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Vertical Greenery System in urban tropical climate and its carbon sequestration potential: A review

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ABSTRACT

This article presents a comprehensive literature review of Vertical Greenery System (VGS) in tropical areas, its benefits, its carbon sequestration potential and its calculation methodologies, and its potential for urban heat island (UHI) and climate change mitigation. The contemporary VGS has evolved from the seventh-century beginnings of the Hanging Gardens of Babylon to the vertical urban farms of today in Singapore and Japan. The VGS has demonstrated a significant role in mitigating urban climate change impacts by the potential use of carbon sequestration from vegetation. However, studies on carbon sequestration rate and the methodologies used for calculation are still rather vague. Therefore, this paper reviews existing methodologies for evaluating carbon sequestration rates in tropical climate plants and makes suggestions of potential plants for optimum carbon sequestering.

1. Introduction

In the past few decades, more rural regions are transforming into urban areas, resulting in more than half of the world's population (54%) now living in urban areas. The highest growth of urbanization occurred in Northern America (82% population living in urban areas), Latin America and the Caribbean (80%), and Europe (73%) whereas populations in Africa (40%) and Asia (48%) continue to exist, largely, in rural areas. However, it is estimated that by 2050, Africa and Asia will have a faster urbanization growth rate than other regions, with an increment of 16% of the population in urban areas (United Nations, 2015, 2016). The tropical region covers 1/3 of the world's land mass, approximately 31% of world's forests (IAP, 2010; FAO, 2016; Yale University, 2017), and is inhabited by 1/3 of the world's population (United Nations, 2016). The developing countries in the tropical region are experiencing the highest urban growth since 1992 with approximately 1 to 3% annual increase, and by 2030 the tropical regions are expected to have more urban areas than rural areas (Meyer and Turner, 1992; United Nations, 2014).

Urbanization has led to many environmental issues such as climate change, global warming, urban heat island effect, air pollution, soil and water contamination, floods and acid rain (Fu et al., 2007; Grimmond, 2007; Firman, 2009). The contribution of cities and buildings to greenhouse gases (GHGs) emissions and energy consumption accumulates over their lifecycle from conception (material collection, transportation, soil excavation, site clearing, etc) to construction (production, transport, distribution, etc), through usage (waste, electricity, energy consumption, maintenance, refurbishment) and finally demolition (disposal, waste) (Graham, 2003). The construction industry has a vital role in creating a more sustainable built environment (Graham, 2003; Williamson et al., 2003), and emerging from this realization are niches categorized as sustainable architecture, ecological architecture, climatic design (Gallo, 2000; Steele, 2005), energy-efficient buildings, green architecture, green building (Graham, 2003; Steele, 2005), and sustainable property development (Keeping and Shiers, 2004).

Coupled with the drastic rate of tropical forest deforestation, with an estimated 7 million hectares annual lost from 2000 to 2010 (FAO, 2016), the importance of cultivating urban greenery is as vital as ever. Vertical Greenery System (VGS) is increasingly being recognized as an approach that is environmentally sustainable and able to mitigate climate change impacts in urban areas (Sheweka and Mohamed, 2012). Vertical Greenery System is a general term referring to any form of plants growing, whether on, up or against wall surfaces that may or may not permanently attach to the building interior wall or façade (Wang et al., 2016). Vertical Greenery System is also known by different terminologies such as green space wall, green wall technologies, green façade, green scaffoldings, bio walls, biofacade walls, vertical garden/wall or living wall (Rahman et al., 2014; Bakar et al., 2013;

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(a) Source: Krystek (2010) (b) Source: Woods and Woods (2009)

Fig. 1. An illustration of Hanging Gardens of Babylon (a) & (b).

Basher et al., 2016; Amir et al., 2014; Jim, 2015). The VGS has been known since the 7th century, through the history of the Hanging Gardens of Babylon found in Iraq, which was deemed as one of the Seven Wonders of the Ancient World (Wang et al., 2016). According to ancient Greek historian, the Hanging Gardens of Babylon were 400 × 400 feet of area and height of 80 feet (Woods and Woods, 2009). "It consists of vaulted terraces which covered by a dome or an arch, raised one above another, resting upon cube-shaped pillars" as shown in Fig. 1. (Krystek, 2010).

The model of contemporary VGS was invented by Stanley Hart White and patented in 1938 (Hindle, 2012). The model of *Vegetation-Bearing Architectonic Structure and System* in Fig. 2 explains a new approach "for producing an architectonic structure of any buildable size, shape or height, whose visible or exposed surfaces may present a permanently growing covering of vegetation" (Hindle, 2012). Since then various models have emerged, adapted from the Stanley model. However, Vertical Greenery System started to attract peoples' attention in the 1980s, when Dr. Patrick Blanc disseminated the model and technique to develop VGS through integrating plants into the facade of buildings. This coincided with rising concerns in the 1980s, of environmental issues and the enforcement of policies to transform green cities (Bakar et al., 2013).

