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# Design strategies for Integration of Green Roofs in Sustainable Housing

Avi Friedman<sup>1</sup>

<sup>1</sup> School of Architecture, McGill University

## ABSTRACT

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Green roofs are the integration of plant material and its supporting structures in buildings. Such an approach provides a habitat for local flora and fauna, helps manage storm water, reduces heat demand in winter and the cooling load in the summer, enhances the aesthetic values of dwellings, provides the occupants with comfort and amenities and strengthens environmental responsibility. Because roofs represent approximately 40 percent to 50 percent of the surfaces in urban areas, green roofs have an important role in drainage and as a result water management as well. In fact, when a green roof is installed on 50 percent or more of the roof's surface, it guarantees 2 points and can contribute 7 additional points toward LEED certification - almost 20 percent of the required rating. This paper classifies green roofs and offers strategies for their integration in residential buildings and examines their benefits, construction principles and applications.

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## KEYWORDS

*Green Roof, classification, maintenance, vegetation, construction*

## 1. CLASSIFICATION OF GREEN ROOFS

A *Green Roof* or *Eco-Roof* is an extension of what is traditionally called a 'roof-top garden', where growing is done in planters. A *Brown Roof* is also included in this classification, to distinguish roofs that are not intentionally planted, but are filled with layers of various materials that would have otherwise been wasted in landfill such as gravel, brick rubble, crushed concrete and subsoils. This accidental process can create valuable ecosystems for plants and insects through self-colonization, similar to brownfield conditions (Mauritius EcoBuilding, 2008).

*Pitched Green Roof* is another type, which originated in Iceland where sod roofs and walls have been in use for thermal reasons for centuries and spread throughout the Scandinavian countries (GreenRoofs, 2010). Pitched roofs are typically simpler to design than flat ones. The slope allows rainfall and excess water to drain more easily, reducing the risk of leakage. Sloped green roofs, therefore, need less waterproofing and drainage methods than flat ones, thereby saving materials and labour costs (Mauritius EcoBuilding 2008). The design of the pitch is

also simplified since it is harder to access and use pitched green roofs for diverse activities and planting. Slopes of up to a maximum of 35 degrees are possible, though some systems mandate no more than 20 degrees to prevent soil slippage and slump, as will be discussed below (Kwok and Grondzik, 2007).

Another classification of green roofs is according to their maintenance level and upkeep. There are three common categories: intensive, semi-intensive and extensive (Fig. 1.1). These systems also vary in cost, depth of soil and type of plants they can support (Lawlor et al., 2006).

### 1.1 EXTENSIVE, SEMI-INTENSIVE AND INTENSIVE ROOFS VARY DEPENDING ON THE DEPTH OF PLANTING MEDIUM AND THE AMOUNT OF MAINTENANCE REQUIRED.

*Extensive Green Roofs* typically require minimal maintenance, are lightweight, inexpensive and have little plant diversity. The plants are grown in a mixture of sand, gravel, crushed brick, leca, perlite, peat, organic matter and some soil (Peck and Kuhn, 2008). This mixture is usually between 2 in. to 6 in. (5 cm to 15 cm) in depth, and full

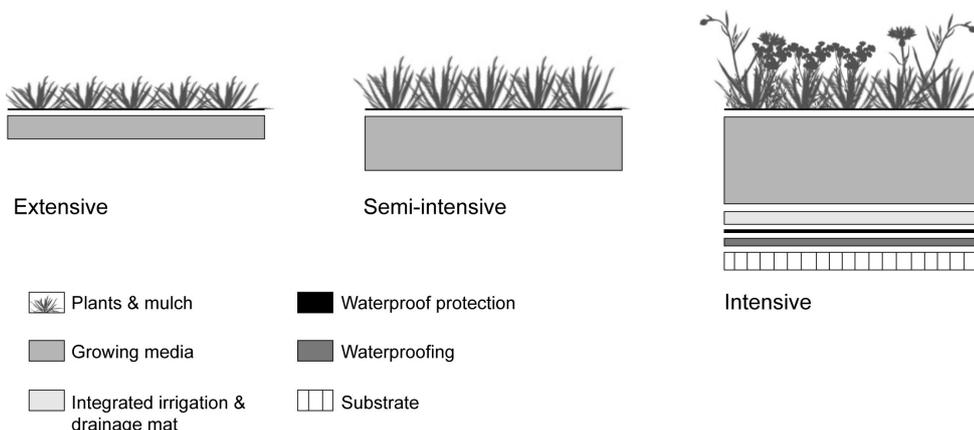


Figure 1.1

*Extensive, semi-intensive and intensive roofs vary depending on the depth of planting medium and the amount of maintenance required.*

