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Cost Analysis of Vertical Greenery in Urban Complex

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Abstract

Vertical greenery has become an important technological means to improve the ecological environment condition in urban high-density areas, especially in central areas of Chinese cities. The cost of vertical greenery has significantly increased both in the decision-making process of architectural design and in the assessment of the sustainability potential of urban complexes. The estimation and evaluation of the cost of vertical greenery have become important obstacles to multi-party investment in the construction of vertical greenery. Considering the factors of the building typology and full life-cycle cost, this paper constructs an assessment model of vertical greenery in seven types in urban complex, and suggests an optimized approach to vertical greenery in an urban complex.

Keywords: Vertical greenery, Cost analysis, Urban complex, Full life-cycle, Evaluation model

1. Introduction

1.1. Urban complexes have become an important factor for rapid vertical greenery development in Shanghai

The total constructed area of housing in Shanghai reached 80,665,400 square meters in 2017, which is equivalent to the total land area of some of the city's districts. Its Vertical Green Development Master Plan is aiming to increase the existing amount of vertical greenery (VG) to 1200 hm^2 by 2035; already the realized annual VG has been over 400,000 square meters since 2015. Vertical greenery has become an important technological means to improve the ecological environment condition in urban high-density areas, especially in central areas of Shanghai.

"Shanghai Skyrise Greenery Technical Guidelines", "Handbook on Green Wall Technology", and "Skyrise Greenery Technical Standards" were published in 2008. Technical standards, including "Guidelines on Construction and Management of Green Pillars Along Highways" and "Guidelines of Skyrise Greenery in New Developments", both published in 2015, have helped to build the strong guideline framework, both politically and technically, for realization of VG in new building construction in Shanghai. Among the new buildings of the past 10 years, the urban complex has been one of the dominant building types, typically comprising significant with floor area. According to the report on the development of Shanghai urban commercial complexes (2016-2017), there were 189 urban commercial complexes in Shanghai by the end of 2016, and 41 new urban commercial complexes were built in 2017. The total building area of the existing urban complexes is 13.76 million square meters by 2016 (Source: Shanghai Business Development Research Center www.commerce.sh.cn).

According to regulations promoting the development of vertical greenery in Shanghai, it is required that 30% of the projected area of new public buildings (especially building complexes) be designated for vertical greenery. The flat roofs of newly-built public buildings (government agencies, hospitals, schools, cultural and sports facilities, etc.) should be green in principle, and the implementation area of roof greening should be not less than 30% of the building area (excepting mechanical and solar energy equipment).

Urban complexes contribute to the new VG development significantly. Take Greenland Being Fun in Xuhui district as an example (see Figure 1-2). A footpath connecting the roof terrace directly from the first floor has been set up, combined with a natural landscape, allowing consumers to get close to and feel nature while shopping and relaxing.

The complex is also known as "The Wonderful Wizard of Oz" of Binjiang, Xuhui. The whole commercial complex is covered with 13,000 square meters of green plants and the roof garden is open to the public all day.

1.2. The estimation and evaluation of the cost of vertical greenery has become an important obstacle to multiparty investment in the construction of vertical greenery

Although the urban complex is required to realize VG, in the current development environment, developers tend

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Figure 1-2. Picture of Xuhui Greenland Being Fun (Source: https://mp.weixin.qq.com/s/S8hZrWREODrAJO8BBMBYnA)

to be more conservative in the application of vertical greenery technology, not only in regards to technical concerns, but due to the lack of refined calculations and reasonable evaluation of the cost of vertical greenery. One reason for this is the superficial estimation of VG without precise definition of the constructed features. The other reason is that a weak understanding of the full life-cycle costs results in a lack of qualified maintenance, and degradation of the planted areas. Moreover, the cost of vertical greenery structure should also be considered more accurately when the Cost-Benefit assessments are undertaken.

2. Methodology and Theoretical Frameworks Regarding the Cost Calculation

Based on the current development, this essay delivers an assessment from two perspectives:

-the impact of vertical greenery on a detailed construction cost breakdown;

-the whole life-cycle cost of vertical greenery.

2.1. Cost analysis based on the typology

According to the complexity of the structural features, vertical greenery can be classified into seven types: extensive green roof, intensive green roof, vertical-climbing green wall, planting carpet vertical green wall, vertical green wall with planting bags, vertical green wall with hanging planting containers and vertical green wall with modular planting containers. Based on the assessment method, the construction cost basically involves basic cost elements of plant acquisition, growing media, irrigation, waterproofing and drainage, labor, and transport cost. The cost per square meter has been listed according to the complexity of system composition, including the planting, growing medium, root barrier, waterproofing, water retention and drainage layers (see Table 1).