Other contemporary usage of VGS include urban farming for high-density cities like Singapore and Kyoto, Japan (CNN, 2012; McKirdy, 2016). Sky Greens in Singapore patented rotating water-powered aluminum frames to farm vegetables such as 'bak choi' and Chinese cabbage, where the plants are farmed indoors using energy-efficient LED lighting (see Fig. 3) (CNN, 2012). As a result of the close proximity of production to the consumer, and the small amount of energy and water used to grow the vegetables, the Sky Greens VGS emits lower CO_2 emissions than conventional production and transportation (CNN, 2012). Urban farming is also seen as an environmentally friendly method for agriculture and farming, as vertically-farmed vegetables do not require pesticides, have a shorter production rate, with more than 90% of the water used is recycled (McKirdy, 2016). SPREAD Co. Ltd., a company based in Kyoto, Japan aimed at sustainable farming, produces 21,000 heads of lettuce daily (see Fig. 4) and approximately 7.7 million annually (McKirdy, 2016).

Another type of VGS is the green wall, which can be classified by green facades and living walls. Green facades consist of climbing plants or plants attached directly to the building walls or installed using cables or trellis (Timur and Karaca, 2013). Green facades can be further categorized into traditional green facades, double-skin green façade or green curtain and perimeter flower pots, whereas living walls can be further categorized into bio-filtration living wall or modular living wall (Wang et al., 2016). Living walls are developed using a continuous or modular system equipped with growth media and irrigation systems (Timur and Karaca, 2013). Living walls provide more options for plant choices and are more suitable for high-rise buildings as it can be applied up to top floors, unlike green walls (Charoenkit and Yiemwattana, 2016). The types of plants used will influence the type of VGS system, for example, VGS based on shrubs require high gravity support as it consists of components such as heavy irrigation system, structural frame, containers, substrate and plants itself. Due to this factor, not all types of walls are suitable for the shrub based green walls. In contrast, climbers based VGS can be applied to most walls as the total system carries less weight. However, VGS based on shrubs produces a high density of coverage than climbers (Jim, 2015).

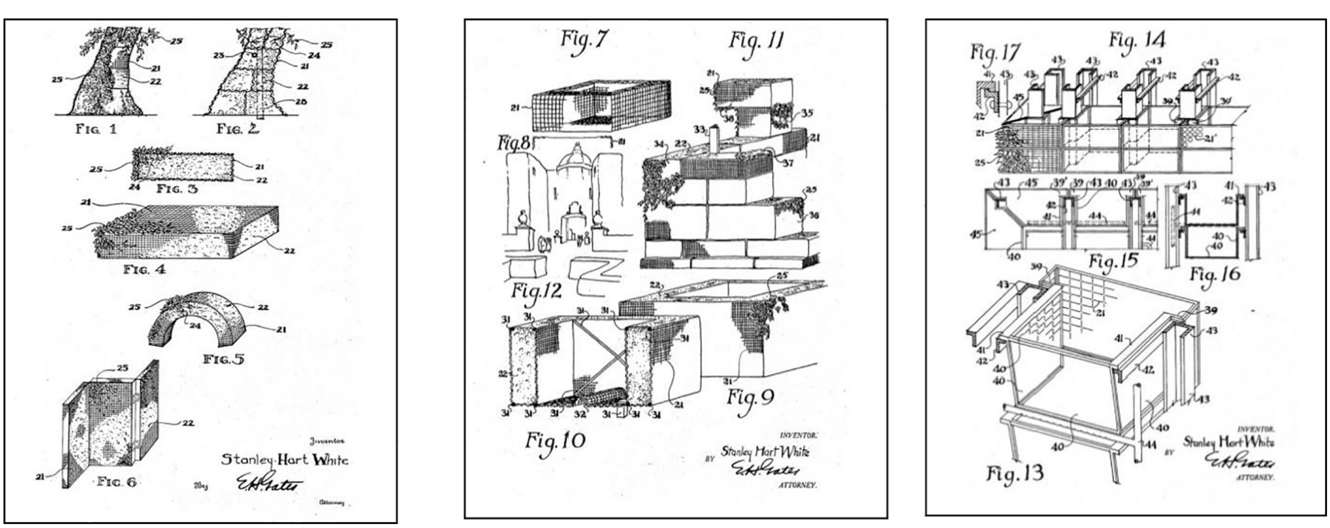

Fig. 2. The Vegetation-Bearing Architectonic Structure and System (1938) by Stanley Hart White (Hindle, 2012).