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MULTI-LAYER BALCONY PLANTING: A BIOMIMETIC CONCEPT OF TROPICAL RAINFOREST

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Abstract

There have been many biomimetic research works which look into the relationship between nature and architecture in order to propose an innovative solution. People have been considering nature as an inspiring source of knowledge. It is also a mentor and measure in creating an innovative solution. This trend is known as biomimicry. However, the basic concept of biomimicry is not merely copying the nature, but it is an abstraction of nature's fundamental principle and function. This study aims to discover the potential of a tropical rainforest as an effective microclimate modifier in the urban setting. By using the 'top-down' or 'problem-based' biomimetic approach, the canopy layers of tropical rainforest can be generated into a multi-layer planting system, as a part of urban green infrastructure. Observation, documentation, and LAI measurement were conducted in this research to determine the appropriate species to be planted in a multi-layer planting concept. The three selected layers were defined based on the density and characteristic of the leaves as well as the Leaf Area Index (LAI). Edible and/or medicinal plants were fully considered in this research to highlight the food security issue and farm-to-table movement. In the future, the recommended plants species will be beneficial as a guideline to determine the appropriate species to be planted on a balcony of a high-rise building in tropical urban setting.

Keywords: Biomimicry, urban green infrastructure, multi-layer planting, tropical rainforest, food security.

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1. Introduction

The depletion of the open spaces due to the urban development has potentially reducing the amount of vegetated areas on the ground level. This is considered as the major cause of the rise of urban temperature, including in Malaysia. Other attributes, such as heat released by air conditioning system, vehicles, and artificial hard surfaces play its roles too. Integrating vegetation on building is one of the possible ways to replace the loss of green space. However, applying vegetation faces the issue of space limitation especially in the urban areas. This condition is made worse by the minimum access to green spaces in the high-rise dwellings. In reality, most of the landscape features are in the communal areas.

Following what Pomeroy (2012) observed, urban densification has led to the reduction of vegetated areas. This phenomenon not only have increased the Urban Heat Island (UHI) level, but also affecting the socio-environmental aspects. Another previous study by Taib, Abdullah, Fadzil, and Yeok, (2010) also discovered that the presence of greeneries, especially on high-rise office building, is required by 96% of the building occupants. As much as 31% of the respondents mentioned garden as a space to relax, as an alternative workspace that is conducive to the respondents (23%), and as a stress reliever (14%).

Gardening activity are known to be beneficial for improving the well-being. The presence of *Mycobacterium vaccae* in soil is proven to help stimulate the immune system, alleviate allergies and symptoms of psoriasis (Kozyrskyl, Bahreinian, & Azad, 2011; Lowry et al., 2007; O'brien et al., 2004). Cultivating edible plants is also beneficial to provide food for the domestic scale. It has been predicted that in the year 2030, there will be 60 per cent of people who will be migrating to the urban. The demand for food supply will be increased along with the number of the urban migrants (Al-chalabi, 2015; Despommier & Ellingsen, 2008). According to Khatun, Harun-Or-Rashid, and Rahmatullah (2011), medicinal plants are also known to provide benefits as a complimentary or alternative medicine in the household level which are easily accessible.

1.1. Biomimicry as a sustainable innovation

Over the years, the innovation and technology derived from nature has increasingly received attention as a promising problem solver. It is believed that nature is a source of knowledge, a mentor and a measure. According to López, Rubio, Martín, and Croxford (2017), biology is now no longer for the biologist, but it is another source of inspiration for the nature-based innovation, or known as biomimicry. It is originated from the Greek word 'bios' meaning life; and 'mimicry' or imitation. In brief, Benyus (2017) described biomimicry as a new knowledge that studying the model of nature by imitating or taking inspiration from the nature to figure out human problems.

