RESEARCH ARTICLE

SAMRIDDHI Volume 14, Special Issue 1, 2022 Print ISSN : 2229-7111 Online ISSN : 2454-5767

Green Roofs- A Review

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ABSTRACT

As the green area continues to get replaced because of the increase in population and urbanization, the requirement to recover this area has become crucial for improving environmental quality. Installation of green roofs is one way that can curb the negative affect of growth and establishment while providing various environmental and economical benefits. Various names are given to green roofs such as “eco-roofs”, “roof-gardens”, etc. And these are roofs with vegetation at the top surface. The most specific reason for installing green roofs in the building is because of its energy efficiency. Along with this, other benefits do exist like their vegetation aids photosynthesis and their soil layer absorbs rainfall, typically leading to development in water runoff quality.

This review paper focuses on green roofs along with research efforts created by researchers. The discussion concentrates on each part of the green roof elements, i.e., vegetation, growth substrate, filter layer, drainage layer, waterproofing layer, and root barrier. This paper also includes experimental studies on the assortment of efficient green roof elements to satisfy public expectations. Moreover, the advantages provided by green roofs are highlighted.

Keywords: Green roofs, vegetation, growth substrate, drainage layer.

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, (2022); DOI : 10.18090/samriddhi.v14spli01.6

INTRODUCTION

Many nations had been confronted to increase urbanization because of economic growth. Primary energy of about 30-40% is used for buildings and released greenhouse gas for about 40-50% [1]. By 2050 nearly 9 billion human beings are predicted to inhabit the Earth and two-thirds of those are expected to live in urban areas (United Nations, 2009). The scarcity of greenery is the consequence of new development and urban population. To mitigate this impact, green roofs have become one option as it acts as an island of biodiversity within urban and suburban environments.

The history of green roofs can be seen during the fifth century in which Babylon’s hanging gardens had been imposed. Later, green roofs become a part of the five points of modern architecture which was discovered by the Swiss architect Le Corbusier [2].

The green roof is the top surface of the rooftop and may be considered as an additional floor of the structure. It can also be called as a “living” structure due to presence of plants and growth substrates [3].

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How to cite this article : Thokchom, S., Shijagurumayum, C., Suresh, T. (2022). Green Roofs- A Review. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology,* Volume 14, Special Issue (1), 30-35.

Source of support : Nil

Conflict of interest : None

Green roofs are commonly categorized as extensive or intensive. The distinction between intensive and extensive green roofs is that one has a prominent layer of soil while the latter has smaller amount of soil. Moreover, an extensive green roof has lesser water requirements and maintenance of roof.

COMPONENTS OF GREEN ROOFS

Green roofs are structurally designed and built to fight against urbanization. They are composed of several elements based on location and requirement. A technical drawing of green roofs elements is shown in figure 1.

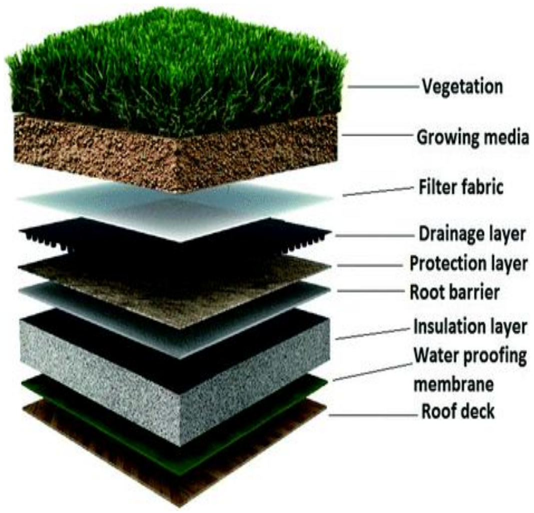

Figure 1: Technical drawing of green roof elements [14]

Vegetation

It is the uppermost layer of the green roof system. The accomplishment of a green roof is decided by the health of the plants. For this reason, the use of Crassulacean Acid Metabolism (CAM) plants is proposed as they can adapt to a dry environment to minimize photorespiration. The air and runoff quality are improved with the help of plants. Even so, [5] we should look into characteristics that can cope with harsh environment on the rooftops:

- capacity to resist drought states;
- persist under negligible nutrient environment;
- short and delicate roots.

Although it is tough to select a plant species that have all favorable qualities, Sedum species (a type of succulent) are favored and dependable as vegetation for green roofs.