saturation will cause an increase in weight between 16 lb./sq. ft. to 35 lb./sq. ft. (78.1 kg/m<sup>2</sup> to 169.4 kg/m<sup>2</sup>) (Peck and Kuhn, 2008; Lawlor et al., 2006). Once the plants take root, maintenance is only needed twice annually for weeding and safety inspections. These plants are typically indigenous and hardy enough to withstand extreme climate conditions (GreenRoofs, 2010). *Semi-intensive roofs* have the same low or no-input practice as an extensive one and similarly use lightweight substrates and modern construction technologies, but they have slightly deeper layers of growing medium of about 4 in. to 8 in. (10 cm to 20 cm) and therefore enable a wider and more diverse range of plants to be grown (Dunnnett and Kingsbury, 2008). While semi-extensive roofs are classified as intermediate between the other two green roofs methods, it is also feasible to combine extensive and intensive techniques on accessible roofs, with larger herbaceous and woody plant material in strategically placed containers or planters to create sustainable gardens.

An *Intensive Green Roof* is similar to traditional gardens, where plants are maintained the way they would be kept on ground. They can support diverse vegetation, are labour-intensive, have deeper soils and heavier weight, cost more and require irrigation, fertilizing and additional maintenance. The substrate here is predominantly soil and can range in depth from 8 in. to 24 in. (20 cm to 60 cm), which allows for trees, shrubs, and a more diverse ecosystem to grow and can weigh over 61 lb./sq. ft. (300 kg/m<sup>2</sup>) (Peck and Kuhn, 2008; BCIT, 2009). Also, because the roof is accessible to people, it requires additional features such as railings, lighting, access and egress (BCIT, 2009; Dunnnett and Kingsbury, 2008). When trees are planted, they need to be protected from, and anchored against, strong winds, which are a concern at

high elevations. It is important to note that dry substrate weighs approximately 60 percent to 70 percent of its total weight when its fully saturated (Optigreen, n.d.).

## 2. ADVANTAGES OF GREEN ROOFS

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Motives for the integration of a green roof in residential design are rooted in social, economic, environmental and cultural aspects, which affect both a single user and the community at large and are described below.

A rooftop patch can be used to grow fruits, vegetables, herbs and flowers particularly in high-density urban areas or where conventional garden space may be limited. Many herb species perform best in free-draining soils in sunny conditions, which are available on rooftops.

The substrate and vegetation also help insulate the building from outside noise. Soil has been found to absorb and block lower frequencies, while plant life blocks the higher ones (Mauritius EcoBuilding, 2008). A green roof with a soil layer of up to 8 in. (20 cm) can reduce noise pollution by up to 50 decibels (LiveRoofs, n.d.).

Furthermore, planted roofs could slow down the spread of fire to and from the building, particularly when the growing medium is saturated. On the other hand, very dry vegetation on a roof can pose a fire hazard. Where fire is a concern, integrating of firebreaks such as gravel or concrete pavers at regular intervals and using fire-retardant plants with high water content, such as sedums, is advised (Mauritius EcoBuilding, 2008).

Green roofs offer thermal insulation that is superior to conventional interior insulation. A green roof prevents heat from escaping out the top in cold climates, and prevents heat from penetrating through in summertime. The insulation values can be increased by using a

low density soil with a high moisture content and large, leafy plants. An 8 in. (20 cm) substrate with an additional 8 in. (20 cm) thick layer of grass has an equivalent insulation value of 6 in. (15 cm) of mineral wool as shown in Figure 2 (Peck and Kuhn, 2008).

## 2.1 COMPARISON BETWEEN INTENSIVE GREEN ROOF (LEFT) AND CONVENTIONALLY CONSTRUCTED AND INSULATED FLAT ONE (RIGHT).

Reductions of up to 90 percent in passive solar gain can be achieved when using green roofs. Indoor temperatures have been shown to be 6°F to 8°F (3°C to 4°C) lower under a green roof when outdoor temperatures are between 77°F and 86°F (25°C and 30°C). An Environment Canada study shows that a typical one-storey building in Toronto with a grass roof and 4 in. (10 cm) of substrate brought about a 25 percent reduction in summer cooling needs, compared with an unvegetated reference roof (Dunnett and Kingsbury, 2008).