The basic concept of biomimicry is not merely creating a copy from the nature, but it is an abstraction of fundamental principle and function of the nature. It is also providing ideas to discover and adapt from nature's design into sustainable building ideas, or nature-based solution (López et al., 2017). In recent years, there have been many biomimetic research works, which look into the relationship between Biology and Architecture to create an innovative solution. Hence, this paper focuses on the biomimetic approach from the canopy layers of tropical rainforest into a multi-layer planting system, as a part of green infrastructure in limited space.

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1.2. Biomimetic concept of a tropical rainforest

In this study, biomimetic solution is applied to seek the appropriate solution based on the biological principles. By observing the nature's model, it is expected to create an innovation by 'doing it nature's way' (Benyus, 2017; Tavsan & Sonmez, 2015). According to El-Zeiny, (2012); Helfman Cohen and Reich, (2016); Nkandu and Alibaba, (2018), biomimetic design solution was created through a bidirectional design process: 'problem-based' or 'top down' and 'solution-based' or 'bottom up' approach. In this research, 'problem-based' or 'top down' approach is applied. The steps of the design process is illustrated in Fig. 1. In this approach, the problem must be identified before looking to the living world for the solution, searching the biological solutions that have solved similar issues, and extracting the biological principles to be generated as a biomimetic solution (see Figure 01).

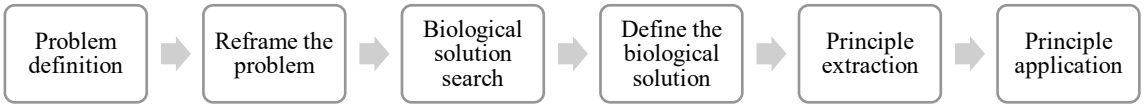

Figure 01. Problem-based or top down approach (El-Zeiny, 2012)

To accommodate the UHI problems in the tropical urban context, tropical rainforest is selected as the biological solution in this research. The ability of tropical rainforest in reducing the temperature as well as carbon dioxide absorber initiates the idea of choosing it as the biological solution for addressing the problem stated. Naturally, there are layers of plant canopy, namely the upper, middle, and field layer in a tropical rainforest. According to Parker and Brown (2000), forest canopy consists of a complex structure and it is significant for environmental interactions, growth, and biotic habitat. The canopy layers of the tropical rainforest bring us an inspiration to the innovation of multiple layer planting while providing benefits to us from their metabolic processes, i.e. photosynthesis and evapotranspiration.

1.3. Multi-layer planting concept

This is also agreed by Shahidan and Jones (2008) in their study. Three layers of plants are proven to contribute high-quality shades. This will increase the humidity level and lowering the air temperature. Besides, more layer of plants will also provide high evaporative comfort cooling as a result of the evapotranspiration process. The variation of density on each layer is significantly reducing the transmission and modifies the solar radiation. This could help to maximise the transpiration and evaporation processes, which helps to create cooler air. As illustrated on Fig. 2, a single leaf layer could absorb as much as 80% visible radiation, 10% is reflected and the last 10% is transmitted. A leaf could absorb infrared radiation as much as 20% from its total value, whereby 50% is reflected, and 30% is transmitted. Hence, it could be justified that the more layers of leaves a could perform better in reducing the solar radiation. In this study, the multi-layering concept focuses on the upper, middle and field/bottom layer. However, due to the space and species constraint, the LAI value for multi-layer planting was adjusted to suits the condition of the limited space.

Leaf Area Index (LAI) is significantly important for characterising the foliar density as well as the thermal behaviour for vertical greeneries due to the shadow effect created by the foliage (Coma et al.,

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2016). LAI is described as a ratio of total-one sided leaf area to the ground surface area (Charoenkit & Yiemwattana, 2016) . In plants, the large LAI value effectively cools the building due to the evaporation effect. In the rainforest context, the upper layer is characterised by loose density plants with broad/spreading form, or plants with LAI value less than 5. The middle layer consists of denser plant canopy, compare to the first layer, or LAI value more than 5. The bottom or field layer is grown with vegetation, which has LAI value more than 5, or thick and dense low shrubs/turf (Shahidan & Jones, 2008; Taib & Abdullah, 2016). To be applied in small scale, these LAI values needs to be adjusted since there are several constraints to be considered such as the dimension of growth space and selection of the plants itself (Figure 02).

