

David Kim Hin Ho

GREENING THE URBAN HABITAT

A Quantitative and
Empirical Approach

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David Kim Hin Ho

University of Hertfordshire, UK & National University of Singapore

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Preface

“Over 100 years ago, this was a mud-flat, swamp. Today, this is a modern city. Ten years from now, this will be a metropolis. Never fear.” (PM Lee Kuan Yew, 1965)

This book introduces the Singapore Green Plot Ratio (GnPR) as an urban planning metric to promote the use of greenery for new and existing buildings in Singapore, with further potential application in other contemporary cities.

Increasing urban greenery enhances the quality of our built environment. Since independence in 1965, through the vision of its founder, Mr Lee Kuan Yew, Singapore has been transformed from a third world city into one of the world’s most liveable metropolises. Today, Singaporeans are privileged to live in a Garden City which is being transformed into a City in a Garden.

According to the National Parks Board (NParks), over the decades, flowering species have been introduced to make our streetscape more vibrant. The pervasive green network of nature reserves, parks, park connectors, tree-lined roads and other natural areas has made living in the city more pleasant. Efforts to conserve the nation’s natural heritage have seen four areas gazetted as nature reserves as well as an increase in wildlife.¹

¹www.nparks.gov.sg [2017]. As Singapore continues to evolve into a City in a Garden, NParks has identified six key areas to guide national efforts towards

The GnPR promotes the enhanced provision of urban greenery in both new and existing buildings. Trees and shrubs not only reduce the energy needed to keep buildings cool but also cleanse and refresh the air we breathe. Urban greenery plays an important role in promoting health and well-being, such as for the mental and emotional growth of both children and adults (Kua & Sia, 2016; Barton & Rogerson, 2017). Urban greenery has even been associated with reducing crime rates (Wolfe & Mennis, 2012). While it is essential that the GnPR retains its original integrity as an urban complement of the LAI, several advantages exist for deploying GnPR in the Singapore Building Construction Authority (BCA)'s Green Mark allocation policy for greenery provision. The argument for urban greenery primarily lies not so much with energy savings but with social sustainability. There is growing support for the argument that greenery adds to real estate value and rental yields. Consequently, this book looks at achievable LAI values and their installation costs for specific plant types, differentiating between plant categories rather than plant species.

This book discusses the GnPR and how it can be used by urban planners and architects for both new and existing developments. Chapter 1 discusses the concept of the Singapore Green Plot Ratio; Chapter 2 provides a survey of international best practices of urban greenery for various land-use types; Chapter 3 suggests various strategies that urban planners and architects can adopt to enhance the provision of urban greenery in new and existing developments; Chapter 4 provides guidance on the capital and maintenance costs for various levels of urban greenery provision and Chapter 5 looks at the way ahead for further enhancements to the GnPR concept.

fulfilling this vision: (1) Engaging and inspiring communities to co-create a greener Singapore; (2) Enhancing competencies of our landscape and horticulture industry; (3) Enriching biodiversity in our urban environment; (4) Establishing world-class gardens; (5) Optimising urban spaces for greenery and recreation; and (6) Rejuvenating urban parks and enliven streetscape.

In its application, GnPR is an urban complement of the leaf area ratio (LAI) concept. Achievable LAI values and the installation costs for specific plant types suggest that urban planners and architects should differentiate using plant categories rather than plant species. Advantages exist for larger plants over the smaller and perhaps faster growing plants. For biodiversity, larger plants are more desirable than smaller ones. In the near future, a new and overall weighted greenery measure, comprising guidelines for providing urban greenery in both new and existing buildings as well as urban landscapes, could further enhance the environmental sustainability of Singapore.

Happy reading,

HO, Kim Hin/David

23 September 2019

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About the Author



Dr HO Kim Hin / David is Honorary Professor in Development Economics and Land Economy, awarded by the University of Hertfordshire, UK. He retired from the National University of Singapore as Tenured Associate Professor end-May 2019. Professor HO spent the last thirty-one years across several sectors, including the military, oil refining, aerospace engineering, public housing, resettlement, land acquisition, land reclamation, real estate investment and development as well as international real estate investing. He spent six years in the real estate industry as part of the executive management group of Singapore Technologies at Pidemco Land Limited, and as part of the senior management team of the Government of Singapore Investment Corporation's GIC Real Estate Private Limited. Seventeen years have been spent in the National University of Singapore at the then School of Building and Estate Management as well as the Department of Real Estate, School of Design and Environment, where his research expertise lay in two subjects: (1) international real estate, in the area of risk behavior behind international real estate investing for both direct and indirect real estate; and (2) urban and public policy analysis involving real estate, sea transport, public housing, land and land use. Schooled in development economics and in land economy at the University of Cambridge, England, he has effectively extended these disciplines to so

examine the two subjects. Apart from being well versed in econometrics, his quantitative interests include financial economics, artificial intelligent modeling in real estate, and system dynamics modeling for real estate market analysis as well as for public policy analysis. He is the Member of the Royal Economics Society (UK), Academic Member of the National Council of Real Estate Investment Fiduciaries (USA), Fellow of the American Real Estate Society (USA), member of the American Economic Association (USA), and member of the Economic Society of Singapore and the Singapore Institute of Management. He holds the degrees of Master of Philosophy (1st Class Honors with Distinction), Honorary Doctor of Letters and the Doctor of Philosophy from the University of Cambridge, UK. He has published widely in top international journals and conferences, and in chapters of books by international academic book publishers. Dr Ho has written 6 major books (including this book) and undertaken many consultancies and funded research projects. He has written a total of about 273 published works (with 90 in peer-reviewed, reputable international journals). He is an editorial board member of the *Journal of Property Research*, *Property Management* and *International Journal of Strategic Property Management*. He is an immediate past Governor of the St Gabriel's Foundation, Singapore, that oversees nine schools in Singapore; and a District Judge equivalent member of the Valuation Review Board of Ministry of Finance, Singapore and the Singapore Courts.

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Introduction

Owing to land scarcity and in spite of real estate development pressures, both nature conservation and greenery replacement are vital considerations for urban planning and architecture in Singapore. The provision of urban greenery in Singapore is a key priority in its physical development, which can be traced back to the period, when Singapore has been subject to rapid industrialisation and urbanisation. The 1968 ‘Garden City’ approach is the vision set by the Singapore government to integrate urban greenery with new real estate developments that influenced subsequent environmental policies.

Over the years, innovative concepts and strategies for environmental sustainability have been introduced under the Singapore Green Plan (1992), which was first reviewed in 1999, before a second revision which brought about the new Singapore Green Plan 2012 (MEWR, 2019). Green initiatives, such as Landscaping for Urban Spaces and High-Rises (LUSH) Programme (URA, 2009), the NParks (National Parks Board) Skyrise Greenery Award (2011) (NParks, 2019) and the Scheme for Green Roofs (2009) (NParks, 2019), all seek to encourage building owners to retrofit existing buildings with green features and to provide space for greenery in new real estate developments. Although 95% of Singapore’s natural forest no longer exists, careful and comprehensive planning has helped to expand the country’s green cover, through parks and green connectors, from 36% in 1986 to 47% in 2007 (NParks, 2008).

Skyrise greenery, such as planting gardens on the rooftop or down the walls, is another strategy that can be used to increase greenery provision for both new and existing developments, particularly in Singapore. Despite assumptions that rooftop gardens are elaborate and require special roofs to bear the weight, modern green roof technologies are lightweight and require minimum maintenance. A variety of local and overseas systems has been widely studied to measure the environmental benefits they provide in dense urban areas, such as the reduction of the urban heat island effect, increased biodiversity, the thermal insulation and energy savings they provide through the reduction of the buildings' cooling loads or the improvement of air quality by trapping airborne dust particles, and the reduction of rainwater flow through soil and vegetation. Although skyrise greenery has become a popular design feature in high-density urban areas such as Singapore, skyrise greenery has yet to be regulated and implemented on an extensive planning scale. The 'Green Plot Ratio (GnPR)' offers one way of promoting the use of skyrise greenery.

Green Plot Ratio (GnPR) — Definition and Calculation

In Singapore, the intensity of real estate development has been controlled through the gross plot ratio (GPR), an urban planning concept which seeks to determine the maximum allowable gross floor area (GFA) to be provided in a new real estate development. GPR is defined as

$$\text{GPR} = \frac{\text{gross floor area}}{\text{site area}}$$

The 'Green Plot Ratio (GnPR)', though conceptually similar to GPR, is designed to take this one step further. An original concept introduced by Dr ONG Boon Lay and further developed by Prof (Dr) HO Kim Hin / David, both formerly of the National University of Singapore (NUS) and its School of Design & Environment (SDE), GnPR allows for a

three-dimensional quantification of greenery present on a site through the use of a common scientific measure known as the 'Leaf Area Index (LAI)', whereas current greenery metrics are largely two-dimensional.

Originally defined as the 'average leaf area index (LAI) of the greenery of a site', LAI was proposed as an ecological measure that assigned values to particular plants, based on the surface area of greenery (Ong, 2003). The GnPR concept uses LAI as a calculation measure within its larger aim to quantify the amount of greenery required in new real estate developments to achieve planning targets for enhanced landscaping. Chapter 1 of this book discusses in detail the definition and algebraic expression of LAI and GnPR. The LAI values for different types of plants can be found in a guidebook, *Leaf Area Index of Tropical Plants*, by NParks (Tan & Sia, 2009). In the guidebook, plants are categorized by groups (such as trees, palms, shrubs, ground covers and turf) and sub-groups (canopy density for trees, canopy type for palms, and structure for shrubs). To calculate the GnPR of a real estate development, the types of plants and canopy type, the number of trees, the area of turf and shrubs, should all be identified.

Hence, given the improved precision in greenery quantification, the GnPR is a unique and enhanced tool for greenery accounting. Several land-use agencies have begun to explore the use of GnPR, including the Jurong Town Corporation (JTC), the Housing & Development Board (HDB) and the Building & Construction Authority (BCA). Chapter 1 also illustrates a sample calculation of the GnPR for a typical building with a site area of 4000 sqm, landscaped with 2 dense trees, 3 trees with open canopy, 11 solitary palms and covered by 20 sqm of dicot shrubs, with 1,500 sqm of turf.

A Small-Scale Pilot Study

In order to evaluate the feasibility and specify the parameters of the GnPR for real estate development control, DP Architects (Singapore) Pte Ltd was appointed as consultant to carry out a small-scale pilot study from 2008 to 2009. This pilot study involved the analysis of greenery provision

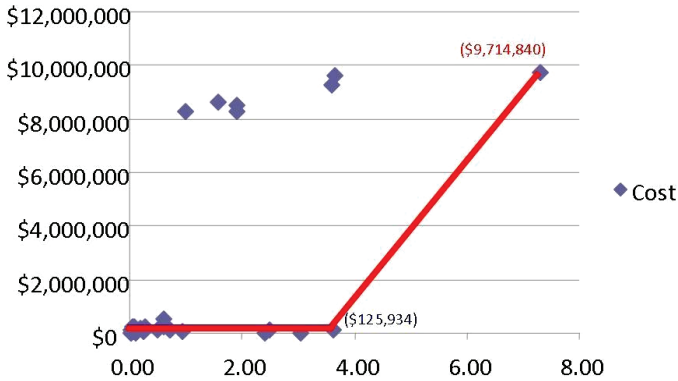


Fig. 0.1. The cost profile figure of construction cost (in S\$) vs. the proposed GnPR
Source: Ho, KHD & Ong BY (NUS/SDE) (2015, 2018); DP architects (Singapore) Pte Ltd (2009)

in a newly completed industrial building, the “Technopreneur Centre”, at 20 Ayer Rajah Road, Singapore. The following conclusions were duly noted after the evaluation of various greenery scenarios to enhance the existing greenery:

- (1) It is observed that the highest GnPR with the lowest installation cost can be achieved by planting trees on the ground level.
- (2) The pilot study explores various landscaping scenarios for the building, ranging from 2% to 10% of the total building construction cost. The results show that the GnPR of up to 4.0 is achievable with an installation cost of approximately S\$125,000 (2%), and that the GnPR of 7.0 is achievable at a cost of S\$9.4 million. The corresponding cost profile is provided in Fig. 0.1.