According to the components above, cost ratio of various components can be evaluated for different structure systems. Both extensive and intensive green roof increased the cost ratio of the planting layer significantly. Further, complex component structures have increased the cost of growing media, water retention and drainage layers. Consequently, the ratio of water retention and drainage layers need to be focused on the territory of an intensive green roof. With regard to the green wall, it is critical to have a reasonable cost ratio between growing media and components in order to have a solid planting performance.

2.2. Full life-cycle cost analysis

Life cycle assessment is an effective method to determine the long-term cost and benefit of green roofs. According to the roof engineering technical specifications regulation (GB50345-2012), planted roofing needs to adopt a level I waterproofing layer with rational use of years of 20 years. Many studies have suggested that roof greening can reduce the temperature fluctuation through plants and growing media. It also reduces the effect of high temperature thermal stress on the waterproofing layer, so that the life span of the roof can be extended (Chen, S.D. Li, S.P. and Jiang, X.D, 2016; Saiz, S. Kennedy, C. Bass, B. et al, 2006; Julian, S. Man Pun, W. Benjamin, H. M. et al, 2014). It widely acknowledged that the average life of green roofs is twice as long as that of traditional roofs. The whole life cycle of a green roof is assumed to be 30-50 years in foreign studies, which is quite common. For example, Susana Saiz (Saiz, S. Kennedy, C. Bass, B. et al, 2006), Sproul Julian (Julian, S. Man Pun, W. Benjamin, H. M. et al, 2014), and Nyuk HienWong (Wong, N.H. Tay, S.F. Wong, R. et al, 2003) have estimated 40-50 years as the whole life cycle of a green roof to analyze its economic benefits. Sanaz Bozorg Chenani (Chenani, S.B. Susanna, L. and Tarja, H, 2015) assumed that the life cycle of green roof was 40 years, and studied the environmental impact of the structural layer materials. Cristina Matos Silva (Silva, C.M. Flores-Colen, I. and Coelho, A, 2015) set the whole life cycle of green roof as 40 years.

Life-cycle cost analysis (LCCA) is a method to evaluate the total cost of buildings and equipment. This data serves as the cost-benefit assessment standard of vertical greenery projects. An assessment formula of vertical greenery can

Table 1. Cost of Vertical greenery (credit: author)

Vertical Green Typology	Components	Cost (Yuan per square meter)
Extensive Green Roof	Root Barrier Layer, Waterproofing Layer, Drainage Layer	35
	Planting Layer (Lawn)	30-100
	Growing Media	10-30
	Material Transportation	20
	Maintenance	100
	Management	50
	Total	400-1000
Intensive Green Roof	Root Barrier Layer, Waterproofing Layer	200
	Drainage Layer, Water Retention Layer	100
	Planting Layer (Trees, Shrubs, Lawn, Ground Cover)	200-4000
	Growing Media	10-30
	Material Transportation	20
	Maintenance	100
	Management	50
	Total	500-5000
Climbing Vertical Green Wall	Plant Material	40-80
	Growing Media	50-60
	Fixing Structure	20-100
	Drainage System	12-50
	Construction, Maintenance, Management	30-50
	Total	120-500
Blanket Vertical Green Wall	Plant Material	80-2000
	Growing Media and Structure	500-2000
	Fixing Structure	50-200
	Irrigation System	15-20
	Construction, Maintenance, Management	160-1000
	Total	1000-6000
Pocket-Style Vertical Green Wall	Plant Material	80-2000
	Fixing Structure	200-350
	Irrigation System	30-40
	Construction, Maintenance, Management	100-500
	Total	400-3000
Hanging Containers Vertical Green Wall	Planting Material	80-2000
	Growing Media and Structure	200-350
	Fixing Structure	50-200
	Irrigation System	15-20
	Construction, Maintenance, Management	100-300
	Total	450-2000
Modular Containers Vertical Green Wall	Plant Material	80-2000
	Growing Media and Structure	200-500
	Fixing Structure	50-200
	Irrigation System	30-40
	Construction, Maintenance, Management	160-500
	Total	700-3000

be concluded based on the two core data above, and it refers to the assessment model of green architecture, classified by construction cost.

$$C_{Total} = C_{Design} + C_{Construction} + C_{Finance} + C_{Maintenance} \quad (1)$$

C_{Total} means project whole-life-cycle cost, C_{Design} is the cost of design and strategy planning, $C_{Construction}$ is the cost during the construction, including labor and material cost, $C_{Maintenance}$ means costs of project operation, maintenance, updates, replacement and disassembly. $C_{Finance}$ means project financial support cost. $C_{Maintenance}$ costs includes repeated material, maintenance, and labor costs, as well as one-time equipment replacement costs. T is the life cycle. This research proposed the life cycle to be 40 years.