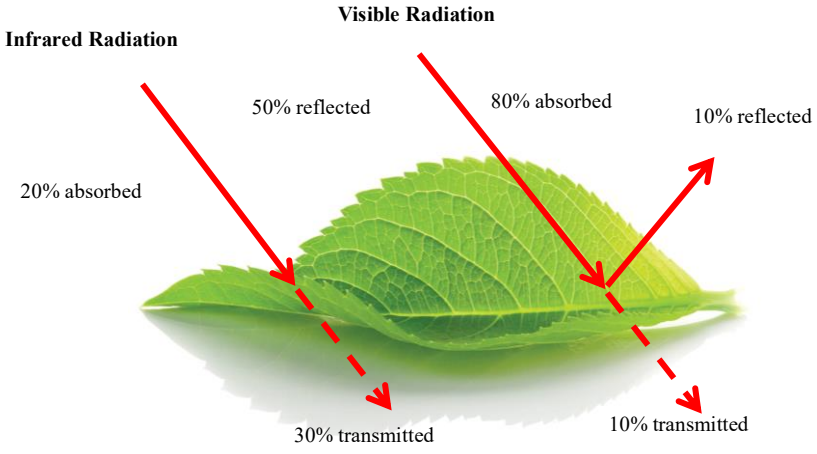

Figure 02. The ability of single layer of leaf in absorbing, reflecting, and transmitting infrared and visible radiation. Source: Modified from Brown & Gillespie (1995)

2. Problem Statement

There is an urgency to add the amount of greeneries without taking up extra space on the ground. On the other hand, it is also required to reconnect the correlation between human and the nature which was gradually diminishing due to the depletion of the green space on the ground. Although greeneries are important as a restorative element as well as a microclimate modifier, unfortunately, not all buildings could provide green space for the occupants. Even though the space is limited, the usable spaces in building could be maximised with the best method to obtain a cost-effective and easy maintenance greenery systems in order to mitigate the UHI problems.

In this research, multi-layer planting concept is selected as a biological solution from the biomimetic concept of a tropical rainforest. This concept is known to perform better in terms of modifying the microclimate through landscape (Shahidan & Jones, 2008; Taib & Abdullah, 2016). Besides, Brown and Gillespie (1995), also agreed that multiple layers of leaves will reduce more transmission compare to single leaf layer. From the four microclimate elements, i.e. air temperature, relative humidity, wind, and radiation, only wind and radiation can be significantly modified by the presence of vegetation. Air temperature and relative humidity are not modified by the landscape. The presence of multiple-layer planting is expected to contribute an innovative yet effective way of planting,

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particularly on a confined space, such as in a balcony. To obtain a maximum result, the selection of plants species must be considered thoroughly considering the strong wind and high heat in the high-rise setting.

3. Research Questions

According to the problems stated previously, the research questions are:

- How does the biomimetic solution can be applied for mitigating UHI through multi-layer planting concept?
- What are the suitable plants species to be planted in the balcony of a high-rise building by using multi-layer planting concept?

4. Purpose of the Study

This study addresses the multi-layer planting concept which is derived from the biomimetic principle of tropical rainforest to suits the urban context. The selection of suitable plants also proposed based on the characteristics to suit the high heat and strong wind in the high-rise setting.

5. Research Methods

This study is an explanatory research and involves qualitative and quantitative method. The qualitative method was used for observing and documenting the physical characteristics of plants. Meanwhile, the quantitative was conducted to measure the LAI value of each species based on the database provided by the National Parks Board Singapore as well as manual measurement by using Plant Canopy Analyzer (Li-Cor LAI-2000). Extensive literature search was also conducted to determine the ethnobotanical usage of the selected plants on each layer. By combining multiple plant species in one system, it could be more efficient in terms of the space used.

