

Sustainability and Maintainability of High Rise Vertical Greenery Systems (VGS): its Lessons and Assessment Scoresheet

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Abstract. *Vertical Greenery Systems (VGS) applied on building has proven economic, environmental and social benefits which made it one of the widely accepted green building design strategies to support sustainable development. However, incorporating vertical greenery systems into innovative facades generates maintainability challenges. This paper highlights the best and good practices Design for Maintainability scoresheet, as well as the VGS defects and issues. The Design for Maintainability (DfM) assessment scoresheet will be beneficial in assessing and avoiding potential VGS defects leading to its maximum performance, longevity and sustainability. This research has established a list of best practice guidelines and measures with weighted scoring system for evaluating the maximum performance and efficient maintainability of VGS applications on facades while minimizing cost, risks, negative environmental impacts and consumption of matter/energy. The paper's contribution will be the improvement of the designers' decision making process, expanded library on vertical greenery systems defects as well as the importance of integrating maintainability of high-rise VGS facades in tropical conditions during its design inception.*

Keywords: *Building Maintainability, Green Building Technologies, Multi-Criteria Decision Assessment, Vertical Greenery Systems (VGS), Singapore.*

1 Introduction

Vertical Greenery Systems (VGS) applied on building has proven economic, environmental and social benefits (Chew and Conejos, 2016; Perini *et al.*, 2017) which made it one of the widely accepted green building design strategies to support sustainable development. However, incorporating vertical greenery systems into innovative facades generates maintainability challenges such as spoilt or falling leaves (Wong *et al.*, 2010), defective irrigation systems and inadequate installation methods which surges costs on operations and maintenance (Safikhani *et al.*, 2014), damaged surfaces due to plant roots infiltrating cracks (Manso and Castro-Gomes, 2015), lack/insufficient maintenance access (Behm and Poh, 2012; Köhler, 2008; Perini and Rosasco, 2013; Pérez *et al.*, 2014).

Chew and Conejos (2016) reports that less research has been undertaken concerning the maintainability of VGSs in tropical settings via design-based values, since this entails the vertical greenery system's sustainability (Emilsson, *et al.*, 2007). There is a need for the development of guidelines for VGS sustainability (Dvorak and Volder, 2010; Giordano *et al.*, 2017) which prompted the development of the Design for Maintainability guidelines for high rise vertical greenery systems in the tropics by Chew *et al.* (2019).

Chew and Conejos (2016) highlights various vertical greenery systems defects and issues in

Singapore and categorize them into technical and environmental defects based on previous research study and continually establishes more evidenced based issues and defects through qualitative approaches in this study in order to ascertain best practices as basis for a Design for Maintainability scoresheet in support for the design decision tool developed to assess the performance of vertical greenery systems.

2 Green Maintainability

The Green Maintainability concept (Chew, 2016; Conejos *et al.*, 2019) was established with the five green maintainability factors which incorporated facility management with sustainability right at the outset; such as: (1) maximizing performance – refers to the optimal competence of the building’s function through design values, building science and engineering, efficient energy use and sustainability; (2) minimizing cost – pertains to the decrease in operations and maintenance costs and boosting savings throughout the entire building lifespan; (3) minimizing risk – denotes to the reduction of possible building defects occurrences and risks in the future; (4) minimizing negative environmental impact – concerns in the decrease of potential damaging effects caused by the discharge of a substance in the environment; and (5) minimizing consumption of matter and energy – indicates the conservation and management of the building’s material, water and energy usage.

3 Research Methods

a) Qualitative Approach - The application of instrumental case study stipulates a comprehensive and in-depth interpretation of the cases, thereby in improving a theory (Stake, 1995), thus this approach was undertaken in the study to determine and establish evidence-based defects of high rise vertical greenery systems in the tropics. The selected instrumental case studies (Table 1) are physically accessible for field observation surveys and a wealth of recent data is on hand. The five green maintainability factors are used qualitatively in assessing the case studies’ vertical greenery systems green maintainability potential via field observation survey and interview with expert and supported by stakeholders’ via walkthrough interviews. b) Quantitative Approach – To provide an assessment scoresheet, a survey was conducted among practitioners and experts involved in designing and installing green facades. The Analytical Hierarchy Process (AHP) which is proven robust (Saaty, 1980) was used in analyzing the coded survey data in excel format.

