Practical Considerations on Design and Installation of Green Roofs: The Waterproofing Challenge

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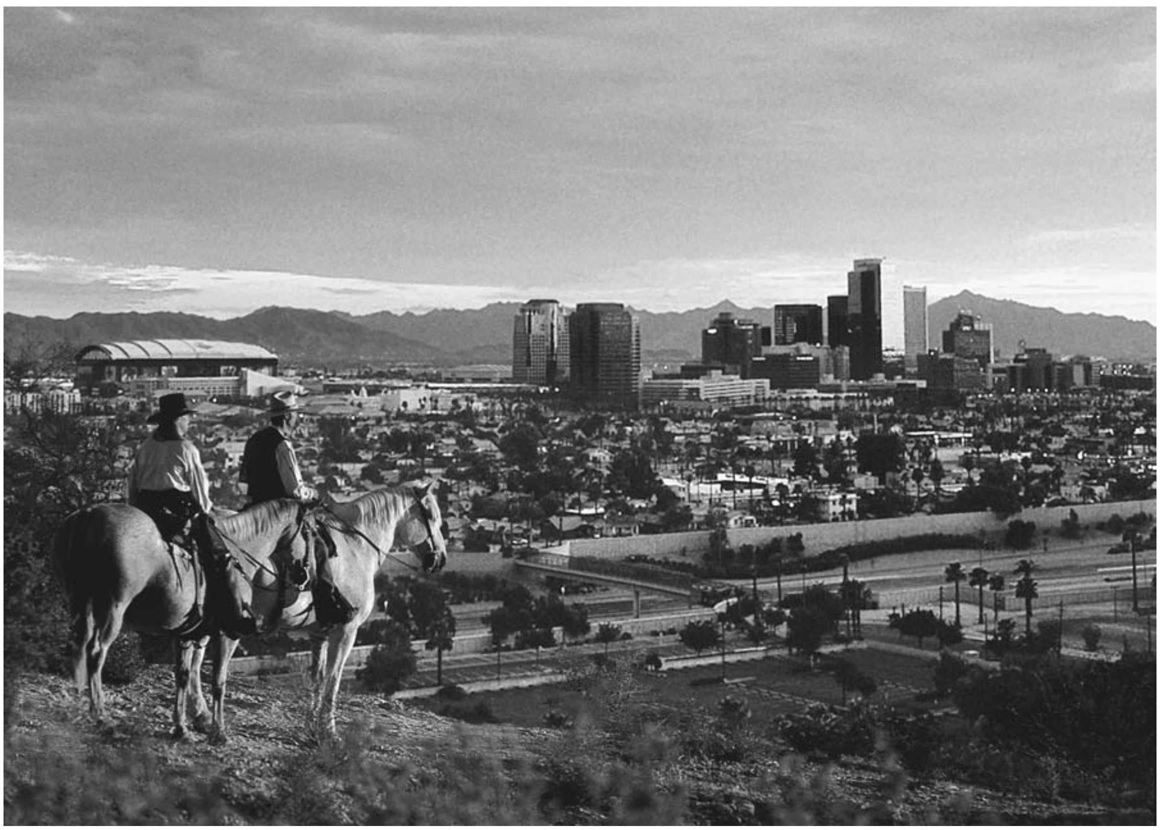

Roof Consultants Institute

ABSTRACT

Roof gardens, commonly referred to today as "green roofs," can be traced back to the Hanging Gardens of Babylon and have been used in parts of Europe and Mexico for centuries. It has been reported that they were introduced to Canada by the Vikings and later the French colonists in Newfoundland and Nova Scotia, through the use of sod as a roof covering. A green roof environment does not demand an entirely different roof design philosophy. The sound principles involved in the design and construction of a conventional or protected roof membrane can be modified and/or adapted to green roofs.

SPEAKER

A graduate of O.A.C., now known as the University of Guelph, **DOUGLAS FISHBURN** has over 40 years of roofing, building envelope, construction, and design experience. He has presented technical papers at several international building symposiums. Mr. Fishburn contributes technical articles to professional trade journals, such as *Plant Engineer, The Canadian Architect*, and *Specifications Canada*. He sits on a number of Canadian General Standard Board (CGSB) committees and the Canadian Standards Association (CSA), which formalizes standards for construction products. In addition, he has lectured at universities and provides training seminars for trade organizations, universities, and government bodies. Mr. Fishburn is a past president of the Ontario Chapter of RCI and has held the position director of the old Region VIII for RCI.

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ABSTRACT

Roof gardens, commonly referred to today as "green roofs," can be traced back to the Hanging Gardens of Babylon and have been used in parts of Europe and Mexico for centuries. It has been reported that they were introduced to Canada by the Vikings and later the French colonists in Newfoundland and Nova Scotia, through the use of sod as a roof covering. A green roof environment does not demand an entirely different roof design philosophy. The sound principles involved in the design and construction of a conventional or protected roof membrane can be modified and/or adapted to green roofs.

Over the last 40 or 50 years in Canada, roof landscaping has been used over parking decks and podiums to improve aesthetics and create market appeal for both commercial and residential buildings. Green roofs offer many operational, financial, environmental, and social benefits. These benefits can be short-lived if the waterproofing assembly fails to provide its principal function: a waterproof environment.

The environment to which it is exposed, its design, method of construction, and frequency of maintenance can impact the durability of any waterproofing system. Improper design, poor construction practices, and lack of proper maintenance have been found to result in premature system failure. There is no reason to think that such factors would have a different impact on green roof applications. In order to mitigate the risk of failure and improve long-term performance, specific considerations must be paid to load requirements, slope and drainage, thermal performance, the design of the details, the waterproofing membrane, testing, and the requirements for maintenance.

This paper focuses on some of the factors impacting on the durability of the waterproofing system, particularly with intensive green roofs, and suggests methods of design and construction that can help achieve long-term watertight service.

Green roofing can range from a carpet of flowers to grasslands to woodlands. The approach to green roofing has been refined over the years and is generally divided into three types: intensive, semi-extensive, and extensive.

Intensive green roofing is characterized by its higher weight, which is due to the depth of growing medium [150 mm (6 inches) or more] required to accommodate larger shrubs and trees. These systems weigh 290 to 967 kg/m^2 (50 to 200lbs/ft^2).

Semi-extensive green roofing is characterized by a depth of growing medium of approximately (150 mm/6 inches). The weight of a semi-extensive system can vary from 169 to 290 kg/m2 (25 to 50lbs/ft^2).

Extensive green roofing is characterized by its lower weight, which is due to reduced depth of growing medium (150mm/6 inches or less), saturated weights between 72 and 169 kg/m^2 (12 to 25 lbs/ft^2), and the use of smaller plants.

The following are the major advantages and disadvantages of green roofing as compared to conventional roofing applications.

Advantages

- Increased design life expectancy compared to a conventional roofing system.
- Decreased roof maintenance.
- Reduced heating and cooling costs.
- Reduced sound.
- May provide fire protection.
- Reduced water run off.
- Aesthetic appeal.
- Improved air quality.
- Food production.
- May expedite municipal approval.
- Qualifies for LEEDS and Energy Star programs.*

Disadvantages

- Higher cost of construction due to increased load capacities and increased height of flashing.
- Higher cost of construction due to landscaping and planting requirements.
- Higher cost of landscape maintenance.
- Higher cost of roof replacement.

- Difficult and costly to find and repair leaks.
- Longer reconstruction periods impact the aesthetics of intensive systems, since mature trees and shrubs are typically replaced with immature ones.