5.1. Site selection

Balcony of a high-rise building was selected as the location of this research. As one of the usable spaces, balcony could be maximised as a personal green space. The ease of accessibility of balcony is beneficial for experiencing nature personally as well as for maintaining it. Despite of the area size, the application of multi-layer planting on balcony must be fully considered in terms of the dimension and the climatic issue, especially if planted on a high-rise. The climatic condition on high-rise differs from the ground level due to the high amount of solar radiation and high wind velocity (Arslan & Sev, 2014; Taib, Abdullah, Ali, Fadzil, & Yeok, 2014). It is a buffer area and serves as a thermal bridge from the outdoor to the indoor and influenced by the various weather conditions from the outdoor. Building orientation and location are important factors to be considered. These factors determine the amount of light intensity received by the plants. Balcony facing to the East receives the morning sun which is ideal for the photosynthesis process.

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5.2. Plant species selection

In high-rise landscape planning, plant selection is an important factor to be considered. This will help to minimise undesirable effects due to the climate or location issues. Based on the previous studies by previous researchers (Sulaiman, Jamli, Zain, Kuttler, & Shahidan, 2013; Tayobong, Sanchez, Apacionado, Balladares, & Medina, 2013; Taib & Abdullah, 2016; Tan, Wong, & Jusuf, 2017), the plant selection criteria are listed in Table 1 as follows:

Table 01. Plants species selection criteria

No.	Factors	Criteria
1.	Weather tolerance	• Plants must be able to survive in the various weather conditions, including high heat and strong wind. • Plants with woody stems are most preferred.
2.	Growth rate	• The selected plants have to be perennial and durable.
3.	Growth pattern & coverage	• Easily to twine and cling to cover the trellis.
4.	Branching density	• Multiple stems are preferred compare to the single/solitary stem to provide multiple layers of radiation filtration.
5.	Leaf size & shape	• Plants with broad leaves are good in filtering radiation but less preferable to be able planted in high wind velocity.
6.	Planting container	• Plants are at risk of drying out faster due to the limited amount of growth media.
7.	Maintenance	• Select plants with low maintenance
8.	Availability	• The availability of the species on the markets will reduce the plant replacement cost and time.
9.	Ethnobotanical uses	• Edible and medicinal plants are more beneficial for the human.

6. Findings

Based on the literature search and observation, there are several sets of plants combinations that could be combined in a multi-layer planting concept. The species name, amount of LAI, the leaf shape, edible parts, and the ethnobotanical usage is tabulated on Table 2. The selected plants are commonly grown in domestic scale in Malaysia, as herbs and spices for cooking, food colouring, natural flavouring, as well as for medicine.

Table 02. Name of selected plant species and the Ethnobotanical usage

Layer	Species	LAI	Leaf Shape	Edible Parts	Ethnobotanical Usage	References
Upper	Butterfly pea flower / Bunga telang *Clitoria ternatea*	2	Ovate, Elliptical	Root, seed, flower	Natural food colour, anti-Urinary Tract Infection/UTI, remedy for abdominal swelling, sore throats and mucus disorders, antioxidant	Kamkaen & Wilkinson (2009); Mukherjee, Kumar, Kumar, & Heinrich (2008). Hossan et al., (2010); National Parks Board (2013); Chusak et al. (2019).
	Coral vine / Air mata pengantin *Antigonon leptosus*	2	Ovate, Cordate	Flower	Anti-high blood pressure, antidiabetic, remedy for flu, cold, menstrual pains, anticoagulant	Vanisree, Alexander-Lindo, DeWitt, & Nair (2008); National Parks Board (2013);