Growth Substrate

The growth of plants along with the success of green roofs are directly linked to the growth substrate. As a result, we should always looked-for the appropriate substrate. Suitable growth substrate helps in improving water quality, reducing peak flow which is overall beneficial to green roofs. Still, it is not realistic to possess all these traits by one material that is going to be used as a growth substrate. Generally, several components of desirable characteristics are mixed in proportion to get the ultimate growth substrate [5]. The substrate with moderate bulk density, remain stable and aerated, minute leakage, provide nutrients to plant can be considered as an ideal growth substrate [6].

Filter layer

The filter layer lies between the growth substrate and the drainage layer. Its function is to prevent the entry of small media particles such as fine soils along with plant debris into the drainage layer and clogging it. A desirable characteristic of the filter layer is to be thin and light-weight [4]. This can be obtained by using polymeric fibers or polyolefins. Regardless of how it is identified, over 30% more precipitation can be retained with thicker fabric in green roofs than [5].

Drainage layer

The drainage layer comes after the filter layer and it acts as an indispensable part for the good outcome of any green roof. In the system, the drainage layer provides an equilibrium between air and water. Keeping in mind that green roof vegetation demands non-water-logged and aerated substrate for good growth, the drainage layer acts as a helping hand in the removal of surplus water.

In green roofs, two types of drainage layers are deployed, namely:

- **Drainage modular panels:** It is made of high-strength plastic materials that has room for water storage as well as permits the withdrawal of surplus water.
- **Drainage granular substances:** In addition to a large pore layout to store water, these substances have some WHC (water holding capacity). Some examples of drainage granular substances include lightweight expanded clay aggregates (LECA), coarse gravel, and stone chips.

Appropriate drainage layer to be used in green roofs relies on cost, construction demand, sort of vegetation, and proportion of the green roofs. In the market, the drainage element is tailored to retain up to 2 liters of water per square meter to furnish plants during dehydrated periods [6].

Waterproofing layer and root barrier

It has been known that the water-proofing layer is not a part of a green roof, despite that it is a necessary condition to include a waterproofing layer in the installation to hold back leakages. Because of the damp soil and drainage layer, the roof has already encountered excessive moisture content. Also, if a leak occurred in the green roof system, we have to dismantle all the layers to locate and mend the leak. In conclusion, it is always recommended to provide waterproof layer.

Root-barrier can be installed depending upon whether it is intensive green roofs or extensive type. The function of the root barrier is to protect the roof structure from root penetration that could damage the structure. In the market, physical barriers which are made up of low-density polyethylene (LDPE) or polyethylene material are available. In some other cases, chemical barriers are used which comprises copper-based products to inhibit root penetration.

Findings of Various Researchers

Fabricio Bianchini et. al. [4] compares the total pollutants released from non-recycled low-density polyethylene (LDPE) and recycled LDPE. Non-recycled LDPE releases 2.8 times more harmful substances to air than recycled LDPE. In addition, NO_2 is removed from the atmosphere during the process of recycling. After analyzing, the quantities of 4 harmful substances (NO_2, SO_2, O_3, and PM_{10}) produced from the recycled LDPE are reduced.

K. Vijayaraghavan et. al. [6] examines if green roofs will behave as sinks or sources of contaminants depending upon several physicochemical factors (pH, conductivity, and total dissolved solids). In their work, *P. grandiflora* was chosen as a test sample (which is locally grown in India). They used local garden soil as substrate-1(sub-1) and a more efficient green roof substrate as sub-2. To analyze the impact of green roofs on the quality of runoff, four green roofs pilot-scale assemblies are prepared. The assembly one or GRA-1 only consists of substrate-1; the GRA-2 consists of only sub-2; the third assembly or GRA-3 had sub-1 plus vegetation (*P. grandifloral)*, and the fourth (GRA-4) composed of sub-2 plus *P. grandiflora*.

Here, the pH of simulated rainfall in all four assemblies is found to have changed. Although pH variation is not consistent, the pH of outflow was always less than tap water (pH 8.5; used as simulated rainfall). Additionally, TDS (total dissolved solids) and conductivity of the outflow runoffs are found to have increased in all four of them.

Colleen Butler et. al. [7] put forward that *Sedum* species helps in cooling the soil. In a dry environment, it acts as a facilitator and as a competitor in wet conditions. They conducted two experiments: a) to examine the influence of *Sedum album* on the functioning of two surrounding plant species- *Agastache rupestris* and *Asclepias verticillata*—for the time of 3 years on a green roof in Massachusetts. *b)* to test the influence of 4 species of *Sedum* on the functioning of a single species *Agastache* 'Black Adder' on a green roof in Massachusetts. They found that ability to retain leaves at the time of water deficiency has been improved in the neighboring plants of *Sedum* species. Despite this fact, the overall growth of focal species has been decreased due to the influence of *Sedum*. Moreover, in the time of warm weather, the soil with 'Black Adder' and one of the species of *Sedum* has cooler temperature than the soil with only 'Black Adder'.