Regardless of the finish, roofs can be classified as either high-slope (which rely upon their ability to shed water), or low-slope (which rely upon waterproofing to provide water-tightness). Low-slope roofs are divided into two types: conventional, where the roof membrane is placed above the roof insulation; or protected, where the roof membrane is placed below the insulation. In green roofing applications, the system must employ water-tight technology, regardless of slope.

While conventional roofs can employ green roof technology, typically intensive green roofs incorporate protected roof membrane designs.

Protected roof membrane

In a protected roof membrane design, the roof membrane is placed under the insulation. With this configuration, regardless of the roof finish (gardens, pavers, or gravel), the roof membrane is shielded from the temperature extremes of the environment and protected from traffic during and following construction.

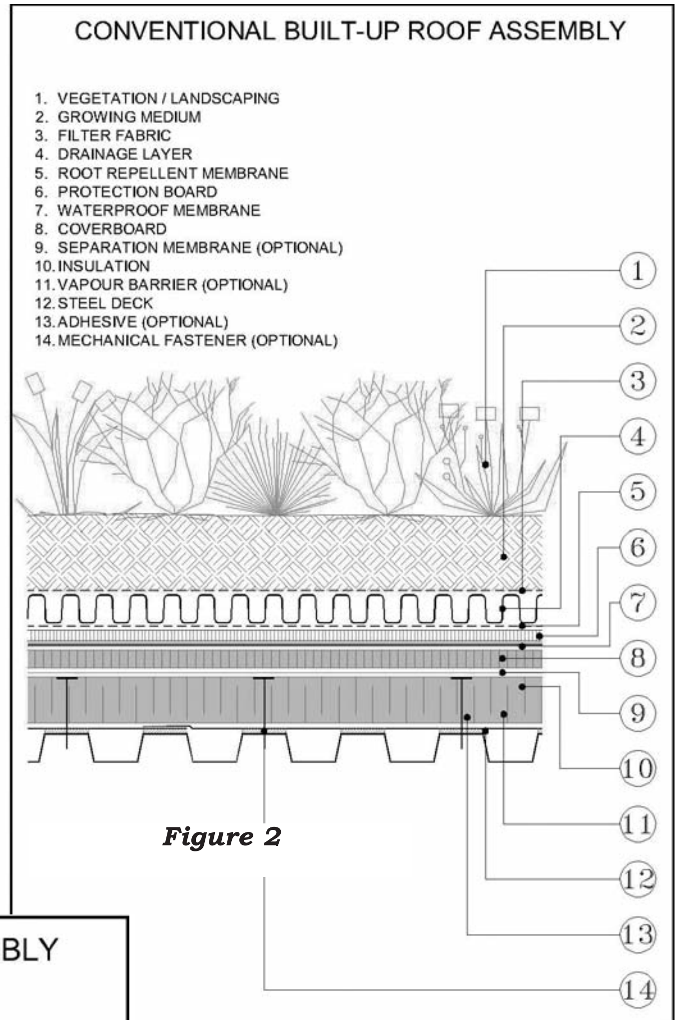

Figure 2

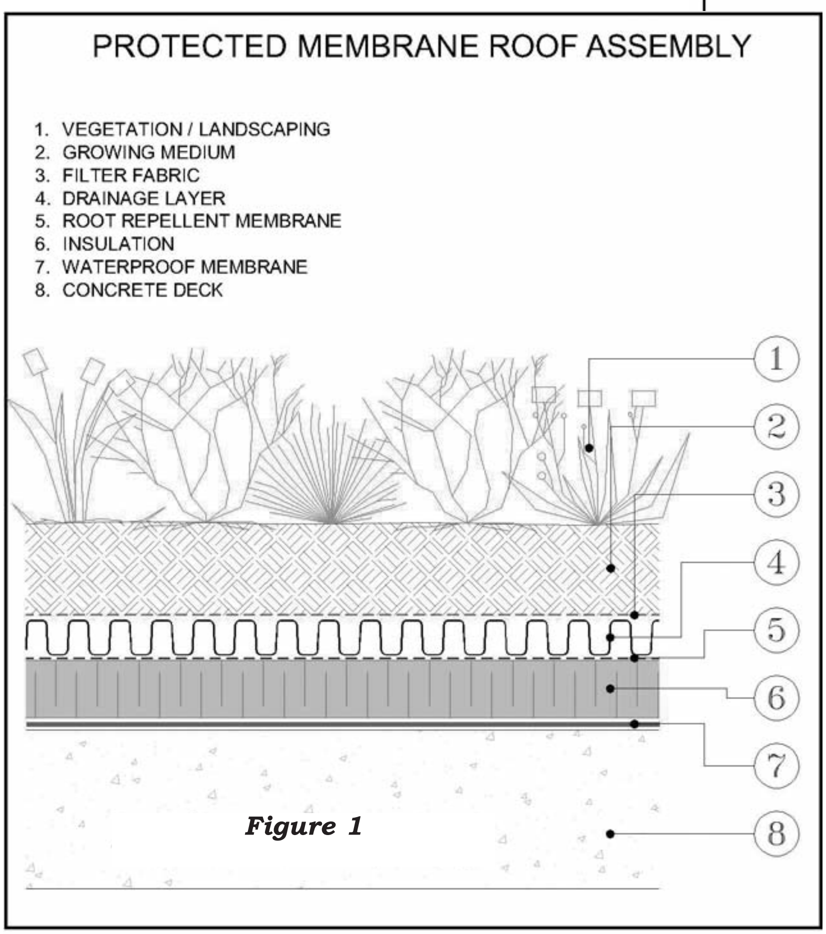

Figure 1

In a protected roof membrane design, the membrane serves the functions of waterproofing, air barrier, and vapor barrier. An example of a protected membrane roof is shown in *Figure 1*.

Conventional roof membrane

In a conventional roof, the membrane is placed above the insulation and typically provides the function of waterproofing. When green roofs utilize a conventional roofing system, they have many of the features and benefits of protected roof membrane assemblies. An example of a conventional roof is shown in *Figure 2.*

Roof Deck and Load Requirements

The roof deck must be designed to carry the anticipated structural loads, including the temporary loads imposed

Figure 3. Courtesy of the Bank of Canada, Ottawa, Ontario, Canada.

Figure 4. Courtesy of the Minto Hotel, Ottawa, Ontario, Canada.

by construction equipment and stockpiling of materials. While a number of roof decks types can be utilized in both intensive and extensive green roofing, the use of concrete is preferred in the construction of intensive green roofs due to its high strength, lower cost, and ease of providing slope to drain.

When concrete decks are left exposed and used as staging areas before the installation of the waterproofing membrane, consideration should be given to using additives in the concrete mix to reduce water absorption, and epoxy-coated rebar to improve the deck's ability to provide long-term service without extensive repair. Provided the deck has been designed to carry the anticipated dead and live loads, lightweight decks, such as wood plank and/or steel, can be employed in the design of green roofs.

The use of lightweight materials in the design of green roofing increases their potential for use in both new and existing buildings. Building up the planting area with polystyrene insulation in lieu of a full depth of soil, using drainage mats in lieu of a heavy layer of gravel, or using planting medium and plant varieties that can grow in a minimum depth of soil will contribute to reduced weight.

One solution to address gravity or live loads is to use planter boxes for larger shrubs and locate them over columns or at the roof perimeter. Examples are shown in *Figures 3* and *4*.

Concrete-topped insulation, rubber walkway pavers, stepping stones, or wood or plastic walkways in traffic zones are all designed to reduce the load on the roof assembly. If wood walkways or paving stones are incorporated in the design, they should be installed to allow easy removal in order to gain access to the waterproofing system. The greater weight of green roofs as compared to conventional roofing systems can be a major limitation from both a cost and functional point of view. An example of stepping stones used to reduce weight is shown in *Figure 5*.