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Table 1. Instrumental Case Studies.

Case Study (Year completed) and Awards Received	Vertical Greenery System (and Implementation)	Height
CS01 Commercial Bldg. (2014) BCA Green Mark Platinum Award	Support type system (Steel structure and high tensile steel cables)	5 storeys (M)
CS02 Mixed-use development (2016) BCA Green Mark Platinum Award	Support type system (Aluminum mesh)	30 storeys
CS03 Educational Bldg. A (2012) BCA UD Marks Platinum Award	Cassette system (Cassette)	6 storeys (M)
CS04 Educational Bldg. B (2015) BCA UD Marks Gold Plus Award	Support type system (Steel mesh)	11 storeys (M; S)
CS05 Educational Bldg. C (2013) BCA Green Mark Platinum Award	Support type system (Steel mesh)	7 storeys (M)
CS06 Residential Condo A (2015) BCA Green Mark Platinum Award	Cassette and planter box type systems (Tray)	22 storeys
CS07 Residential Condo B (2012) BCA Green Mark Platinum Award	Wire trellis support and planter box systems (Steel mesh)	25 storeys (S)
CS08 Residential Condo C (2013) BCA Green Mark Platinum Award	Support type system (Steel mesh)	24 storeys
CS09 Residential Condo D (2011) BCA Green Mark Gold Award	Support type system (High tensile steel cables)	6 storeys (M)
CS10 Residential Condo E (2014) BCA Green Mark Gold Award	Support type system (High tensile steel cables)	34 storeys (S)
CS11 Residential Condo F (2014) BCA Green Mark Platinum Award	Pocket type system (Substrate panel)	6 storeys

Source: Conejos et al. (2019).

4 Discussion of Findings

The identified critical high rise vertical greenery systems defects are due to lack of coordination among professionals lack of/insufficient coordination among building professionals which sometimes led to design oversights or inconsistencies. The following critical defects are:

- Lack of maintenance considerations such as insufficient/lack of maintenance access and safety issues/risks during cleaning and repairs. In some case studies, workers have to get through private balconies, pump rooms and air-conditioning units; climb over pool, parapet or glass enclosure; pass through pillars and traverse into narrow corridors that inhibits bulky maintenance equipment.
- VGS installation at the pool deck or over it which required frequent cleaning to preserve water quality.
- Lack/improper drainage system due to flat gradient or no screeding or lacking drains which causes water stagnation/ponding that will lead to pest infestation, mosquito breeding and algae/mould growth. In some instances, the drainage gutter has chokage issues due to falling leaves leading to water stagnation and possible mosquito breeding that will affect the health of residents and the public.
- Issues concerning infrequent/improper maintenance regimes due to the evident fallen leaves and dirt accumulation caused by heavy rainfall and strong winds. In some cases, the vines on the steel cable have thickened putting additional load to the support as it was not pruned or well maintained.
- Withering plants due to the suitability of plant species where in some cases where non-

tropical plants were installed which led to the drying and dying of plant species. The wrong choice of plant species can be considered a design oversight.

- Poor/faulty irrigation and water dripping issues caused by chokage or faulty components will lead to irregular plant growth or plants dying, rust of structural components, and high water consumption costs.
- Insufficient sunlight exposure also prevents plant growth and lead to plant dying or premature plant replacement regardless of proper irrigation regimes.
- Issues on maintenance cost (i.e. LCC) which entails a high cost of expenses when maintaining defective VGS.



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Figure 1. Some Defects of Vertical Greenery Systems.
(Source: Chew and Conejos, 2016).