Further GnPR Research

After the small-scale pilot study, the NUS-NParks joint research project was undertaken to develop landscape guidelines for the application of the ‘Green Plot Ratio (GnPR)’ concept in Singapore.¹

¹Funded through the Ministry of National Development (MND) Research Fund, the research project is a multi-agency collaboration between the National

The research project identifies three key knowledge gaps that hinder the widespread application of the GnPR concept:

- (1) Optimal levels of GnPR that are to be appropriate for various land-use types and these levels need to be benchmarked against the current levels of greenery provision.
- (2) GnPR only stipulates the greenery quantum but it can also encourage the concentration of some plants, especially our existing native trees; the planting of certain local species; and the development of ecological or natural landscapes over the manicured gardens.
- (3) Greenery provision comes with inevitable capital and maintenance costs. There is therefore the need to understand the impact of the various levels of GnPR provision with such costs, before the application of the GnPR guidelines.

An essential requisite of the research project is to understand the current state-of-the-art concerning the provision of urban greenery. Therefore, Chapter 3 of this book provides a comprehensive and in-depth review of the international best practices for urban greenery in new and existing buildings.

Chapter 4 discusses in detail the associated statistical analysis and the subsequent GnPR optimisation to evaluate the audit and the design scenario data. This chapter recommends the optimal GnPR level for

University of Singapore (NUS), the JTC Corporation (JTC), the Housing & Development Board (HDB) and the Urban Redevelopment Authority (URA). The research project is awarded by the Building & Construction Authority (BCA) in April 2008 to the National Parks Board (NParks) as the Lead Organization. The purpose of the research project is “To Develop Landscape Guidelines for the Application of Green Plot Ratio (GnPR) in Singapore”. The project formally commenced in July 2009 with Dr HO Kim Hin David, NUS, as Principal Investigator, and with the fieldwork support from architectural consultant Broadway Malyan (Singapore) Ltd, cost consultant Rider Levett Bucknall (Singapore) Ltd and structural consultant JS Tan & Associates (Singapore) Ltd.

four land uses and the 'Public Places' use via the study of key factors that influence the GnPR level and the Marginal Cost (MC) analysis model. The 'Optimal GnPR (Design and Economic)' is defined to be a range, with low and top boundaries, for each land use.

Finally, Chapter 5 provides the conclusions that complete the potential landscape guidelines for the application of the optimal GnPR levels to facilitate sustainable land scape development in Singapore. Such guidelines provide the environmental, economic, aesthetic and social benefits of greenery for urban built-up areas. These guidelines illustrate greenery possibilities for real estate assets, e.g. a building, while taking into consideration its installation and maintenance costs.

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The Singapore Ministry of National Development Research Fund (MNDRF) for the built environment was awarded to Singapore's Building and Construction Authority (BCA) on 9 July 2009, to commission the National University of Singapore (NUS) as principal investigator and the National Parks Board (NParks) as lead organisation, to look closely at the green plot ratio (GnPR) in Singapore. Fieldwork support was sourced from the architectural consultant Broadway Malyan (Singapore) Ltd., the cost consultant Rider Levett Bucknall (Singapore) Ltd. and the structural consultant JS Tan & Associates (Singapore) Ltd., in the period from 11 July 2011 to 11 July 2012.

The GnPR was developed by Dr ONG Boon Lay to guide the provision of greenery in urban settings. GnPR is a step up from the gross plot ratio (GPR) currently deployed in Singapore to measure the development intensity of a building. The key difference between GnPR and current greenery metrics is that GnPR allows for a three-dimensional quantification of the greenery present on a site through the deployment of a common scientific measure known as the leaf area index (LAI). In comparison, current greenery metrics are largely two-dimensional. Given the improved precision in greenery quantification, GnPR seeks to be an enhanced greenery accounting tool. Several land use agencies are currently exploring the adoption of GnPR, including the Jurong Town Corporation (JTC), the Housing & Development Board (HDB) and BCA.

This book is undertaken in recognition of the presence of key knowledge gaps that prevent the widespread application of GnPR. These knowledge gaps were presented in the introduction as:

1. The need for the Optimal GnPR levels appropriate for the various land use types to be benchmarked against current levels of greenery provision.
2. That GnPR not only stipulates the greenery quantum but also encourages the concentration of some plants — especially existing native trees — the planting of certain local species, and the development of ecological or natural landscapes over manicured gardens.
3. That greenery provision comes with the inevitable installation capital and maintenance costs. There is therefore a need to understand the impact of the various GnPR provision levels (with such costs taken into consideration) prior to determining the GnPR implementation guidelines.

This book is multi-faceted in nature, comprising several stages. It has two specific objectives:

- To identify the impact of various greenery provision levels on their installation capital and maintenance costs;
- To give potential recommendations and guidelines for the implementation of optimal GnPR levels, within an urban design framework to facilitate a sustainable landscape for Singapore.

The book's survey fieldwork commenced in March 2010, spanning over one year and nine months and mainly involved two key stages:

1. Consultancy stage: where a building audit was used to determine the GnPR of 100 existing buildings in Singapore, based on current greenery provisions and desktop simulation studies to increase

GnPR, within an urban design framework, and with respect to installation cost, maintenance costs and structural limitations.

2. Statistical analysis report stage: where optimal GnPR levels for the major land use types were established on the basis of sound statistical analytical models.

No equivalent research similar to the multi-faceted complexity of this book's study has been undertaken elsewhere. The book details the rigorous setting up of the optimal GnPR levels and of more precisely regulating greenery provision within a direct real estate development in Singapore. The book could be a significant contributor to landscape architecture, urban design and the urban planning disciplines. With the first section introducing the book, providing the background, the objectives, the strategic value and collaboration benefits, the subsequent sections discuss the book's research stages, its methodology and key findings at each stage.

The second section discusses GnPR as an imperative metric for quantifying Singapore's greenery, offering GnPR calculation examples and their corresponding design applications. The third section describes the building audit of 100 existing buildings spread across the commercial, industrial and residential land use types. The fifth section discusses the statistical analysis using a robust heuristic GnPR optimisation model, to derive the optimal GnPR values for various land use types. Finally, the sixth section comprehensively discusses the various requirements relating to greenery provision in conjunction with the potential landscape guidelines, summarising the book's key findings and highlighting the book's contributions and recommendations.

GnPR an Indicator of Greenery in Singapore

The importance of nature conservation and greenery replacement emerged owing to land scarcity in Singapore. Singapore's greenery provision has thus

been a key priority in the city's development and can be traced back to the period when the country was undergoing rapid industrialisation and urbanisation. The 1968 'Garden City' approach was a vision set by the government to integrate the environment with direct real estate development that influenced subsequent environmental policies. Over the years, sustainability-oriented concepts and strategies have been introduced under the Singapore Green Plan (introduced in 1992, reviewed in 1999 and 2012, and now known as SGP2012) (MEWR, 2006; MEWR, 2019) and through initiative-based programmes like the 'Landscaping for Urban Spaces and High-Rises (LUSH)' programme (URA, 2009), the NParks Skyrise Greenery Award (NParks, 2008; NParks, 2019) and the Green Roof Incentive Scheme (GRIS) (NParks, 2019; NParks, 2011), which aim to encourage building owners to retrofit existing buildings with green features and to provide greenery spaces in new developments. Even though 95 per cent of Singapore's natural forests have been lost, careful and comprehensive planning has expanded the city state's green cover from 36 per cent to 47 per cent between 1986 and 2007, in the form of parks and green connectors (NParks, 2008).

Urban skyrise greenery, like gardens on roof tops or along building walls, is a potential way to increase greenery provision. Despite assumptions that roof top gardens are elaborate and require special roofs to bear their weight, most modern green roof technologies are lightweight and require minimum maintenance. A variety of local and overseas systems have been studied to measure the environmental benefits in dense urban areas, like the reduction of the urban heat island effect, increased biodiversity, thermal insulation and energy savings by reducing a building's cooling load, or the improvement of air quality by trapping airborne dust particles, and the reduction of rainwater flow via the absorption and evaporation of rain from soil and vegetation. Although skyrise greenery in high-density urban areas is viewed as one of the most rapidly developing building features, it has yet to be regulated and implemented on an extensive planning scale.

As mentioned earlier, a primary objective of this book is to derive appropriate skyrise greenery levels for different building types, using the GnPR concept and metric to help quantify this.

GnPR Definition and Calculation

GnPR was originally defined as the LAI of the greenery of a site — an ecological measure that assigns values to particular plants based on the surface area of greenery (Ong B. L., 2003). The current definition by NParks states that GnPR is ‘the area weighted average leaf area index of a site’ (Tan & Sia, 2009). GnPR can be expressed as shown in Eq. (1.1):

$$\begin{aligned} \text{GnPR} &= \frac{\text{total leaf area}}{\text{site area}} \\ &= \frac{\sum \text{LAI}_1 \times \text{Canopy Area}_{1...} + \text{LAI}_n \times \text{Canopy Area}_n}{\text{Site Area}}, \quad (1.1) \end{aligned}$$

where LAI is a leaf area index defined as the one-sided area of leaf tissue per unit ground surface area. LAI values for different plant types can be found in *Leaf Area Index of Tropical Plants: A Guidebook on Its Use in the Calculation of Green Plot Ratio* (Tan & Sia, 2009), published by NParks. In the guidebook, plants are categorised into groups — trees, palms, shrubs, ground covers and turf — with sub-groups defined by canopy density (for trees), canopy type (for palms) and structure (for shrubs). To calculate the GnPR of a direct real estate development, the plant types and canopy type should be identified, as well as the number of trees and the areas of turf and shrubs.

An example of the simple calculation of the GnPR in a building lot with a site area of 4,000 sq. m. and landscaped with two dense trees, three trees with open canopies, 11 solitary palms, 20 sq. m. of dicot shrubs and 1,500 sq. m. of turf, is illustrated in Fig. 1.1 while the GnPR stepwise calculation is presented in Table 1.1.



Fig. 1.1. An example of the GnPR calculation of a direct real estate development
Source: Author (2018; Broadway Malyan Ltd, 2012)

Table 1.1. The GnPR stepwise calculation (from left to right)

Plant	Canopy type	Canopy area, sq. m. per unit (A)	LAI value (B)	Number of units (C)	Leaf area, A x B x C
Trees	Dense	60	4	2	480
	Intermediate	60	3	0	0
	Open	60	2.5	3	450
Palm	Solitary	20	2.5	11	550
	Cluster	17	4	0	0
Shrub	Dicotyledonous	1	3.5	0	0
	Monocotyledonous	1	4.5	20	90
Turf			2	1500	0
Total leaf area					1,570.0
Site area					4,000.0
Green Plot Ratio Leaf area/Site area					0.4

Source: Author, 2018; Broadway Malyan Ltd, 2012

Methodology

Over the years, sustainability-oriented concepts and policies like the LUSH programme, the International Skyrise Greenery Conference and the Skyrise Greenery awards, have been initiated by government agencies to encourage the greenery of built-up areas in Singapore. GnPR has been adopted by various government agencies and research groups as the greenery accounting tool linked to these greenery provision initiatives and their correlating environmental benefits. For example, the GnPR is deployed as the greenery provision measurement within a public or private non-residential development for the BCA Green Mark Building Award. Both HDB and JTC have also adopted GnPR as the accounting tool to quantify, plan and regulate the amount of greenery in housing and industrial estates. Several studies at NUS have adopted GnPR to study the relationship between the amount of greenery and the surface and ambient temperatures of a building, and between the amount of greenery and the overall high-density environment (Jones, 1992; Santamouris, 2001; Jusuf & Wong, 2009). However, the optimal GnPR level for the various land use types, as well as their installation and maintenance costs with respect to the various GnPR levels, have not been researched (Ong B., 1996; Ong B., 1999; Ong B. L., 2003; Ong, Ho, & Ho, 2012; Whitford, Ennos, & Handley, 2001; Yang & Ong, 2004). Therefore, this book seeks to ascertain the achievable GnPR values which can be incorporated for various building types via a series of design simulations and the statistical analysis of the resulting output data of the simulations.