While the structural requirements can be easily accounted for during initial construction, owners may not be willing to pay the additional costs to upgrade the structure to carry the additional load capacity required for green roofs.

While existing protected membrane roofs may be viewed as good candidates for green roofing, the load capacity needs to be carefully considered. Many protected membrane roofs that are more than 20 years old could have the necessary spare load capacity to install extensive green roofing.

This is due to the fact that these roofs were typically designed with the insulation being bonded to the roof membrane. These roofs were positively ballasted to prevent insulation floatation, which would result in damage to the roof membrane.

The weight of the gravel ballast was typically a minimum of 48.8 kg/m^2 for 50 mm of insulation or less. The weight was increased at a rate of 24.4 kg/m^2 for every 25 mm of additional insulation. Roofs installed with 100 mm of insulation are typically ballasted at 107 kg/m^2.

Within the last 15 years, many protected roofs were designed as lightweight systems. With protected lightweight systems, the insulation was loose-laid and a water-

Figure 5. Courtesy of the Minto Hotel, Ottawa, Ontario, Canada.

permeable fabric installed over the insulation. The ballast was installed at a weight of 48.8 kg/m^2. The insulation was expected to float under ponding water conditions.

If the roof periodically ponds water (which can occur if positive slope has not been provided or control flow drains are used), the water-permeable fabric was expected to keep the insulation boards in alignment like a raft floating on water.

Designers and contractors must proceed with caution when substituting the gravel ballast on lightweight protected roof membrane assemblies and installing an extensive green roof cover, particularly when the roof has been constructed with 100 mm of insulation. The unsaturated weight of growing medium or less dense soils may be insufficient to prevent floatation, and failure of the landscaping will result.

The Canadian national and provincial building codes are not static; they change to reflect increased or decreased snow loads. In recent years, the snow loads in Toronto have been reduced. This reduction may, in some cases, allow additional load capacity for the installation of green roofs.

Conventional roofs, such as modified membrane or built-up roofs, are typically much lighter than protected membrane roof assemblies and may offer more flexibility in the design of green roofing in regards to gravity loads. The weight of a built-up roof membrane can be reduced to approximately that of a modified roof membrane by substituting the bitumen and gravel surfacing with a ply of modified membrane cap sheet. Depending on the design of the system, this reduction in weight is approximately 25 kg/m^2. These systems are generally referred to as hybrid roof membranes, and are outlined elsewhere in this paper.

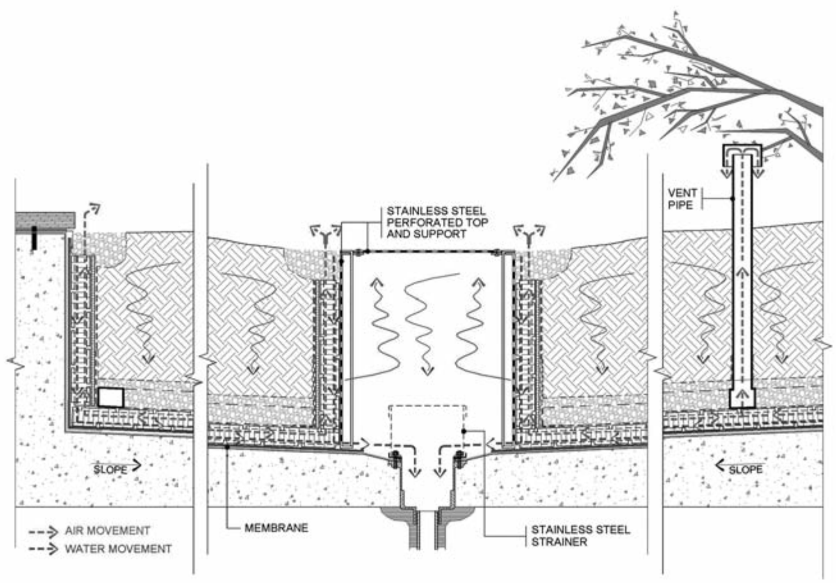

Figure 7

Slope and Drainage

Landscape roofing increases the control of stormwater management since it absorbs rainwater and either releases it more slowly into the storm drainage system or releases the water through evaporation. While the installation of landscape roofing may eliminate the requirements for control flow drains, municipalities may dictate otherwise.

The use of controlled flow drains should be avoided since they can back up water into the landscaping and increase the effects of wetting and drying of the roof membrane.

Roof decks should be designed to shed water effectively. A slope of 2% or a 1/4-inch fall per linear foot should be considered the minimum requirement. On slopes in excess of 8%, a restraint system may be required in order to keep the roofing system and landscaping in place.

A restraint system must transfer the gravity load to the structure, but must also be designed to accommodate drainage. If insufficient slope is provided, long-term creep deflection of the structure or oversights in construction can collect silt that washes out of the growing medium and collect at low points, thereby blocking drainage paths. To aid in obtaining positive roof drainage in addition to positive slope, roof drains should be installed in a sump that will allow them to be set below roof level. Drainage sumps on concrete decks should be a minimum of 1200 mm x 1200 mm and should slope gradually from general roof level to a minimum 19 mm at the roof drain.

Excessive slope can cause wrinkling of the roof membrane and break adhesive bonds between membrane layers. The sump should be designed to accommodate variations in construction and ensure clamping rings do not restrict water flow. Clamping rings with drainage slots at the bottom are preferred in order to allow 100% drainage at the membrane level. A buildup of silt around roof drains will encourage vegetation growth and

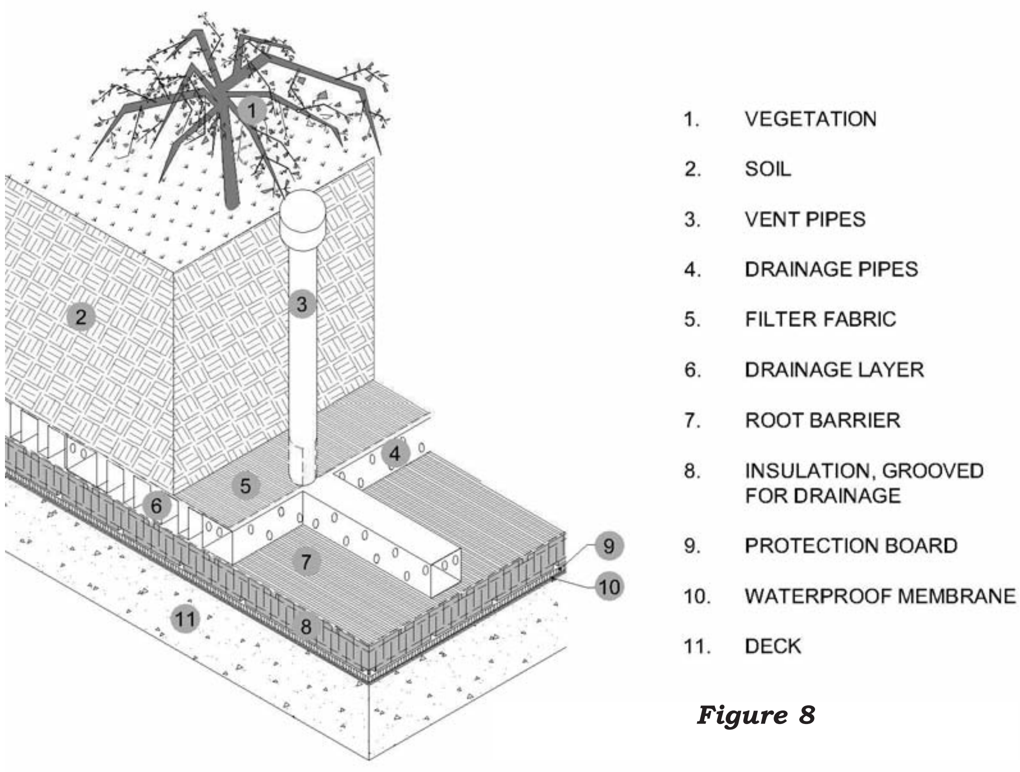

Figure 8

restrict drainage paths. *Figure 6* illustrates an example of a roof drain for a conventional extensive green roof.