When green roofs are constructed properly such that the likelihood of leaks and damp penetration to the house is minimized, they can last longer than conventional ones, which will result in obvious cost benefits. In fact, studies have shown

that green roofs may last two to three times longer than conventional ones and will receive less maintenance (Mauritius EcoBuilding, 2008). Plants can shield the roof from the elements, including the sun's ultraviolet (UV) radiation that degrades components, dry winds which cause cracks, and up to 90 percent less contraction and expansion due to temperature fluctuations (LiveRoofs, n.d.).

Finally, green roofs can offer a pleasant roofscape view, eliminating the unsightly expanse of dark asphalt and gravel. Even where roofs are inaccessible but clearly visible, attractive planting can be beneficial. The therapeutic effects of having green plants and nature around one are known to be considerable and include stress reduction, lowering blood pressure, relief of muscle tension and increase in overall positive feelings (LiveRoof, n.d.; Sassi, 2006).

When the load-bearing capacity is sufficient, green roofs can provide outdoor recreational areas for several dwelling units in neighbourhoods with little ground-level space. In an apartment block development, for instance, casual activities, such as clothes drying, barbecuing, and fitness can take place. It has the advantage of controlled access, thereby creating a safer place.

The enhancement of biodiversity through the use of green roofs is closely linked to the choice of

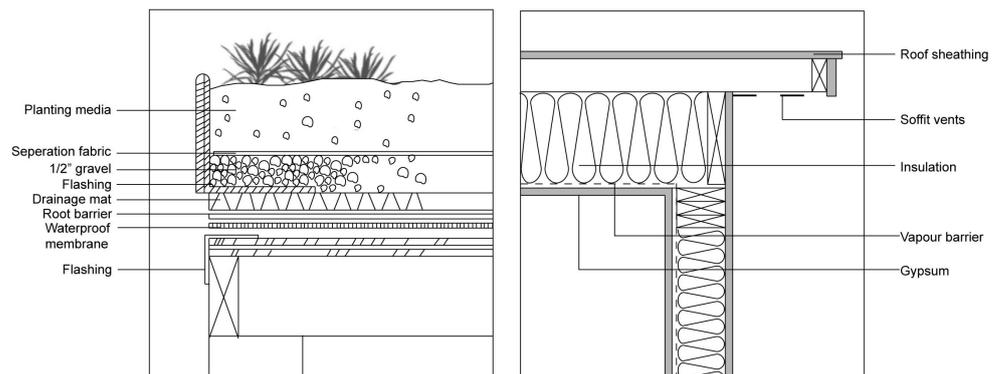


Figure 2.1

*Comparison between intensive green roof (left) and conventionally constructed and insulated flat one (right).*

plant species and the habitat or vegetation type used. Extensive roofs, which are not designed to be walked on and are, therefore, isolated, and can be potentially very good undisturbed habitat for flora and fauna such as butterflies, insects and birds. Green roofs can also be the place on which community garden for urban agriculture can be located.

A green roof not only affects the home's indoor thermal conditions, it also influences the climate of the city as a whole by reducing the urban *heat island effect*. Heat island effect is caused by a large, hard surface area that absorbs, reflects and re-radiates the sun's heat. This in turn leads to air currents, dust, smog, and micro-climate changes. Green roofs mitigate this phenomenon by cooling, slowing down currents, and filtering out air pollutants and dust (Peck and Kuhn, 2008). Rainfall on land covered with vegetation is different than rainfall on the hard surface of built-up areas. The vast majority of precipitation on a green roof is absorbed by plants and through them is transpired back to the atmosphere. On man-made hard surfaces (e.g. asphalt, concrete, roof tiles), on the other hand, water cannot be absorbed and runs off, through drainage systems, into rivers. The main aim of conventional drainage systems is to remove a maximum amount of water from an area as quickly as possible to prevent flash flooding. As a result, around 75 percent of rainfall on urban areas is lost as surface runoff compared to around five percent for a forested area (Dunnnett and Kingsbury, 2008).

Green roofs can reduce the amount of water leaving a site, either through retention, detention or by capturing it and reusing the water for irrigation or domestic purposes. This also reduces pressure on urban drainage systems, enabling ground-water to be replenished, providing areas of habitat and amenity wetlands,

reducing flood risk and lowering infrastructure cost. Because roofs represent approximately 40 percent to 50 percent of the surfaces in urban areas, green roofs have an important role in such drainage (Lawlor et al., 2006).