Stage 1: The best landscaping technologies, practices and the kit of parts

Stage 1 comprises a comprehensive review of the existing greening and landscaping technologies and practices in Singapore and worldwide. The review establishes the broad planting strategies of greenery provision within a direct real estate development, as illustrated in Fig. 1.2 and outlined in Table 1.2.

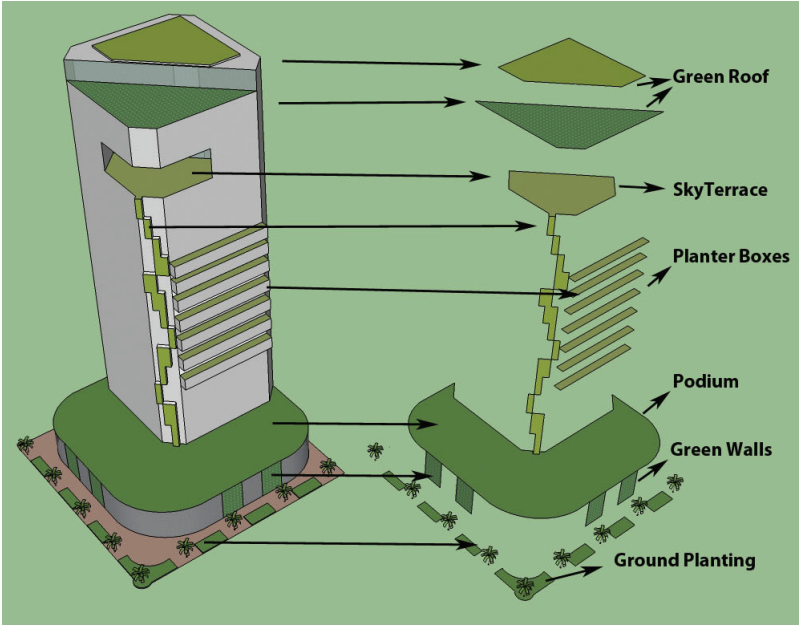


Fig. 1.2. An example of the GnPR calculation of a direct real estate development
Source: Author (2018; Broadway Malyan Ltd, 2012)

Table 1.2. Greenery provision planning strategies for a direct real estate development

- | |
|---|
| 1. Landscaping on the ground level, including application of turf, trees, palms and shrubs. |
| 2. Landscaping on the podium and rooftop levels with the use of extensive and intensive green roof systems, trellises and planter boxes. |
| 3. Vertical greenery, such as green walls with support and module systems on the façade of a building or planter boxes on the balconies. |
| 4. Sky terraces and planting boxes or balconies integrated in a building structure. |

Source: Author (2018)

These strategies are the landscape elements, as used and defined in the associated design simulations, denoted as the ‘Kit of Parts’. They are applied at the design stage for what the study calls the ‘existing scenario’ as well as for four other simulated scenarios.

Stage 2: The building audit and building categorisation

The main objectives of the Building Audit stage were to measure the GnPR values for 100 existing buildings surveyed in Singapore, and to conduct the corresponding quantitative and qualitative analyses. The quantitative analysis included the different buildings' parameters — like each building's location, scale, height, mass, plot ratio, site coverage, gross floor ratio and existing GnPR. The qualitative analysis included a field survey conducted from March 2010 to July 2012, a period of about a year and nine months. The resulting 'Building Audit Report' mainly involved two key stages: the consultancy stage and the statistical analysis report stage (as mentioned at the beginning of this chapter).

The 100 buildings audited were categorised by land use (i.e. commercial, industrial, residential and residential-commercial mixed land use). Land use types were further sub-divided as follows:

- The commercial sector: i.e. office, hotel, retail, mixed-use typologies.
- The industrial sector: includes business or research park, factories and warehouse typologies.
- The residential sector: strata landed housing, public housing and condominium typologies.
- The mixed residential-commercial land use: includes both the private mixed and public mixed building types.

The building form was studied to explore the possibility of relating the landscaping strategies to specific building typologies. However, the 'Statistical Analysis Report' showed no such correlation between the GnPR and the building form. On the basis of the statistical analysis report, the following five building form categories that showed correlations with the GnPR levels are listed in Table 1.3.

Although strata-landed housing and social spaces were studied, their sample size was too small for significant recommendations to be made. Therefore, the results and the potential landscape guidelines for these building types are not included in this book.

Table 1.3. The five building form categories correlated with the GnPR levels

-
1. Location (i.e. whether it is in the Central Area or outside the Central Area).
 2. Period of building construction (defined as before the year 2000 or after).
 3. Density (i.e. low, medium, medium-high, high or very high).
 4. Site coverage (i.e. low or high).
 5. Cost of greenery provision (in three subcategories: up to S\$500,000; S\$500,000–S\$1 million; S\$1 million–2.5 million; and more than S\$2.5 million).
-

Source: Author (2018)

Further cost analysis using the design simulations model found the optimal GnPR value for business parks and landed housing building types to be lower than some of the range of values for the larger land use categories they fall under (i.e. industrial and residential land use types, respectively) owing to their respective lower GnPR values. This may have contributed to the overall lower GnPR value for their larger land use categories. After several evaluation rounds, categorisation by land use sub-type was determined as the most feasible means to calculate and apply the GnPR in Singapore. The existing GnPRs for seven out of the ten land use categories are summarised in Table 1.4.

Stage 3: The design response

To explore the extent of greenery achievable in the 100 buildings audited in the field survey, five GnPR design scenarios were devised to increase the buildings’ GnPR values under a sequential (incremental) GnPR cost approach, in order to assess the correlation between the GnPR and cost (see Fig. 1.3):

1. **Existing scenario** considers the existing planting conditions of a building (i.e. all present greenery on the building’s horizontal and vertical levels).
2. **Enhanced 1 scenario** is a simulated design scenario that maximises planting on the ground level.

Table 1.4. Existing GnPRs for the ten land use types: Means, medians and standard deviations

Sub-use	Mean
HDB flat	3.0923
Condominium	2.6767
Public-mix	0.2325
Private-mix	2.2425
Hotel	1.2233
Office	1.0656
Retail	0.9060
Mixed-commercial	0.8450
Bus Park	2.3440
Factory	0.5691
Total	1.5930

Source: Author (2018; Broadway Malyan Ltd, 2012)

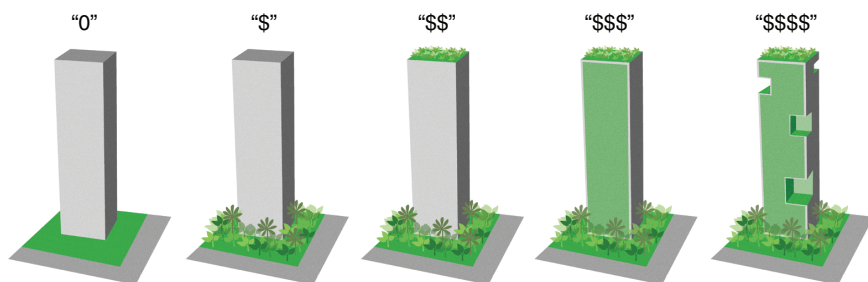


Fig. 1.3. Design scenarios: The sequential increase in greenery

Source: Author (2018; Broadway Malyan Ltd, 2012)

3. **Enhanced 2 scenario** adds on to the Enhanced 1 scenario and applies planting on rooftops and/or on podiums without any structural alterations.
4. **Maximum scenario** combines the Enhanced 1 and 2 scenarios with the addition of planting in the form of green walls on possible vertical surfaces without any major structural alterations to a building.

5. **Ultimate scenario** is the ‘drawing board scenario’ in which the building is assumed as yet-to-be-built, and structural changes are applied to the building design in order to maximise greenery; for example, through the addition of sky terraces.

Derivation of Existing Greenery Maintenance Cost

The 100 buildings audited were categorised into three land use types, namely, commercial land use (including mixed-use types), residential, and industrial. Residential land use was sub-divided into private and public residential land use sub-types. Key considerations included the pricing strategy among the contractors and the feedback from consultants. The site area analysis was based on the unit rates for existing maintenance costs and on a reasonable band to develop the building categorisation (see Table 1.5).

Table 1.5. Building categorisation by existing maintenance cost band

Land use		Site area (m ²)	Band
Commercial		2,000 to 9,999	Small
		10,000 to 19,999	Medium
		20,000 to 49,999	Large
		<2,000 and ≥50,000	Anomalies
Residential	Public	10,000 to 19,999	Small
		20,000 to 29,999	Medium
		30,000 to 49,999	Large
		<10,000 and ≥50,000	Anomalies
	Private	10,000 to 19,999	Small
		20,000 to 29,999	Medium
		30,000 to 49,999	Large
		<10,000 and ≥50,000	Anomalies
		7,000 to 17,999	Small
		18,000 to 26,999	Medium
		27,000 to 49,999	Large
		<7,000 and ≥50,000	Anomalies
Industrial		7,000 to 17,999	Small
		18,000 to 26,999	Medium
		27,000 to 49,999	Large
		<7,000 and ≥50,000	Anomalies

NB. The building types are grouped by their corresponding land uses.

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

Where available, the tender returns for the 100 buildings were consolidated. The returns were calculated by the cost per sq. m. to derive the average unit rate for each maintenance cost band. These average unit rates were applied to the buildings within their respective bands. An existing maintenance cost value, based on the individual site area, was imputed for each building.

Derivation of the Greenery Maintenance and Installation Capital Costs for the Enhanced 1, Enhanced 2, Maximum and Ultimate Design Scenarios

The GnPR design scenario maintenance costs — other than that of the ‘Existing scenario’ — were imputed and based on a ratio approach. The installation capital cost of greenery for all the 100 buildings in the ‘Existing’ scenario were imputed and compared with the greenery maintenance cost for all the 100 buildings, to derive a ratio of 0.1029. The implication was that for every S\$1 of installation capital cost spent on greenery, S\$0.1029 was spent on maintaining the greenery. This was applicable across all the components of the ‘Kit of Parts’ except for green walls, the methodology of which is explained in the next section.

Derivation of Maintenance Costs for Green Walls in the Maximum Design Scenario

Owing to the absence of available tender returns, the unit rate for the maintenance cost of green walls was determined based on an existing building with a green wall feature. The unit rate derived was applied to all buildings with the green wall option in the ‘Maximum’ design scenario.

The ten-year maintenance cost for the existing to ultimate design scenarios

The green wall maintenance cost was multiplied by ten to obtain the maintenance cost over a ten-year period. It should be noted that owing

to the uncertainty of global economic and market conditions, inflation was not taken into account for this ten-year period.

Qualification of the maintenance and installation capital cost estimates

Only the maintenance cost for the buildings' 'Existing' scenarios was based on tender returns; this same basis was not applied to the other GnPR design scenarios. Besides the 'Existing' scenario, the maintenance and installation costs for the other GnPR design scenarios were derived using the ratio approach. The corresponding 13 cost estimates, owing to the unique nature of each building across each building category, are listed below but are not all inclusive:

1. Prevailing Goods and Services Tax
2. Professional consultancy fees
3. Authority submission fees
4. Costs fluctuations due to market conditions and overtime
5. Costs of tendering and contractual set-up
6. Contractual bonuses and penalties
7. Legal fees
8. Individual site constraints and latent conditions
9. Special equipment and tools
10. Negotiated contracts
11. Economies of scale achievable by various contractors due to their business operations
12. Irregular intervals or additional intervals of servicing
13. Current market competition

GnPR Statistical Analysis, Optimisation Objectives and Methodology

The purpose of the statistical analysis was to ascertain the optimal GnPR levels for selected land use categories via an in-depth investigation of

several factors that influence the GnPR level of the direct real estate development, namely:

- Land use
- Year of building construction
- Building density
- Site coverage and location
- Installation, maintenance and total (i.e. installation + maintenance) costs.

The statistical analysis augmented the building audit of the 100 buildings. It examined the correlation between the GnPR and various key factors using the Analysis of Variance (ANOVA) model. The significant key factors that influenced GnPR levels were combined under an explanation-based and estimated General Linear Model (GLM).

The Marginal Cost Analysis (MCA) model was used to estimate the returns to scale that are expected of a profit-seeking private real estate developer-investor. It also allocates a building greenery budget that corresponds to the minima turning point at the margin per additional GnPR level, and beyond which there are no returns to scale. The MCA model, divided by land use type, was estimated and accordingly graphed together with its approximated polynomial function, to reflect the narrow GnPR band around its minimum U-shaped point. This narrow GnPR band is generally indicative of the optimal GnPR for each land use. The empirical data was obtained from the building audit of the 100 buildings.