While most landscape architects are well aware of the requirements for irrigation and drainage to maintain the plant material, often little consideration is paid to the impact of water on the performance and durability of the waterproofing system.

While membranes used in these types of applications have watertight characteristics, membranes will have a tendency to absorb moisture over time when immersed in water.

Typically an increase in the membrane's moisture content will erode its performance characteristics and shorten its life expectancy. Increased rainfall, low temperatures, and slow drying conditions characterize late fall days in most of Canada. Wet soil will become frozen during long periods of freezing temperatures, which will prevent topside drying. A buildup of snow on the roof will retard surface drainage; however, increased water run off may occur when the soil becomes frozen and snow cover is minimal.

Good slope and evaporation will minimize the moisture content of extensive green roofs when installed over conventional roof systems. The installation of a drainage and venting system in intensive green roofs will improve both summer and winter drainage and promote drying at the membrane level, thereby improving the system's response to moisture control. This is achieved by providing continuous drainage and venting paths at flashings, and roof drains that are connected to drainage pipes at the insulation level. The drainage pipes are vented to the roof surface to promote drying. The system is shown in both sectional and isometric views in *Figures 7* and *8*.

The plant material or landscape furniture (such as benches or planters) can camouflage the vent pipes. Three types of drainage pipes are available: round, square, or triangle. The latter two are preferred, due to their ability to evacuate water and increase water-carrying capacity at a lower drainage plane.

Due to their exposure to moisture and the corrosive nature of some fertilizers, the use of drains that are made of corrosive-resistant material, such as copper or stainless steel, should be considered. If corrosive-resistant drains are not available, preference should be given to fitting drains with stainless steel bolts, clamping rings, and strainers. Roof drains must be accessible for regular inspection and maintenance.

Roof drains in intensive landscaping may be located a meter or more below the surface and access wells need to be provided as shown in *Figure 7*. These wells also serve as shafts for ventilation. Roof drain strainers should be hinged to facilitate cleaning.

If cast-iron drains are used, they should be painted or coated to improve their durability. The coating must be compatible with the roof membrane. Bolts used to secure strainers should be stainless steel wiped with Teflon Dope to minimize rusting and to make future removal easier. Attention to these details will avoid excessive damage and the need to replace roof drains at considerable risk and cost when the waterproofing system is eventually replaced.

Heat loss and the collection of silt due to soil wash out can result in retained moisture around drains, providing an ideal environment for vegetation growth. The use of zinc strips at drain screens will retard moss and other vegetation growth and assist in keeping drainage paths open. Underscoring the insulation

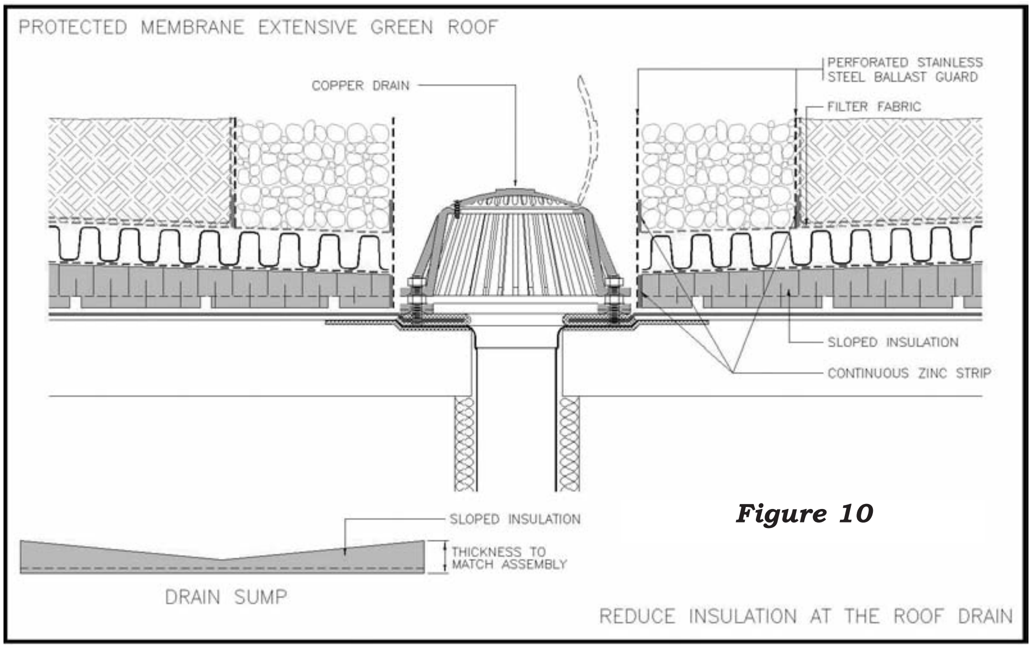

Figure 10

to provide routes for drainage and reducing the insulation thickness at the drains will also improve drainage and drying of the sub-surface components. This subject is reviewed in more detail under the heading of "Roof Insulation."

Roof Insulation

Green roofs designed with a protected membrane place great demands on the insulation component of the system. The type of insulation used must have good physical and moisture-resistant properties. Type 4 extruded polystyrene is one such insulation. Use of a high density material should be considered when the roof is to be subjected to increased loads such as roof planters, waterfall features, or heavy traffic during or following construction.

It is recommended that the insulation be loose-laid. Loose-laid insulation will speed construction and allow for salvage and reuse when repair or replacement is required, thereby reducing cost and lessening the impact on the environment. On roofs with slopes approaching 8%, care must be used to prevent insulation slippage (as outlined in the "Slope and Drainage" section). When calculating heating and cooling loads, the growing medium can add to the system's thermal performance and may be substituted for part of the insulation.

While the drainage of green roofs has not been extensively analyzed, it is believed that approximately 80% of all water drains should be above the insulation and 20% at the membrane level. Drainage under the insulation is a slow process. It is retarded by the offset of insulation boards one to another, water tension, irregularities in the deck over which the membrane is installed, and irregularities in the roof membrane that result in variations in the membrane thickness, particularly when liquid-applied systems are installed. Side laps in the membrane can dam water when the membrane is laid across the slope, such as in the case of single-ply systems.

In order to improve drainage and provide a direct path of water to the roof drains at the membrane level, drainage grooves should be installed around the perimeter and in the field of each insulation board. The drainage grooves can range from 13 mm to 19 mm wide and deep, and can be installed by the insulation manufacturer or contractor. Depending upon the construction schedule and anticipated loads from construction traffic, the underscoring of insulation may eliminate the requirements for a drainage mat and protection board on some systems. An example of drainage grooves is shown in *Figure 9*.

In order to promote drainage, reducing the thickness of the insulation at roof drains is recommended, since more water is shed from the surface of the roof insulation than below it. Reducing the insulation thickness and increasing the thickness of landscaping at the drains will offset any floatation at the low points of the roof.

This will also increase the heat loss adjacent to the roof drains, which will assist in keeping drainage paths open in the winter months. An example of reducing the insulation at roof drains for landscape roofing is shown in *Figure 10*.

When the roof membrane is installed above the insulation, the insulation should be installed with a high-density coverboard in order to improve the roof membrane resistance to puncture from traffic.

