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Analysis of rainwater utilization technology and current situation in roof garden

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Abstract. The urban water environment has been deteriorating over the last decade due to land development and climate change, increasing the pressure on urban stormwater drainage systems. With economic development, the value of buildings has also been challenged at a higher level. Roof garden, as a new form of roof treatment, can effectively increase the urban greening area and compensate for the ecological and water environments that have been damaged by building development and utilization. This paper analyzes the advancement of roof garden by comparing it with the traditional sloped roof. The analysis finds that roof gardens can store water and control drainage, and have significant advantages in reducing rainwater discharge, reducing building water demand, and improving the urban water cycle. Roof gardens not only have the ability to utilize rainwater efficiently, but also come with a series of economic, ecological, and social benefits, such as improving the urban heat island effect, saving the amount of water demanded by buildings, and energy consumption. By analyzing domestic and international cases of roof gardens, it is verified that roof gardens are designed as a combination of utility and aesthetics.

Keywords: Roof Garden, Water Utilization, Water Drainage.

1. Introduction

In recent years, as urbanization continues to grow, economic buildings continue to take up areas of urban greenery, reducing the capacity of land and vegetation to store and drain water, and increasing the pressure on urban stormwater drainage systems. At the same time, the atmospheric movements driven by climate warming have intensified, surface temperatures have been rising, and precipitation changes have become increasingly significant [1]. This has also led to frequent extreme precipitation events that are highly susceptible to induced flooding. This has resulted in substantial economic losses and even loss of life, placing higher demands on urban drainage and water storage systems.

In recent decades, countries around the world have given corresponding policies and measures to improve the urban flooding problem, such as roof gardens, sponge cities, SUDS, LID control and so on. Roof garden as an important way of urban rainwater harvesting and utilization has been greatly promoted by European and American countries. This design can absorb water through the roots and leaves of plants, and can also construct a reservoir so that rainwater can be efficiently utilized. This makes the advantages of roof gardens even more significant, not only can effectively reduce the runoff from the roof and the surface, but also play an important role in flood control, effectively alleviating the contradiction between urban water supply and demand [2]. In addition, the concept of green roofs not only meets the need for environmental protection but also the need for urban landscaping. The concept also shows great potential on an economic level, creating sustainable value for the city [3]. At the same time, the introduction of roof gardens can not only compensate for the urban green area occupied by the building but also improve the urban heat island effect, purify the urban air and effectively reduce environmental noise. Through the addition of specific measures to improve the design can also have wind, earthquake and other functions [4]. This multi-functional design of the building's practicality and environmental benefits are perfectly integrated to achieve a harmonious symbiosis of architecture and nature.

In summary, as a representative of urban green buildings, roof gardens have good ecological and environmental benefits as well as socio-economic values, and the research and application of its rainwater utilization technology is of great significance for realizing the sustainable use of urban water resources. Therefore, this paper summarizes the research on roof gardens and related examples in recent years, hoping that it can provide guidance and help for future design and research.

Firstly, this paper analyses the advantages and characteristics of roof gardens in terms of rainwater utilization by discussing the design concepts and characteristics of roof gardens. Secondly, this paper reveals the innovation and sustainability of roof gardens in stormwater management by analysing the roles of green roofs and traditional roofs in urban stormwater drainage, building water storage and urban water environment. Finally, the role of roof gardens in rainwater utilization systems is verified through case studies of Saitama Plaza in Japan and the Food Building of Inner Mongolia Agricultural University.

2. Roof Garden Overview

2.1. Concept of Roof Garden

The roof is the top of buildings and structures as a carrier, with the plants as the theme of the configuration, not with the natural soil directly bordering the greening method, which is a variety of roof planting methods of the general term [5]. A green roof usually consists of a vegetation layer, a filter fabric, a drainage and water storage layer, a protection fleece, an anti-root barrier and a water proofing membrane, then connected to the roof slab by structural support [6].

