Characteristics of Green Roof and Vertical Greening Systems and Its Application Prospect in Hong Kong

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Abstract. Under the background of urban population growth and increasingly prominent urban environmental problems. Green infrastructure in line with sustainable development is considered a possible solution. This paper aims to study the application of green roofs (GR) and vertical greening systems (VGS) in densely developed cities, such as Tokyo and Singapore, and provide a reference for Hong Kong. This study believes that GR and VGS have great potential in alleviating urban environmental problems in Hong Kong and can effectively provide more green development space. At the same time, it plays an active role in alleviating the urban heat island effect, reducing air pollution and energy consumption. Currently, there are some urgent problems with the application of GR and VGS in Hong Kong, such as construction cost recovery, hidden dangers of public safety, and technical construction difficulties. In addition, this paper suggests that Hong Kong should provide more investment and support for GR and VGS in legislation and technology to promote their promotion and popularization.

Keywords: Building greening; Green infrastructure; Green roof; Vertical greening system.

1. Introduction

Excessive resource consumption is pervasive due to the ongoing industrialization and urbanization processes, and it has become urgently necessary to find a solution. The United Nations has established the objective of sustainable cities and communities in order to enhance people's quality of life [1]. Countries have also proposed cutting-edge low-carbon development policies in this area [2]. China has created a pilot plan for low-carbon cities to solve urban low-carbon development concerns with practical methods such as enhancing traffic situation and energy efficiency to accomplish its carbon peaking targets by 2030 and carbon neutrality by 2060. Green building practices, as a specific method of constructing energy-saving measures, have gained popularity as a means of reducing emissions, pollution, negative environmental effects, and energy consumption as well as increasing the sustainability of buildings.

Under the background that the concept of sustainable development continues to affect the urban development strategies of various countries, some emerging concepts of green building and building greening have been put forward and put into practice in developed regions led by Europe [3, 4]. This model is also gradually applied to China. In developed coastal cities such as Shenzhen, there has also been some progress in the development of hard surfaces such as building facades and bridge decks. Hong Kong, China, has limited urban green space as a typical area with dense buildings, rapid development and limited land resources. However, there are a few relevant solutions, such as the application of green roofs (GR) and vertical greening systems (VGS).

Combined with the characteristics of building greening, this paper refers to the solutions of foreign-intensive cities and puts forward some ideas for the application of new building greening in Hong Kong.

2. Green roof and vertical greening system

GR and VGS belong to the category of building greening. Building greening is the process of forming green areas inside or outside the structure according to the characteristics of specific sites [5]. It aims to protect the ecology, beautify the environment and improve the quality of life. At present,

building greening focuses on the development of a new mode of integrated development of greening vegetation and people, buildings and cities.

2.1. Concepts and theories

Green roof (GR) refers to a multi-layer system covering vegetation on the drainage soil layer of the building roof [6]. When emphasizing its ornamental value, it is usually called a roof garden. In Europe, GR has become a universal and effective measure to improve the environment, save energy and protect buildings. For cities, GR is also expected to play an active role in alleviating the urban heat island (UHI) effect and urban air pollution. The concept of GR is not only reflected in its function but also contains aesthetic and social values. In terms of aesthetics, GR adds to the landscape value of buildings. From a social perspective, GR helps improve residents' quality of life, provides an outdoor space for leisure and entertainment, and promotes community sharing and interaction.

Vertical greening system (VGS) is a less-studied building greening scheme, which can be generally divided into green walls (GW) and living walls. The green wall, also known as a vertical garden, is a form of vegetation that does not rely on soil. It uses the inherent ability of plants to adapt to the surrounding environment to achieve the effect of covering the wall so as to achieve the purpose of greening. In order to increase the existence of green space and meet the public's demand for the natural environment, climbing plants are usually used in large areas in GW. In addition to improving air quality, GW can also reduce temperature and humidity while effectively purifying indoor air. It’s beautiful, sustainable and energy-saving characteristics give it a wide range of applications. Living walls can be further classified as biofilter or modular living walls [7]. It usually uses prefabricated modules containing soil, plants and irrigation systems. This system has a wide selection of plants, including climbing plants, herbs, shrubs or small trees. In general, buildings need to use new wall structures to design living walls.

2.2. Advantages and disadvantages

GR and VGS have many advantages different from other green infrastructures, especially in the proportion of public space occupation, design flexibility, greening coverage, and aesthetic value. From a macro perspective, the two schemes can reduce the urban temperature and promote air convection. From the microscopic point of view, it is also conducive to the formation of a small area ecosystem, reducing indoor temperature and prolonging the service life of buildings.

