Structure and Functions of Green Roof and Its Development in Urban Areas, China

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Abstract. The green roof is an environmentally friendly design, which is important for sustainable development and improvement of resilience in urban areas. This paper offers a systematically review of the classification, material selection, functionality, limiting factors of green roofs, and provides suggestions. The green roof is classified into intensive, extensive and semi-intensive ones according to the substrate depth and vegetation type. Its basic structure includes vegetation, substrate, filter, drainage, protection, anti-root, insulation and waterproofing layers from top to base. Among which, vegetation, waterproofing and drainage are vital layers to decide the roof efficient. The factors such as light, temperature and humidity conditions of the site are vital for determination of vegetations for a green roof. Green roofs provide benefits for urban areas via saving energy, reducing stormwater runoff and improving aesthetic. Roof load-bearing, seepage, survival of vegetations and support from all sectors are the main issues for the development of green roofs at current stage.

Keywords: Green roof; energy saving; stormwater runoff retentivity; aesthetic effect.

1. Introduction

Nowadays, the development of science and technology are constantly changing our surroundings. With the continuous growth of the population and the acceleration of urbanization, environmental issues like global warming and greenhouse effect have gradually become the focus of people's attention. Additionally, the globalization around the world leads to the increasing demand for buildings, land, water and energy [1]. In this context, the concept of sustainable development is increasingly being promoted. Measures such as energy saving, emission reduction and low-carbon living have been implemented.

A study of United Nations Environmental Program shows that constructing and maintaining buildings requires around 40% of the global primary energy, which accounts for 33% of the greenhouse gas emissions worldwide [1]. To avoid the situation being worse, environmentally friendly buildings like green buildings have been implemented in urban areas in recent years, which contribute to the reduction of energy use. Moreover, as an essential part of buildings, roofs occupy 20%-25% of the total urban surface area [1]. Thus, there is great potential for green roofs to influence the surroundings, even the urban environments.

Generally speaking, green roofs refer to as the engineered roofing systems, partially or completely covered with vegetation and growing media, usually consist of a base layer, a root layer and a plant layer. Green roofs are classified as intensive or extensive. The former one has a deeper organic growing substrate and soil, while the later one has a simpler and lighter profile. For urban buildings, effective green roof treatments can cool the urban environment, reducing the costs of temperature control of buildings while mitigating the heat island effect. Green roofs also serve to treat stormwater by reducing surface runoff and filtering pollutants. In addition, green roofs can effectively expand the green space of the city and enhance the visual aesthetics of the city.

Currently, the research on green roofs mainly focuses on the design scheme of a certain function, lacking systematic discussion and description. This paper systematically analyses and discusses urban green roofs from their design, material selection, to their functionality, and puts forward problems, suggestions and improvement schemes.

2. Current Situation and Development Trend

At the present stage, green roof construction is more widely carried out in developed countries throughout the world. Europe is one of the most developed regions for green roofs. Countries such as Germany, Switzerland, the Netherlands and Sweden are leaders in the field of green roofs. These countries have made significant progress in terms of government support, technological innovation and market promotion [2]. The green roof market in North America is also growing rapidly. Cities such as Toronto and Chicago have adopted aggressive policies and incentives to promote the application of green roofs. In addition, New York has established a Green Roof Tax Credit Program to encourage the installation of green roofs on buildings [3]. The green roof market in the Asia-Pacific region is also emerging. For example, Singapore has implemented green roofs and vertical greening on many buildings through government guidance and incentives to improve the ecology and environment of the city [4]. Meanwhile, some metropolis in China, such as Shanghai and Beijing, have begun to promote green roofs as part of urban greening and environmental improvements.

As a sustainable urban development program, green roofs are gradually gaining worldwide attention and popularity. In the future, cities would pay more attention to the construction of ecosystems and the standards for green buildings would become more popular. With the progress of science and technology, the technology of green roofs is also constantly being innovated. For example, various new lightweight greening systems, automatic irrigation and monitoring equipment, sustainable materials and plant varieties have emerged. These innovative technologies enable green roofs easier to implement and maintain. Overall, the trend of green roofs is moving towards a more comprehensive, innovative and sustainable approach. Through multi-party collaboration, technological innovation and community participation, green roofs are expected to play a more important role in future urban development.