Roof garden early by the ruling class, religious worship, etc. used for landscaping, but with the emergence of European turf roofs began to shift to practicality. In 1882, in the United States, New York, Cassino Roof Theatre built the first profit-making roof gardens, roof gardens have also begun commercial use development. In recent decades, with the rapid development of urban construction, people's living environment and quality of life requirements have increasingly improved, and roof gardens are architects gradually more attention. In addition, due to the significant improvement of roof gardens on urban water supply and drainage systems, more and more people are also considering this design in urban construction. Onsite treatment such as green stormwater infrastructure (GSI) and Low Impact Development (LID) recognizes green roofs as a practice [7], and in 2012 China included them as one of the technical measures for low-impact development in the theory of "sponge cities", a new type of rainwater management system.

2.2. Benefits of Roof Garden

Roof garden can effectively increase the greening area of the city and bring a series of ecological, economic and social benefits to the city and buildings. Its ecological benefits are mainly achieved through the various absorption and adsorption effects of green plants to purify the air, reduce heat radiation and sound exposure. A large area of green space can also improve the naturalness of the city and increase biodiversity. The economic benefits are mainly realized through the shielding and protecting effect of vegetation roofing on buildings, which can save the expenditure on temperature control equipment and energy consumption, prolong the service life of buildings, and add value to buildings. In addition, expanding a green space in the urban hard landscape also brings social benefits such as beautifying the environment, improving the comfort of the city, and providing resting places.

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The roof garden's role in rainwater utilization includes reducing rainwater discharge, lowering the amount of water stored in the building, and improving the urban water environment, while covering the above three aspects. This part will be specifically developed in Section 3 below.

2.3. Classification and characteristics of Roof Garden

Roof gardens make flexible use of the edge of the house related to the main body of the building to open up new green space, creating a green space in a city with tight land use, as well as connecting the indoor and outdoor spaces and diluting the geometric architectural boundaries [8].

According to the form of the roof on which they are located, they can be divided into sloping and flat roof gardens. A drainage slope greater than 10% of the sloped roof simpler to plant lawn or vine plants, a flat roof can be used for plants, water and other elements of flexible landscaping. According to the spatial organization, it can be divided into open, semi-open and closed roof garden. Open roof gardens are usually connected to the roof slab of the building and are located at the top. Semi-open roof gardens are connected to the roof slabs of some areas of the building and are sheltered from the rest of the building. Enclosed roof gardens are enclosed by the building, creating a patio-like space [9]. According to the function, it can be divided into public leisure type, residential type and scientific research green roof garden. In addition to the benefits of greening, the public recreational type also has fun, commercial and other uses, and is the most common form of roof garden. Residential roof gardens are generally configured through plants, making full use of space for greening, which can make the living environment more natural and fresher. Research green roof garden is generally used for scientific research and production, and can also be set up according to the need for small greenhouse and other facilities. In addition to the above classification criteria, it can also be divided according to the complexity of roof greening, the spatial distribution of roof buildings, and the type of building.

3. Comparison between green roofs and traditional roofs

3.1. Role for urban stormwater utilization systems

Urban rainwater harvesting and utilization methods include four types of rainwater utilization methods: roofing, green roofs, parks and recharge to groundwater. As one of the important components, rainwater utilization based on green roofs has a significant effect on both drainage and water storage [10]. Vegetation in a green roof system has a significant intercepting effect on rainwater, and the planting substrate also absorbs large amounts of water. The absorbed rainwater can be used for plant metabolism and the rest can be diffused into the atmosphere in the form of evaporation and plant transpiration. In this way the effect of stagnant rainwater can be achieved, effectively cutting roof and surface runoff and reducing the pressure on the urban drainage system. Calculation results have shown that green roofs can reduce rainwater runoff by about 70% [11]. Reducing water runoff and lowering the amount of water stored in buildings also saves labour and costs, and reduces wastewater treatment expenses.

During rainy flood seasons, the ability of a green roof system to hold stormwater can act as a flood control. Traditional roofs channel roof runoff through slopes to surface runoff, which then pools into natural waterways. However, during the flood season, when the rainfall increases, the river rainfall flow also increases, and when it reaches the maximum value, it forms the rainfall flood peak. By reducing the surface runoff into the natural watercourse, the roof garden can reduce the flood peak and slow down the time of the flood peak value when the rainfall is large, provide a certain buffer and reduce the pressure on the urban drainage system.

