Multi-layer planting as a strategy of greening the transitional space in high-rise buildings: A review

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Abstract. The issues regarding the rapid development in the urban have resulted in the increasing number of infrastructure built, including the high-rise buildings to accommodate the urban dwellers. Lack of greenery due to the land limitation in the urban area has increased the surface radiation as well as the air temperature that leads to the Urban Heat Island (UHI) phenomena. Where urban land is limited, growing plants vertically could be a solution. Plants, which are widely known as one of the sustainability elements in the built environment could be integrated in building as a part of urban flaming by growing edible plant species. This is also to address the food security issue in the urban as well as high-density cities. Since space is limited, the function of transitional space could be optimized for the green space. This paper explores the strategy of greening transitional space in the high-rise setting. To give a maximum impact in a limited space, multi-layer planting concept could be introduced. This concept is believed that multiple layers of plants could modify the microclimate, as well as the radiation to the building, compare to single layer plant. In addition to that, the method selected also determines the efficacy of the vertical greenery. However, there are many other limitations related to the multi-layer planting method if installed in a transitional space that needs to be further studied. Despite its limitations, the application of vertical greenery with multi-layer planting concept could be a promising solution for greening the limited space as well as improving the thermal comfort in the high-rise building.

1. Introduction
The phenomena of vegetation on buildings have emerged in many densely populated countries for the past few years, including in Malaysia and Singapore. It is considered as a key element of urban transformation as the most innovative and rapidly developing features of city planning, architecture, and ecological landscaping. The trend of urban migration to the city centre has currently become an issue in most developing countries. As a result, landed property will become scarce, and developers are focusing more on the construction of high-rise building for the dwellers and unintentionally creating a potential loss in open space. The moist green spaces are diminishing and replaced by impermeable surfaces, which lead to the Urban Heat Island (UHI) phenomena. The basic requirement for the need of greenery is somehow is often overlooked. Perini et al. agreed that by combining the vegetation and the building could address the environmental issue in the dense urban environment [1]. This is also in line with the concept on ‘Urban Green Infrastructure’ that could be defined as ‘a set of man-made elements, which provides multiple ecosystem services at building and urban scales.’ The most innovative among these functions are green roofs (GR) and vertical greenery systems (VGS), such as vertical garden and green
façade [2]. By integrating the environmental principles and aesthetic factor, the beautiful patterns from the variety of plants applied in the building has successfully created a new perspective of sustainable art that could enhance the visual appeal for the public. An additional value to the system is using edible plants or also known as urban farming that addresses the food security issue especially in the high-density cities.

The ultimate goal of greeneries in the high-rise building is to modify the microclimate to overcome the issue of increasing temperature in the urban area. For areas that could not be covered by the tree shades, VGS could be a possible solution. In general, the application of greeneries in the high-rise building is commonly applied in wide and public spaces as in the rooftop, podium, including on the façade itself. Nevertheless, not many high-rise buildings purposely allocate their space for the green spaces. In this case, transitional spaces, such as the atrium, sky court, lobby, corridor, and even in the balcony, could be optimized. Therefore, the system or method of VGS must be carefully considered. It has to be effective, economical, feasible, and aesthetically pleasing to suit the climatic condition the high-rise building, which is different than planting on the ground level. Although the benefits of VGS on the building are promising, very little studies have been conducted emphasizing on the application of VGS in transitional space particularly on the high-rise building. Hence, this paper aims to address the need for identifying the strategy of VGS application in the transitional space, particularly in the high-rise building. Several layers of plants will be used for enhancing the efficacy in modifying the microclimate. This method is defined as the multi-layer planting concept. By incorporating multiple layers of plants, it is believed that the more plant canopy applied, the better the efficacy in terms of filtering solar radiation.

