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Promoting Vertical Greening in High-rise Residential Buildings within Urban Areas

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Same as many urban cites, Hong Kong is a densely populated area. To improve the residential environment, increase greenery coverage is a viable and economical solution. Despite the widespread interest in the application of vertical greenery, little application has been observed in residential developments in Hong Kong. Most research in vertical greenery focuses on the benefits and technical issues of the system. This study aims to identify the effective strategies to foster vertical greenery implementation in Hong Kong. A questionnaire survey was conducted with 60 architectural practices. Survey results indicate that the industry agrees on the benefits of vertical greening. While the high initial and maintenance cost was identified as a major obstacle to green wall implementation, several public policies were suggested to promote vertical greenery, including financial support from the government for the installation, provision of gross floor area concession, mandatory green wall installation in new buildings and funding support in related researches. The study contributes to a relatively sparse body of literature by investigating possible strategies to foster vertical greenery in an urban city. The findings shed light on the underlying problems and provide ideas on the promotion of vertical greening in Hong Kong and other urban areas.
Keywords: Green buildings, Urban design, Vertical greening

Introduction

According to the United Nations' latest findings, more than half of the world's population resided in urban cities in 2016. Some of these cities such as Beijing and Shanghai are facing a severe air pollution problem with the increasing density of population and buildings. Many people suggest that introduction of greenery to the city is one of the possible methods to alleviate these problems. However, green space is at a premium in urban cities. To increase land supply to meet the growing population, many greenfield sites have been used for facility or housing construction. To effectively increase the green area within a city, greenery must be extended to the three-dimensional spaces such as vertical greening, sky gardens and green roofs.

Similar to many urban cities, Hong Kong is characterised by its high-rise concrete buildings. Widely known as the "concrete jungle", the air quality of Hong Kong is alarmingly poor. A recent study conducted by the University of Hong Kong indicated that the pollutants found in the Hong Kong air were three times higher than New York and double that of London. In addition, the urban heat island (UHI) effect arisen from the congested living environment increases the energy consumption on air-conditioning. Despite the need and desire to promote green buildings, vertical greening implementation in Hong Kong is far lagging behind other green cities such as Singapore.

To cope with the future expansion of the population, increasing the application of vertical greening is of paramount importance. This paper investigates the barriers to vertical greening implementation in Hong Kong and to identify suitable policies for promoting vertical greening. The results contribute to the understanding of the concerns and interests of the developers with respect to vertical greening application.

Vertical Greening and its Benefits

Vertical greening system, also known as green walls or green facades, is a living and self-regenerating cladding system for buildings. The system consists of vegetated wall surfaces with plants that are either rooted into the ground, in the wall itself or in structural system attached to the wall [1]. To create a suitable growth condition for the plants, support structure and irrigation system are mounted on the façade. Vertical greening outperforms green roofs in its cooling ability during summer, especially in high-density urban environment such as Hong Kong [2],[3]. In addition, vertical greenery can reduce the façade temperature up to 16oC and migrate urban heat island effect [4]. Besides cooling ability, a green wall can act as a biofilter to filter out dust and reduce particulate matter from the air [5]. Furthermore, photosynthesis of vegetation improves the air quality by absorbing carbon dioxide, which helps to alleviate the climate problem in urban areas [6]. Vertical greening also has proven performance in blocking sound, up to 9.9 dB at 800

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Hz one-third octave bandwidth [7]. In case of narrow street canyons, road noise can be efficiently reduced up to 4.4dBA [8].

Besides the above environmental advances, vertical greening systems also provide ecological benefit by improving the biodiversity as they create a habitat for microorganisms and small animals such as insects and birds [9]. The green living walls serve as a food source and as a desirable nesting or breeding place.

