

Utilization and impact of green roof technology in maintaining the ecological balance

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Summary

Pursuing an environmentally friendly and sustainable system in the modern world has shed new light on green roof technology, a concept that has been introduced previously. However, the rise of urban cities with limited space and increased human activities has ascertained its importance in achieving sustainable agriculture and architecture simultaneously. The numerous lists of benefits have intrigued a new interest among urban developers and landscape architects, resulting in various research on the topic. The article covers the basic concept of green roofs, their functionalities in creating an ecologically balanced environment and why they must be considered in the developing urbanization of the country.

JAE 2023, Vol 15

Received: 15 February 2023

Accepted: 30 April 2023

Published: 30 June 2023

<https://doi.org/10.58628/JAE-2315-103>

Associated Editor: Dr. SM Haldhar

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Keywords: Living roof, roof garden, stormwater, environment, ecological balance

Introduction

The growth in the building construction sector is witnessed to be moving along with economic growth in different parts of the world. It was estimated that around 43 megacities would have a population of more than 10 million by 2030.⁵⁵ The consequence will be an increased emission of greenhouse gases which will be contributed directly by a decrease in vegetation due to limited space and also directly as urbanization will increase the emission of these gases as a result of various human activities.¹ The influence of climate change on the rise in temperature and heat waves is apparent.³⁰ Major cities in the country are also witnessing the same, with death cases reported yearly due to heat waves. This led to increased energy usage through coolers and air conditioners, resulting in increased greenhouse gas emissions that further perpetuate global warming.

A significant risk has also been imposed in water sources due to changes in precipitation, reducing surface and groundwater availability.⁵⁰ This trend is in favour of continuing in the next 10 years, with the consequence being water shortage for multiple uses. In addition, high-density residential and commercial areas lessen the vegetative cover that is supposed to regulate the air temperature and maintain ecological balance. Natural vegetation facilitates evapotranspiration and provides shade, lowering the surface air temperature.⁷ There is indeed a great challenge to maintain the ecological balance and improve water availability with respect to climate change amid the urban city expansion. Thus, the need to implement resolving measures has become a subject of utmost importance.

Among different interventions to address the issue over the years, the installation of a green roof has reinstated its importance as it not only ameliorates the environmental crisis but is becoming socially acceptable from an aesthetic point of view. Green roof dates back thousands of years, although there is only a little physical evidence and records on the exact timeline.⁴² The establishment of a vegetative rooftop system in the Hanging Gardens of Babylon has been reported to be one of the first documented record.^{15, 37} The Romans were known to plant trees on the rooftop and were often imported for this purpose.³⁴ In contrast, the Norwegians in the 1700s used soils on their roofs for insulation on which grasses were planted to hold them in place.¹⁹ During the Middle Ages, it was recorded that roof gardens were reportedly owned either by upper-class people or by the Benedictine monks. In the past, different types of roof gardens became part of historic places and were an essential element of sustainable architecture.^{28,42}

Towards the modern era, the idea of green roofs was kept alive in many places worldwide, not so extensively, mostly to serve a specific purpose. These purposes include protection from extreme cold by layering the roof established with turf grasses or cooling the building temperature during hot days.^{44, 34} With the dawn of modern architecture in the 20th century, architects like Le Corbusier started implementing green roofs and green walls in their design to instil the idea of naturalism in the constructions and achieve an aesthetic purpose. This has led to many historic designs with the basic concept of a green roof. As technology advances, this idea of a living roof on a concrete building was brought to life by a model that was displayed in the "World Expo in Paris" in the year 1867 that has an illustration of a waterproof green roof with a proper drainage system; this was considered to be one of the initial design of an extensive green roof.¹⁴ The development of green roofs from then on became a technological approach that aspires to

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harvest its environmental benefits while serving the purpose of visual and aesthetic intent. Urban planning and environmental policies have succeeded in gaining more interest in green roofs in several countries in the recent years.^{14, 17}

Green roofs in the modern world

Recent innovation and research have helped establish a proper system out of which people can harness the benefits without compromising the life of a building. In recent understanding, a green roof or living roof is an open space on the roof of a construction building that is partially or may be covered entirely with vegetation grown over a waterproofing membrane. They are a model of the typical garden laid on the roof of a building.¹³ It consists of biotic and abiotic components organized to serve as a green space in severe environmental conditions.^{34&61} Jim (2017)¹⁸ defines a green roof as a “human-made establishment product on the roof of a house, including erecting a structural framework with appropriate mechanical strength”. Another definition mentioned it as “a building roof which is entirely or partially covered with vegetation and growth medium. It can be a sloped roof surface or a flat designed to sustain vegetation besides working as a fully functioning roof”.¹⁶ Therefore, a green roof is a horizontal living system that helps in the mitigation of several problems⁴ and a modern energy-efficient construction technology.²⁵