They also have different degrees of shortcomings and application restrictions. Taking GR as an example, its initial cost and technical requirements are high, its maintenance is complex, and there are also many requirements and restrictions on parameters such as roof slope and bearing capacity. These problems are severe in some countries and regions with low water prices and poor economic development. For countries with large land areas, the public land resources are enough to provide an area for greening, and the necessity of GR is low. Therefore, GR is generally most applicable in developed countries and intensive cities with small land areas. Although the cost of VGS is relatively low, there are also concerns about the risk of plant fall and the impact of mosquito nuisance, and the range of plant options is relatively limited. In general, VGS also faces issues similar to GR that need to be considered.

3. Existing successful application cases

3.1. Application in Tokyo, Japan

Tokyo is one of the most densely populated cities in the world. In order to mitigate the urban heat island effect and protect the ecological environment, green infrastructures are widely used in Japan. According to the statistics of the Tokyo Environment Agency, the installation area of GR and GW in Tokyo has exceeded 250 hectares. Since both GR and GW need to cover the building shell with vegetation, they are collectively referred to as aboveground greening in Japan [8]. The measures implemented by the Tokyo government to increase ground greening include advocating and

promulgating legislative reforms. For example, for new, renovated or expanded buildings, when the flat roof area of private facilities exceeds 1000 square meters, and the flat roof area of public facilities exceeds 250 square meters, the green coverage rate of the roof shall not be less than 20%.

When considering the possibility of specific implementation, taking Sumida District in Tokyo as an example, it is estimated that about a quarter of the available roof area can accommodate GR installation. In addition, when considering the implementation of roof greening transformation, it is worth noting that about 59% of Sumida district shows a high potential of utilizing the benefits of roof greening [9]. In GR in Tokyo, perennial herbs, such as lawn grass, ground cover plants and flowers, are generally planted. For some large GR, shrubs and small trees will be planted. These plants can increase biodiversity, increase air oxygen content, and alleviate the urban heat island effect. At the same time, it can also provide shade for the public.

3.2. Application in Singapore

Benefiting from the popularity of the concept of green environmental protection and financial and technical support, VGS has a wide range of advanced applications in Singapore. There are many famous buildings, such as Sentosa Hotel and Changi Airport. Taking Changi Airport as an example, a large number of VGS technologies are used in the exterior wall and interior. The success of its landscape design stems from integrating natural elements and advanced technology.

The T3 terminal has a central waterfall and a vast multi-storey Vertical Garden (Fig. 1a). Its exterior walls are mostly transparent curtain glass, which provides natural light for plant growth. Plant species include shrubs, evergreen trees, common wetlands, and tropical plants (such as hemp leaves and palm trees). The top layer plants are in the outer zone, while the bottom layer plants are close to the center. This three-dimensional design reflects the idea of order and continuity. Sunlight can irradiate all plants to the greatest extent, and the appearance is more layered.

In addition, the T3 terminal also has large green walls (Fig. 1b), which operate through double-layer cable support system and innovative skylight roof design. The cable support device connects the grid and shows effective vegetation control and maintenance. The transparent design of the roof structure allows natural light to enter the interior of the building. At the same time, in order to ensure that the low-lying vegetation has sufficient light, it is necessary to carry out technical intervention through artificial light [10]. The indoor three-dimensional garden composed of many plants can play a positive role in reducing indoor temperature, reducing energy consumption and promoting air circulation. The permission of relevant scientific and technological intervention also provides a strong guarantee for the stability of three-dimensional ecological communities.

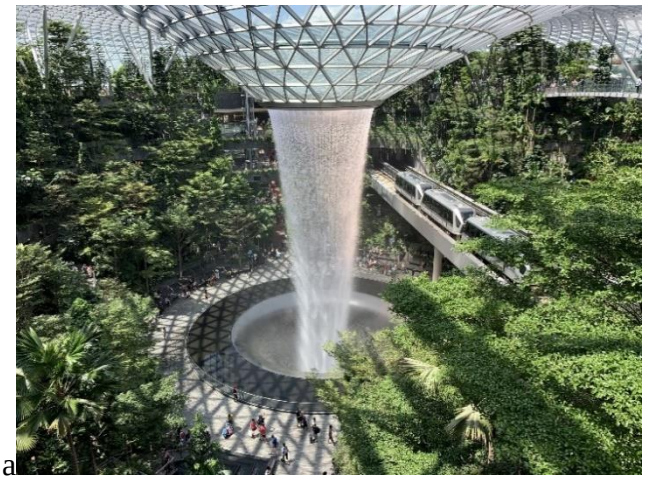
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Fig. 1. (a) A central waterfall and a vast multi-storey vertical garden and (b) Green wall in T3 terminal.