Greening Initiatives by the Hong Kong Government

The popularity of vertical greening is growing across the globe due to its environmental and ecological benefits. The Hong Kong government has initiated various plans to improve greenery in the city. The Greening Master Plans (GMPs) has been implemented since 2004, to provide an overall greening framework by identifying suitable locations for planting with desirable species. The Development Bureau released a plant application guide for skyrise greenery in 2013. The guide recommends a range of species for developers to plant in their sky gardens [10]. In 2011, the government allows some green features such as communal sky gardens, acoustic fins, noise barriers, balconies, etc. to be excluded from the gross floor area calculation [11]. As the land price is extremely high in Hong Kong, the policy is a significant incentive for developers to implement greenery in new buildings. However, the policy does not include vertical greening as one of the exemptible green features. According to the Sustainable Building Design Guidelines published in 2016, site areas of more than 1000m2 is required to have at least 10% greenery area in the primary zone, i.e. the vertical zone within 15m from the street level [12]. Although green walls can be considered as greenery area under the regulation, the maximum area of green walls countable to the greenery area is limited to 30%. Thus, the incentive for developers to install large-scale green walls is heavily reduced.

Considering the design and installation guidelines for greening systems, the Hong Kong government has only published simple reference materials for the design, installation and maintenance of green roofs. Formal guidelines or practice notes on vertical greening implementation are still lacking.

Barriers to vertical greening implementation

Although many studies related to vertical greening have been done over the past years, most of them are focused on the benefits and impacts of green walls. Empirical researches on the barriers to green wall implementation are scarce. A survey in Singapore indicates several major concerns or barriers to vertical greening application, including heavy maintenance work, high capital cost, lack of information and awareness, lack of subsidies and the pest control problem [13].

Since green roofs are often considered and applied together with green walls, studies on the barriers to green roof application are reviewed as well. A few studies were conducted in Hong Kong to explore the constraints and barriers to green roof implementation. Leigh and Orange, an architectural firm in Hong Kong, investigated the barriers to green roof installation in the city. The firm identified lack of knowledge and awareness, lack of incentive, high cost and lack of available roof area were the major barriers [14]. Zhang et al. obtained similar findings in their study. Out of the 11 barriers recommended, lack of promotion, lack of incentive and high maintenance cost were the most significant ones [15]. Tables 1 summarises the barriers identified in various studies.

Table 1: List of Barriers to Green Roofs and Green Walls Installation

Barriers to Green Roofs and Green Walls Installation	References
Damage to structure	[13]
Affect the structural load bearing capacity of the building	[13], [14], [15]
Require high implementation cost	[13], [14], [15]
Requires high maintenance cost	[13], [14], [15]
Lack of technical information	[13], [14]
Lack of information on maintenance requirements	[13]
Lack of information on plants that will perform well	[13], [14]
Lack of awareness of the benefits and performance	[13], [14], [15]
Attract pest and unwanted animals	[13]
Increase the chances of ponding and mosquito breeding	[13]
Lack of grants and subsidies for implementation	[13], [14], [15]
Limited available space for installation	[14]
Age of existing building	[15]

Objectives of the Study

Although the environmental contributions of vertical greenery to sustainable living in high-density cities are accepted worldwide, the application of green walls in Hong Kong is mainly found in government buildings. Private developments especially residential buildings that contribute to the largest building stock in Hong Kong present little sign of vertical greening. The objectives of this study are to understand the perceived barriers against the adoption of vertical greening and to identify suitable strategies to increase the implementation in high-rise residential buildings.

Methodology

Primary data was collected by questionnaire survey and semi-structured interviews. Perceptions of the benefits, barriers and

public policies related to vertical greenery were collected from architects by questionnaire sent to architectural firms. Follow-up interviews were conducted to clarify answers in the questionnaire survey and to generate more accurate representations of their views.

Questionnaire Design

The questionnaire sought the following information from the respondents: 1) basic demographic data including gender and company background; 2) awareness of vertical greenery; 3) perceived benefits of vertical greenery; 4) barriers to vertical greenery and 5) policies to encourage vertical greenery. After collecting the demographic data, respondents were asked if they had seen any green walls in the city, and if they could mention any examples. Data for the questions related to the perceived importance of benefits and barriers to vertical greenery were obtained with a Likert scale of 1–5, where 1 meant strongly agree and 5 meant strongly disagree. From the review of previous studies, 5 perceived benefits of vertical greenery, including (A1) improve air quality, (A2) introduce biodiversity into urban environment, (A3) reduce noise, (A4) reduce air-conditioning energy consumption and (A5) improve appearance were included in the questionnaire. The list of potential barriers to vertical greenery were compiled based on the past studies listed in Table 1. Similar barriers were merged, such as "attracted pest and unwanted animals" and "increase the chances of ponding and mosquito breeding" were combined as B8 (attract pests and unwanted animals). Furthermore, the item "lack of information on plants that will perform well" was removed because the Hong Kong government had released guidelines for plant selection, which was not available in Singapore when the previous study was conducted. The list of barriers adopted for this study was summarised in Table 2.