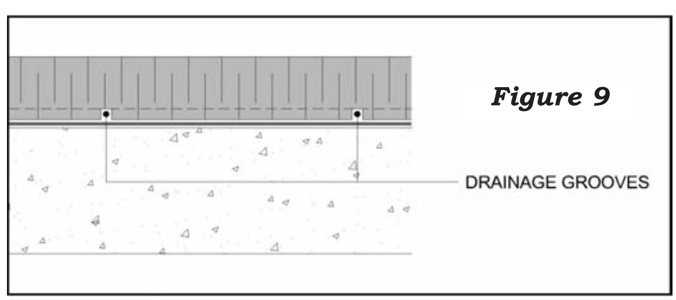

Figure 9

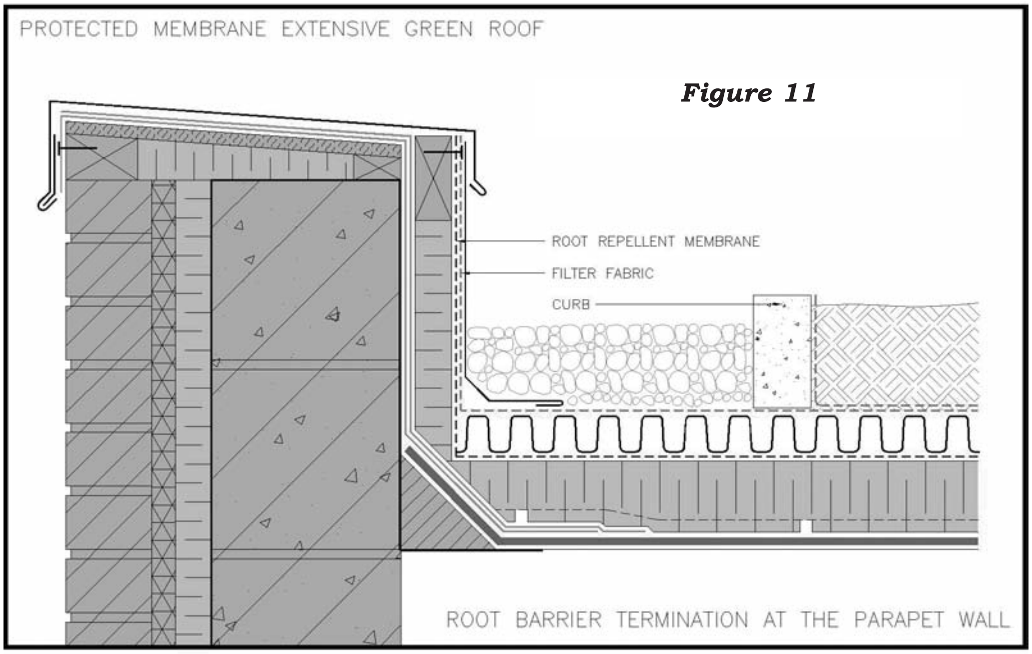

Figure 11

Waterproof Membrane

The incorporation of a root barrier was not generally included in most early landscape roofing designs; however, the protection of the waterproofing membrane from root penetration is now receiving general acceptance. Some membranes, such as polyvinyl chloride (PVC), provide a natural root barrier. Those incorporating organic material such as asphalt-based products are susceptible to micro-organic activity and root penetration.

Roots can infiltrate small deficiencies in the membrane and lap joints, resulting in a breach of the waterproof membrane. Protection from penetration can be provided with sheet root barriers. Other membranes, such as modified membranes, can be manufactured with foil films or be chemically altered to avert root penetration.

To prevent roots from congesting drainage routes leading to drying at the insulation level in protected membrane roofs, a root barrier should be used above the insulation as shown in *Figure 11*.

The level of protection against root penetration must be assessed with each project, since some plant varieties have more aggressive and deeper root systems. Planting shrubs and trees that have aggressive root systems in concrete planters is one approach to root containment.

To be effective, a sheet root barrier must be sealed at overlap and around penetrations such as soil pipes, and carried up flashings at parapets, walls, and curbs. During the design stage, chemically altered membranes must be verified to be compatible with other components, such as metal flashings built into the membrane layer. *Figures 11* and *12* provide examples of where to terminate the root barrier at a parapet wall and vent pipe.

Countries such as Germany have adopted standardized membrane testing for root penetrations. For example, root penetration is tested under the German FLL green roof standard over a three to five-year period. While testing for root membrane penetrations is now under review by ASTM, to date there is no Canadian test standard.

While most single-ply membranes, such as loose-laid ethylene propylene-diene membrane (EPDM) and polyvinyl chloride (PVC), have been used for landscaped roofs, great care in the design and application must be employed. These systems do not have the benefit of redundancy,

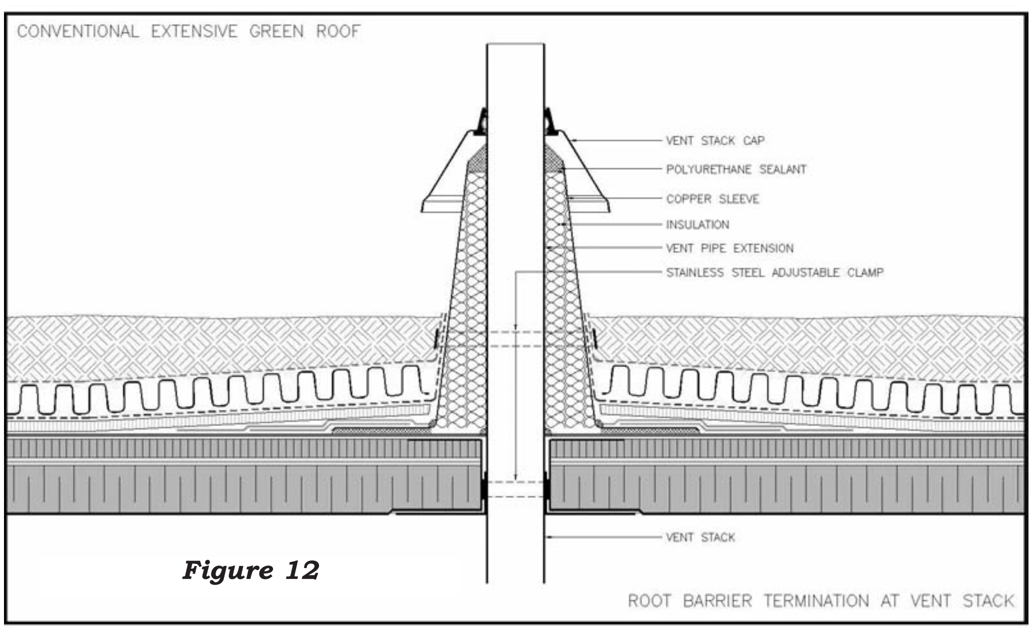

Figure 12

and have a tendency to be more easily damaged by construction traffic.

Because single-ply membranes characteristically do not have the mass of multi-ply membranes, defects in the deck such as trowel ridges in concrete decks or small stones tracked onto the working surface can puncture the membrane from the underside. If a single ply system is used on a concrete surface, such as in a protected roof assembly, it should be installed with a moisture-resistant underlay vent such as polyester felt.

Thicker membranes have improved physical characteristics and may carry longer manufacturer's warranties. In short: the thicker, the better. While changes in technology have improved the performance of field seams in elastomeric membranes, the use of a cover strip over the seam will increase long-term performance.

Single-ply membranes can be solidly glued to the substrate or installed with water cut-off mastic to limit the spread of water under the membrane should a leak occur, however, field experience has shown that single-ply membranes have only limited success unless increased care is provided. Multiple layer systems that are solidly bonded to the deck (such as hot rubber, built-up membrane using kettle-modified SEBS mopping asphalts, or prefabricated modified membranes), offer good water resistance.