A heuristic optimisation model was subsequently used to ascertain the optimal GnPR levels. The model adopts a heuristic algorithm that conforms to the usual practice of imposing constraints on a maximising objective function. An increasing GnPR function can be represented by incrementing the Standard Deviation (SD) from the mean GnPR, within the boundary range of between $+0.25SD$ and $+2.0SD$. In practice and for normally distributed GnPR, approximately 95 per cent of the

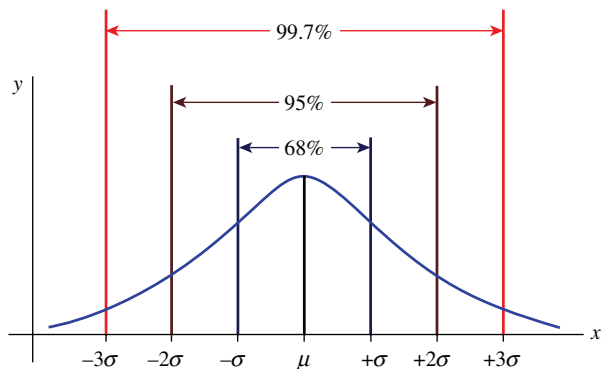


Fig. 1.4. The normal distribution of the GnPR

Source: Author (2018)

data points fall within the spread of $\pm 1.96SD$, i.e. $\pm 2.0SD$ from its mean if the distribution of the GnPR values is normal, as illustrated in Fig. 1.4.

The 95 per cent confidence interval represents the extreme $+2SD$ boundary condition for the GnPR, at which the optimal GnPR can be realistically achieved. The 3-step rule of the GnPR heuristic optimisation model is as follows:

1. The lowest and closest GnPR values for an incremental SD to the Ultimate GnPR was chosen as that particular highest boundary for the optimal GnPR level;
2. On practical grounds, the Optimum GnPR was appropriately presented as a range between the high and low optimal GnPRs;
3. The high optimal GnPR must not exceed the Ultimate GnPR value.

Analysis of the Factors Influencing GnPR

The importance of four main factors that influence GnPR levels — namely, the ‘Period of building construction’ (i.e. before or after 2000), ‘Building site coverage’ (i.e. below or more than 50 per cent), ‘Building density’

(i.e. the gross plot ratio) and ‘Cost’ — was derived from the foregoing statistical analysis. The following inferences can be made:

- The greenery innovation trend that is accepted by developers in Singapore tends to yield a higher GnPR for new developments than older developments.
- The lower the site coverage, the higher the GnPR as there is more greenery on the ground level and more available space for the application of the ‘Kit of Parts’. From the building audit data, it was observed that greenery on the ground level is a significant contributor to a building’s GnPR value for most building types except for office towers, as office buildings usually cover the maximum area of a building lot. Planting on the ground level is also a cheaper option as it does not require altering a building’s existing structure.
- The statistical analysis showed that a GnPR of 2.0 is achievable, and with a budget of less than S\$2 million.

Nevertheless, the coefficients of significance for ‘building location’ and ‘building age’ that were found in the statistical modelling cannot be readily applied to the estimation of the GnPR level for a specific land use owing to the small building sample within each category and the unequal distribution of samples in the various land use categories of this study. For example, all public mixed-use buildings in this study that were built before the year of 2000 had relatively low GnPR values, and were of medium-high density and high site coverage, whereas the private mixed-use buildings in the study were largely more recently constructed buildings that have high GnPR values, with high site coverage and very high density.

An attempt was made to determine the correlation between GnPR level and buildings built before 1989, the year when GFA regulations were first launched. In fact, it took more time than expected for private real estate developers to respond to the regulations. Thus, a slight increase in GnPR level was observed much later around 2000. The land sub-use type

was chosen as the only factor affecting a building's GnPR level instead of the 'land use building type', as some of the sub-land-uses (like factories and strata-landed housing) pulled down the GnPR values for the larger residential and industrial categories they fall under.

The mean GnPR for each of the ten sub-land-use categories, for the existing and the four simulated design scenarios, are presented in Table 1.6. For information and for the purpose of subsequent GnPR optimisations, Table 1.7 provides the summary of the various mean greenery costs of the 100 audited buildings for the existing and four simulated design scenarios per building, namely, the 'Enhanced 1', 'Enhanced 2', 'Maximum' and 'Ultimate' design scenarios by land use.

Table 1.8 shows another version of the summary for the various greenery cost means per sq. m. of the 100 audited buildings for the five design scenarios per building. On the whole, the mean maintenance, installation and total costs rose sharply between the 'Maximum' and 'Ultimate' design scenarios across all land use types. However, the mean maintenance, installation and total costs were found to either rise more gradually, stagnate or decline between the 'Enhanced 2' and the 'Maximum' design scenarios.

The highest mean total cost of about S\$315 per sq. m. was observed for the 'Ultimate' design scenario for the sub-land-use 'Factory' category, with a high mean installation cost of about S\$232 per sq. m. and the much lower mean maintenance cost of about S\$83 per sq. m. The lowest mean total cost of about S\$14 per sq. m. was observed for the 'Existing' design scenario of the sub-land-use 'Business park' category, which also had the third-lowest mean installation cost of about S\$7 per sq. m. and the second lowest mean maintenance cost of about S\$7 per sq. m. The sub-land-use 'Factory' category had the lowest mean installation cost of about S\$3 per sq. m. for the 'Existing' scenario, but a relatively high mean maintenance cost of S\$13 per sq. m. and a mean total cost of about S\$16 per sq. m. The sub-land-use 'Mixed-residential' category has the

Table 1.6. Mean GnPRs and Standard Deviations (SDs) by land sub-use type for the five scenarios

Land sub-use	Scenario	Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
HDB flat	Mean	3.0923	3.8115	4.0077	4.2177	4.6346
	Std. deviation	1.61416	1.60818	1.56088	1.62125	1.53055
Condominium	Mean	2.6767	3.2200	3.4647	3.5980	4.0820
	Std. deviation	1.36903	1.44079	1.40175	1.42636	1.37851
Public-mixed	Mean	0.2325	0.3850	1.0925	1.5925	2.0425
	Std. deviation	0.10966	0.25723	0.35929	0.29579	0.60846
Private-mixed	Mean	2.2425	2.6538	2.9638	3.0625	3.3012
	Std. deviation	1.19791	1.22219	1.38578	1.38393	1.49180
Hotel	Mean	1.2233	1.7867	2.0033	2.2567	2.5500
	Std. deviation	0.77120	1.07202	0.96736	1.19580	1.30180
Office	Mean	1.0656	1.5633	2.1111	2.5356	3.3089
	Std. deviation	1.17932	1.42585	1.24561	1.18417	1.25508
Retail	Mean	0.9060	1.2933	1.5727	1.9113	2.3760
	Std. deviation	0.57765	0.70957	0.66893	1.19970	1.20250
Mixed-commercial	Mean	0.8450	1.0270	1.5910	1.7660	2.6280
	Std. deviation	1.00972	0.99490	0.99845	1.01488	1.40723
Business Park	Mean	2.3440	2.8000	3.2520	3.2920	3.7400
	Std. deviation	0.64493	0.76443	0.67559	0.64913	0.62598
Factory	Mean	0.5691	1.1536	1.6282	1.6955	2.0182
	Std. deviation	0.40488	0.74462	1.05432	1.06925	1.22446
Total	Mean	1.5930	2.0662	2.4338	2.6415	3.1306
	Std. deviation	1.38433	1.51744	1.44952	1.49055	1.52355

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

Table 1.7. Greenery provision costs for the five design scenarios. (a) Installation cost; (b) Maintenance cost; (c) Total cost of greenery

Land sub-use\ Installation cost	Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate (with structural changes)
HDB flat	\$887,641	\$1,302,276	\$2,335,785	\$4,603,695	\$7,388,652
Condominium	\$709,636	\$1,473,408	\$2,579,998	\$4,164,848	\$11,740,713
Public-mixed	\$48,311	\$72,760	\$1,291,837	\$4,527,544	\$6,996,449
Private-mixed	\$1,468,389	\$1,754,234	\$2,687,731	\$3,660,955	\$7,491,917
Hotel	\$197,604	\$348,622	\$757,615	\$2,146,947	\$3,153,058
Office	\$112,273	\$217,693	\$665,087	\$1,950,180	\$3,925,787
Retail	\$394,066	\$726,860	\$1,360,066	\$3,521,412	\$5,170,964
Mixed- commercial	\$80,774	\$153,331	\$735,828	\$1,309,833	\$4,096,703
Business Park	\$584,648	\$800,689	\$2,274,989	\$2,900,474	\$6,196,491
Factory	\$206,540	\$649,151	\$2,455,535	\$3,123,403	\$7,558,520
Total	\$495,467	\$832,763	\$1,849,148	\$3,302,702	\$6,781,291
Land sub use\ Maintenance cost	Existing	Optimum 1	Optimum 2	Maximum	Ultimate
HDB flat	\$227,916	\$266,085	\$455,146	\$950,303	\$1,467,103
Condominium	\$913,562	\$1,083,481	\$1,282,376	\$1,711,264	\$2,264,867
Public-mix	\$133,668	\$180,134	\$635,372	\$1,397,640	\$1,801,985
Private-mix	\$442,756	\$502,371	\$660,417	\$845,075	\$1,158,877
Hotel	\$447,879	\$740,798	\$799,689	\$1,037,141	\$1,159,887
Office	\$376,095	\$561,118	\$640,026	\$948,152	\$944,567
Retail	\$388,704	\$518,536	\$625,122	\$1,192,145	\$1,367,613
Mixed- commercial	\$297,458	\$584,986	\$735,560	\$866,860	\$1,069,287
Business Park	\$843,869	\$989,513	\$1,252,182	\$1,368,438	\$1,823,736
Factory	\$398,882	\$1,158,534	\$1,496,107	\$1,655,429	\$2,194,344
Total	\$457,103	\$672,804	\$872,596	\$1,220,304	\$1,589,119

Table 1.7. (Continued)

Land sub-use\	Enhanced		Enhanced		Maximum	Ultimate
Total cost	Existing	1	2			
HDB	\$1,115,557	\$1,568,361	\$2,790,931	\$5,553,998	\$8,855,755	
Condo	\$1,623,198	\$2,556,889	\$3,862,373	\$5,876,111	\$14,005,580	
Public-mixed	\$181,979	\$252,894	\$1,927,210	\$5,925,184	\$8,798,434	
Private-mixed	\$1,911,146	\$2,256,605	\$3,348,148	\$4,506,030	\$8,650,794	
Hotel	\$645,482	\$1,089,420	\$1,557,304	\$3,184,088	\$4,312,945	
Office	\$488,368	\$778,811	\$1,305,113	\$2,898,332	\$4,870,354	
Retail	\$782,769	\$1,245,396	\$1,985,188	\$4,713,556	\$6,538,577	
Mixed-commercial	\$378,232	\$738,316	\$1,471,389	\$2,176,693	\$5,165,990	
Business Park	\$1,428,517	\$1,790,202	\$3,527,170	\$4,268,911	\$8,020,227	
Factory	\$605,422	\$1,807,686	\$3,951,642	\$4,778,832	\$9,752,865	
Total	\$952,570	\$1,505,567	\$2,721,743	\$4,523,006	\$8,370,410	

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

Table 1.8. Total cost of greenery per sq. m. for the four design scenarios

Land sub-use	Scenario	Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
Maintenance Cost (\$\$ per sq. m., over ten years)						
Residential	Mean	13.61	15.34	18.35	27.03	35.38
	Std. deviation	27.87	28.58	30.71	34.98	36.63
Mixed-residential	Mean	5.55	6.51	10.10	14.76	19.46
	Std. deviation	6.08	6.90	9.72	10.50	15.47
Commercial (Hotel, office, retail, mixed)	Mean	15.14	22.38	25.64	36.01	40.99
	Std. deviation	18.12	25.75	26.44	33.29	36.39
Factory	Mean	13.00	53.75	64.62	69.26	82.93
	Std. deviation	11.42	67.33	82.74	82.75	105.09