5 Design for Maintainability (DfM) Scoresheet

In previous research studies, the *Design for Maintainability (DfM)* guidelines (Chew *et al.* 2019) and checklist (Conejos, *et al.* 2019) for vertical greenery systems has been established. In this study, the checklist is further developed into a graded scoring system which will assess

the vertical greenery systems' total performance according to the five green maintainability factors. The DfM scoresheet for high rise vertical greenery systems, highlights fourteen (14) design criteria with corresponding DfM good practice measures/guidelines and corresponding percentage scores with a total score of 100% when summed up (Table 2). The design criteria are grouped under the five green maintainability factors with corresponding percentages that totaled to 100% such as (1) maximizing performance – 21.47%; (2) minimizing cost – 17.45%; (3) minimizing risk – 30.81%; (4) minimizing negative environmental impact – 13.85%; and (5) minimizing consumption of matter and energy – 16.42%. Each design criterion is equally distributed according to the scoring percentage of each green maintainability factor. Based on the practitioner and expert survey results, the most critical green maintainability factor to be considered is minimizing risk which pertains to safety measures including fire safety and quality workmanship.

The importance of considering the green maintainability of a building throughout its life cycle will improve the sustainability and performance of high-rise vertical greenery systems in the tropics. The proposed checklist may aid in addressing the maximum performance and efficient maintainability of VGS applications on facades while minimizing cost, risks, negative environmental impacts and consumption of matter/energy.

6 Conclusions

This research has shown that considering maintainability right at the design inception is of great importance. Designing vertical greenery systems that are highly performing and easy to maintain guarantees long term sustainability. This paper highlights the evidence based defects and issues of vertical greenery systems under tropical conditions and through ascertaining best and good practices has introduced a set of Design for Maintainability (DfM) guidelines translated into a weighted scoresheet for assessment. The development of the Design for Maintainability (DfM) scoresheet for VGS is a valuable method in assessing the sustainability and maintainability potential of high-rise vertical greenery systems. The best practices and evidence based defects derived from these case studies and stakeholder insights will be useful in improving the decision making process for designers when it comes to the choice and design of VGS, as well as the expansion of the vertical greenery defects library. Lastly, one of the most important goals of VGS implementation is to promote a biophilic environment within high density areas as well as support climate change adaptation through the greening of the built environment.

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Table 2. Design for Maintainability (DfM) Scoresheet for High Rise VGS.