3. Classification and Materials

3.1. Green Roof Classification

Green roofs, here, is categorized as intensive, semi-intensive, and extensive green roofs. The semi-intensive one has a more complex layer structure than extensive green roofs, but have lower carrying capacity than intensive green roofs [1].

Intensive green roofs are combinations of green vegetation, artificial landscaping, pavilions and streams, with a substrate depth of over 15-20 cm, providing diverse choice of vegetations from lawns and evergreens to shrubs and trees [1]. Therefore, this system requires frequent maintenance and advanced green roof irrigation systems. The design of intensive green roofs offers high water retentivity, reducing stormwater runoff by up to 85% compared to traditional roofs [1]. Intensive green roofs have great potential for biodiversity, usually used to create recreational spaces for human beings.

Extensive green roofs, also known as "eco-carpet", is one of the simplest forms of roof greening. The depth of the system is typically less than 15 cm, planted with drought-resistant vegetation, ranging from mosses and Sedum to lawn groundcover [1]. Due to the light weight, low cost and easy maintenance, extensive green roofs usually implemented when there is limitation of loads and maintenance budget. Moreover, since the low requirements of additional structural support and technical demand, extensive green roofs are suitable for roofs with large areas and slopes.

Semi-intensive green roofs are vegetated to a medium depth, typically 13-24 cm. With a more complex vegetation selection, semi-intensive green roofs consisting mainly of low shrubs and colorful flowers, which have a more aesthetic effect. Semi-intensive green roof systems are characterized by the need for moderate maintenance and occasional irrigation. Compared to extensive green roofs, semi-intensive one retains more water and provides an ecologically rich environment. Although require high maintenance, this green roof system has the potential to be a clever combination of natural and artificial landscaping.

3.2. Structure and Materials

A green roof is usually composed of several parts, from the top to the bottom are the vegetation, substrate, and base layer, respectively. Among which the base layer including filter, drainage, protection, anti-root, insulation and waterproofing layers. Usually, the waterproofing and the anti-root layers are integrated with each other (Figure 1).

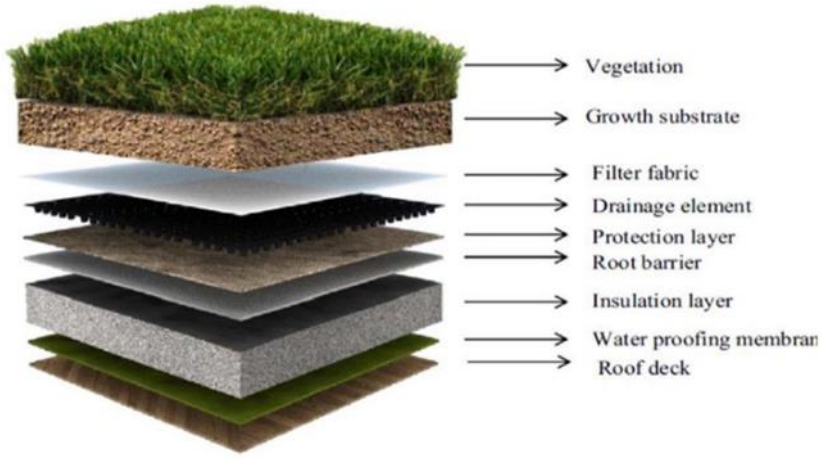


Fig. 1 Green roof layers [5].

3.2.1. Filter Layer

This layer has the effect of intercepting smaller particles such as vegetation debris, avoiding clogging of the drainage layer and increasing the lifespan of the green roof system. In order to achieve a water permeability 10 times higher than that of the substrate, small pores are required for the filter layer [1].