(Continued)

Table 1.8. *(Continued)*

Land sub-use	Scenario	Enhanced				
		Existing	1	2	Maximum	Ultimate
Business Park	Mean	7.15	9.30	13.97	15.02	20.86
	Std.	5.16	3.86	4.91	5.63	8.37
	deviation					
Installation Cost (S\$ per sq. m.)						
Residential	Mean	10.93	18.31	34.78	27.03	120.11
	Std.	9.49	12.56	26.05	34.98	108.82
	deviation					
Mixed-residential	Mean	14.45	16.11	30.91	14.76	85.57
	Std.	18.30	18.51	29.64	10.50	33.49
	deviation					
Commercial (Hotel, Office, Retail, Mixed)	Mean	5.37	13.27	31.89	36.01	124.08
	Std.	7.99	30.46	38.54	33.29	105.49
	deviation					
Factory	Mean	2.87	18.49	76.65	69.26	232.23
	Std.	2.20	23.80	115.80	82.75	329.60
	deviation					
Business park	Mean	6.63	9.12	34.37	15.02	78.72
	Std.	2.62	2.68	22.44	5.63	34.70
	deviation					
Total cost (S\$ per sq. m.)						
Residential	Mean	24.53	33.66	53.13	92.68	155.49
	Std.	35.60	38.30	53.67	82.11	128.09
	deviation					
Mixed-residential	Mean	20.00	22.62	41.01	66.76	105.04
	Std.	23.78	24.54	38.52	43.42	46.82
	deviation					
Commercial (Hotel, Office, Retail, Mixed)	Mean	20.51	35.65	57.52	107.27	165.07
	Std.	21.70	50.99	59.24	112.95	135.37
	deviation					

Table 1.8. (Continued)

Land sub-use	Scenario	Enhanced				
		Existing	1	2	Maximum	Ultimate
Factory	Mean	15.87	72.24	141.26	166.42	315.16
	Std. deviation	11.44	72.42	187.59	186.92	422.20
Business park	Mean	13.78	18.42	48.34	55.02	99.58
	Std. deviation	4.83	2.32	25.44	26.46	42.13

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

lowest mean maintenance cost of about S\$5.6 per sq. m. for the ‘Existing’ scenario, but with a mean installation cost of about S\$14 per sq. m. and a mean total cost of about S\$20 per sq. m.

Figure 1.5 depicts the hyperbolic slow-to-sharp rising trend of GnPR with the assigned total cost from the ‘Existing’ to the ‘Ultimate’ scenarios. Each land sub-use type’s average level of increase in GnPR between their ‘Existing’ to ‘Ultimate’ design scenarios is as follows:

- Residential — by 1.5, with total cost increase of S\$10 million;
- Mixed (Residential-commercial) — by 1.3, with total cost increase of S\$7.4 million;
- Commercial — by 1.7, with total cost increase of S\$4.9 million;
- Factory — by 1.5, with total cost increase of S\$8.9 million;
- Business park — by 1.3, with total cost increase of S\$6.6 million

Their average increase in GnPR level from the ‘Maximum’ to the ‘Ultimate’ design scenario is as follows:

- Residential — by 0.5, with total cost increase of S\$5.9 million;
- Mixed (Residential-commercial) — by 0.3, with total cost increase of S\$3.7 million;
- Commercial — by 0.6, with total cost increase of S\$2.0 million;

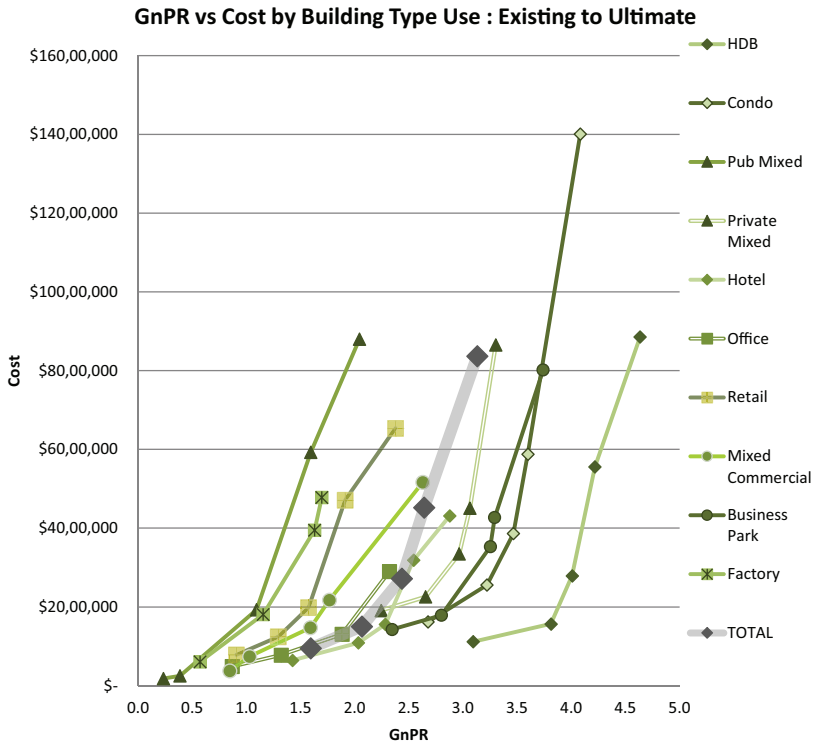


Fig. 1.5. GnPR vs. the total cost

Source: Author (2018)

- Factory — by 0.4, with total cost increase of S\$4.8 million;
- Business park — by 0.4, with total cost increase of S\$3.9 million.

A GnPR of 3.1 is thus observed to be achievable with a total cost of S\$8.4 million for the ‘Ultimate’ design scenario, while a GnPR of 2.6 with a total cost of S\$4.6 million is achievable for the ‘Maximum’ design scenario.

The Marginal Cost Analysis (MCA) Model

The MCA model’s empirical data was obtained from the building audit of 100 buildings. The associated Average Cost model, defined to be the total cost divided by GnPR level, is plotted in conjunction with the MCA model

to generally validate the U-shape nature of the MCA model (observed in Fig. 1.5). The MCA model by the four land use categories was estimated and accordingly charted in a graph, together with its approximated polynomial function, to determine the narrow GnPR band around its minimum U-shaped point that reflects the optimal GnPR by land use. The narrow band is highlighted as the lowest marginal cost (MC) band as part of the figure's title of the respective MCA model concerned. The corresponding Average Cost curves represent a more smoothened version of the MCA model's curves and they broadly affirm the same pattern of the MC curves.

The MCA model itself was estimated using the building audit data. The lowest MC was found to be at the following GnPR levels for five land uses:

Land use, GnPR levels and the total cost

- Residential land use: the existing condition's GnPR is 3.41 while the combined option's is 3.67 with a total cost of S\$1,536,819.
- Mixed (residential-commercial) land use: the existing condition's GnPR is 1.03 while the combined option's is 2.71 with a total cost of S\$5,125,360.
- Commercial land use: the existing condition's GnPR is 0.56 while the combined option's is 2.13 with a total cost of S\$425,440.
- Industrial land use (business parks): the existing condition's GnPR is 1.73 while the combined option's is 1.97 with a total cost of S\$265,992.
- Industrial land use (factories): the existing condition's GnPR is 0.25 while the combined option's is 1.66 with a total cost of S\$14,274,033.

Optimal GnPR values for various building types in Singapore

The optimised GnPR in Tables 1.9, 1.10 and 1.11 adopt the heuristic algorithm that conforms to the usual practice of imposing constraints on a maximising objective function. The design and economic optimisation approaches are shown below. Such an increasing function for GnPR is

Table 1.9. Heuristic optimisation model, Part 1: Design optimisation
(Part 1: Heuristically modelled optimal gnpr by land use: Design optimisation)

Land Use	Building Type	Mean GnPR					GnPR distribution (<2SD = 95%confidence)										Optimal GnPR	
		Enhanced					mean+										low high	
		Existing	1	2	Maximum	Ultimate	Mean	SD	0.25SD	0.5SD	0.75SD	1SD	1.25SD	1.5SD	1.75SD	2SD		
Residential	Public	3.09	3.81	4.01	4.22	4.63	3.09	1.61	3.50	3.90	4.30	4.71	5.11	5.51	5.92	6.32	3.1	4.3
	Private	2.68	3.22	3.46	3.60	4.08	2.68	1.37	3.02	3.36	3.70	4.05	4.39	4.73	5.07	5.41	2.7	4.1
	Strata landed Housing	0.98	1.50	2.15	2.15	2.97	0.98	0.34	1.06	1.15	1.23	1.32	1.40	1.49	1.57	1.66	1.0	1.7
Mixed Residential-Commercial	Public	0.23	0.39	1.09	1.59	2.04	0.23	0.11	0.26	0.29	0.31	0.34	0.37	0.40	0.42	0.45	0.2	0.5
	Private	2.24	2.65	2.96	3.06	3.30	2.24	1.20	2.54	2.84	3.14	3.44	3.74	4.04	4.34	4.64	2.2	3.1
Commercial	Hotel	1.22	1.79	2.00	2.26	2.55	1.22	0.77	1.42	1.61	1.80	1.99	2.19	2.38	2.57	2.77	1.2	2.4
	Office	1.07	1.56	2.11	2.54	3.31	1.07	1.18	1.36	1.66	1.95	2.24	2.54	2.83	3.13	3.42	1.1	3.1
	Retail	0.91	1.29	1.57	1.91	2.38	0.91	0.58	1.05	1.19	1.34	1.48	1.63	1.77	1.92	2.06	0.9	2.1
Industrial	Mixed	0.85	1.03	1.59	1.77	2.63	0.85	1.01	1.10	1.35	1.60	1.85	2.11	2.36	2.61	2.86	0.8	2.6
	Business park	2.34	2.80	3.25	3.29	3.74	2.34	0.64	2.51	2.67	2.83	2.99	3.15	3.31	3.47	3.63	2.3	3.6
	Factory and warehouse	0.57	1.15	1.63	1.70	2.02	0.57	0.40	0.67	0.77	0.87	0.97	1.08	1.18	1.28	1.38	0.6	1.4
Public space		0.59	0.93	1.12	1.19	1.59	0.59	0.13	0.62	0.65	0.69	0.72	0.75	0.79	0.82	0.85	0.6	0.9

Source: Author (2016)

Table 1.10. Heuristic optimisation model, Part 2: Marginal Cost (MC)
(Part 2: Heuristically modelled optimal GnPR by land use: Economic optimisation)

Land use	Building type	Existing design scenario		Ultimate design scenario		Marginal cost optimisation		Optimal GnPR (design)		Optimal GnPR (design and economic)		Comments
		GnPR	TC	GnPR	TC	GnPR	MC	low	high	low	high	
Residential	Public	3.092	1,115,557	4.635	8,855,755	4.70	2,376,191	3.1	4.3	3.1	4.7	The high GnPR is changed
	Private	2.677	1,623,198	4.082	14,005,580	2.30	325,771	2.7	4.1	2.7	4.1	
	St Landed	0.98	652,391	2.965	8,306,573			1.0	1.7	1.0	1.7	
Mixed	Public	0.233	181,979	2.043	8,798,434	1.30	7,612,063	0.2	0.5	0.2	0.5	No. of samples is too small
Residential-Commercial	Private	2.243	1,911,146	3.301	8,650,794	4.2	4,789,357	2.2	3.1	2.2	4.2	The high GnPR is changed
Commercial	Hotel	1.223	645,482	2.55	4,312,945	1.30	1,666,747	1.2	2.4	1.2	2.4	
	Office	1.066	488,368	3.309	4,870,354	0.90	364,344	1.1	3.1	1.1	3.1	
	Retail	0.906	782,769	2.376	6,538,577	2.50	1,137,304	0.9	2.6	0.9	2.6	
	Mixed	0.845	378,232	2.628	5,165,990	1.60	624,423	0.8	2.6	0.8	2.6	
Industrial	Business park	2.344	1,428,517	3.74	8,020,227	1.97	265,992	2.3	3.6	2.3	3.7	No. of samples is too small
	Factory and warehouse	0.569	605,422	2.018	9,752,865	1.23	453,529	0.6	1.4	0.6	1.4	
Public space		0.585	666,752	1.585	12,272,284			0.6	0.9	0.6	0.9	

Source: Author (2016)

Table 1.11. Optimal GnPR

Land use	Building type	Optimal GnPR (design and economic)	
		Low	High
Residential	Public	3.1	4.7
	Private	2.7	4.1
Mixed residential-commercial	Public	0.2	0.5
	Private	2.2	4.2
Commercial	Hotel	1.2	2.4
	Office	1.1	3.1
	Retail	0.9	2.6
	Mixed	0.8	2.6
Industrial	Business park	2.3	3.7
	Factory and warehouse	0.6	1.4

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

represented by increasing the standard deviation (SD) from the mean GnPR within the boundary range of between +0.25SD and +2.0SD. In practice, for a normally distributed GnPR, approximately 95 per cent of the data points would fall within the spread of $\pm 1.96SD$, i.e. $\pm 2.0SD$ from its mean. Such a 95 per cent confidence interval would represent the extreme +2SD boundary condition for GnPR, at which the optimal value can be realistically achieved. The step wise rules of the GnPR heuristic optimisation model are outlined below. The lowest and closest GnPR value for an incremental SD to the Ultimate GnPR is chosen as that particular highest boundary for the optimal GnPR level. On practical grounds, the optimum GnPR is appropriately presented as a range between the high and low optimum GnPR, making sure the high optimum GnPR does not exceed the Ultimate GnPR value.