Table 2: List of Barriers Used in the Questionnaire Survey

Item Code	Barriers
B1	Damage to structure
B2	Affect the structural load bearing capacity of the building
B3	Require high implementation cost
B4	Requires high maintenance cost
B5	Lack of technical information
B6	Lack of information on maintenance requirements
B7	Lack of promotion of the benefits and performance
B8	Attract pest and unwanted animals
B9	Lack of grants and subsidies for implementation

In the last part of the questionnaire, respondents were invited to indicate at most three public policies that can promote vertical greenery in residential buildings. Space was provided for the respondent to add comments or to make remarks.

Data collection

The questionnaire survey was posted to a random sample of 280 architectural practices in Hong Kong. The sample was drawn from the Directory of Architectural Practices published by the Hong Kong Institute of Architects. The survey was done between March 2017 and June 2017.

Follow-up interviews were arranged during June 2017. Eleven professionals accepted the invitations and the interviews were taken place in the interviewees' offices in August.

Statistical Analysis

Data from the survey were entered into SPSS 23.0 for analysis. Internal consistency of the data was tested first, followed by the analysis of descriptive statistics and relative importance indices.

Internal consistency test

Cronbach's alpha (α) is a measure of the internal reliability of data collected for questions within each category [16]. In the questionnaire, there were 5 questions related to the perceived benefits of vertical greenery and 14 questions related to the barriers against vertical greenery application. Answers to these questions were tested by Cronbach's alpha test to verify the internal consistency of the questions asked in each construct. The range of alpha is from 0 to positive 1. The higher the value, the more consistent the data are measuring the same construct.

Relative importance index

Relative importance index (RII) was used by many researchers to analyse and rank the factors under a category [17]. The relative importance index for each Likert scale question was computed using equation (1):

$$RII = \frac{\sum (f \times s')}{N \times w} \quad (1)$$

where RII = relative importance index

s' = score rated to question by respondents, ranging from 1 to 5 (1 = strongly agree and 5 = strongly disagree)

f = frequency of responses to each rating

N = total number of responses concerning each question

w = highest weight (i.e. 5 in this case)

The indices (RIIs) were then used to determine the rank of each item within a category.

Results

A total of 60 responses were obtained from the questionnaire survey, representing 21.4% response rate. The respondents' profile is shown in Table 3.

Table 3: Profile of the Respondents

Nature of Firms	Male	Female	Total
Large firm employs more than 50 architects	20	7	27
Medium firm employs 10-50 architects	5	8	13
Small firm employs less than 10 architects	6	14	20
Total	**31**	**29**	**60**

Table 4: Cronbach's Alpha of Each Question Group

Group Item	Question Group	Cronbach's α
1	Benefits of vertical greenery (A)	0.670
2	Barriers of vertical greenery (B)	0.721

More than 80% of the respondents could identify an example of green walls in Hong Kong, but only 20% had seen a green wall in Hong Kong. Most of the respondents explained that they learnt about the local applications of vertical greening through seminars and trade journals. The results indicate that green walls have not yet installed to a recognisable level.

Cronbach's alpha

As a general rule, the minimum acceptable value of α coefficient is 0.60 [18]. From Table 4, the coefficient of the benefit group is above 0.60, indicating that the items within this group presented an acceptable level of internal consistency. The alpha coefficient of the barrier group is above 0.70, indicating a high internal consistency. The results confirm that the grouping of question items into perceived benefits of vertical greening and potential barriers to vertical greening is statistically acceptable.