Name of Building and Location:				
Building Profile:				
Instructions: Please refer to the following Guide Statements when assessing the Vertical Greenery Systems applied to high rise building. The scoring system is categorized according to the five green maintainability factors with a corresponding total percentage at the leftmost column as reference. The Ranking result will be: Level 1 – 0% to 40% indicates low maintainability potential; Level 2 – 41% to 60% indicates adequate maintainability potential; and Level 3 – 61 to 100% indicates high maintainability potential.				
Design Categories	Design Criteria	Good Practice Measures (incl. standards/guidelines/expert sources)	(√)	(%)
Maximising performance	Climatic conditions	Availability of natural elements	Consider the proper orientation of the VGS, as well as the areas with strong winds due to location of the building itself or the placement of VGS on higher altitudes. Provide sufficient soil depth for the roots to grow more freely (i.e. planter box size of 500w x 600d with enough soil).	21.47
		Consider alternative approaches such as hydroponics, light soil in skyrise greenery, as well as artificial lighting system to address insufficient sunlight exposure on VGS.		
	Design considerations	Green wall systems	Consider VGS height, system capacity, lifespan and its replaceability.	
		Plant suitability and sustainability	Specify the right plant species (e.g. native plants which are adapted to the local climate; plant appropriately for sunny/ shady areas, wet grounds, high traffic areas, etc.), as well as ensure that it considers the maintenance frequencies and cost issues.	
			Avoid selecting plant species with excessive shedding of leaves and do not use some plant species (e.g. species of bromeliad, alocasia) that trap water and will require regular monitoring for signs of mosquito breeding.	
	Coordination among professions	Recommend more than one species to ensure even coverage and ensure the correct plant spacing for the desired plant coverage.		
Structural stability and material durability	Structural stability	Ensure that all involved stakeholders; design and construction professionals involved in the project are properly informed and involved in every decision making from the design, construction, operations and maintenance aspects/process.		
	Material durability	Structural integrity of the green wall system should be certified by a professional structural engineer. Design the structure with a 1.5x safety factor. Consider climber plants for high-rise VGS, as it can grow from ground level to the 10th storey.		
Maintenance considerations	Life cycle cost	Specify the use of quality materials (i.e. durable and stain-resistant materials) and ensure that the material selection considers the maintenance frequencies and cost issues.		
	Maintenance Access	LCC considerations include capital cost, ownership cost, operating cost and disposal cost.		
Minimising cost		Provide easy and safe maintenance access (i.e. access via the front of green wall and access system considerations pertaining to the type, coverage, number of access provided to all facade areas at every level. Each maintenance walkway level should have direct access to the building's permanent stairs core to ease worker movement during normal operations and emergencies. All designated access/inspection points should be marked and identified. Provide proper maintenance access such as footpath leading to the tap. The greenery cascading down should not be encroaching a currently-owned space or directly under a water features. No unmaintained vegetation over private spaces.	17.45	
		Provide permanent rear access and workspace (e.g. walkways and platforms) alongside the elevated greenery surfaces, allowing safe maintenance access to all parts of the green wall. The rear access must be designed with edge protection to prevent worker falling out during maintenance. The maintenance walkway should have a minimum 600mm internal clearance width. Access should be designed via passive means as much as possible, not only to reduce reliance on BMUs and other equipment required to facilitate accessibility but also to reduce instances of inconvenience to building inhabitants.		
	For green wall no more than 2m in height, allow maintenance access from the front via suitable elevated work platform (e.g. ladder stand platform, tower scaffold, etc.), pole pruner and/or a combination of these equipment. For green wall more than 2m in height, provide a flat stable landing surface of adequate loading capacity in-front to allow safe and effective deployment of suitable elevated work platform and equipment. Also, provide a flat hard paved foreground landing with adequate load bearing capacity for safe deployment of elevated work platform such as MEWPs (mobile elevated work platforms). While, for green wall more than 4m in height, the foreground when turfed/vegetated, should be designed, dimensioned and installed with suitable supporting underlayers to provide adequate load bearing capacity for safe and effective deployment of MEWPs. Structural elements should not be covered by VGS for easy periodic inspection.			
	Frequency of Inspection and Maintenance	Put in place a regular maintenance schedule conducted by qualified workers to look out for potential risks, hazards and problems. Conduct periodic inspections of supporting structures to ensure that structural integrity is maintained. Perform visual inspection for structural corrosion, etc. Routinely monitor plant growth for plants' health status (i.e. pruning and ensure proper soil and irrigation, prevent unlikely planter bursting/ damage due to overwatering and root growth). Install pre-planted panels safely and ensure quality workmanship. Provide a growing medium that is dense to sustain chosen plants and to provide the proper nutrient needs. Follow and maintain a three-month pre-planting period for plant replacement so that plants will not die from shock.		
Drainage system	Drainage system management (e.g. gradient and water ponding)	Conform to BS 4428:1989 for proper drainage layout and system of landscape areas and ensure that planters should be on a gradient that directs excess water towards the drain. Specify drains adjacent to planters at the base of the VGS. Drain gradient should be in the range of 1:300 to 1:200 to avoid water stagnation. Consider using drainage trays at the base of the installation and provide metal drain covers. The width: depth ratio of drain should not be less than 1:2 so as to		