Components of Green Roof

The components that make up a green roof consist of vegetation, specific substrate or growing media, a water system with proper drainage facilities, and a waterproof membrane.^{14, 35, 51} The green roof should be capable of offering an appropriate environment to sustain vegetal growth.¹ The components of green roofs and their properties or thickness varies with the roof type and the climatic conditions.⁹ According to Lestari et al. (2020)²⁹ and Dunnet & Kinngsbury (2004)¹⁴, the construction of green roof system in general consists of the components such as vegetation, substrate/growing media, filter layer, drainage system, waterproof membrane and roof structure (Fig 1). A thorough perception of the components and the purpose of the green roof must be determined in order to achieve its goal and install an efficient system.⁴⁷

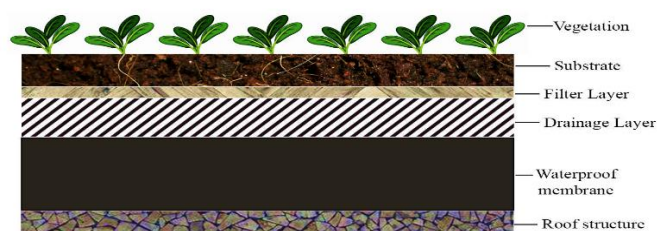


Figure 1. A green roof with different component layers^{14, 29}

Table 1. Different plant species suitable for green roof

Succulents	<i>Sedum, Sempervivum, Echeveria, Aloe</i>
Climbers	<i>Ficus repens, Thunbergia alata, Vernonia</i>
Flowering annuals	<i>Marigold, chrysanthemum, dahlia, sweet alyssum, antirrhinum, verbena, phlox, stocks</i>
Herbaceous perennials	<i>Portulaca, Pelargonium, golden rod, periwinkle</i>
Trees	<i>Callistemon lanceolatus, Plumeria sp., Mimosa elengi, Gliricidia maculata</i>

Categories of green roof

Each layer component must be examined and selected carefully for a complete system. The growing media should have great water-holding capacity and optimizes plant growth.⁴⁹ As the substrate is directly responsible for the plant growth and establishment, selection must be carefully made. Lightweight materials supplemented with organic or mineral additives with low density and high porosity are recommended.^{3, 32} Addition of peat, sand and moss helps reduce the substrate's weight load.²⁶ The selected substrate's physical and chemical characteristics should be specific, such as high air-filled porosity and low bulk density.¹²

The drainage layer aims to remove the excess water and two materials generally used for drainage are the modular panels and granular materials.⁵⁷ They must also be responsible for retaining sufficient water that is needed for plant growth while removing the excess amount and preventing waterlogged conditions.²⁴ An expanded perlite as a draining material⁵⁰ and expanded clay³¹ were successfully used to lessen the weight of the green roof. Porous volcanic gravel as a drainage layer performed well under fluctuating humidity and temperature.²³ The system can also be equipped with a passive irrigation system in which the rainwater drained through this layer is stored in a reservoir and taken up by the plants via a sponge-like mat placed below the growing media.⁵⁸

The filter layer is generally a geotextile fabric used to prevent the growing media from being washed away and prevents clogging between the drainage layer and the media⁶ as this can deteriorate its performance over time. It may also come with an additional layer of root inhibitor like mild herbicide or copper.⁵⁸ The layer must be able to withstand the load overhead and have great tensile strength and resistance as well as high water permeability.^{11, 12}

The waterproof membrane should be sturdy and reliable to prevent water damage and roof leakage.²⁶ The membrane prevents the building from infiltration and is at the same time protected by the vegetation from exposure to sunlight and radiation. Bituminous flexible membranes are the most commonly used material for the layer.¹¹

The plants or vegetation must be selected considering the climate conditions including radiation, humidity, rainfall and wind. Another important characteristic for plant selection is the depth of root penetration, which will help determine the plant type for different green roof systems. *Sedum* is the most preferred species of the plant due to its high visual rating and great drought tolerance.^{38, 34} Many other plant species are also used to add more diversity for use in green roofs (Table 1).

There are two major groups of green roof types: intensive and extensive.³⁵ A third group which is a blend of both types called semi-intensive type, is also included.²⁰ Extensive green roofs are also known as shallow green roofs owing to the shallower substrate depth of approximately 4 inches or less. They support lesser vegetation and do not require intense irrigation.¹ Plants are usually ornamental grasses and succulents that are lightweight and shallow-rooted. It is the ideal system for private and residential buildings.¹⁴ The main advantages of an extensive roof include low maintenance and requirements and low capital cost compared to intensive roofs.⁸ A separate drainage layer is generally not included in this system.