Based on the cost-efficiency method and fixed-cost method of LCCA, the vertical greenery assessment model construction incorporates the data analysis conclusion of cost-benefit difference and forms two core data control of the model:

The first one is to control the ratio of system efficiency and overall cost of the life cycle, which draws lessons from the cost-efficiency method of LCCA. System efficiency is mainly core control element in the cost management of vertical greenery. In the model, the vertical proportion of cost is compared, that is, the proportion of each cost in the whole life cycle.

The second one is to fix the extra cost and select the optimum effect scheme which draw lessons from the fixed-cost method of LCCA assessment. In the model, the horizontal proportion of cost is compared, that is, the proportion of increased cost due to the vertical greenery construction. This data is used as the cost and benefit assessment criterion of vertical greenery project.

On the basis of selecting the above two core data and referring to the assessment model of green building according to the classification cost, this paper forms the vertical greenery assessment model formula.

Based on the cost ratio of 7 vertical greenery types in whole-life-cycle cost in Eastern China, and the proportion of the cost increase of each due to the implementation of vertical greenery, the evaluation model was substituted for analysis.

$$C_{Total} = (C_{Design} + C_{Construction} + \sum_{L=1}^{T} C_{Maintenance} + C_{Finance} - C_{Design}2 - C_{Construction}2) / (C_{design}2 - C_{construction}2) \quad (2)$$

Under the whole life cycle, various costs of greenery in city complexes would increase the cost ratio because of the implementation of vertical greenery (see Table 2). $C_{Design}2$ is the design cost of roof and façade for a city complex without vertical greenery.

$\Delta C_{Construction}2$ is the construction cost of roof and façade for a city complex without vertical greenery.

$$\Delta C_i = C_i / C_{Total} \quad (3)$$

(i could be Design, Construction or Finance)

ΔC_i is the design, construction or finance cost ratio of vertical greenery in a city complex, among the total cost under whole life cycle.

$$\Delta C_{Maintenance} = \sum_{L=1}^{T} C_{Maintenance} / C_{Total} \quad (4)$$

$\Delta C_{Maintenance}$ is the maintenance cost ratio of vertical greenery in a city complex among the total cost under whole life cycle (Chai, H.X. Hu, X.B. Peng, S.J. and Wang, T.Y, 2010).

In terms of intensive green roof, a 40% cost ratio between planting cost and overall construction cost is recommended. In terms of climbing vertical green walls, the cost ratio between fixing structures and overall construction cost is suggested to be 20%. In terms of blanket vertical green walls, the cost ratio between growing media, as well as structures and overall construction cost, is recommended to be 80%.

Under the whole life cycle of green roofs, intensive green roof material and construction costs account for about 85% of the whole life cycle cost, and the extensive green roof is about 56%. The cost management of green roofs is recommended to focus on the vegetation cost, waterproofing and drainage material cost in the early stage. Due to the high unit cost of vegetation regarding intensive green roofs, it is recommended to focus on the initial vegetation cost. Under the whole life cycle of the vertical green wall, the cost ratio of the growing media and structures is about 30-70%. The management cost of the vertical green wall can focus on the optimization of the growing media and structures. The operation and maintenance cost is also an important factor of cost control.

3. Application and Discussion

Based on the cost analysis above, cost control in the design stage and the maintenance cost throughout the life cycle could be implemented into the different design phases.

Table 2. Mean value model assessment chart of vertical greenery under whole life cycle (credit: author)

Cost / Vertical Green Typology	Additional Cost Ratio	Single item cost ratio			
	ΔC_{Total}	ΔC_{Design}	$\Delta C_{Construction}$	$\Delta C_{Maintenance}$	$\Delta C_{Finance}$
Extensive Green Roof	15%	3%	50%-55%	30%-35%	5%
Intensive Green Roof	80%	3%	70%-75%	15%	5%
Climbing Vertical Green Wall	15%-20%	3%	70%-80%	10%	5%
Blanket Vertical Green Wall	100%-200%	3%-5%	70%	20%-25%	5%
Pocket-Style Vertical Green Wall	80%-100%	3%-5%	70%	15%-25%	5%
Hanging Containers Vertical Green Wall	80%-100%	3%-5%	50%-60%	15%-25%	5%
Modular Containers Vertical Green Wall	100%-150%	5%	65%-70%	20%	5%

3.1. Integrated understanding of vertical greenery design in the architecture design process

Compared with common vertical greenery design, the advantages of design based on the assessment model include high community and environmental value, and superior integration with the architecture. It also reduces repeat input costs and maximizes the economic value. Integrated vertical greenery design can be completed simultaneously by using the assessment model during the detailed design phase.