Means and standard deviations

Table 5 presents the means and standard deviations of the perceived benefits of vertical greening. All items are above 4.0, indicating a general agreement on the positive impacts of vertical greening.

For the potential barriers, all the mean scores are above 3.0 as shown in Table 6. Compared with the figures in Table 5, the mean scores of the potential barriers are generally lower than that of the perceived benefits.

Relative Importance Indices

Table 7 provides a full list of relative importance index (*RII*) and ranking of the perceived benefits. The numbers in the "rank" column represents the sequential ranking of the items. The closer an item's score approaches 1, the higher is its perceived importance. Among the five perceived benefits, "improve appearance" was considered as the most significant benefit. "Reduce air-conditioning energy consumption", "improve air quality" and "introduce biodiversity into urban environment"

Table 5: Mean Scores of Perceived Benefits of Vertical Greening

Item Code	Benefits	Mean	Standard deviation
A1	Improve air quality	4.033	0.736
A2	Introduce biodiversity into urban environment	4.017	0.770
A3	Reduce noise	3.517	1.066
A4	Reduce air-conditioning energy consumption	4.050	0.928
A5	Improve appearance	4.567	0.647
	Average score of A1 to A5:	**4.037**	

Table 6: Mean Scores of Potential Barriers of Vertical Greening

Item Code	Barriers	Mean	Standard deviation
B1	Damage to structure	3.800	0.935
B2	Affect the structural load bearing capacity of the building	3.683	0.930
B3	Require high implementation cost	4.250	0.654
B4	Requires high maintenance cost	4.000	0.823
B5	Lack of technical information	3.517	0.792
B6	Lack of information on maintenance requirements	3.650	0.732
B7	Lack of promotion of the benefits and performance	3.883	0.804
B8	Attract pests and unwanted animals	4.233	0.767
B9	Lack of grants and subsidies for implementation	4.183	0.854
	Average score of B1 to B9:	**3.911**	

scored similar values, with all the RIIs close to 0.8. "Reduce noise" is the least significant benefit as compared with the rest.

Table 7: Relative Importance Index (*RII*) of the Perceived Benefits of Vertical Greening

Rank	Item Code	Benefits	*RII*
1	A5	Improve appearance	0.913
2	A4	Reduce air-conditioning energy consumption	0.810
3	A1	Improve air quality	0.807
4	A2	Introduce biodiversity into urban environment	0.803
5	A3	Reduce noise	0.703

Table 8: Relative Importance Index (*RII*) of the Potential Barriers of Vertical Greening

Rank	Item Code	Barriers	*RII*
1	B3	Require high implementation cost	0.850
2	B8	Attract pests and unwanted animals	0.847
3	B9	Lack of grants and subsidies for implementation	0.837
4	B4	Requires high maintenance cost	0.800
5	B7	Lack of promotion of the benefits and performance	0.777
6	B1	Damage to structure	0.760
7	B2	Affect the structural load bearing capacity of the building	0.737
8	B6	Lack of information on maintenance requirements	0.730
9	B5	Lack of technical information	0.703

As shown in Table 8, "require high implementation cost" is the most critical barrier to vertical greenery. Another three potential barriers that scored above or equal to 0.8 include "attract pests and unwanted animals", "lack of grants and subsidies for implementation" and "requires high maintenance cost". The views reflect the concerns of developers and potential buyers of the residential units. "Lack of technical information" was considered as the least significant barrier to vertical green wall implementation.

Public policies

In the final part of the questionnaire, respondents were invited to indicate at most three public policies that could promote the implementation of vertical greenery. The suggestions can be categorised into eight policies as illustrated in Table 9. More than 50% of the respondents opted "subsidy from the government" as the public policy that should be implemented to boost vertical greening. More than one-third of the respondents opined that "gross floor area concession", "mandatory enforcement" and "provision of research fund" should be used to foster the uptake of vertical greenery.