Part 1: Design optimisation (see Table 1.9)

1. The mean GnPR for the ‘Existing’ design scenario is the low boundary of the Optimal GnPR.

2. The mean GnPR for the 'Ultimate' design scenario is compared with the GnPR values within the $+0.25SD$ and $+2.0SD$ boundary range.
3. The lowest and closest GnPR value for an incrementing SD to the mean GnPR for the 'Ultimate' design scenario is chosen as that particular highest boundary for the Optimal GnPR level.
4. The 2SD rule should hit at least the GnPR of the 'Enhanced 1' design scenario.

Part 2: Economic optimisation (see Table 1.10)

1. The total cost (TC) for the 'Existing' and 'Ultimate' design scenarios are provided for information. The TC comprises the green landscaping investment cost and the ten-year maintenance cost for the low and high GnPR values, for private real estate developer-investors.
2. The presented cost figures are the associated design cost of greenery (i.e. the cost that is nearest to the modelled optimum GnPR values).
3. The optimal marginal GnPR values are compared with the optimal design GnPR values: The optimal value derived by the economic approach should be within the optimal GnPR range derived by the design approach. This indicates that the optimal GnPR (for the design and economic optimisations) is conditioned by the returns to scale that are expected of greenery investing.

The results of the heuristically modelled Optimal GnPR for ten building types are summarised in Table 1.11.

Concluding Remarks

So far, two objectives, namely, to provide the optimal levels of the green plot ratio (GnPR) for the various land-use types; and to establish the capital and maintenance costs for various levels of greenery provision have been achieved. We next progress onwards to completing the potential landscape guidelines for the application of the optimal GnPR levels, to facilitate a sustainable land scape for Singapore.

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02 Urban Greenery Provision and GnPR

GnPR was mooted as an original concept by Ong (1996, 1999, 2002 and 2004), former Senior Lecturer, Department of Architecture, School of Design & Environment, National University of Singapore. Conveyed to Ho (2010 and Ong *et al.*, 2012), GnPR is meant to guide urban greenery provision. Conceptually similar to the gross plot ratio (GPR) that is currently used in Singapore to measure the development intensity of a building, the key difference is that GnPR allows a three-dimensional quantification of greenery that is present on a site, through the use of a common scientific measure known as the Leaf Area Index (LAI), in contrast to the largely two-dimensional current greenery metrics. Given the improved precision in urban greenery quantification, GnPR could be a unique and enhanced tool for urban greenery accounting. Outstanding issues that cause key knowledge gaps and prevent the widespread adoption of the GnPR are:

- That optimal levels of GnPR should be appropriate for various land-use types and such levels need to be benchmarked against current levels of greenery provision.
- That GnPR currently only stipulates the greenery quantum. Ideally, the GnPR should also encourage the concentration of some plants (especially existing native trees), the planting of certain local species, and the development of ecological or natural landscapes over the manicured gardens.

Urban greenery provision comes with inevitable capital and maintenance costs. There is a need to understand the impact of the various GnPR provision levels, relative to such costs.

Consisting of several stages of investigation, this book seeks to deepen the understanding and adoption of the GnPR in the built-up areas of Singapore and other similar cities.

This book's strategic value is its multi-faceted complexity; no equivalent studies of this kind have been undertaken elsewhere. The book is concerned with the rigorous set-up of optimal GnPR levels, and with a more precise regulation of urban greenery provision within a real estate development project in Singapore, can be a significant contributor to the disciplines of urban design, urban planning, landscape and architecture.

GnPR — A Unique Urban Greenery Metric

Provision of greenery has been a key priority in Singapore's development and can be traced back to when the country was undergoing rapid industrialisation and urbanisation. The 1968 'Garden City' approach was the vision set by the government to integrate the environment with developments that influence subsequent environmental policies. Over the years, sustainability-oriented concepts and strategies were introduced under the Singapore Green Plan (MEWR, 2019) and through initiative-based programmes like the LUSH programme (URA, 2009), and the NParks' Skyrise Greenery Award (NParks, 2008); (NParks, 2019) and the Skyrise Greenery Incentive Scheme (NParks, 2019) — both of which encourage building owners to retrofit their existing buildings with green features and give greenery space provision in new developments. Even though 95 per cent of Singapore's natural forest has been lost, careful and comprehensive planning in the form of parks and green connectors have expanded the city's green cover from 36 per cent to 47 per cent between 1986 and 2007 (MEWR, 2002).

Skyrise greenery — i.e. planting gardens on rooftops or along walls — is another potential way that can increase greenery provision. Despite assumptions that rooftop gardens are elaborate and require special roofs to bear the resulting weight, most modern green roof technologies are lightweight and require minimum maintenance. Furthermore, from measurements using a variety of local and overseas systems, their environmental benefits in dense urban areas are many, including the reduction of the urban heat island effect, increased biodiversity, thermal insulation and energy savings via the reduction of cooling load, or the improvement of air quality by trapping airborne dust particles, and the reduction of rainwater flow through the absorption and evaporation of rain by soil and vegetation (Santamouris, 2001); (Jusuf & Wong, 2009). In high-density urban areas, skyrise greenery is viewed as one of the most rapidly developing building features, but has yet to be regulated and implemented on an extensive planning scale. This book therefore adopts the GnPR concept to derive the appropriate levels of skyrise greenery for different building types; to identify the capital and maintenance costs associated with greenery provision; and to possibly extend GnPR to landscape guidelines for Singapore (Ho & Orlenko, 2012; 2014).

GnPR Definition and Imputation

GnPR is defined as the “average LAI of the greenery of a site”, an ecological measure based on the surface area of greenery that assigns values to particular plants (Ong B. L., 2003). The current definition developed by NParks reiterates that GnPR is ‘the area weighted average leaf area index of a site’ (Tan & Sia, 2009). GnPR is expressed by Eq. (2.1).

$$\begin{aligned}
 GnPR &= \frac{\text{total leaf area}}{\text{site area}} \\
 &= \frac{\sum LAI_1 \times Canopy Area_{1...} + LAI_n \times Canopy Area_n}{\text{Site Area}}, \quad (2.1)
 \end{aligned}$$



Fig. 2.1. An example of the GnPR calculation of a real estate development

Source: Author, 2018; Broadway Malyan Ltd, 2012

where LAI is the area of one side of the leaf tissue per unit ground surface area. LAI values for different types of plants can be found in the book ‘Calculation of the Green Plot Ratio & Leaf Area Index of Tropical Plants’, published by NParks in 2009. In the book, plants are categorised into groups and sub-groups. To calculate GnPR of a development, the plant type, canopy type, the number of trees, as well as the area of turf and shrubs should be identified. An example of GnPR imputation of a building lot with a site area of 4,000 sq. m., landscaped with two dense trees, three open canopy trees, and 11 solitary palms, and covered by 20 sq. m. of dicot shrubs and 1,500 sq. m. of turf, is illustrated and tabulated in Fig. 2.1 and Table 2.1.

The Study Approach

Singapore’s chronic and acute land scarcity (its total land area is about 640 sq. km) makes nature conservation and greenery replacement very important. Sustainability-oriented policies and concepts including the

Table 2.1. GnPR calculation of development illustrated in Fig. 2.1

Plant	Canopy type	Canopy area, sq. m. per unit	LAI value	Number of units	Leaf area, A × B × C
		(A)	(B)	(C)	
Trees	Dense	60	4	2	480
	Intermediate	60	3	0	0
	Open	60	2.5	3	450
Palm	Solitary	20	2.5	11	550
	Cluster	17	4	0	0
Shrub	Dicotyledonous	1	3.5	0	0
	Monocotyledonous	1	4.5	20	90
Turf			2	1,500	0
Total leaf area					1,570.0
Site area					4,000.0
Green Plot Ratio Leaf area/Site area					0.4

Source: Author, 2018; Broadway Malyan Ltd, 2012

LUSH Programme, the 'International Skyrise Greenery Conference' and the 'Skyrise Greenery awards' were introduced to encourage the greening of Singapore's built-up areas. GnPR has been adopted in various studies, like those by Jones (1992) and by Karlik and Winer (2001), as well as by government agencies over the years, not only as a tool for greenery accounting but also as part of the initiatives and correlations with greenery's environmental benefits. For example, BCA has adopted GnPR for its Green Mark Building Award as a measurement of greenery provision within a non-residential development. GnPR is also currently being explored by HDB and JTC in Singapore for use as an accounting tool to quantify, plan and regulate the amount of greenery in housing and industrial estates.

Several National University of Singapore (NUS) studies have used GnPR to study the relationship between the amount of greenery and the surface and ambient temperatures of a building, as well as the overall high-density physical environment. However, the optimal GnPR level for

various land-use types and the costs that are associated with the application of various GnPR levels has remained unknown. Consequently, through a series of design simulations and the statistical analysis of the data obtained from these simulations, this book seeks to determine achievable GnPR values, which can be readily incorporated into a building type.

Stage 1 — The Best Landscaping Technologies and Practices, and the “Kit of Parts”

This study’s first stage is a comprehensive review of existing greening and landscaping technologies and practices in Singapore and around the world. The review established the broad planting strategies of greenery provision within a real estate development, listed in the following bullet list and illustrated in Fig. 2.2.

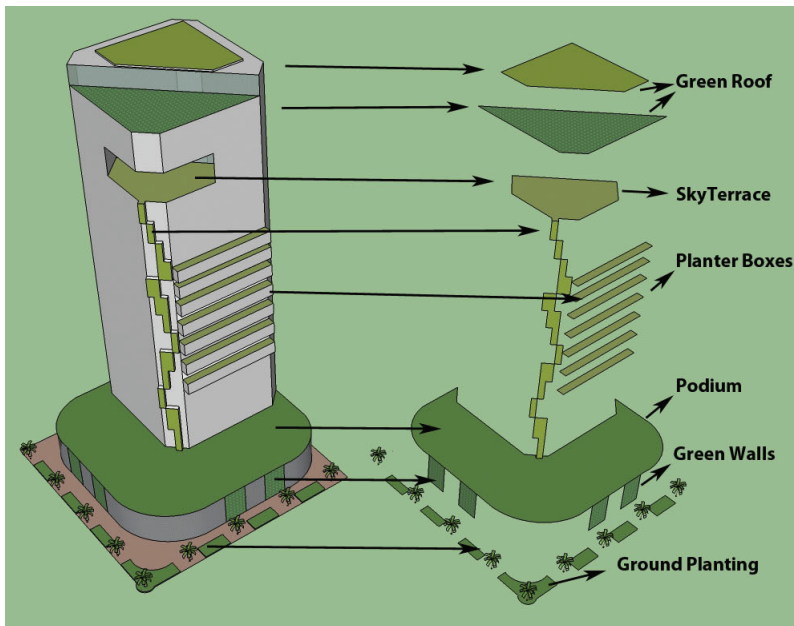


Fig. 2.2. Skyrise greenery strategies

Source: Author, 2018; Broadway Malyan Ltd, (2012)

- Landscaping on the ground level; including the application of turf, trees, palms and shrubs;
- Landscaping on podium and rooftop levels; with the use of extensive and intensive green roof systems, trellises and planter boxes;
- Vertical greenery; like green walls with support and module systems on the façade of a building or planter boxes on the balconies;
- Sky terraces and planting boxes or balconies integrated in a building structure.