D. Bradley Rowe et. al. [8] experimented on twenty-five succulents (several species of *Graptopetalum, Phedimus, Rhodolia,* and *Sedum*) by growing them at three media depths (2.5, 5.0, and 7.5 cm) for a time of 7 years to find the result of plant behavior, along with the significance of analysis of species as plant group, can control root activity. Out of 25 succulents propagated, only six of them were able to live in all three media till the end of the 7th year.

Among the 23 surviving species, no notable differences were found at 2.5 cm during the first season. The same case was seen at 5.0 cm media depth. But most of the species showed superior growth at 7.5 cm depth during the first season. These comprise *P. spurius* 'Leningrad White', *S. hispanicum*, *S. album* 'Bella d'Inverno', *S. diffusum*, *S. acre*, *S. reflexum S. mexicanum*, *S. middendorffianum*, and *S. mexicanum.*

Susan Morgan et al. [9, 10] studied total suspended solids (TSS) and turbidity in the runoff from four growth media in planted and unplanted pots of over six months. The growth media include bottom ash, haydite, lava, and arkalyte. They found that the highest mean turbidity and mean TSS were seen in pots (unplanted and planted) with growth media as lava and haydite, but bottom ash and arkalyte gave the least mean turbidity and mean TSS. TSS was reduced by 17% and turbidity by 44% in the first watering event. From their result, it implies that compared to vegetation, the media had a greater impact on turbidity and TSS.

Yanling Li et. al. [11] specified their findings from fifty-two journals and indicated that the concentrations of obscure pollutants do not pose a hazard to the environment. These pollutants include heavy metals, BOD, TSS, and turbidity. But nitrogen and phosphorous present in green roof runoff does raise a warning to the environment. Study results reveal that phosphorus discharges surpass EPA's (Environmental Protection Agency) freshwater standard most of the time. Even though nitrogen is more leachable than phosphorus, it has lower discharges as compared to the standard.

Shrikant Pandey et. al. [12] compared two test structures to determine their cooling potential. One test structure has a green roof while the other has an RCC roof. Measurement of air temperature was performed during the summer period and was found that a structure with a green roof has a lower temperature in contrast to the RCC roof. The result indicates that the dry bulb temperature (DBT) of room 1 (bare RCC roof) was between 21.28 and 37.48ºC and between 17.88 and 33.68ºC in room 2 (with the green roof). Thus, the green roof cooling system purposes a balance indoor temperature along with lower heat flux flowing out through the roof in comparison to a bare RCC roof.

Aruna V et. al. [13] analyzed the runoff generation for sub-catchment and the effectiveness of low-impact development practices (green roofs) in mitigating the runoff at the source for the design storm of 2yr. The sub-catchment with the highest percent of imperviousness generated the highest runoff depth of about 291.31 mm in the base case which can be reduced by about 11.41% in case of 100% replacement of existing roof area to green roof and 25% replacement of results in 3.83% runoff reduction.

MATERIALS USED

The studied species and materials used by different researchers are shown in Table-1.

Table-1 : Materials Used

Sl. no.	Researchers	Study species/ Materials used
1.	Colleen Butler et. al. [7]	S. album, Agastache rupestris, Asclepias verticillate. Agastache 'Black Adder'
2.	D. Bradley Rowe et. al. [8]	For media: slate, grade sand, Dolomite, composted yard waste. For plant species: Graptopetalum, Phedimus, Rhodolia, and Sedum.
3.	K. Vijayaraghavan et. al. [6]	(50*50*50) cm glass assemblies, geotextile, Green roof substrate (red soil, clay, cow manure, vermiculite, perlite, crushed peat, coco-peat), P.grandiflora.
4.	Susan Morgan et. al. [9]	Polyethylene knit fabric bags, aniodized aluminium tray. Growth media (arkalyte, haydite, lava, bottom ash). Sedum kamtschaticum.
5.	Shrikant Pandey et. al. [12]	Shrubs, Single-layer polymer, Soil, Cement plaster, RCC slab.

RESULTS AND DISCUSSIONS

Polymers degrade at a slow rate and on a volume basis, it generates 20% of landfills input. Recycling and reusing avoid the production of new materials and so become an attractive option. Although the process of recycling harm the environment, green roofs can deplete the pollution produced in the air in long run [4].