Green roofs have additional benefits. As air pollution causes respiratory diseases and breathing difficulties, planted roofs can filter out fine airborne particles as the air passes over the plants, settling onto leaf and stem surfaces. This material will then be washed off into the soil by the rain. Trees and larger vegetation can also absorb gaseous pollutants in their tissues.

### 3. CONSTRUCTION PRINCIPLES AND COMPONENTS

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Despite its many benefits, the construction of green roofs poses a challenge. Careful attention needs to be paid to various factors that affect the roof's performance, which will be outlined below.

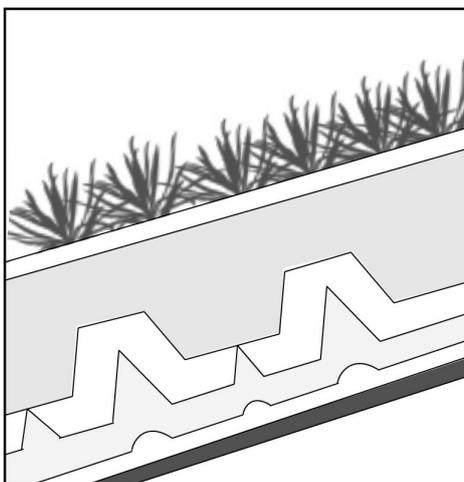
Structural considerations of green roofs have to take into account the intensive and the extensive types that were discussed above, since each one has a different weight. Lightweight extensive systems with substrate depths of 2 in. to 6 in. (5 cm to 15 cm), for instance, increase the load on a roof by between approximately 14 lb./sq. ft. and 35 lb./sq. ft. (70 kg/m<sup>2</sup> and 170 kg/m<sup>2</sup>). Each country or region will also have its own building standard for the minimum capacity of a roof. In Ontario, Canada, for example, roofs must be designed to support a loading of at least 40 lb./sq. ft. (195 kg/m<sup>2</sup>) (Peck and Kuhn, 2008). This takes into account a typical winter snow loading of 22 lb./sq. ft. (107 kg/m<sup>2</sup>). It then leaves 18 lb./sq. ft. (88 kg/m<sup>2</sup>) spare capacity - enough for a simple extensive system (Dunnnett and Kingsbury,

2008). Furthermore, in calculating load, it must be noted that the weight of green-roof materials will vary greatly depending on how compacted and how moist they are (Portland Online, 2006). Besides bearing capacity, another construction consideration in pitched green roofs is slippage. The maximum possible slope is controlled by the friction coefficient between the two slipperiest materials. Virtually no green roofs avoid having a fabric-membrane or membrane-membrane interface for example, at root barriers and sheet drains. These are the planes along which slope movement will occur. Without additional slope stabilization measures, it is unwise to design green roofs for slopes steeper than 2:12 (9.5 degrees). Figure 3.1 illustrates two green roof slope designs. Slipping and slumping can be countered by the use of horizontal strapping, laths, battens or grids. In using these methods, green roofs can readily be constructed on pitches up to 7:12 (35 degrees) that is the angle of repose for most granular materials. To build on steeper pitches, than the ones noted above,

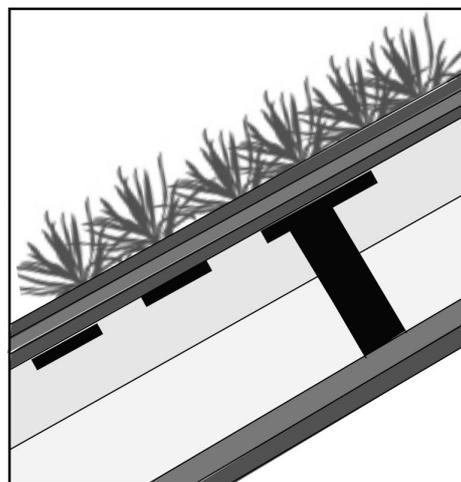
it is necessary to use special media mixes and devices (Dunnnett and Kingsbury, 2008).