Usually, vertical greenery design begins after architecture design has been completed, and thus cannot be integrated with the design of the roof and building façades. Since the base design has already been completed, there is limited capacity for change to basic architecture elements. The resulting greenery design is often a monotype, and plantings are limited by structural constraints. The growing media, irrigation, waterproofing and drainage systems are evenly, often indiscriminately distributed. This may mean that irrigation may be absent, and the volume of growing media is limited by structural bearing capacity.

By comparison, if the design of vertical greenery is undertaken during the base architectural design stage of urban complex project, the integrated design of vertical greenery is synchronized with the project planning, and can be coordinated with the design of building structure and mechanical and electrical equipment. Green forms can be designed flexibly and reasonably, combining with building roof, building façade and basic building components. Plant species, growth media, irrigation, waterproofing and drainage systems can be designed and selected reasonably according to different greening requirements. If the greenery designer gets involved in the architectural design stage as early as possible, the vertical greenery will be much better able to respond to the architectural form of the city complex. The vertical greenery structural system will be integrated with the building, so that a reasonable form of greenery and synchronization in construction with building can be considered in cost control exercises. This would reduce the investment cost of greenery. The design method of vertical greenery is therefore established as follows:

(1) Analyze and sort out green space typologies, and reasonably manage investment costs;

(2) Integrate vertical greenery construction with building construction to reduce comprehensive construction costs;

(3) Reasonably select the greenery structures and control the construction sequence, and control the construction cost;

(4) Consider maintenance in the design stage, to reduce ongoing maintenance costs.

3.2. Maintenance suggestion

Effective maintenance is a key factor in the success of vertical greenery. Typical vertical greenery design usually cannot meet the demands of maintenance, nor provide an insight into ongoing maintenance costs. For integrated vertical greenery design, in the maintenance stage, the key point of cost control is to consider the maintenance cost under manual or facility participation conditions, to achieve the economical and reasonable investment. Ecological green roofs are low-maintenance. In general, indigenous species should be used, so that they could thrive under harsh conditions, such as drought or too much sun exposure. Most green roofs are often over-maintained, for example, by over-watering or over-fertilization. In fact, they can be left to their natural growth patterns with little intervention. Intensive green roofs need effective maintenance, which is also an important factor of sustainability after completion.

Maintenance of green roofs mainly includes structural layer, plant and roof environmental sanitation maintenance. For the structural layer, the water-tightness of the waterproofing layer is tested annually through the water permeability test of concrete. The drainage canal is inspected monthly, and the drainage system is maintained once every two months. The plant maintenance includes plant irrigation, fertilization, pruning, weeding, insect control and replacement. Alongside these actions, the green roof is irrigated at a rate of about 780 L/m^2 annually; is fertilized 1-2 times a year; and its growth medium needs to be renewed every 4-5 years. Trees and shrubs are pruned twice a year, and the frequency of lawn pruning largely depends on the lawn and grass species used in the design. Formal lawns may need to be cut up to 9 times a year, while fallow grass is pruned up to 3 times a year. Weeds should be inspected 9 times a year and pruned up to 3 times a year. If the green roof is installed correctly, there should be almost no weeds on the green roof. Plant diseases and insect pests should be inspected 4 times a year, especially during plant cultivation. In addition, the environmental sanitation of green roofs needs to be maintained every week, mainly including clearing litter, and dumping garbage bins, which largely depends on the type of green roofs and the number of tourists (Architectural services department, 2006).

4. Discussion

In this study, regions with similar climatic conditions, costs of soft and hard materials, and labor were taken into account. This includes Hunan, Guangdong, Jiangxi, Hubei, Shandong, Anhui, Jiangsu, Zhejiang, Fujian provinces and Shanghai. This paper has not yet explored the possibility of full life-cycle costs in the model of benefit estimation (including operations), so the above discussion only focuses on the content of cost estimation. The above price content does not take into account the increase of operation and maintenance costs, owing to price fluctuation or special weather conditions (including the maintenance differences between the four seasons).

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