up and are not generating any runoff.



All profiles are generating runoff, and the retention-based and detention along with retention-based profiles are entering the macro-pore filling phase. The macro-filling phase is much shorter for the retention-based profiles compared with the retention along with detention profile, and shortly, rainfall rates are equal to runoff rates for the retention profile.



The macropores of the detention layer profile continue to fill up contrary to the other two profiles. Some runoff is generated, but at much lower rates than the rainfall. The reason for this is that the detention layer is restricting the maximum flow rate, causing some backup in the profile. Runoff will have the same rates and rainfall until full saturation is achieved on the green roof. The detention profile then slowly drains out, thereby delaying the peak runoff volume of the rainfall.

and friction on the surface of the roofing membrane remain the same whether the roof is vegetated or not.

How a vegetated roof can achieve more efficient detention

Though it is possible to achieve detention via increased distance to drain and reduction of the slope, those two changes are often impractical or impermissible. However, the introduction of friction to a vegetated roof system is possible. A new technology involves replacing the traditional fast-draining drainage layer with a 'friction' or 'detention' layer specially calibrated to flow freely at low volumes but to slowdown runoff at higher volumes. Hence, the friction slows runoff enough to ensure that during large storms, runoff rates are lower than rainfall, thus causing a temporary accumulation of water within the vegetated roof. This accumulated water is detention. The water then slowly drains out, often within six to 12 hours of the large rainfall event.

Friction-detention technology offers uniformity and redundancy. Detention is activated by the friction-detention layer's own large surface rather than relying on a single-flow restrictor at a roof drain (which can fail or clog). Uniform detention is advantageous because it means it can work on roofs sloped up to two per cent, as well as flat roofs. Blue and blue-green technology that achieve detention through ponding almost always require a dead flat surface, not always possible to construct. If placed on a sloped roof, ponding-based blue/blue-green technology does not use the surface area efficiently, as most of the water is stored on the lowest part of the roof. If there are internal roof drains, the detention area makes up less than half the roof, which is an inefficient use of space. Further, ponding blue/blue-green technology on sloped roofs would concentrate all the weight around roof drains, versus distributing evenly. This is why those options are almost always limited to dead flat roofs.

In addition to better uniformity, the friction-based blue-green solutions distribute water more evenly throughout and across the entire roof because the whole surface of the detention layer is providing resistance. This uniform resistance or 'friction' causes temporary accumulation of water above the said layer. This excess water is then filtered back up and throughout the entire vegetated roof profile causing all the pores in the system to fill with water. When a vegetated roof profile is temporarily sunk in water in this manner, it ensures every pore is fully saturated. In contrast, a cross-section of a vegetated roof system after a rainfall event would reveal some wet and dry areas. Rain flows through most vegetated systems by preferential flow paths that prevent 100 per cent saturation of the profile. Fully saturating a vegetated roof via friction-detention has many advantages as it increases retention (all the dry areas are now saturated), provides plants with an increased and more even distribution of water, and as a result, increases evapotranspiration, which helps to recharge the vegetated system for the next rainfall.[13]

The research behind vegetated systems with friction-based detention

The images in Figure 1 show the difference in water filling and emptying pore spaces between a conventional vegetated roof using simple drainage cups to expedite fast drainage, a vegetated roof with a retention layer, such as mineral wool, and a vegetated roof with both retention as well as friction-detention layers. The images are based on data from two years of research and several hundreds of tests at the Green Roof Diagnostics (the firm of one of the authors) rain laboratory.[14] The full animation can be found on www.purple-roof.com. The images/animation has been produced with the purpose to describe this phenomenon conceptually.

> A detention layer in vegetated roof systems helps manage the excess stormwater runoff onsite by mimicking friction found in watersheds and aquifers.

Among the various features of a friction-detention vegetated roof, most advantageous is that it can temporarily store and passively release 75 to 100 mm (3 to 4 in.) of rain and can be applied on sloped roofs.

Conclusion

New, innovative technology provides engineers, architects, and building owners the option of incorporating detention into the vegetated roof design for quantifiable and reliable stormwater management. This is best suited to projects in dense urban areas with a large footprint where bioswales or permeable parking is uncommon. Ideally, it is designed at the inception of a project helping to downsize or eliminate a cistern. However, if not designed from the start, a qualified engineer may compute rainfall detention calculations for the site and allow for a vegetated roof detention system substitution to achieve the required rooftop SWM. This helps the building owners achieve ROI by saving valuable space, while meeting municipal requirements to reduce runoff volume and lessen the potential and severity of urban flooding.

Notes

[1] Read *Biomimicry: Innovation Inspired by Nature* by Janine Benyus, published in 1997 by Harper Collins.

[2] Refer to *Sustainability: Essentials for Business* by Scott T. Young and Kanwalroop Kathy Dhanda, published in 2013 by Sage Publications Inc.

[3] Consult "Report on the Environmental Benefits and Costs of Green Roof Technology" by D. Banting, H. Doshi, J. Li, and P. Missious for the City of Toronto.

[4] Read "Sedum cools soil and can improve neighboring plant performance during water deficit on a green roof" by C. Butler and C.M. Orians for *Ecological Engineering*, 2011.

[5] See Note 4.

[6] For more information, read "Review on the roles and effects of growing media on plant performance in green roofs in world climates" by F. Kazemi and R. Mohorko, published in 2017 in *Urban Forestry and Urban Greening,* and "Moisture Measurements as Performance Criteria for Extensive Living Roof Substrates" by E. Fassman and R.J. Simcock in the *Journal of Environmental Engineering*, 2011.

[7] Consult B. Garner's Green Roof Diagnostics data accessible via Purple-Roof Green Roof Modeler, 2019.

[8] Read "Green roof performance towards management of runoff water quantity and quality: A review" by Berndtsson J. Czemiel for *Ecological Engineering*, 2010.

[9] See Note 4.

[10] Details at M. Welsh's "Toronto keeps flooding when it rains hard" article in the *Toronto Star* and M. Mann's "The age of the flood," article in *Toronto Life*.

[11] Read G.N. Ilya Bañares' "Flooded walkways, subway service reopened after another night of flooding in Toronto" article in the *Toronto Star*.

[12] Consult G. Marr's "Buying a Condo, Maybe you should get the parking spot too," published in the *Financial Post* in 2015 and the Ibis World Report, "Parking Lots & Garages – Canada Market Research Report," published in May 2019. The calculation is based on average parking fee of $20 per day for 365 days.

[13] See Note 8.

[14] See Note 7.

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