They also provide the redundancy of a multi-ply system and (in the case of leaks) will limit moisture ingress to localized areas since they are bonded to the deck.

Additional layers of membrane can be added if needed to build up low points and eliminate water ponding on the membrane surface. Should a leak occur, the disruption and cost to remove the landscaping in order to gain access to the roof membrane could be substantial. To avoid this, it is prudent to increase the number of plies of membrane beyond that normally recommended for conventional use. Increasing the number of plies will have a minor impact on cost, but can have a major impact on long-term performance and roof service life.

When constructing a built-up membrane, the use of glass or polyester felts is recommended. In addition, the installation of a cap sheet such as 250 gm/m^2 polyester cap sheet over a bituminous built-up or hot rubber membrane will improve the system's crack bridging ability, tensile strength, and puncture resistance.

The use of a granule-surfaced cap sheet as a surface to the membrane also provides a resistant work surface, prevents the insulation from becoming adhered to the membrane, and aids in drainage by reducing water film tension. Due to the ability to spot physical damage, should it occur, light-colored membranes are preferred.

Because asphalt-based products such as membranes constructed with asphalt or hot rubber are subject to root penetration, the use of a modified cap sheet that has been chemically formulated to deter root penetrations, as the top layer will substantially improve the durability of the system. *Figure 13* shows a chemically resistant, modified cap sheet being installed over a built-up membrane.

When incorporating ponds and waterfalls into landscape roofing designs, an additional, independent waterproofing system should be installed. Large areas of landscaping should be separated into smaller sections by the installation of area dividers.

Figure 13

The separation allows for precise moisture control according to the requirements of any given section, and enables a wider variety of flora to be successfully established, which can add to overall aesthetics. The required drainage slope while minimizing the impact of elevations at wall junctions can also be achieved. In addition, this approach will reduce the cost of repairs should the need arise, since the leaks would be contained within smaller areas.

While drainage mats and root barriers are important elements in a landscape roofing design, they can also contribute to trapping moisture in the roof assembly. Trapped moisture within protected roof assemblies due to restricted topside venting can increase the moisture content of the membrane and insulation, even if type 4 polystyrene insulation is used. Good drainage and topside venting are prerequisites if long-term performance is to be achieved. More study is required on the negative impact of root barriers and drainage mats on topside venting.

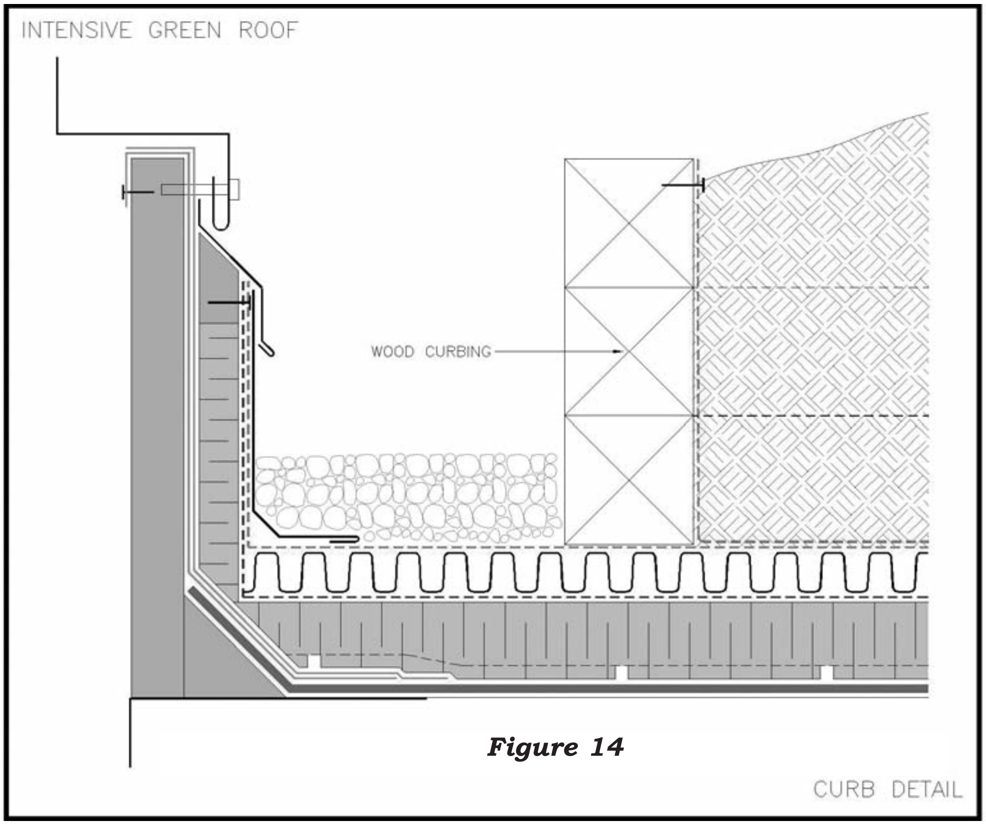

Figure 14

Figure 15. Courtesy of the Minto Hotel, Ottawa, Ontario, Canada.

Flashing

Flashings typically represent 70% of all waterproofing problems. The detailing of flashings on roofs or podiums often poses increased challenges. In addition to landscaping, these areas often house rooftop mechanical equipment, and may incorporate conduits for electrical and mechanical services, lightning protection, railings, fall arrest systems, and davit arms for window-washing equipment. Because rooftop equipment penetrates the moisture and thermal plane, flashings must be designed not only to be watertight but also to prevent condensation and air leakage, and be insulated to provide thermal continuity.

Flashings at roof access points are of particular concern. Either flashing heights must be raised to accommodate the depth of growing medium, or curbs provided to separate the flashings from plantings or patio areas.

The use of curbs can allow deeper depths of growing medium without substantially increasing flashings heights, examples of which are shown in *Figures 14* and *15*.

F.L.L. standards as used in Europe typically provide a vertical separation (border) between the curbs and flashings. This separation allows for phased construction and prevents conflict between the trades during initial construction. The separation can be designed to allow for drainage, provide a fire barrier, and allow for foot traffic to gain access to the flashings and plant areas. The width of the gravel bed can be tailored to each project but is typically shown at 500mm.

When a border is provided at exterior parapet walls, the height of the parapet and the size of the aggregate used must be sufficient to prevent the roof and roof gardens from being dislodged. Wind issues have not typically been a problem when constructing roof gardens at or near grade level; however, their use on taller structures is a concern. Building code and Factory Mutual requirements must be considered early in the design stage.

While L.L.C. recommendations in regard to positioning the gravel bed adjacent to flashings have merit, typically when designing parking decks in North America, the landscaping has been typically carried up to the flashings with good success.

Given specific requirements of the design, the width of the gravel bed could be reduced, providing a vertical and horizontal drainage plane, and should be provided adjacent to all flashings to encourage drainage away from these critical points. The drainage plane at flashings can also be used to vent moisture out of the system and minimize the impact of local environment on the membrane and flashings.

The drainage plane can be provided by a combination of insulation, protection board, and crushed aggregate or river stone. It is also recommended that root barriers, drainage mats, and insulation be installed parallel to the roof perimeter. This will facilitate ease of finish and access, should a leak occur.

Where possible, membrane flashings should be carried over and turned down the outside face of the building. The top of all flashings should be sloped to drain to the building interior. Depending on the type of membrane flashing, between 4 to 8% slope is recommended.

In order to improve long-term performance, covering the vertical portions of the roof flashing with insulation is recommended. This approach will not only reduce the impact of roof traffic and the external environment on the performance of roof flashings; it improves the overall thermal performance, helps to eliminate condensation traps, and reduces the need and frequency of maintenance.