An intensive green roof is also called deep green roofs as they have a deeper vegetative structure with a substrate depth range of 8 to 24 inches. They are more labour intensive, require higher maintenance and is more commonly used in commercial structures and large-scale

constructions.⁴⁰ They allow more vegetation with different species to replicate a natural landscape and be used for agriculture. Besides grasses and succulents, annual and perennial herbs, trees are also planted.³⁴ It gives the best insulation and temperature regulation, which serves as the main advantage. They are normally designed to provide recreation space and for entertainment.⁴⁸ Garden enrichment items like small ponds, benches or walkways can also be added features in this system. The intensive system has a higher potential of decreasing water runoff and stormwater management.²⁷ Semi-intensive combines the elements of both the former types by combining the environmental benefits of the intensive type but is cost-effective comparatively.²¹ The depth of the growing media in semi-intensive ranges from 5 to 8 inches. It can retain more stormwater than extensive type and requires moderate irrigation. It supports more vegetation range as compared to the extensive type.¹

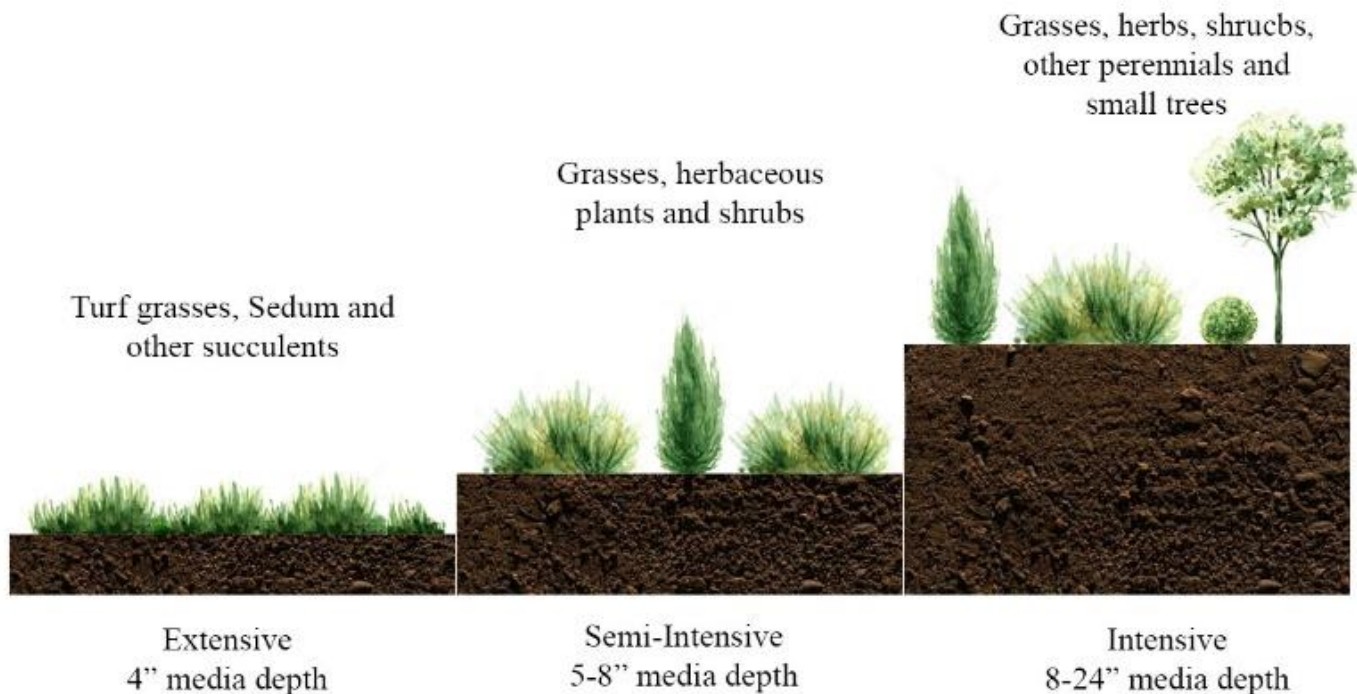


Figure 2. Different categories of green roof^{20, 35}

Table 2. Comparative characteristics of different categories of green roof

Characteristics	Extensive	Semi-intensive	Intensive	Reference
Substrate	4 inches or lower	5 to 8 inches	8 to 24 inches	Hossain et al. 2019 ²⁰
Vegetation diversity	Grasses and succulents	Grasses, herbs and shrubs	Grasses, annual, perennials and trees	Hossain et al. 2019 ²⁰
Cost and Maintenance	Low	Medium	High	Berndtsson 2010 ⁸
Purpose	Private residence	Private and small public buildings	Public and corporate buildings	Oberndorfer et al. 2007 ⁴⁰
Weight	Lightweight (60-150 kg/m ²)	Intermediate (100-200 kg/m ²)	Heavyweight (300-150 kg/m ²)	Cascone et al. 2011 ¹¹
Irrigation	Less requirement	Less requirement	More requirement	Oberndorfer et al. 2007 ⁴⁰