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						Balasubramani et al. (2015)
	Blue trumpet vine *Thunbergia grandiflora*	2	Oblong lanceolate, hairy	Leaves, flower	Antioxidant, antidiabetic, anti-inflammatory, antipyretic properties	Chan et al. (2011)
	Daun kaduk / Wild pepper *Piper sarmentosum*	4.5	Cordate	Leaves, stems, flowers	Salad, treating cough, flu, asthma, malarial fever, reduce blood sugar, diuretic, antioxidant	National Parks Board (2013); Rahman et al. (1999)
Middle	Indian borage (small leaves) *Plectranthus amboinicus 'Variegatus' P. sp.*	4.5	Obovate, hairy	Leaves	Herbs. cough reliever antioxidant, anti-bacterial, bio-preservative agent, natural insecticides	Bhatt & Negi (2012); National Parks Board (2013)
	Indian borage (variegated) *P. madagasca-riensis 'Variegated Mintleaf'*	4.5	Ovate, hairy	Leaves		
	Stevia *Stevia rebaudiana*	4.5	Obovate; Oval; Elliptical	Leaves	Natural sweetener, anti-diabetic, anti-hypertension, anti-obesity, anti-fatigue, skin care	National Parks Board (2013); Rizwan et al. (2018)
	Basil family *Ocimum basilicum; Ocimum x africanum Lour.*	3.5	Oval	Leaves	Herbs and spices, anti-microbial, antioxidant, insect repellent, anti-inflammatory, anti-pyretic, analgesic, anti-carcinogenic, immunomodulatory, cardio-protective	National Parks Board (2013); Pandey et al. (2014)
	Mint family *Menta piperita; Mentha spicata L.*	3.5	Ovate; Lanceolate; Oblong	Leaves	Natural flavouring, anti-fungal, natural antioxidants, anti-microbial	National Parks Board (2013); Prakash et al. (2016)
	Cekur, Kencur *Kaempferia galanga*	3.5	Elliptical	Rhizome, leaves	Herbs & salad, anti-inflammatory, treat sprains & ulcers, anti-hypertensive, anti-asthma, promote digestion, analgesic, treat colds, coughs	National Parks Board (2013); Yao et al. (2018)
Field	Pandan *Pandanus amaryllifolius Roxb.*	4.5	Linear	Leaves	Natural food colouring and flavouring, anti-rheumatism; anti-diabetic, natural pest repellent, antiviral, antioxidant, and anti-hyperglycaemic	National Parks Board (2013); Saenthaweesuk et al. (2016)
	Periwinkle/ Kemunting Cina *Catharantus roseus*	4.5	Elliptical	Leaves	Anti-diabetes, anti-hypertensive, asthma and menstrual disorder remedy, anti-cancer drugs to treat leukaemia and Hogkins' Disease, anti-inflammatory	National Parks Board (2013); Tiong et al. (2013)
	Bunga tahi ayam *Lantana camara*	4.5	Ovate	Leaves	Antioxidant, anti-bacterial, anti-pyretic, larvicidal, insecticidal, anti-microbial, wound healing and anti-hyperglycaemic	Saxena et al. (2012); National Parks Board (2013)
	Cat whiskers/ Misai Kucing/ Java tea *Orthosiphon aristatus*	4.5	Ovate	Leaves	Anti-rheumatic fever, remedy for gout, anti-diabetic, anti-microbial, diuretic, hypouricemic, antioxidant, anti-inflammatory, hepato-protective, renal protective, anti-hypertensive, anti-hyperlipidaemic, and anorexic activities.	Khatun et al. (2011); Ameer et al. (2012)

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The selected plants are categorised into three layers as a mimicry of the tropical rainforest: upper, middle, and field layer. In this research, these layers are labelled as 'first' for the upper layer, 'second' as the middle layer, and 'third' as the field layer.