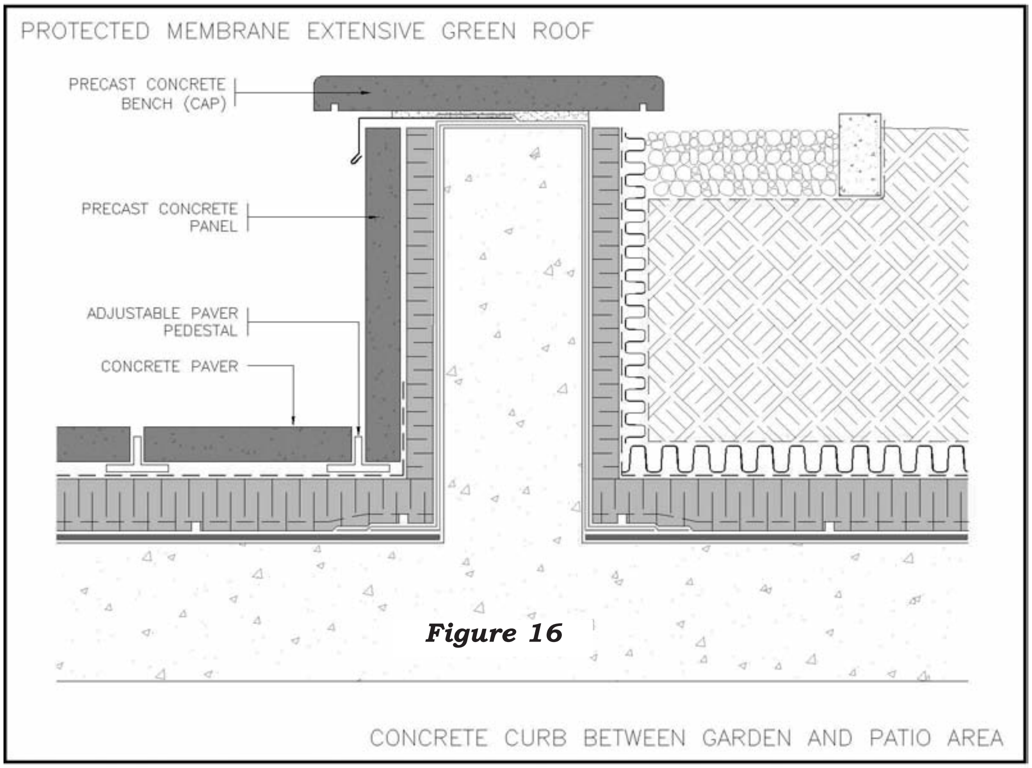

Figure 16

In order to meet minimal height standards, membrane flashing can be carried up the walls and hidden behind siding or pavers as shown in *Figure 16*.

While tradeoffs are common in design and construction, watertightness should not be sacrificed for aesthetics. Due to their resistance to corrosion, copper or stainless steel materials are recommended to flash roof penetrations, such as soil pipes or exhaust stacks, that are built into the waterproofing membrane. Depending upon their location, high-grade pre-finished metal, copper, or stainless sheet counter flashings are also recommended for the same reasons.

Aluminium flashings are not recommended due to poor performance when exposed to some fertilizers, and due to their high thermal coefficient of expansion.

While this article primarily reviews the application of landscape roofing on protected membrane roofs, the application of extensive green roofs is also finding acceptance on conventional roofs.

When a landscape roof is installed on a conventional roof assembly, many of the benefits normally associated with protected roofing systems (shielding the membrane from environmental extremes) can also apply to the conventional roof. There are, however, exceptions.

Flashings on conventional roofing have typically been the “weak link.” Many of the problems associated with flashings can be mitigated on conventional roofs by insulating them similar to protected membrane roofs as shown earlier in this paper.

A comparison of a typical conventional roof design at a parapet wall is shown in *Figure 17*. An alternate approach as suggested in this paper is shown in *Figures 18* and *19*.

Testing

Leaks in green roofs can be costly to investigate and repair. Most membrane manufacturer warranties include clauses that state the cost of removal and replacement of the overburden in order to gain access to their membrane is not covered by the warranty.

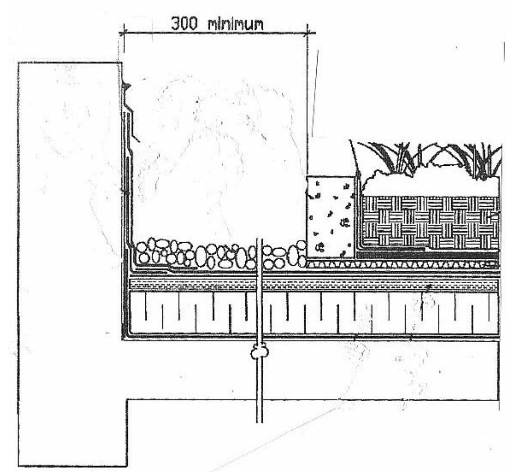

Figure 17 – From a report on environmental benefits and cost of landscape roofing technology for the city of Toronto. Typical Sopranature green roof assembly on conventional roof (adapted from Soprema Inc.).