1.25-2 mm and 1.25-4 mm were the particle sizes of substrate-1 and substrate-2, respectively. The bulk densities were found to be 1395 kg/m and 435kg/m for sub-1 and sub-2, respectively. The water holding capacity (WHC) of two substrates was noted as 30.5% for sub-1 and 39.4% for sub-2. Regarding the air-filled porosities (AFP), sub-2 exhibited 19.5% AFP which is quite high in contrast to 1.7% of substrate-1 [6].

The focal species were most affected by *Sedum* in a positive manner and these leads to no competition for light. If there were no rain for 5 days, nearly all of the non-*Sedum* experienced harsh wilting and partial leaf loss [7].

Survival to harsh winter is greater for plants grown in deeper media depths (5.0 and 7.5 cm) as compared to those grown at shallow depth (2.5 cm). For those grown at the shallow media depth, only 9 were able to survive the winter in the first year out of 25 species. In contrast to this, twelve and fourteen species for the 5.0 and 7.5 cm depths, respectively [8]. Thus, deeper media depths permit immense variety in plant material and usually persuade plants to be in good health under vast biomass.

In the first event of watering, initial turbidity and total suspended solids concentration were high. This is because of the smut rinsed from the pine bark particles mixed with the media. But for all growing media, the vegetation helps in reducing turbidity and TSS as compared to its initial amount. And with time turbidity and TSS is minimized [9, 10].

If green roofs are widely adopted, CO_2 concentration is noticeably decreased around the green roof site. In the area near the green roof, CO_2 concentration stick around 9.3% [11].

High temperatures and diurnal temperature variation undergone by the normal roofing system during summer were minimized if it is replaced by green roofs. Although green roofs cannot provide 100% thermal comfort, it lessens the demand for air-conditioning and help in toning down pollution from the surrounding [12].

It can be stated that the higher the percentage replacement of roof area higher the runoff reduction. The runoff reduction potential ranges from 2-11%, 2-9%, 1-7%, 0.83-3.83% in case of 100%, 75%, 50%, and 25% replacement [13].

ADVANTAGES OF GREEN ROOF [15]

The advantages of implementing a green roof are given in Table-2.

Table-2: Advantages of Implementing Green Roof

Advantages	Findings
Environmental	Natural filtration: green roof helps in absorbing dust and clean the air. Thus, acts as a natural air filter. Stormwater management: Green roof acts as porous surfaces and control storm waters. Acoustics: Green roof has the potential to control and minimize sound reflection. It can reduce noise level up to 8-10 decibel.
Economic	Energy: green roof provide shading, insulation, evapotranspiration, and increase in thermal mass. This leads to consuming less energy. Green roof has been assigned as a mechanism to diminish urban heat island. Green roof escalates the life period of the rooftop by shielding them from stress diurnal, thermal and UV radiation variation.
Social	Places for recreation and relaxation can be created through green roof. Green roof confirmed that exposure to the Mother Earth has a cognitive influence and improves human health. Performance of employee is improved in green roof building. Thus, plants have a good impression on the people .

CONCLUSION

Rapid urbanization shows a drastic decline in the open spaces available for vegetative growth. As such, a green roof is a feasible solution towards achieving a balance between urbanization and thriving vegetative growth at the same time and space. Moreover, building green roofs aids to reduce climate change as it greatly reduces air pollution. Each and every layer of a green roof has a notable impression on its performance. It is evident that *Sedum* species almost fulfilled most of the required characteristics of vegetation. Growth media also participate in the successful implementation of green roofs. As per the climatic condition, it is advisable to develop growth medium using locally accessible substance for the productive growth of vegetation. Another significance of green roofs is the water quality improvement by minimizing the pollutants accumulation like heavy metals, total suspended solids, nitrogen, etc. It was observed that the usage of recycled low-density polyethylene (LDPE) as a drainage layer mitigates the release of toxic substances in comparison to non-recycled LDPE. To elevate the ecological balance provided by green roofs, it is of great importance to search for substances that can substitute the current practice of polymer. Furthermore, green roofs act as a remedy in reducing storm-water runoff volume.

All in all, green roofs are an appealing alternative to conventional roof surfaces. However, the impression of green roofs and their long-term profits are quite new to a developing country like India. Thus, Government initiatives will help largely in spreading awareness. This technology needs more special attention in investment for research. We can hope for green roofs in every corner of the world in the future.

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