2. Benefits of Greeneries on Building

In general, there are four microclimate elements that could affect the thermal comfort, i.e. temperature, humidity, radiation, and the wind. However, only wind and radiation that could be modified by the evapotranspiration (the combination process of evaporation and transpiration) process of plants. It is believed that evapotranspiration from the soil-vegetation systems is a microclimate moderator [3], [4]. The advantages of having plants in buildings are undeniable regarding the impact on the building. Integrating greeneries on the building is recognized as a promising approach for the application in the hot and humid climate. The advantages of integrating vegetation in building has led many scholars in conducting research focusing on the contribution of greeneries in building, mainly on energy efficiency, cooling strategy, and thermal comfort improvement [1]–[3], [5]–[11], carbon sequestration of plants [12], [13], noise barrier by applying VGS [14], growing food plants on biofaçade [15], [16], as well as occupants’ comfort, satisfaction and productivity [17], [18]. The importance of greeneries application in a building has influenced many researchers to develop and innovate on the method, technology, as well as optimizing their benefits in buildings.

It has been proven that both living wall and green façade could reduce the outdoor wall surface and air temperature up to 11°C and 4.71°C respectively [9], [19]. It is also studied that vertical climbing plants, or biofaçade, has its maximum performance in the daytime in terms of its shading, evapotranspiration, and photosynthesis [9]. Wong also agreed that the maximum reduction of wall temperature was recorded at 11.58°C by applying living wall or carrier system [20]. This reduction was strongly related to the soil substrate attached to the wall surfaces. Wall cavity temperature was also reduced with the application of living wall by 8°C and green façade in building by 6.5°C. Furthermore, indoor temperature was also reduced by 3°C and 4°C by the application of living wall and green façade respectively [21]. A recent study by Widiatutti, Prianto, and Budi resulted that indoor surface temperature on the façade was reduced up to 2.1°C with the living wall application on the east-facing façade [22]. However, according to Sunakorn and Yimprayoon, biofacade is less efficient to decrease the temperature in the night time [9]. In spite of its thermal performance, Wang, Er, and Abdul-Rahman identified that wall mounted or freestanding living wall is also effective to improve the aesthetic value as it could enhance the visual impact, hide unsightly features, as well as could screen and isolate views
These advantages are useful to be applied in transitional space as a visual barrier-cum-artistic element that could enhance the artistic value of space. VGS or biofaçade installation should be externally movable for the ease of maintenance, particularly in a high-rise building where space and access are limited. Poorly maintained vegetation could fail to provide the benefits of the greeneries.

3. Multi-layer Planting Concept
The presence of multi-layer planting concept is not new in nature and it is commonly found naturally in the tropical rainforest setting which is known as the tropical rainforest canopy layer. These layers are consists of four different layers, i.e. emergent layer, canopy layer, understory layer, and forest layer. These plant layers are grown in the ground and naturally capable in stabilizing the day and night time temperature by lowering evaporation rate as well as providing a high level of humidity. The quantity, as well as the canopy density of a plant is a critical factor to be considered in modifying the microclimate in a certain area due to its evapotranspiration. Moreover, it was found out that plant canopy could create shade by its foliage geometry. Furthermore, plant canopy could reduce glare as well as to block the diffuse light from the sky and surrounding surfaces, resulting in reduced surface temperature. A single layer of leaf could approximate absorb 50% visible and infrared radiation, 30% reflected and only 20% transmitted, as figured in Figure 1. Therefore, the more layers of leaves are expected to be effective in reducing the intensity of solar radiation, resulting high-quality shades.

![Figure 1. Amount of radiation absorbed, reflected and transmitted on single leaf layer](image1.png)

![Figure 2. The schematic diagram of three canopy layers, adopted from Shahidan and Jones](image2.png)

To be applicable in the urban setting where space is limited, three layers are considered acceptable. Those layers are the upper, middle and field layer (refer to Figure 2). Three layers of plant cover will provide a good quality of shade, promote high humidity level as well as to reduce the overall surrounding...
air temperature [3]. In multi-layer planting concept, each layer of plants has its characteristic and function in modifying microclimate by the different density of the plants. This is determined by the Leaf Area Index (LAI) value.