Importance of Roof Garden

Environmental impact

The initial intent of green roofs was to restore the environment and protect the roof membranes at the same time, which evolved over the years to multiple

applications.²⁵ Donnell-Kilmer (2012)¹³ cited that creating a rooftop garden results in many benefits, including throughout the city or town considered a macro-level or around the building's residential environment at the micro-level. It is one of the main approaches to a

sustainable environment.²⁸ They reduce the overall temperature and solar irradiation, reducing the building's heat flux up to 50%⁴¹ and reducing heat flow by more than 75%.³⁰ A report made by Banting et al. (2005)⁵ showed 60% absorption of total solar radiation by plants and soil in green roofs with 13% transmission into soil and 27% reflection. Kohler et al. (2002)²² has observed that indoor temperature under a green roof was recorded to be approximately 3-4°C lower than outside temperature.

The installation of green roofs also saves energy consumption by providing insulation for the buildings.^{33, 54} The thermal insulation depends upon the substrate's layers and water content.⁴⁵ The total energy consumption computed annually is reported to reduce by 1%, with 6% reduction during winter and 0.5% reduction during summer.² They can also maximize the life span of a roof as it protects the roof components against harsh environments, fluctuations in temperature and UV radiations.¹⁶ Stabilization of temperature using vegetation cover reportedly may increase the useful life of the building by 20 years or more.

Mitigation of stormwater has been a proven impact on the system.⁵³ Stormwater is retained in the roof surface via the green roof, which helps to lower the thermal load of a building and reduces the number of water run-offs.³⁹ It, therefore evenly distributes the runoff by slow release of water through the drainage membrane of the green roof.^{10, 52}

Vegetations on the roof create an aesthetic outlook of the environment⁴³ and provide a cooler environment through evapotranspiration.²² They help in air purification by absorbing carbon dioxide, releasing oxygen²⁶, and neutralizing other harmful gases. It provides relieve to the people by blanketing the noise pollution of urban cities that affects the daily life⁵⁹, including the traffic noise.⁵⁶ They have the potential to act as a noise barrier and create a more comfortable workspace by insulating against rainfall.²¹

Social and economic impact

Besides the environmental impact, green roofs can also impact the social community by providing a source of recreation and activity. It provides therapeutic benefits as gardening can stimulate physical and mental recharge and also promotes a platform for social exchanges and interactions.⁴⁷ They provide relief to the urban lifestyle that is weighted down by human populations and constructions. Therefore, replenishing greenery in urban areas can be achieved through the adoption of a green roof system.³⁶ Green roof not only increases the economic value of a building and boosts its marketability⁴⁶ when supplemented with different types of plants, including vegetables and fruits it can become a source of food for consumption or local markets. They can supplement the diet and provide nutritional foods, engaging people with small-scale agricultural activity.

According to a survey conducted among 310 professionals by Rahman et al. (2013)⁴⁷, majority had agreed that the main advantage is heat mitigation (71.3%) and its aesthetic value (38.6) (Table 3).

Table 3. Comparative per cent score of green roofs advantages⁴⁷

Advantages	Percent Score (%)
Mitigation of Urban Heat Island (UHI)	71.3
Aesthetic impact	38.6
Green area alternative	28.7
Save environment	27.7
Storm water management	19.8
Insulation	18.8
Increase green mark point	16.8
Soften building facade	16.8
Impact on education	14.9
Creation of natural habitat	13.9
Save energy	11.9
Air quality improvement	10.9
Increase life span of roof	8.9
Psychological impact	5.0
Noise reduction	3.0

Conclusion

An urban ecosystem needs vegetation as a significant component to reduce greenhouse gases, lower atmospheric temperature, and maintain ecological balance. The only possible strategy to incorporate vegetation as a part of urbanization with limited land is through green roof technology. Although the general concept of green roofs has yet to be very recent, its practical application is still very limited as the initial cost is perceived to be on the higher side. However, the idea that a more straightforward and affordable yet effective system can be developed must be imparted to the masses. Intensive research has been conducted in the type of technology to be used and the required construction materials. However, future studies can focus on the type of vegetation and suitable substrate that can be used in different systems, emphasising their aesthetic, therapeutic and environmental impact.

Declarations of interests

All authors of this manuscript declare that they have no conflict of interest.

Data sharing

All relevant data are within the manuscript.

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