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			<p>facilitate ease of access. Provide anchor points or ladders to facilitate safety and access to drains and supporting system parts, for periodic inspection and maintenance.</p> <p>Drainage systems require regular maintenance and fixtures should be checked visually on a regular basis and thoroughly cleaned annually (BS 7370-5:1998). Test to ensure that during and after installation, the drainage systems effectively convey water to the storm water drainage system at ground level. Inspect systems, especially modular systems, for water ponding due to clogged drainage holes which allow mosquito breeding.</p>			
Minimising risk	Installation and maintenance methods	Safety measures (incl. fire safety and quality of workmanship)	<p>Safety and maintenance concerns must be thought of and addressed early during the design stage. Adhere to the Workplace Safety and Health Act concerning the safe design, construction and maintenance of scaffolding, working platforms and gondolas (BS 6150:2006+ A1: 2014, SS 542:2008). Maintain construction quality control during the installation of green wall components, installation of fixtures and fittings and vegetation planting. Installation of VGS should be performed by registered and specially trained workers to ensure quality workmanship. Ensure quality control during the installation of green wall components, fixtures and fittings.</p>	30.81		
			<p>Adequate site supervision should be performed to make sure that workers understand and comply with the established safe work procedures, safety rules and work methods, including the proper usage of all personal protective equipment provided to avoid fall from heights and falling objects. Use scaffoldings as per SS CP 14:1996 and ensure the proper supervision of workers at heights. Implement a comprehensive safety plan for working on the facade (e.g. fall prevention fall prevention systems and personal fall arrest, and a permit-to-work system. Ensure that maintenance personnel know the proper usage of fall protection systems (BS EN 363:2008). Conform to ASME A120.1-2014 for the safe use of permanently installed building maintenance units for facade maintenance.</p>			
			<p>Considerations for fire-rated VGS materials to be specified as per SCDF requirements. Specify fire-rated VGS materials as per SCDF requirements. Provide a sufficient buffer between VGS and facade openings (e.g. balconies, windows) to prevent fire encroachment into interior spaces and reduce the chances of biomass which contributes to fire risk. Ensure that chances of biomass contributing to fire risk should be reduced and kept at a distance.</p>			
Minimising negative environmental impact	Biological growth and animal management control	Algae and mould prevention	<p>Choose plants that do not trap water and harbour pests and disease pathogens. During and after installation, prevent any biological growth (e.g. mosses, lichens, algae) as much as possible. When necessary and not on regular basis, treat such growth with anti-algae/anti-fungus solutions. Remove mould, lichen and other growths with a stiff brush.</p>	13.85		
			<p>Planters or modules should be designed to be sufficiently deep to contain the spread of roots. Roots should be contained within planters/pockets to prevent encroaching onto building's facade walls. Keep the plants away from the building's walls by having a gap in between the wall and the VGS. Conduct periodic inspections to ensure that root growth are controlled to avoid penetration on walls. Waterproofing system at landscaped areas and planters should be designed and installed by root resistant and/or alongside a suitable root barrier. Ensure good housekeeping practices and control root growth to prevent damage of waterproofing membrane.</p>			
			<p>Pest and bird nesting control</p> <p>Inspect systems, especially modular systems, for water ponding due to clogged drainage holes which allow mosquito breeding. Scope of works by maintenance contractors should include looking out for mosquito breeding sites (e.g. instances of water ponding) near VGS. Plants suspected of harbouring pests and disease pathogens should not be introduced into any new or existing planting areas, as eradication of pests and pathogens once established will be difficult. Choose plants that do not trap water and harbour pests and disease pathogens. Inspect plants periodically for pest infestation and disease infection. Do not use pesticides and fungicides to prevent them from contaminating run-offs and eventually the groundwater. Fertilizers and insecticides should be approved by the Agra-Food & Veterinary Authority of Singapore.</p> <p>Conduct periodic inspections to ensure that branches have not thickened to avoid bird nesting. Conduct annual or semi-annual inspections to control or prevent bird interaction with VGS for plant survival.</p>			
Minimising consumption of matter and energy	Water and irrigation and electrical and lighting systems	Water and energy efficiency	<p>Specify a drip-based irrigation system complete with built-in rainwater harvesting and recycled water to minimise water consumption. Consider the use of automatic-irrigation system with rain sensor. Recommend the use of an adjustable automated irrigation system based on weather conditions to reduce amount of water. Energy efficiency considerations should include material selection, testing, fixing/ mounting/ installation methods.</p>	16.42		
Total Score					100.00	

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