4. Application prospects and evaluation in Hong Kong

4.1. Overview of Hong Kong

Hong Kong has a significant position in terms of politics, commerce, and culture. The financial and tourist sectors are also well-developed. High levels of globalization, independence, and many contemporary amenities define it. Hong Kong is situated along China's eastern coast, with the South China Sea to its east. Of the four seasons, summer exhibits the highest levels of precipitation. With a variety of landforms, the topography is mostly mountainous with some lowland areas. The flow varies significantly between the dry and rainy seasons despite the rivers' scarcity and shortness. The Hong Kong Special Administrative Region is home to several forest nature reserves. The majority of tropical and subtropical plants may be planted in Hong Kong due to its favorable climate [11].

One of the world's cities with the densest populations is Hong Kong. Due to their central location and dense distribution, high-rise structures are vulnerable to UHI. The suburban and urban regions range in temperature, and some of the issues it has are comparable to those in Tokyo, Japan. Hong Kong's population density on land is 6890 persons per square kilometer [12], and a lot of high-rise structures are built to house a large population. The limited land resources and urbanization progress in Hong Kong are factors in this circumstance.

4.2. Application status and prospect in Hong Kong

4.2.1. Current application status

Hong Kong's awareness of building greening is constantly improving, and GI has been applied in some areas. The application's purpose is mainly to save energy consumption and alleviate the urban heat island effect. For GR, most of the studies affirmed its high ornamental value, but there were few related studies on quantitative benefits. At the same time, considering the high implementation cost and technical difficulty, GR has less practical application in Hong Kong. The practical application cases of VGS are also relatively rare. Previous studies have shown that the reduction in carbon emissions brought about by its VGS energy saving can offset the cost of 50-year life of VGS [13]. Therefore, it can be considered that the construction of VGS in Hong Kong is an environmentally sustainable approach.

4.2.2. Application prospect

The UHI effect was effectively handled in Hong Kong by VGS. With plants covering 30% to 50% of the facade, it is possible to lower daytime and nighttime temperatures in Hong Kong's high-density urban environment by 1 °C. It also improves the thermal comfort of daytime walkers by at least one degree of heat [14]. As a result, this article offers some recommendations on how to design green buildings that are appropriate for Hong Kong's urban areas:

(1) The service lives of certain buildings in Hong Kong have been reduced by long-term solar radiation and rainfall erosion due to their antiquated architecture. It is more practicable to apply GW to the outside walls of historical buildings rather than developing new building facilities appropriate for VGS on the basis of existing structures and carrying out restoration and repair, given property rights concerns and other challenges in Hong Kong.

(2) When considering subsequent maintenance, it is necessary to consider the high labor cost, water cost and maintenance difficulty caused by high-rise buildings in Hong Kong. Drip irrigation and sprinkler irrigation can be considered to reduce water consumption. Use environmental parameter monitoring devices and plant growth detection systems to reduce the frequency of manual inspection.

(3) Refer to the relevant solutions implemented in Singapore to promote the application of VGS in the interior facade, especially in extensive public facilities (such as airports and high-speed railway stations) through artificial light and high transparent roofs. In places with many people, VGS will play a more significant role in purifying indoor air, reducing room temperature and beautifying the environment.

(4) Introduce incentive policies and mandatory measures. At the beginning of the 20th century, Tokyo legislated on the GR construction of new buildings. Hong Kong can also promote the development of green buildings through various incentives and necessary mandatory measures. Moreover, consider conducting pilot projects in public places.

4.3. Possible difficulties and challenges

Although the GR and VGS can promote the sustainable development of Hong Kong, there are still some problems in the actual operation:

4.3.1. Difficult to renovate or rebuild

Both GR and VGS require irrigation and drainage systems, concrete frames and other structures, while buildings built a long time ago have less reserved public space; The floor height is generally high, and the construction is difficult; Including property rights and other issues, it is difficult to obtain construction permit. All these will pose challenges to the reconstruction project.

4.3.2. High cost

Additional water resources are required to ensure the growth of high-rise plants, and human resources are required for later maintenance. In order to properly calculate the water demand of plants, some new buildings will even use computer technology so that the water demand of plants can be guaranteed in different weather and seasons. In the face of high costs, reconstruction and new construction projects may only be carried out in local areas, such as high-grade residential buildings and public buildings constructed by the government.

4.3.3. Impacts on people's lives

Bird and insect nuisance, ventilation and lighting in buildings are likely to become new problems for residents. If this problem cannot be well solved, it may cause problems such as the low willingness of the public to build green infrastructure and poor response, which will hinder the promotion and popularization.