Table 9: Summary of Frequency of Public Policies Identified by Respondents

Rank	Public Policies	Number of responses	Percentage of responses
1	Subsidy from government	38	63.3%
2	Gross floor area (GFA) concession	24	40.0%
3	Mandatory enforcement	23	38.3%
4	Provision of research fund	22	36.7%
5	Promotion among public	21	35.0%
6	Partial subsidy from government	20	33.3%
7	Education in colleges and universities	19	31.7%
8	Guidelines and code of practice for installation and maintenance	12	20.0%

In the interviews conducted with the 11 professionals, similar findings were obtained. Most of the interviewees concurred that financial support from the government and GFA exemption should be the most effective measures to promote vertical greening in residential developments.

Possible Strategies to Promote Vertical Greening

From the survey and interview results, four public policies can be suggested, namely financial support from the government, gross floor area concession, mandatory green wall enforcement in new buildings and government funding to related researches.

Financial support from the government

The survey results indicate that the benefits of vertical greenery are widely accepted by the industry. The main reason to the low adoption rate of vertical greenery is likely due to the high implementation and maintenance cost. Considering residential property as a commodity primarily built for sale rather than rental, low construction cost is critical to the

developers to maximise their profit. Financial support from the government is therefore the most effective strategy to encourage the private sector to implement vertical greening. Especially for the existing buildings where the initial and maintenance cost of green walls may be much higher, financial aid is essential to the building owners to minimise their cost outlay.

Gross floor area concession

To attract private developers to install green walls in new buildings, provision of gross floor area (GFA) concession will be a viable measure. The shortage of residential land in Hong Kong has contributed to the rapidly rising home prices and rents. If a certain percentage of GFA concession can be granted to the new developments that apply green walls, developers can construct more storeys and in turn gain more profit. This is a good alternative to government's financial support if the government wants to reduce its public expenditure on vertical greenery promotion.

Mandatory green wall enforcement in new buildings

Although mandatory requirement may limit the design of new buildings, good regulation is always the most effective approach to enforce the private sector to take up new initiatives. As in the case of Singapore, all new buildings and existing buildings that undergo retrofitting have to meet a minimum green level that corresponds to the 'Certified Level' under the Building and Construction Authority (BCA) Green Mark Scheme since 2008. The scheme was launched by the Singapore government to promote sustainable construction in the country. The mandatory system ensures buildings are environmentally sustainable. Since then, high-rise greenery in Singapore, which includes green roof and vertical greening, has increased substantially to 72ha in 2015. The mandatory Green Mark Scheme is proven to be a successful tool to boost up greenery coverage. Similar regulation can be implemented by the Hong Kong government in stages, starting from the new residential developments in the city center to those in the suburban areas.

Government funding to related researches

Although the benefits of vertical greenery are understood by most professionals, technical guidelines related to green wall designs that can thrive in the Hong Kong climate are still limited. Government should take the lead to sponsor local researches related to the design and maintenance of green walls, such as the flowering and non-flowering species for growth in Hong Kong green walls and the wall drainage design to cater for Hong Kong rainfall. Research results can improve developers' confidence in the viability of green walls. Also, detailed technical guidelines can be compiled if more findings about the installation and maintenance of green walls are available.

Limitations

A potential limitation was the possibility of individual's bias in the responses, which cannot be detected or discounted. Besides, it should be noted that the data was collected in Hong Kong only. The results and suggestions are applicable particularly to the Hong Kong context. Since legislative and cultural differences may be apparent in other places, further research is recommended in western countries to establish the degree of generalisability of the findings.

Conclusion

The living environment of Hong Kong is getting worse due to the pollution problem. Increasing more greenery such as green walls in the city can help to improve the situation. A questionnaire survey conducted with 60 architectural practices reveal that the benefits of vertical greenery is promising. However, local architects are facing barriers to implement green walls in their design, including the high implementation and maintenance cost of vertical greening, pests and unwanted animals attracted to the building and lack of grants and subsidies to support the building owners.

From the survey and interview results, we can conclude that public policies can effectively promote the installation of green walls in the city. These policies include financial support from the government for the installation, provision of gross floor area concession, mandatory green wall enforcement in new buildings and funding support in related researches. Findings of this study provide insights into the underlying problems of green wall application. The recommended strategies can help legislators formulate policies to promote vertical greenery in urban areas.

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