3.2. Role in building water demand

Roof gardens can effectively reduce the amount of water required by a building. Conventional sloped roofs cannot store water; their slopes drain rainwater directly and quickly, causing it to flow into the city's drainage system. When a building needs water, it has to reclaim it again from the city water system. Roof gardens, however, are different in that excess rainwater is usually removed through drainage pipes.

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Through proper design of the drainage pipe system, water can be recycled inside the building, thus realizing the sustainable use of rainwater resources.

In addition, roof gardens can also be combined with cisterns or catchment tanks to accumulate rainwater during rainfall. After treatment, rainwater can be used for activities that do not require high water quality, such as flushing toilets, air-conditioning cooling water, and cleaning water. The vegetation layer of roof gardens can be watered by rainwater, and water from the cisterns can also be called nearby for watering when the soil is dry in the dry season. This initiative reduces the maintenance resources for green roofs and further saves the building's water requirements. Roof gardens therefore also have a better direct economic impact on the buildings in which they are located.

3.3. Role for the urban water environment

Roof gardens can contribute to improving the urban water environment. The hard surfaces of traditional buildings replace the natural ground, expanding the area of impermeable underlayment and making it difficult for rainwater to seep into the ground. When rainwater cannot infiltrate into the soil, it generates surface runoff, which can lead to flooding. In addition, the hardening of the natural underlayment caused by traditional construction has led to a decline in the groundwater table over the years as buildings are developed, a phenomenon that is widely seen in many cities in China. Over-exploitation of land has also led to localized seawater back-ups, pollution of underground freshwater resources, soil salinization and destruction of water sources [12]. Roof gardens, as an important infiltration technique, can also reduce the frequency of urban flooding and damage to the urban water cycle.

Roof gardens also help to improve the water quality of the urban water environment. Atmospheric pollutants caused by urban construction will settle with rainfall, and will also further deteriorate the water quality of the urban water cycle if directly infiltrated without treatment. Traditional roofing compounds in roofing materials and dust, bird droppings, leaves and other pollutants will enter the roof rainwater runoff, contaminating the water quality and at the same time exacerbating the deterioration of the urban drainage network system [13]. As mentioned above, roof gardens can store water and are more controllable in terms of rainwater discharge, so the collected rainwater can be processed and then introduced into the ground through drainpipes, slowly infiltrating to replenish groundwater. When the rainwater flows through the vegetation layer, the plants can also absorb some of the harmful substances in the water, playing a layer of filtration, reducing the process and cost of subsequent water treatment.

4. Case studies of roof gardens

4.1. International case

The Saitama Plaza Roof Garden in Japan was constructed on the site of a railroad in the city centre, connecting the gymnasium and many residential, office, and commercial buildings, with an area of 11,100 m^2. 220 zelkova trees were planted in the roof garden, evenly distributed in a dot-like pattern. Beech trees have the advantages of a stable landscape effect, easy cultivation and maintenance, resistance to drought and barrenness, soil consolidation and wind resistance. A 6m×6m tree array contains four beech trees and a square seat, which conforms to the arrangement of the building's column network. The large-scale planting of trees on the roof is a rare case, and the architects created a modernist "forest in the sky" based on the design concepts of "New Japanese Style" and "Minimalism" [14]. Figure 1 showed the aerial view of the roof garden [14].

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Figure 1. Saitama Plaza Roof Garden Aerial View [14].

The ground floor is covered with granite and permeable panels assumed to be on a PC skeleton, which allows for rapid drainage in the event of heavy rainfall. Rainwater can be used to irrigate the beech trees during rainfall, and when there is too much rainwater, the excess rainwater can be discharged through the dense drainage wells set up on the ground floor, preventing the plants from rotting and wilting, and ensuring that the roof load does not exceed the safety limits. The Saitama Plaza Roof Garden takes into account social, aesthetic and ecological functions, and comprehensively solves a series of problems such as roof loading, waterproofing, watering, irrigation and drainage with a seemingly simple plan layout, making it an excellent example of a recreational roof garden.