**3.1 GREEN ROOFS CAN BE DESIGNED WITH VARIOUS SLOPES. STEEPER SLOPES WILL BE SUBJECT TO GREATER MOISTURE STRESS AND WILL REQUIRE DIFFERENT DESIGNS.**

In addition, roofs also need to withstand high wind uplift due to their exposed conditions. A strip of gravel, stones or pavers around the roof's edge can prevent wind damage. Such strips are also often used as vegetation barriers, preventing damage by plants to the edges where the waterproofing layer rises above the surface of the growing medium. Finally, irrigation for green roofs should also be designed and controlled, part of which could be provided by rainwater storage and recycling systems. Four main irrigation methods are used on green roofs: surface spray with traditional sprinklers, drip and tube, capillary and standing water systems. Figure 3.2 illustrates these methods. In general,



*Pitched roof up to 20 degrees*



*Pitched roof up to 35 degrees with a slippage-preventing measure*

**Figure 3.1**

*Green roofs can be designed with various slopes. Steeper slopes will be subject to greater moisture stress and will require different designs.*

traditional surface spray is less recommended because it wastes water and can cause surface rooting (GreenRoofs 2010).

### 3.2 VARIOUS IRRIGATION METHODS FOR GREEN ROOFS.

Green roofs can be constructed over any type of deck, whether steel, wood or concrete, as long as the structural considerations discussed above are met. Layering components in a green roof for residential use remains consistent throughout the different situations. These components have to satisfy weather-proofing, protecting the roof surface from root penetration and damage, drainage and the support and growth of the vegetation layer (Werthmann 2007). These components are illustrated in Figure 3.3 and are discussed below.

### 3.3 THE VARIOUS COMPONENTS OF GREEN ROOFS.

The *weatherproof membrane* consists of the built-up roof, single-ply and fluid-applied membranes. *Built-up roofs* are commonly encountered and are composed of conventional bitumen/asphalt roofing felt or bituminized fabrics. These roofing materials generally have a lifespan of fifteen to twenty years and are susceptible to degradation from temperature extremes and ultraviolet radiation - both of which cause cracking and leakage, although a layer of substrate and vegetation will reduce this. Equally important is their susceptibility to plant root growth. A root protection barrier must therefore always be used with such membranes. This type of roof, however, is not recommended as a base for a green roof (Cantor, 2008). There are other types of built-up roofing systems that are more robust and entirely different in material

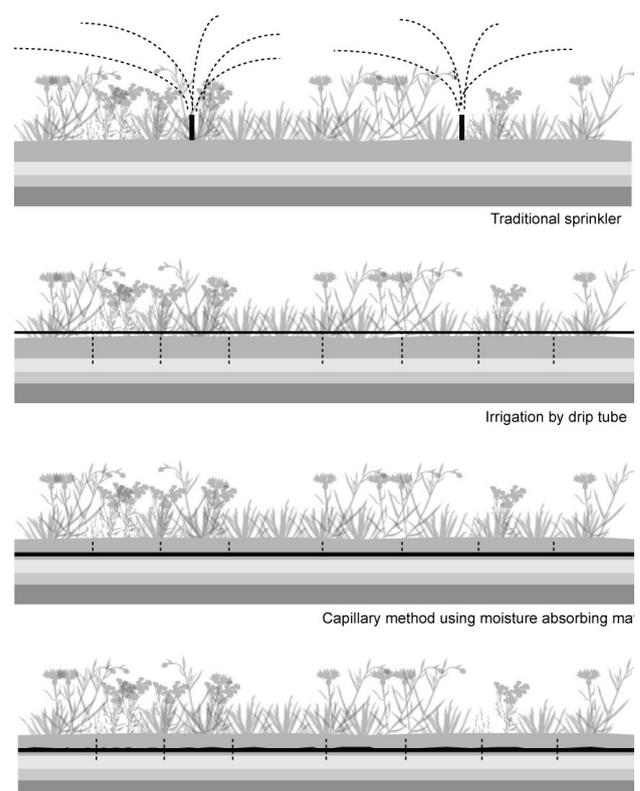


Figure 3.2

*Various irrigation methods for green roofs.*

and performances than conventional asphalt/felt built-up systems.

*Single-ply roof membranes* are rolled sheets of inorganic plastic or synthetic rubber material that are overlapped at the joints and sealed with heat. They may also be available as tiles (i.e. sometimes made of recycled rubber). These membranes can be very effective if properly applied. The seams or bonds between the sheets and tiles can, however, be weak points that may be exploited by plant roots and can cause leaks. Sealing material can be susceptible

to degradation from UV rays, therefore it is essential that all parts of the liner are protected from sunlight. On the other hand, fluid-applied membranes are available in hot or cold liquid form that is sprayed or painted onto the surface of the roof and forms a complete seal when set, eliminating joint problems. They are also easier to apply to vertical or irregularly shaped surfaces (Werthmann, 2007).