Such broad planting strategies of greenery provision within a real estate development were subject to design simulations while the landscape elements of interest were introduced as the “Kit of Parts”.

Stage 2 of Study — The Building Audit and Building Categorisation

The study's second stage measured GnPR values for 100 existing buildings in Singapore and conducted corresponding qualitative and quantitative analyses. The quantitative analyses included the different buildings' parameters, such as location, scale, height, mass, plot ratio, site coverage, gross floor ratio and existing GnPR. The qualitative analyses were conducted via a survey from which the 'Building Audit' report resulted.

The 100 buildings audited were categorised by four land use types: commercial, industrial, residential and mixed-use residential-commercial. The land use types were then sub-divided in the following manner:

- the commercial sector: comprising office, hotel, retail, mixed-use typologies;
- the industrial sector: comprising business parks, factories and warehouse typologies;
- the residential sector: comprising strata landed housing, public housing and condominium typologies; and

- the mixed residential-commercial sector: comprising private-mixed and public-mixed building types.

The building form was examined to explore the possibility of relating the landscaping strategies to specific building typologies. However, the resulting ‘Statistical Analysis Report’ showed no correlation between the GnPR and building form. Instead, the following factors showed a clear correlation with GnPR levels:

- Location (whether a building was within the Central Area or outside the Central Area);
- Period of building construction (whether a building was built before the year 2000 or after).
- Density (of the building; whether it was low, medium, medium-high, high or very high);
- Site coverage (low or high); and the
- Cost of greenery provision (up to S\$500,000; S\$500,000–S\$1 million; from S\$1–2.5 million; and more than S\$ 2.5 million).

All costs and building values are in S\$ terms. Although strata-landed housing building type and social spaces were covered in the audit, their sample sizes were too small for conclusive recommendations. Thus, their associated results are not included in this book or in the potential landscape guidelines.

Additionally, from further cost analysis, the optimal GnPR value for business parks and landed housing was found to be lower than some of the range of values from the design simulations model. These building sub-types may thus have contributed to a lower overall GnPR value for the larger land use categories they fall under, owing to their respective lower GnPR values. After several evaluation rounds, categorising the buildings by land use sub-type instead was determined to be the most feasible for GnPR application. The existing GnPR for ten land use categories can be found in Table 2.2.

Table 2.2. The ten land use types and their mean GnPRs

Sub use	Mean GnPR
HDB flat	3.0923
Condominium	2.6767
Public mixed	0.2325
Private mixed	2.2425
Hotel	1.2233
Office	1.0656
Retail	0.9060
Mix-commercial	0.8450
Business park	2.3440
Factory	0.5691
Total	1.5930

Source: Author (2018); Broadway Malyan Ltd (2012)

Stage 3 of Study — The Design Response

To explore the achievable greenery of the 100 audited buildings in Singapore, a total of five GnPR design scenarios were devised to increase GnPR from an existing scenario, using a sequential GnPR incremental-cost approach, to assess the correlation between the GnPR and its associated cost range in Fig. 2.3. The scenarios are defined as follows:

1. Existing scenario — considers the existing planting conditions of a building with all the present greenery on the horizontal and vertical levels.
2. Enhanced 1 scenario — a simulated design scenario that maximises planting on the ground.
3. Enhanced 2 scenario — adds on to the Enhanced 1 scenario by planting on rooftops and/or on podiums without any structural alterations.
4. Maximum scenario — a combination of the Enhanced 1 and 2 scenarios, with the addition of planting in the form of green walls on vertical surfaces, without any major structural alterations to a building.

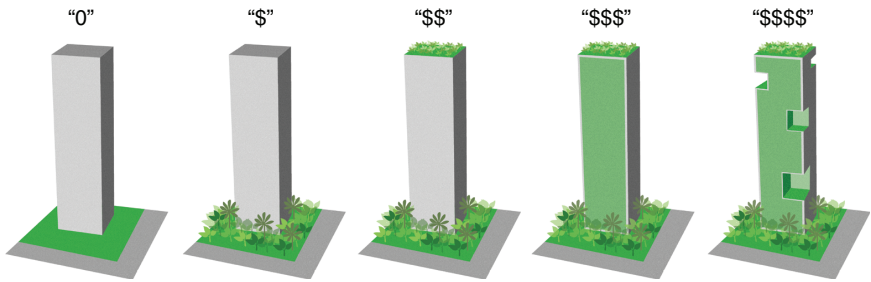


Fig. 2.3. The design scenarios — Sequential increase in greenery

Source: Author (2018); Broadway Malyan Ltd (2012)

5. Ultimate scenario — the ‘drawing board scenario’ where the building is considered yet-to-be-built and that structural changes will be applied to the building design — for example, the addition of sky terraces — in order to maximise greenery.

The design principles applied to the 100 audited buildings took into consideration existing landscape guidelines, best landscaping practices and the social, economic, environmental, spatial, cultural and technological conditional aspects that explore the constraints and opportunities for GnPR maximisation.

Maintenance and Installation Costs

This section briefly discusses the methodology to derive the maintenance and installation costs for the five GnPR design scenarios. All the cost estimates used and provided by the consultants were correct as of end-October 2011. The 100 audited buildings were categorised into three broad land use types: commercial (inclusive of mixed-use), residential and industrial. The residential category was sub-divided into private and public residential land-use sub-types. Key considerations that were taken into account included the pricing strategy among the contractors, and the feedback from the consultants. The site area analyses were based on the ‘unit rates’ for existing maintenance costs for each land use type, and on a reasonable band, to help develop the building categorisation in Table 2.3.

Table 2.3. Building categorisation by cost

Land use		Site area (m ²)	Band
Commercial		2,000 to 9,999	Small
		10,000 to 19,999	Medium
		20,000 to 49,999	Large
		<2,000 and ≥50,000	Anomalies
Residential	Public	10,000 to 19,999	Small
		20,000 to 29,999	Medium
		30,000 to 49,999	Large
		<10,000 and ≥50,000	Anomalies
	Private	10,000 to 19,999	Small
		20,000 to 29,999	Medium
		30,000 to 49,999	Large
		<10,000 and ≥50,000	Anomalies
Industrial		7,000 to 17,999	Small
		18,000 to 26,999	Medium
		27,000 to 49,999	Large
		<7,000 and ≥50,000	Anomalies

NB. The building types are grouped into the corresponding land uses.

Source: Author (2018); Broadway Malyan Ltd. (2012)

Where available, the tender returns for the 100 audited buildings were consolidated. The cost values were then imputed by the cost per sq. m. to derive the average unit rate for each band in Table 2.3. The average unit rates are applied to the buildings within their respective bands. An existing maintenance cost value, based on the individual site area, is imputed for each building.

Derivation of the Greenery Maintenance and Capital (Installation) Costs for the Enhanced 1, Enhanced 2, Maximum and Ultimate Design Scenarios

Besides the 'Existing' scenario, all the costs for the GnPR design scenarios were imputed and based on a ratio approach. The greenery capital (installation) costs of all 100 audited buildings in the 'Existing' scenario were imputed and compared to the maintenance cost of each of the

audited buildings, to derive a ratio of 0.1029. This means that for every S\$1 of capital cost spent on greenery, S\$0.1029 is spent on maintaining the greenery. This is applicable across all aspects of the “Kit of Parts” except for green walls.

Derivation of the Green Walls Maintenance Cost in the Maximum Design Scenario

Owing to the absence of available tender returns, the unit rate for the maintenance cost of green walls was determined based on an existing building with a green wall feature. The unit rate was applied to all buildings with the green wall option in the ‘Maximum Design Scenario’.

Maintenance Cost Over a 10-year Period in the Existing to Ultimate Scenarios

The maintenance cost was multiplied by ten to obtain a maintenance cost over a ten-year period. Due to uncertainty factors in the global economy and in market conditions, inflation was not accounted for in this period.

Qualification of the Maintenance and Installation Cost Estimates

Only the maintenance cost for the ‘Existing’ scenario was based on tender returns. Maintenance costs for the other design scenarios were obtained via the ratio approach. Due to the unique nature of each building across all categories, factors such as but not limited to those listed below, were excluded from the cost estimates:

1. Prevailing goods and services tax,
2. Professional consultancy fees,
3. Authority submission fees,
4. Costs fluctuations owing to market conditions and overtime,
5. Costs of tendering and contractual set-up,
6. Contractual bonuses and penalties,
7. Legal fees,

8. Individual site constraints and latent conditions,
9. Special equipment and tools,
10. Negotiated contracts,
11. Economies of scale achievable by various contractors owing to their business operations,
12. Irregular intervals or additional intervals of servicing, and
13. Current market competition.

GnPR Statistical Analysis and Optimisation

The purpose of the statistical analysis was to determine optimal GnPR levels for selected land use categories, via an in-depth investigation of several factors that influence the GnPR level of the development, namely:

- Land use;
- Year of building construction;
- Building density;
- Site coverage and location; as well as
- Installation, maintenance and total cost (= installation + maintenance costs).

The statistical analysis augmented the 100 building audit, examining the correlation between GnPR and various factors via the ANOVA model. Subsequently, the significant factors that influence a building's GnPR level were combined under an explanation-based and estimated general linear model (GLM). The MCA model was then used to establish the returns to scale that are expected of a profit-seeking private developer-investor, allocating a budget for the building greenery corresponding to the 'minima' turning point at the margin per additional GnPR level. Beyond this GnPR level, there would be no returns to scale.

The MCA model by land uses was estimated and charted accordingly into a graph, together with its approximated polynomial function, to reflect the narrow GnPR band around its minimum U-shaped point that

is generally indicative of the optimal GnPR by land use. The empirical data was obtained from the audit of the 100 domestic buildings.

To ascertain each building type's optimal GnPR level, a heuristic optimisation model was subsequently adopted, using a heuristic algorithm that conforms to the usual practice of imposing constraints on a maximising objective function. The increasing GnPR function can be represented by incremental standard deviation (SD) from the mean GnPR within the boundary range of between $+0.25SD$ and $+2.0SD$. In practice and for normally distributed GnPR, approximately 95 per cent of the data points would fall within the spread of $\pm 1.96SD$, i.e. $\pm 2.0SD$ from its mean if distribution of the GnPR values is normal, as illustrated in Fig. 2.4.

The 95 per cent confidence interval would represent the extreme $+2SD$ boundary condition for GnPR which the optimal GnPR can realistically achieve. The four-step rule of the GnPR heuristic optimisation model are devised as follows: the lowest and closest GnPR value for an incremental SD to the 'Ultimate' GnPR is chosen as that particular highest boundary for the optimal GnPR level. On practical grounds, the 'Optimum' GnPR is appropriately presented as a range between the high and low Optimal GnPR. The high Optimal GnPR does not exceed the 'Ultimate' GnPR value.

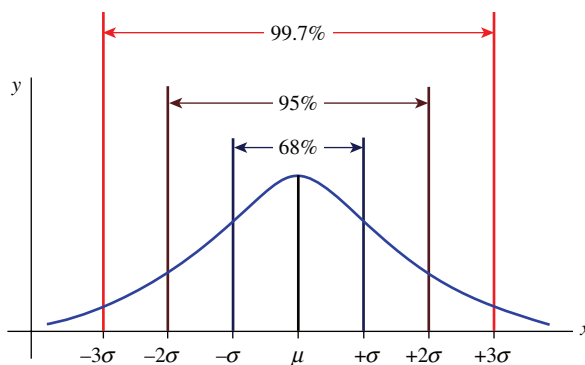


Fig. 2.4. The normal distribution

Source: Author (2018)

Analysis of Factors Influencing GnPR

Four main factors that influence a building's GnPR level, namely the 'period of building construction (before or after the year 2000)', 'building site coverage (below or more than 50 per cent)', 'building density (or gross plot ratio)' and 'cost' were shown to be important through the statistical analysis. The following conclusions can be affirmed:

- The greenery innovation trend that is now accepted by real estate developers in Singapore tends to yield a higher GnPR for new (post-2000) real estate developments compared to older developments;
- The lower the site coverage, the higher the GnPR, as there is more greenery on the ground level, as well as more available space for the application of the 'Kit of Parts'. From the building audit data, it was readily observed that greenery on the ground level is a significant contributor to a building's GnPR value for most building types except office towers, as office buildings usually cover the maximum area of a building lot. Planting on the ground level is also a cheaper option as it doesn't require altering the building structure.
- The statistical analysis showed that a GnPR of 2.0 is achievable with a budget of less than S\$2 million.