4.2. Domestic case

The Food Science Building of Inner Mongolia Agricultural University is located in Hohhot, Inner Mongolia, with a total area of about 528 m^2. The roof garden is functionally divided into scenery ornamental area, rest and recreation area, and learning and practice area, and each area is differentiated according to the dynamic environment and static environment. Between the areas, the space is divided by garden trees, and attractions such as pavilions, observation decks, bars, and practice planting substrates are set up to create the theme of "interesting learning" [15].

Due to the weak load-bearing capacity of the college building, it is difficult to plant tall trees. Among the cold-tolerant and resistant shallow-rooted plants commonly found in Hohhot, various shrubs such as honeysuckle, white lilac, chaste tree, and herbaceous plants such as marigold, early grass, and peacock weed were selected to create a roof garden landscape in the northern border style through different colours and shapes. The growing period of these plants is from April to August, and the long days and short nights and high precipitation in Hohhot are very favourable to the photosynthesis of roof greening.

The Food Science Building of Inner Mongolia Agricultural University, as a case of a campus roof garden, is compatible with the characteristics of leisure and recreation and scientific research greening. Functionally, it combines the needs of the student and faculty population and also highlights the characteristics of the agricultural university. The landscape design extends the building space, creates a garden landscape, and also satisfies the use of the masses.

5. Suggestion

Roof gardens have a long history of development in developed countries, but they have only begun to emerge in China in recent decades with rapid economic development. Relevant research is still in the preliminary stage, in terms of policy and technology are not mature enough, and there is no particularly complete evaluation system. As for policy, China can refer to the existing laws and regulations in the developed countries, and establish a perfect, efficient and operable general legal system in combination with China's specific environmental conditions and process characteristics, and local regulations should be established in each region according to different climatic and environmental conditions. Technically, roof gardens can be improved through improved design to improve various urban environmental problems and further enhance the value of the building. Individual regions can also more accurately determine spatial planning and plant selection based on regional climatic conditions.

In addition, roof gardens, as a highly efficient rainwater utilization technique, should be called upon to be promoted and developed in more regions of China. An increase in the number of cases can help establish a more complete evaluation system for green roofs and provide more sample data for future research, thus promoting the further development of roof garden technology in a more efficient and economical direction. If roof garden technology can be widely used in China, the capacity of cities to withstand extreme precipitation will be stronger, and problems such as the water environment and heat island effect can be effectively improved.

6. Conclusion

This paper explains that roof gardens can play a significant role in stormwater utilization systems by reviewing the relevant literature and comparing them with traditional roofs. In terms of drainage, roof gardens can store rainwater, effectively reduce runoff, and improve the resilience of cities to flooding by reducing and delaying flood peaks. In terms of water storage, roof gardens can also store rainwater and reduce the amount of water needed for buildings. In addition, roof gardens can also improve the urban water cycle and the water quality of the urban water environment. This paper then analyses two case studies to demonstrate that roof gardens can also be multifunctional to add value to a building, meeting the requirements of aesthetics and functionality. The choice of vegetation is also influenced by the design concept, regional climate, landscape and other factors. At the same time, roof loading and drainage should be improved to ensure the safety of the building.

China's roof garden technology is not mature enough and needs to be targeted to improve the design. Policies are also not perfect, can learn from developed countries that have laws and regulations to form their system. If it can be promoted in practice, it can bring great benefits to many aspects of the city. With the promotion of the technology, the increase in the number of research samples can also further promote the development of related scientific research, forming a virtuous cycle.

This paper focuses on the role of roof gardens in drainage, but does not expand in detail on other multifunctional aspects such as thermal effects and building design. Although the development of roof gardens in terms of rainwater harvesting and utilization is slow, the development of multifunctionality is more effective in adding value to the building. This also contributes to the diffusion and dissemination of technology. Therefore, the exploration of other aspects should also be strengthened in future research so that it can be more flexible to adapt to more situations and meet different development needs. Only when this technology is more widely used will research in turn be able to create more opportunities for breakthroughs, leading to more functional and more effective roof gardens.

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