LAI is a key parameter in order to characterize the foliar density as well as the thermal behavior for vertical greeneries due to the shadow effect created by the foliage [27]. According to Charoenkit and Yiemwattana, LAI is the ratio of total-one sided leaf area to the ground surface area [12]. This could be defined as the large LAI value could effectively cool the building and lower the cooling load due to the evaporation effect. The larger the LAI value, the higher the effect of shading quality, magnitude of transpiration process, and higher effect of radiation filtration. However, there is lack of study regarding this concept if applied in the form of vertical planting and planted in limited spaces although the presence of greeneries in building is beneficial. Therefore there is a need to explore the potential of multi-layer planting concept for limited spaces, such as the transitional spaces.

4. Selection of Plant Species for Multi-layer Planting Concept
To enhance the efficacy of the multi-layer planting, the quality of selected plant species must be considered carefully. As stated by Shahidan and Jones on their research, the characteristics, functions, and LAI values of the plants are different for the upper, middle, and the field layer [3]. Moreover, the effectiveness also depends on the density, thickness, and the type of plants selected on each layer. In order to address the food security issue, edible plants could be applied together with the ornamental plants since both types of plants could improve the thermal comfort as well as giving aesthetic value at once.

4.1. Upper Layer
The upper layer consists of tall and loose density plants with broad/spreading foliage or plants that have the LAI value below than 5 in order to partially filter the amount of light and radiation. Creepers and vines are suitable to be applied on this layer due to the plant morphology and the LAI value. Based on Yok and Sia, commonly planted creepers and climbing plants for urban landscapes are Kock's Bauhinia (Bauhinia kockiana), Bleeding heart vine (Clerodendrum thomsonia), Maiden’s jealousy (Tristellateia australasiae), Rangon creeper (Quisqualis indica), and Blue trumpet vine (Thunbergia grandiflora) [28]. Besides filtering solar radiation, the creepers could be as a food producer by growing edible plants, such as Ivy gourd (Coccinia grandis), Mexican creeper (Antigonon leptopus), Winged bean (Psophocarpus tetragonobulus), Sweet pea (Pisum sativum), Long bean (Vigna unguiculata sesquipedalis) and Kidney bean (Phaseolus vulgaris) [9], [15], [16]. These plants will partially filter the solar radiation and provide shade. In this layer, light and radiation are still transmitted through this layer for the photosynthesis process of the middle and field layer.

4.2. Middle Layer
In this layer, radiation is filtered by high-density plants, or ideally plants with LAI value 5 or more and the transmissivity level is below 10%. Plants with these characteristics are known could provide high-quality shade. Medium-height plant species with round/oval solid form and broad leaf characters are favorable to improve the absorption and filter more radiation. This condition will allow retaining more moisture and reducing the evaporation of soil water. Air temperature also will be reduced due to the shading effect in this layer.

4.3. Field Layer
The purpose of this layer is also to reduce the air temperature as well as generate evaporative comfort cooling. Low shrubs with thick, high-density foliage (LAI value >5) are suitable to be applied in this
layer in order to maximize the evaporation and transpiration process, stabilize the ambient temperature as well as to absorb excessive thermal heat.

Another factor needs to be taken into account before integrating vegetation in the building is the climatic factor, especially when the greeneries is applied to the high-rise building where the climatic condition is different compare to the similar garden at ground level. According to Hopkins and Goodwin, these climatic differences are the wind, light, and salt content (airborne salt) [29]. The plants selected for multi-layer planting may be ornamental, edible plants, or the combination of both. Edible plants are also beneficial for solving food and medicinal import problems, absorbs CO₂, as well as could reduce the temperature. Nevertheless, edible plants require regular care and trimming to ensure the leaf and fruits produced are growing optimally until harvested.

The final concern of plant if planted in the high-rise building is the ability to withstand the wind, has no broad leaf and weak branches, and good when exposed to the sun (hardy plants), particularly if grown on the West-oriented building. As studied by Taib, not all palm trees could withstand the high wind due to the leaf shape [30]. In was stated that Ruffled Fan Palm (Licuala grandis) is less suitable to be planted in the windy open space such as in the rooftop due to the wide-shaped leaves, although it can stand on the full sun. However, Lady Palm (Rhapis excelsa) is more resilient towards the wind due to the narrow palmate leaves and strong branches.