4.3.4. Fire hazards

During construction, it is necessary to consider whether the external fire will spread to the building through the green plants on the external cladding or facade, and whether the internal fire will spread to the plants on the facade, affecting escape and aggravating the fire. The plants are too dry and the fire protection system is old, which may be the potential hidden danger of expanding the fire.

4.3.5. Risks of falling objects

High-altitude wind is usually strong, and in summer and autumn, Hong Kong may face the threat of typhoons. The protection and fixation of plant branches and stems will be a crucial safety issue.

5. Conclusion

This review discusses the application possibility and Development Assumption of GR and VGS in Hong Kong. GR and VGS adapt to the concept of low-carbon development and sustainable development, provide solutions to potential urban environmental problems, and are both options for Hong Kong to build green infrastructure. GR and VGS can make more effective use of urban space, which is one of the best solutions to solve the greening problem of dense cities. From the urban point of view, GR and VGS can alleviate the urban heat island effect, adjust the local climate, promote urban convection, and reduce air pollution. From the architectural perspective, it can reduce erosion and prolong the service life of buildings. From the residents' perspective, it can reduce energy consumption and electricity expenditure. Other ecological benefits are difficult to quantify, such as increasing biodiversity.

Given the intensive development strategy of Hong Kong as an international city, this paper also studies the international experience by investigating the application of green infrastructure in Tokyo

and Singapore. Combined with the relatively complete application of GR and VGS, this paper suggests that Hong Kong should conduct more research and practice in establishing scientific and technological support, indoor greening, public facilities greening and other directions.
However, noteworthy problems still exist. As far as Hong Kong is concerned, there are still urgent problems to be solved in aspects such as construction cost recovery, hidden dangers of public safety, and technical construction difficulties.

References

[1] UN, Sustainable Development Goals, 2016 https://sustainabledevelopment.un.org/?menu=1300

[2] Ali, S., Hussain, T., Zhang, G., Nurunnabi, M., & Li, B. The implementation of sustainable development goals in "BRICS" countries. Sustainability, 2018, 10(7), 2513.

[3] Brenner, J., Schmidt, S., & Albert, C. Localizing and prioritizing roof greening opportunities for urban heat island mitigation: insights from the city of Krefeld, Germany. Landscape Ecology, 2023, 38(7), 1697-1712.

[4] Campiotti, C. A., Gatti, L., Campiotti, A., Consorti, L., De Rossi, P., Bibbiani, C. & Latini, A. Vertical greenery as natural tool for improving energy efficiency of buildings. Horticulturae, 2022, 8(6), 526.

[5] Zhou Tiejun, Wang Dachuan, Xiong Jianwu. Form, function and cognition: The role of architectural greening in green buildings and ecological cities. Science China: Technology Science, 2015, 45.9: 951-963.

[6] Berardi, U., GhaffarianHoseini, A., & GhaffarianHoseini, A. State-of-the-art analysis of the environmental benefits of green roof. Applied energy, 2014, 115, 411-428.

[7] Wang, C., Er, S. S., & Abdul-Rahman, H. Indoor vertical greenery system in urban tropics. Indoor and Built Environment, 2016, 25(2), 340-356.

[8] Jim, C. Y., Hui, L. C., & Rupprecht, C. D. Public perceptions of green roof and green walls in Tokyo, Japan: A call to heighten awareness. Environmental Management, 2022, 70(1), 35-53.

[9] Aleksejeva, J., Voulgaris, G., & Gasparatos, A. Assessing the potential of strategic green roof implementation for green infrastructure: Insights from Sumida ward, Tokyo. Urban Forestry & Urban Greening, 2022, 74, 127632.

[10] Seo, D. Articulate Design Thinking for Sustainable Airport Environment: A Case Study of Singapore Changi Airport T3. Transportation Research Procedia, 2021, 56, 136-142.

[11] CTBUH (Council on Tall Buildings and Urban Habitat), 2023 Hong Kong - The Skyscraper Center. https://www.skyscrapercenter.com/city/hong-kong

[12] Commercial Office of the Economic Affairs Department of the Liaison Office of the Central Pe ople's Government in HK SAR, 2019 Introduction to Hong Kong. http://hk.mofcom.gov.cn/articl e/ddgk/zwdili/201904/20190402849305.shtml

[13] Pan, L., & Chu, L. M. Energy saving potential and life cycle environmental impacts of a vertical greenery system in Hong Kong: A case study. Building and Environment, 2016, 96, 293-300.

[14] Morakinyo, T. E., Lai, A., Lau, K. K. L., & Ng, E. Thermal benefits of vertical greening in a high-density city: Case study of Hong Kong. Urban Forestry & Urban Greening, 2019, 37, 42-55.