A *root protection barrier* is extremely important. If the membrane on a roof upon which a green roof is to be installed contains bitumen, asphalt, or any other organic material, it is crucial that a continuous separation is maintained between the membrane and the plant layer because the membrane will be susceptible to root penetration and the activity of micro-organisms - these organic oil-based materials are not root proof. If the roof is not completely flat, then any pockets of water can also form the basis of plant growth on a roof - again there must be protection from root damage. Plants particularly known to have aggressive roots that can penetrate the membranes are bamboo, lupines and blackberry (BCIT 2009).

A *drainage layer* is necessary to protect the waterproof roof membrane. The function of the drainage layer is to remove excess water or underflow as quickly as possible to prevent saturation. Without "greening", flat roofs are 50 percent more susceptible to damage after five years than slightly sloped roofs as a result of water collecting and pooling. Roofs require a slope of at least two percent and a drainage layer to drain properly. It is important to place the drains at the lowest point half way between structural supports. Regular maintenance is necessary to prevent the drains from any clogs or blockage that might cause water accumulation (BCIT, 2009). Also, one needs to avoid using vine plants on the edge of a green roof because

these might grow into the gutters and block the drainage path.

Because green-roof vegetation, particularly of the extensive type, is selected to be drought-resistant and tolerant of dry, free-draining soils, prolonged soil saturation is likely to cause plant failure, rotting, sour and anaerobic conditions and may also lose its thermal insulating properties. Drainage can be achieved in several ways, especially for flat roofs less than five degrees, which requires more specialized techniques. In addition, combining a drainage layer with a water-storage layer below it not only further reduces runoff compared to those without such a layer by 11 percent to 17 percent, but acts as a reservoir for plants to draw upon in dry weather (Dunnett and Kingsbury, 2008).

The last layer for green roofs is the *growing medium or substrate*, which absorbs and retains water while at the same time provide free-draining properties. Specifications for materials used in the substrate layer should be advised by experts since it is not necessarily a concern of the architect.

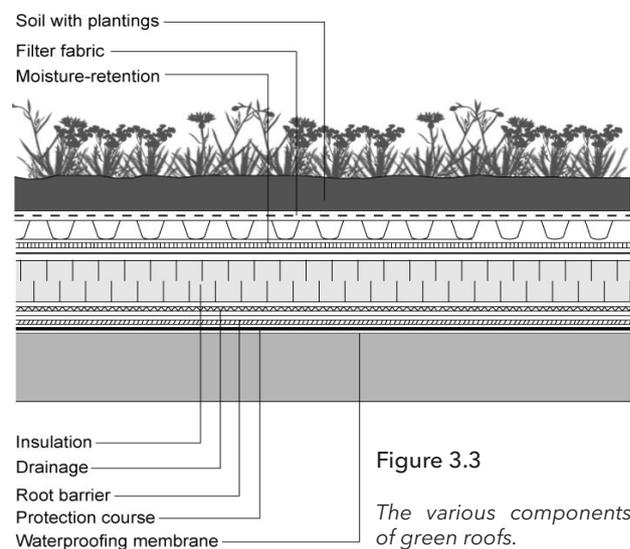


Figure 3.3

The various components of green roofs.

When all functional layers of green roofs are properly applied, planting can begin. Specification of plants on green roofs can be determined from various sources. In general, there are four main approaches to establishing vegetation on green roofs: direct application of seed or cuttings, planting of pot-grown plants or plugs, laying of pre-grown vegetation mats including turf, and spontaneous colonization. Plants on these roof gardens are encouraged to be sustainable, that is, to be able to grow without the need for regular and prolonged irrigation unless using recycled water and feeding (Cantor, 2008). On the other hand, accessibility and visibility of the roof are also particularly interesting in architectural language, as related to the type of plants chosen.

#### 4. CONCLUSION

Despite the many benefits to dwellers and their neighbors alike, green roof design is still globally in its early stages. A number of municipalities, such as Toronto, Canada, have implemented by-laws that require the implementation of green roofs on any new construction project. While these initiatives present a step in the right direction, the building industry is still a long way off from understanding the full extent of green roof implementation and management. Architects and designers must work in consortium with agricultural specialists to develop innovative approaches and design guidelines for rooftop growing. It is also needs to be recognized that green roofs are not the ultimate strategy for every building. Their choice and specific application needs to consider the type of building, budget, climate and the maintenance skills of the occupants to name a few factors.

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