Currently, the filter layer adopts the two materials: granular materials and non-woven geotextiles, between which the latter is more widely used. Granular materials such as lapillus, pumice and pozzolana, have a water permeability of more than 0.3 m/s. Non-woven geotextiles are permeable geosynthetics made of synthetic fibers by needling or weaving, with a permeability of 7.8 x 10^{-2} m/s [1].

3.2.2. Drainage Layer

The drainage layer is also an important part of green roofs. On one hand, the drainage layer provides a ventilated environment for vegetation growth by discharging excess water from the substrate [1]. On the other hand, the load on the building structure is reduced while excess water is drained, making the green roof system safer to operate [1]. Generally speaking, both granular materials and modular panels could be used for the drainage layer [1]. The characteristics and aggregates of the typical materials are shown in Table 1.

Table 1. Materials used for the drainage layer [1].

	granular material	modular panel
Thickness	>6 cm	2.5-12 cm
Density/Weight	150 kg/m3	20 kg/m2
Main aggregates	Pozzolana, pumice, lapilli, expanded clay, expanded pearlite andslate, crushed bricks	High-strength synthetic/plastic materials (polyethylene or polystyrene)
Compressive strength	>1.5 N/mm2	Longitudinal tensile strength: >7.0kN/m Tensile strength: >7.0 kN/m

3.2.3. Protection Layer

The purpose of designing a protection layer is to make sure the waterproofing and anti-root membrane are protected [1]. The protection layer is required to endure the loads and stresses that occur during both the construction and operational processes [1]. Geogrids, geotextiles and

polystyrene can be used as the materials for protection layer, with a thickness of at least 3 mm and a compressive strength of more than 150 kPa [1].

3.2.4. Anti-root Layer

While designing a green roof, an anti-root layer is needed to avoid damage to the waterproofing layer and chemical alterations caused by the intrusion of plant roots [1]. The existence of holes or gaps, localized pooling on the roof, etc. are the causes of root penetration and leakage. Therefore, the anti-root layer must be laid in such a way that the gaps are eliminated and there is no puddle of water. In addition, plant roots spread to meet their natural growth needs, so materials that prevent the growth of roots are beneficial in preventing root penetration. Elastomeric SBS and APP modified asphalt waterproofing membrane are more widely used.

3.2.5. Insulation Layer

An insulation layer is not necessary for green roofs, which is typically applied when retrofitting existing roofs [5]. It can avoid the retained water in the green roof system to absorb heat in cool environment [5]. The materials used to manufacture the insulation layer need to meet the requirements of light weight, durable and small heat transfer coefficient, usually inorganic thermal insulation materials such as glass wool, slag wool or rock wool.

3.2.6. Waterproofing Layer

The waterproofing layer is a vital part of the green roof design, which protect the roofs against the leakage of water from the upper layers. The importance of the waterproofing layer is not only in its watertightness, but also in its demanding maintenance requirements, since once the green roofs leak during implementation, all structures have to be removed [1]. Thus, the choice of materials for waterproofing layer is critical. The most common material is the bituminous flexible membrane. It is categorized into three types: elastomeric, plastomeric, and elasto-plastomeric [1]. Their components and characteristics are shown in Table 2.

Table 2. Types of bituminous flexible membrane [1].

	Elastomeric	Plastomeric	Elasto-plastomeric
Component	Elastomeric polymer and bitumen	Plastomeric polymer and bitumen	Combination of elastomeric and plastomeric
Characteristic	Flexible at low temperatures; Excellent elasticity	Stable at high temperatures; High resistance to UV exposure	Highly adaptable to temperature; Elasticity; Resistance to UV exposure