To maintain the efficacy of the performance, both technical and environmental problems need to be closely considered before any application of vegetation in building. Besides, inappropriate plant selection can lead to various problems that include plant losses, excessive growth, higher maintenance, unattractive structures, poor public perception, and inability to provide benefits. One of the crucial issues that need to be highlighted if incorporating edible plants is the pest management practice. The use of chemicals can be avoided by using companion planting or manual weeding.

5. Greening Transitional Spaces
Due to its spatial characteristics, transitional spaces are often related with open area. Additionally, these opened area is easily influenced by variable weather conditions as it is close to natural environment while an enclosed area is totally separated from the exterior environment and generally equipped with air conditioner [31]. Transitional space, or transient space, is a space that is not directly occupied by any major activities in the building. It is located in between the interior and exterior environment, acting as both buffer spaces and physical links [32][33]. This could be the balcony, terrace, porch, foyer, lobby, external or internal corridor, as well as courtyard or atrium. These spaces have a large implication to occupants experience and building energy consumption. Even though it is not directly occupied, transitional space consumes more energy compared to other occupied parts of building of similar size when being conditioned for achieving the same comfort requirement [31]. Although this area is commonly used as a communal area and equipped with mechanical cooling devices, transitional space could be optimized as a green space.

Building orientation is also determining the intensity of the light, which is strongly affecting the photosynthesis process. The East-facing transitional space receives the morning sun for few hours, which is ideal for the plants, but late morning sun may begin to cause heat problems. On the other side, West-facing balcony receives the highest amount of daylight as well as the heat. Therefore, plants that are grown on this balcony must able to tolerate the high light intensities. These environmental factors could be elucidated by (1) evaluate the climate condition on the location, (2) select the most suitable plants including the growing media, and (3) modify the structure if possible [34]. Since the building regulations may limit the occupants for structural modification, it needs an effective method by applying the multi-layer planting concept to overcome the limitations.

As stated by Prihatmanti and Taib, the overall dimension of VGS needs to be carefully considered due to the space limitation such as in the balcony. The most feasible area for placing the greeneries is located on the side of the balcony unblocking the view [35]. To maintain the efficacy as well as the
aesthetic factor, regular maintenance needs to be conducted since plants are living things. Poor maintenance could lead to unwanted species growth, wilted or overgrown plants, and might fail to provide the benefits of having vegetation on the buildings.

6. Conclusions
Living in a high-rise building is a sensible alternative to accommodate urban sprawl where the land is scarce. In reality, not all buildings could provide green spaces due to the space efficiency and economic issues. In this case, transitional space could be optimized for green space, such as Vertical Greenery System (VGS). The availability of transitional space in a high-rise building is unavoidable such as in the corridor, atrium, and lift lobby. Although it is commonly equipped with a mechanical cooling device, this space could be explored further.

The benefits of having plants in buildings are undeniable, particularly in modifying the microclimate and energy efficiency issues. Integrating plants on buildings is considered as one of the promising solutions for replacing the greenery on the ground level. By growing plants vertically, it could help to grow food and medicinal plants, improving the thermal performance as well as a design element in the building. However, several technical factors need to be closely considered before the application in order to prevent damages and design mistakes. Those are the structure, dimension plant species, growing media, and the maintenance. Furthermore, environmental factor such as the heat intensity, wind, and airborne salt also might affect the quality of the vegetation.

To enhance the efficacy, multi-layer planting concept could be introduced. Three layers of plants (upper, middle, and field layer) with different foliage density on each layer are believed could improve the thermal comfort. Moreover, this planting concept could be an alternative in growing food plants vertically. From this review, it can be concluded that VGS application with multi-layer planting concept is beneficial to be applied in high-rise building as well as to address the food security issue in the urban context. In spite of the space limitation, VGS design can be customized to be an effective greenery system that could provide desirable thermal performance and as an aesthetic element.

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