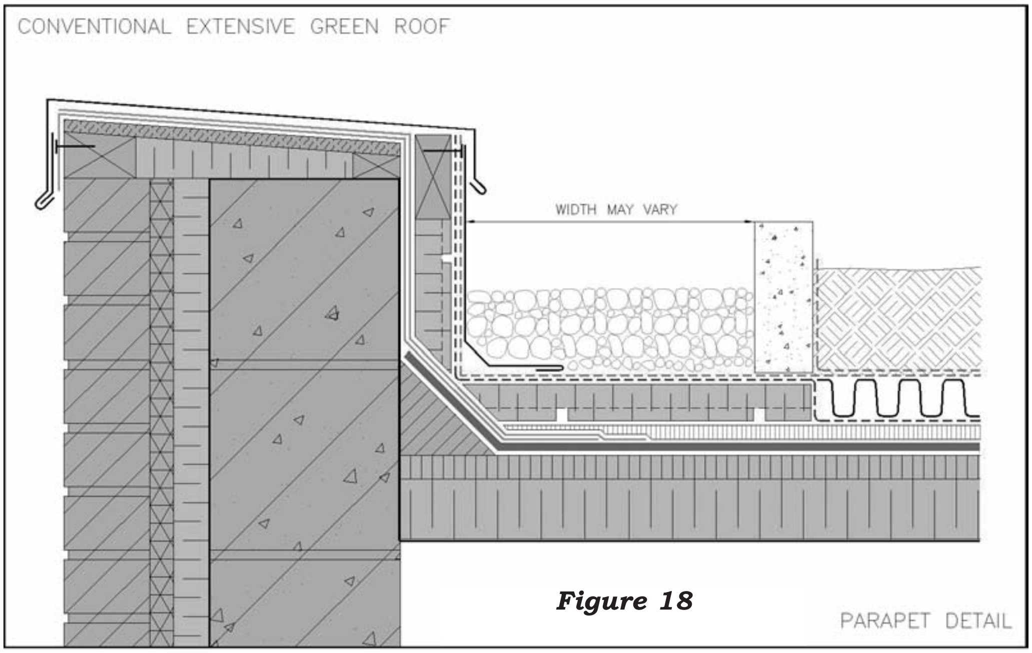

Figure 18

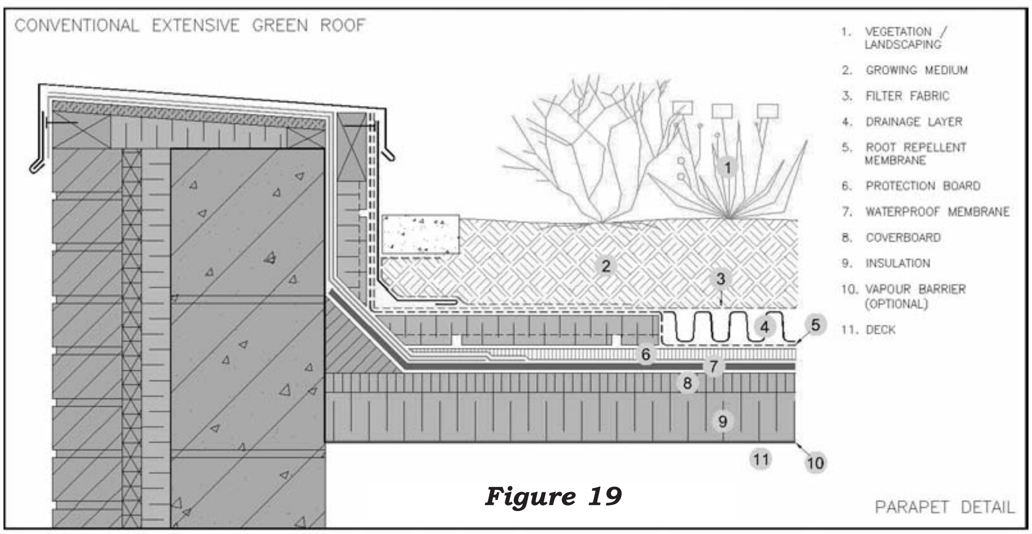

Figure 19

Some warranties also give the manufacturer the right to claim against third parties to recover the cost to investigate and repair should it be proven that the leak was not the result of defects in the membrane. This could apply to leaks that result from damage caused by others, or leaks in walls that eventually find their way to the building interior.

While the use of modular systems makes the green roof forklift accessible and reduces the time and cost of investigating and repairing leaks, testing of the system to ensure it is defect and leak free should be incorporated into all landscape roofing construction. Compared on a per square meter basis, repairs due to leaks after landscaping and planting is completed can be four to ten times greater than the cost of repair at time of initial construction. In order to minimize in-service problems, some form of testing is recommended.

Although visual inspection during construction provides useful information, testing can also include water testing, infrared, nuclear, capacitance, electric field vector mapping, moisture sensors, and air pressure. These test methods are often used in concert with one another.

This paper does not review the features and benefits of the particular test methods, but is intended to highlight some of the systems available.

Positive bonding of the waterproofing membrane offers advantages over loose-laid systems; however, some single-ply systems, such as PVC, can be installed with double welds that allow them to be pressure treated with air to confirm their continuity.

When water testing is employed, the test is completed on the exposed waterproofing membrane by dividing the roof into zones, temporarily capping the roof drains, and flooding the roof surface with water to a depth of approximately 100 mm.

The water is left over a 24- or 48-hour period. The water-tightness of the membrane is determined by a visual inspection of the building interior. In the case of new construction, the test should be conducted prior to the completion of interior finishes to reduce the possibility of damage, should a leak occur. Flood tests should include a spray test of flashings to ensure that seals are intact.

The use of electronic field vector mapping to test the continuity of the membrane is relatively new and has proven to be beneficial in not only detecting leaks but also defects in the waterproof membrane.

The grid wire used with this system can be left in place to allow for future in-service monitoring. During construction, wireless electronic moisture sensors with an alarm and a telephone interface can also be installed in a grid pattern under the roof membrane to monitor performance.

Maintenance

Regardless of the type of system (intensive or extensive) or membrane installed, all green roofs require periodic inspection and maintenance. This section addresses the maintenance of the waterproofing system, not the plant material. Experience has shown that it is less expensive to provide periodic maintenance in order to maximize the system's service life than it is to have it fail from neglect.

Because the membrane is not accessible for inspection without the removal of the landscaping or plant material, maintenance of the system generally includes keeping the surface and roof drains clean of debris, ensuring that caulking seals are maintained, metal flashings are kept in place, and deteriorated or damaged membrane and flashings are repaired in a timely manner.

While there is usually great care in the design and installation of a green roof, based on the author's experience, this same care is not often afforded to roof modifications (such as the installations of new roof openings) after the architect, engineers, and contractors have left the site. To aid in the maintenance and modification of the roof, information on the roof construction, together with the recommended maintenance procedure, needs to be provided to the owner or building operator at the end of the project. On larger projects, these records can be incorporated into the building commissioning process.

A maintenance inspection is recommended in both the spring and late fall, as well as prior to the lapse of the contract or manufacturer warranties. Most roofing trade organizations, such as the Canadian Roofing Contractors' Association, provide information on the frequency and type of maintenance required for roofs in general. Specific maintenance information is available and forms part of most extended warranty agreements available from membrane manufacturers.

CONCLUSION

Green roofs can provide aesthetic appeal and improved moisture, thermal, and sound control. However, the benefits of green roofing will not be achieved if the waterproofing system leaks prematurely, requiring its removal and replacement.

Depending upon its design and accessibility, the cost of replacement can be 4 to 10 times the cost of original construction.

While other types of roof assemblies can be used, roofs of protected membrane design provide the best chance of success due to the fact that the insulation covers and protects the roof membrane. The roof deck must be designed to carry the anticipated structural loads, and be sloped to achieve positive roof drainage. A minimum slope of 2% is recommended. As mentioned, slopes above 8% need to be given specific consideration to avoid slippage.

Roof drains must be installed below roof level and be corrosion resistant. Access to drains must be provided to allow for inspection and maintenance. A means of improving drainage and drying the subsurface system at the insulation and membrane level needs to be implemented. This can be completed by underscoring the insulation, providing drainage mats, and installing vent pipes.

Designs should include continuous drainage and venting channels adjacent to the flashings and drains. Type 4 polystyrene insulation provides good service in green roofs due to its physical characteristics and moisture-resistant properties. Where possible, insulation should be installed in one layer.

The waterproofing membrane serves more than one function. Membranes that are solidly adhered to the deck will limit the spread of water, should a leak occur. Multi-layer systems provide the benefit of redundancy. The installation of a cap sheet on hot rubber or built-up roof membranes will improve the membrane's durability and long-term service. A root-resistant membrane is recommended over a root barrier to better facilitate topside venting.

Special considerations need to be implemented when using single-ply membranes; the thicker the membrane, the better. Double welds or cover strips will improve the seam's ability to provide long-term service. Large areas should be compartmentalized to reduce the spread of water, should a leak occur.

Flashings typically represent 70% of all problems. Flashings should be designed of sufficient height and be durable enough to survive in the environment to which they are exposed. Designs must include continuity of the moisture/air/vapor barrier and thermal barrier. The flashings should be accessible for inspection and maintenance. The continuity of the waterproofing membrane needs to be tested during initial installation.

Systems are available to monitor in-service performance. In-service inspection and maintenance are important and should be completed on a regular basis. Failure to do so will increase the risk of leaks, shorten the life expectancy of the system, and may nullify long-term warranties.

In summary, design of green roofs must focus on providing long-term service, making provisions for structural load, thermal efficiency, and moisture control. Designs must provide for inspection and maintenance. Aesthetics should not override function.

With attention to these factors, the benefits of roof gardens can be realized and their contribution toward the improvement of the urban environment will be long-lived.

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*LEEDS is a program sponsored by the United States Green Roof Building Council. Leadership in Energy and Environmental Design (LEED) certification program offers local tax incentive credits to buildings for using sustainable technology and practices. In August 2003, Canada became a Leeds licensee. The program is operated by the Canadian Green Building Council. Energy Star is a program of the Environmental Protection Agency, USA (EPA) that provides energy efficiency performance ratings.