3.3. Vegetation Selection

The vegetation layer represents a functional part of the green roof system, so the choice of vegetation is crucial. In order to select the optimized plant species for a typical green roof system, light, temperature and humidity conditions of the site are vital factors [6]. Firstly, roofs are usually not shaded, so tolerance to direct sunlight is considered first when selecting green roof plants. For example, *Agavestricta salm-dyck, Spinifex and Bellis perennis* are sunlight-loving plants that required full sunlight, which are suitable for roofs with direct sunlight [6]. Secondly, temperature is also an essential parameter especially in area with low temperature. Cold hardiness is the criterion for whether plants can survive independently throughout the year [6]. If plants have low cold hardiness, they require special treatment in cold conditions and the energy consumption of the green roof system will increase. *Atriplex lentiformis, Cotula squalida and Ficus* pumila are cold tolerant species [6]. Thirdly, irrigation of plants on green roofs is more difficult than that of ground-level greenery due to their location on top of the building [6]. Therefore, drought-tolerant plants such as *Achillea milifoliumi, Euphorbia albomarginata and Juniperus horizontalis* are more preferred, especially in water-scarce areas [6]. Above all, only a combination of the three factors above could the vegetation for the green roof be determined.

4. Functions and Advantages

4.1. Energy saving

Green roofs are especially important today as the urban heat island effect is on the rise. It can reduce direct solar radiation by absorbing 60% and reflecting 20%-30% of the radiation, which contributes to energy saving for cooling and heating [7]. This goal could be achieved by the transpiration and photosynthesis of vegetations. On one hand, green plants can absorb solar radiation and heat from the environment, and through transpiration, the absorbed water is dispersed into the atmosphere in a gaseous state, which not only moistens the air, but also carries away a part of the heat, thus lowering the temperature of the surroundings [7]. On the other hand, the plant leaves photosynthesize to absorb heat energy, blocking a part of the solar radiation from reaching the soil layer at the same time, thus the temperature of the soil layer is lowered [7]. Meanwhile, compared with the bare roof, the soil layer has a higher specific heat capacity and lower dynamic thermal transmittance, resulting in a good heat insulation material [7].

Dong et al. [8] conducted a study about the cooling effect of urban green roof system in Xiamen Island, China. Results showed that the average land surface temperature of the roof lowered by 0.4 °C for each additional 1000 m^2 of green roof area [8]. This study provided a rationale for green roofs in high-density urban areas to save cooling energy. Similar results were discovered in the study developed by Ran and Tang [9], which simulated the energy-saving efficiency of green roof in Shanghai, China using DesignBuilder software. According to the result, combined with intermittent ventilation, the green roof had an energy saving rate of 26.7% [9].

4.2. Reduction of Urban Stormwater Runofff

The green roof system is an effective way to realize the goal of sponge city. Runoff from the roofs of buildings is one of the major factors leading to urban flooding, so retrofitting urban building roofs to green roofs can effectively alleviate the pressure of urban stormwater runoff. The mechanism for treating stormwater in green roof systems is that the substrate which contains soil absorbs partial stormwater, extending the time to reach the runoff peak [7]. Subsequently, stormwater is released through evapotranspiration and returns to the atmosphere [7]. The primary factor determining the retentivity of a green roof system is the substrate layer [7]. The thicker the soil substrate, the more stormwater it can absorb and the more retentivity it has [7]. Therefore, intensive green roofs generally have higher retentivity than that of extensive green roofs. Vegetation type is another factor that influences the retentivity of green roofs. Plants with higher transpiration efficiencies are able to exchange water between the soil substrate the atmosphere more quickly [7], as in the case of C3 plants, which are more preferred than CAM plants in vegetation selection of green roofs [7].

Moreover, climate is another important factor controlling the green roof retentivity. Roehr and Kong [10] investigated the green roofs effectivities in Shanghai, Vancouver and Kelowna, showing that the annual rooftop runoff reduction was 55%, 29% and 100%, respectively. Research has shown that the drier the climate, the better the runoff retentivity of green roofs. Liu et al. [11] found that the average annual runoff retentivity of Lanzhou, a region with dry continental climate, was 73.8%, which was much higher than that of other humid climate regions in China.