a) First layer

Shade-loving plants are prioritised in the selection due to the location of the balcony. However, there is a limitation in selecting edible and/or medicinal creepers/vines that are shade loving. Whereas Butterfly Pea Flower (*C. ternatea*), Coral Vine (*A. leptopus*), and Blue Trumpet Vine (*T. grandiflora*) are sun-loving plants. Daun Kaduk or Wild pepper (*P. sarmentosum*) is recommended to be grown in shady places and requires regular watering compare to *C. ternatea*, *A. leptopus*, and *T. grandiflora.*

b) Second layer

The plants on the second layer are small sized potted plants which must be able to grow in a small container, i.e. Indian Borage (*P. amboinicus 'Variegatus' P. sp* and *P. madagascariensis 'Variegated Mintleaf'),* Stevia *(S. rebaudiana),* Basil family (*O. basilicum; Ocimum x africanum Lour.),* Mint family (*M. piperita; M. spicata L.),* Cekur/Kencur *(K. galangal).* However, plants with thick and wide leaves such as *P. madagascariensis 'Variegated Mintleaf'* and *K. galangal* are more resistant to dryness compare to plants with thin and small leaves (Stevia, Mint, and Basil). Frequent watering by using automatic irrigation system is recommended for plants with thin and small leaves.

c) Third layer

This layer receives the most sunlight and exposed to the wind, therefore, the plants on this layer must have woody stems and small leaves. The suitable plants for this layer are Pandan *(P. amaryllifolius Roxb.),* Periwinkle/Kemunting Cina *(C. roseus),* Bunga Tahi Ayam *(L. camara),* Cat whiskers/Misai Kucing/Java tea *(O. aristatus).* These plants required regular watering to prevent dryness from the excessive heat on the balcony.

The plants listed on Table 2 were purposely selected with varieties of leaf shapes. According to Wahab and Ismail, (2012), wide leaves such as Cordate and Elliptical are beneficial for reducing the air temperature. While the Linear, Spatulae, and Lanceolate could perform better by decreasing the air temperature and humidity. It is also potential in absorbing chemical airborne pollutants. It is believed that wide leaves have better leaf performance due to the amount of stoma, particularly if applied in small spaces. Besides shape, the roughness of the leaf surface also brings benefits for decreasing air pollution. Hairy, wax-covered, and wrinkled leaves are potential biofilter. They are able to capture more dust/particulate matter (PM) compare to smooth and glossy leaves.

Based on the previous study, there is a positive correlation between PM accumulation with hair density on the leaves and the quantity of leaf waxes (Sæbø et al., 2012; Zhang, Wang, & Niu, (2017). By selecting the most effective species, it is expected to be able to reduce the air temperature, humidity, as well as airborne pollutants which is important in the urban setting. Having greeneries on the high-rise building's balcony could re-establish the connection of human with the nature. This is also agreed by

Kabisch, Korn, Stadler, & Bonn (2017) that connectedness with nature will significantly improve the well-being of the human.

7. Conclusion

The addition of green spaces in the urban is known to be beneficial not only to the people, but also to the environment. By having greeneries in the urban, it will result a better and liveable city which lead to a better sense of well-being. As stated previously, the presence of greeneries is known to mitigate the UHI, a stress reliever, and providing food in the domestic scale. Moreover, it could promote the biodiversity in the urban context. Apart from that, the application of greeneries is also a sustainable public art which could enhance the aesthetic value in the urban. In this research, biomimetic design method is used in multi-layer planting concept which is inspired by the tree canopy layers of a forest that is applicable for high-rise setting. It opens up a whole new world of nature-based innovative ideas for transforming the built environment while optimising the human well-being as well as the food security issue in the urban. Three-tiered of plants which are stacked vertically is the feasible option in a limited space. However, the plants selected for balcony planting must have high survival rate due to the climatic condition in the balcony, especially on East & West facing building. Regularity of maintenance is important to maintain the growth performance of the plants. Future research investigating the performance of multi-layer planting concept is needed to develop the wider possibility of plants species combination. In the future, Green Plot Ratio (GnPR) needs to be developed further to quantify the value of the urban high-rise greeneries which will be beneficial for the green building assessment requirement as well as to reduce the UHI temperature.

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