4.3. Enhancement of Aesthetic

Green roofs can also increase the areas of green space in cities, improving the cityscape and providing places for recreation and entertainment. To achieve better aesthetic effect, the design of green roofs should take into account the integration with surroundings. Firstly, the architectural design should consider the special requirements of roof greening thoroughly, such as roof load-bearing, roof leakage, lighting, water supply and drainage, leakage prevention and so. Secondly, the green roof design should be adapted to local conditions. To be more specific, the sculpture, paths, lighting, pools, fountains, vegetations, pavilions and architectural styles should be integrated with each other within a limited roof area.

5. Discussion

Although the concept of green roof is increasingly being promoted in urban areas and its environmental value is more widely known, it has not yet been widely adopted. The green roof has a huge market space in China and has the ability to form a new greening industry. However, as a new technology, roof greening is at the beginning stage, and the technology needs to be further improved. To this end, the following issues are raised for common discussion.

First, the design of green roofs should consider the issue of roof load-bearing, which is related to safety and economic efficiency. The load-bearing capacity of a building is limited by the load-bearing capacity of the beams and foundations under the green roof. Since the structural bearing capacity of the building directly affects the cost of the building, the allowable load of the roof is limited by the building cost, which means that the average load of the green roof system can only be controlled within a certain range, especially when green roofs are implemented on the buildings with no original roof design. Therefore, it is necessary to take into account the roof load-bearing and environmental benefits, choosing lightweight plants with a smaller volume, and try to avoid the selection of tall trees.

Second, the problem of seepage should be taken into account. As the vegetation underneath remains wet for a long time after absorbing water and has the corrosive effect of acid, alkali and salt, might leading to long-term damage to the waterproof layer. Meanwhile, many plants such as banyan, Bauhinia and other root systems have strong penetration ability, which is easy to cause damage to the roof structure and result in leakage. A difficult point for the prevention of green roof leakage is that the roof is covered with soil and greenery, hence, it is difficult to find out where the leakage point is. One solution is to follow the direction of water flow to find the leakage point of the corresponding leakage site, dividing the area out to repair or replace the waterproofing layer, then observe whether the leakage still occur or not.

Third, the survival of vegetations on roofs with harsh conditions is also a challenge. It is not an easy task for plants to grow on the roof, since the ecological factors of the roof are significantly different from that of the ground. With the increase in storey height, ecological factors such as light, temperature, humidity and wind show different changes. For example, the roof is characterized by strong solar radiation, high heating rate, and large temperature difference. Therefore, it is necessary to choose plant varieties suitable for the roof growing environment according to the growth characteristics of various types of plants. It is advisable to choose vegetations that are resistant to cold, heat, drought and barren. To ensure survival, bag planting seedlings are recommended since they can better retain water.

Last, it should be noted that roofs are public areas so the implementation of green roofs on a building requires the unanimous approval of all the direct stakeholders. In the case of residential buildings, for example, many residents have concerns about leakage and worry that the implementation of green roofs would affect their daily life. Under this circumstance, quality assurance needs to be given to the residents, e.g., a detailed implementation plan stating that the waterproofing design of the green roof system is reasonable, which is able to achieve non-leakage during the durability.

6. Conclusion

This paper made a systematically analysis and discussion about the design, material selection, functionality of urban green roofs, identified key issues of green roofs and proposed suggestions for improvement.

A green roof mainly consists of vegetation, substrate, filter, drainage, protection, anti-root, insulation and waterproofing layers. It is divided into intensive, extensive and semi-intensive types. Light, temperature and humidity are the three primary factors that determine the selection of green roof vegetations.

Green roofs serve three main functions, contributing to the sustainable urban development. First, it can reduce the heat island effect and energy consumption through the transpiration and

photosynthesis of vegetations. Then, the green roof system is an effective method to stormwater treatment, which could be achieved by absorbing partial stormwater and delaying the appearance of peak runoff. Next, green roofs can provide better aesthetic effect for buildings.

However, green roofs are still at the beginning stage in China, which are technically immature. The issue of roof load-bearing, seepage, survival of vegetations and support from all sectors should be taken into account.

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