Nevertheless, the associated coefficients of significance, such as 'building location' and the 'building age', cannot be readily applied to the estimation of the GnPR level for a specific land use, owing to the small building sample within each category and the unequal distribution of samples in the various land use categories. For example, all the public mixed-use buildings audited that were built before 2000 have relatively low GnPR values, and were of medium-high density and high site coverage; whereas the private mixed-use buildings were largely more recently constructed buildings that have high GnPR values, and were of high site coverage and very high density.

An attempt was made to determine the correlation between GnPR level and buildings built before 1989, the year when the GFA regulations

were first launched. The land sub-use type was chosen to be the only factor affecting the GnPR level instead of ‘land use building type’, as some of the sub-uses, like factories and strata-landed housing, have lower GnPR values than most other sub-uses that make up the larger residential and industrial categories they fall under.

The mean GnPR for the ten sub-use categories, and the five design scenarios are presented in Table 2.4. For information and to enable subsequent GnPR optimisation purposes, Table 2.5 duly presents the

Table 2.4. Mean GnPRs and standard deviations for the ten sub-use categories

Sub use		GnPR existing	GnPR enhanced 1	GnPR enhanced 2	GnPR maximum	GnPR ultimate
HDB	Mean	3.0923	3.8115	4.0077	4.2177	4.6346
	Std. deviation	1.61416	1.60818	1.56088	1.62125	1.53055
Condo	Mean	2.6767	3.2200	3.4647	3.5980	4.0820
	Std. deviation	1.36903	1.44079	1.40175	1.42636	1.37851
Public mix	Mean	0.2325	0.3850	1.0925	1.5925	2.0425
	Std. deviation	0.10966	0.25723	0.35929	0.29579	0.60846
Private mix	Mean	2.2425	2.6538	2.9638	3.0625	3.3012
	Std. deviation	1.19791	1.22219	1.38578	1.38393	1.49180
Hotel	Mean	1.2233	1.7867	2.0033	2.2567	2.5500
	Std. deviation	0.77120	1.07202	0.96736	1.19580	1.30180
Office	Mean	1.0656	1.5633	2.1111	2.5356	3.3089
	Std. deviation	1.17932	1.42585	1.24561	1.18417	1.25508
Retail	Mean	0.9060	1.2933	1.5727	1.9113	2.3760
	Std. deviation	0.57765	0.70957	0.66893	1.19970	1.20250
Mix commercial	Mean	0.8450	1.0270	1.5910	1.7660	2.6280
	Std. deviation	1.00972	0.99490	0.99845	1.01488	1.40723
Business park	Mean	2.3440	2.8000	3.2520	3.2920	3.7400
	Std. deviation	0.64493	0.76443	0.67559	0.64913	0.62598
Factory	Mean	0.5691	1.1536	1.6282	1.6955	2.0182
	Std. deviation	0.40488	0.74462	1.05432	1.06925	1.22446
Total	Mean	1.5930	2.0662	2.4338	2.6415	3.1306
	Std. deviation	1.38433	1.51744	1.44952	1.49055	1.52355

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

Table 2.5. Installation, maintenance and total cost of greenery for the five design scenarios

Sub use	Installation cost existing	Installation cost enhanced 1	Installation cost enhanced 2	Installation cost maximum	Installation cost ultimate (structural changes)
HDB flat	\$887,641	\$1,302,276	\$2,335,785	\$4,603,695	\$7,388,652
Condominium	\$709,636	\$1,473,408	\$2,579,998	\$4,164,848	\$11,740,713
Public mixed	\$48,311	\$72,760	\$1,291,837	\$4,527,544	\$6,996,449
Private mixed	\$1,468,389	\$1,754,234	\$2,687,731	\$3,660,955	\$7,491,917
Hotel	\$197,604	\$348,622	\$757,615	\$2,146,947	\$3,153,058
Office	\$112,273	\$217,693	\$665,087	\$1,950,180	\$3,925,787
Retail	\$394,066	\$726,860	\$1,360,066	\$3,521,412	\$5,170,964
Mixed commercial	\$80,774	\$153,331	\$735,828	\$1,309,833	\$4,096,703
Business Park	\$584,648	\$800,689	\$2,274,989	\$2,900,474	\$6,196,491
Factory	\$206,540	\$649,151	\$2,455,535	\$3,123,403	\$7,558,520
Total	\$495,467	\$832,763	\$1,849,148	\$3,302,702	\$6,781,291

Sub use	Maintenance cost existing	Maintenance cost optimum 1	Maintenance cost optimum 2	Maintenance cost maximum	Maintenance cost ultimate
HDB flat	\$227,916	\$266,085	\$455,146	\$950,303	\$1,467,103
Condominium	\$913,562	\$1,083,481	\$1,282,376	\$1,711,264	\$2,264,867
Public mixed	\$133,668	\$180,134	\$635,372	\$1,397,640	\$1,801,985
Private mixed	\$442,756	\$502,371	\$660,417	\$845,075	\$1,158,877
Hotel	\$447,879	\$740,798	\$799,689	\$1,037,141	\$1,159,887
Office	\$376,095	\$561,118	\$640,026	\$948,152	\$944,567
Retail	\$388,704	\$518,536	\$625,122	\$1,192,145	\$1,367,613
Mix commercial	\$297,458	\$584,986	\$735,560	\$866,860	\$1,069,287
Business Park	\$843,869	\$989,513	\$1,252,182	\$1,368,438	\$1,823,736
Factory	\$398,882	\$1,158,534	\$1,496,107	\$1,655,429	\$2,194,344
Total	\$457,103	\$672,804	\$872,596	\$1,220,304	\$1,589,119

Sub use	Total cost existing	Total cost enhanced 1	Total cost enhanced 2	Total cost maximum	Total cost ultimate
HDB	\$1,115,557	\$1,568,361	\$2,790,931	\$5,553,998	\$8,855,755
Condo	\$1,623,198	\$2,556,889	\$3,862,373	\$5,876,111	\$14,005,580
Public mix	\$181,979	\$252,894	\$1,927,210	\$5,925,184	\$8,798,434
Private mix	\$1,911,146	\$2,256,605	\$3,348,148	\$4,506,030	\$8,650,794
Hotel	\$645,482	\$1,089,420	\$1,557,304	\$3,184,088	\$4,312,945
Office	\$488,368	\$778,811	\$1,305,113	\$2,898,332	\$4,870,354
Retail	\$782,769	\$1,245,396	\$1,985,188	\$4,713,556	\$6,538,577
Mix commercial	\$378,232	\$738,316	\$1,471,389	\$2,176,693	\$5,165,990
Business Park	\$1,428,517	\$1,790,202	\$3,527,170	\$4,268,911	\$8,020,227
Factory	\$605,422	\$1,807,686	\$3,951,642	\$4,778,832	\$9,752,865
Total	\$952,570	\$1,505,567	\$2,721,743	\$4,523,006	\$8,370,410

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

mean greenery cost of the various 100 audited domestic buildings, for the five design scenarios per building by land use.

Another version of the summary for the means of various greenery costs per sq. m. of the audited buildings for the five design scenarios per building by land use is presented in Table 2.6. On the whole, the mean maintenance, installation and total costs for all ten sub-use types rise sharply between the 'Maximum' and 'Ultimate' design scenarios. However, the mean maintenance, installation and total costs were found to either rise more gradually, stagnate or decline between the 'Enhanced 2' and 'Maximum' scenarios.

The highest mean total cost of about S\$315 per sq. m. was observed for the 'Ultimate' scenario for the 'Factory' sub-land use category, with a high mean installation cost of about S\$232 per sq. m. and the much lower mean maintenance cost of about S\$83 per sq. m. The 'Existing' scenario of the 'Business Park' sub-land use category had the lowest mean total cost of approximately S\$14 per sq. m., the third lowest mean installation cost of about S\$7 per sq. m., and the second lowest mean maintenance cost of about S\$7 per sq. m. The 'Factory' sub-land use category had the lowest mean installation cost of about S\$3 per sq. m. for the 'Existing' scenario but a relatively high mean maintenance cost of S\$13 per sq. m. and a mean total cost of about S\$16 per sq. m. for the same scenario. The 'Mixed-residential' sub-land use category had the lowest mean maintenance cost of about S\$5.6 per sq. m. for the 'Existing' scenario, but the mean installation cost of S\$14 per sq. m. and a mean total cost of about S\$20 per sq. m.

Figure 2.5 depicts the hyperbolic slow-to-sharp rising trend of GnPR with the assigned 'Total Cost (\$)' from the 'Existing' to the 'Ultimate' design scenarios. The average increase of GnPR level from the 'Existing' to the 'Ultimate' scenario was observed as follows:

- Residential — by 1.5 with total cost increase of S\$10 million;
- Mixed (Residential-Commercial) — by 1.3 with total cost increase of S\$7.4 million;

Table 2.6. Total cost of greenery per sq. m. for the five design scenarios

Design scenario		Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
Maintenance cost (\$\$ per sq. m., 10-year)						
Residential	Mean	13.61	15.34	18.35	27.03	35.38
	Std. deviation	27.87	28.58	30.71	34.98	36.63
Mixed residential	Mean	5.55	6.51	10.10	14.76	19.46
	Std. deviation	6.08	6.90	9.72	10.50	15.47
Commercial (Hotel, Office, Retail, Mixed)	Mean	15.14	22.38	25.64	36.01	40.99
	Std. deviation	18.12	25.75	26.44	33.29	36.39
Factory	Mean	13.00	53.75	64.62	69.26	82.93
	Std. deviation	11.42	67.33	82.74	82.75	105.09
Business park	Mean	7.15	9.30	13.97	15.02	20.86
	Std. deviation	5.16	3.86	4.91	5.63	8.37
Installation cost (\$\$ per sq. m.)						
Residential	Mean	10.93	18.31	34.78	27.03	120.11
	Std. deviation	9.49	12.56	26.05	34.98	108.82
Mixed residential	Mean	14.45	16.11	30.91	14.76	85.57
	Std. deviation	18.30	18.51	29.64	10.50	33.49
Commercial (Hotel, Office, Retail, Mixed)	Mean	5.37	13.27	31.89	36.01	124.08
	Std. deviation	7.99	30.46	38.54	33.29	105.49

(Continued)

Table 2.6. (Continued)

Design scenario		Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
Factory	Mean	2.87	18.49	76.65	69.26	232.23
	Std. deviation	2.20	23.80	115.80	82.75	329.60
Business park	Mean	6.63	9.12	34.37	15.02	78.72
	Std. deviation	2.62	2.68	22.44	5.63	34.70
Total cost (\$\$ per sq. m.)						
Residential	Mean	24.53	33.66	53.13	92.68	155.49
	Std. deviation	35.60	38.30	53.67	82.11	128.09
Mixed residential	Mean	20.00	22.62	41.01	66.76	105.04
	Std. deviation	23.78	24.54	38.52	43.42	46.82
Commercial (Hotel, Office, Retail, Mixed)	Mean	20.51	35.65	57.52	107.27	165.07
	Std. deviation	21.70	50.99	59.24	112.95	135.37
Factory	Mean	15.87	72.24	141.26	166.42	315.16
	Std. deviation	11.44	72.42	187.59	186.92	422.20
Business park	Mean	13.78	18.42	48.34	55.02	99.58
	Std. deviation	4.83	2.32	25.44	26.46	42.13

Source: Pomeroy & Broadway Malyan (2012); Author (2018)

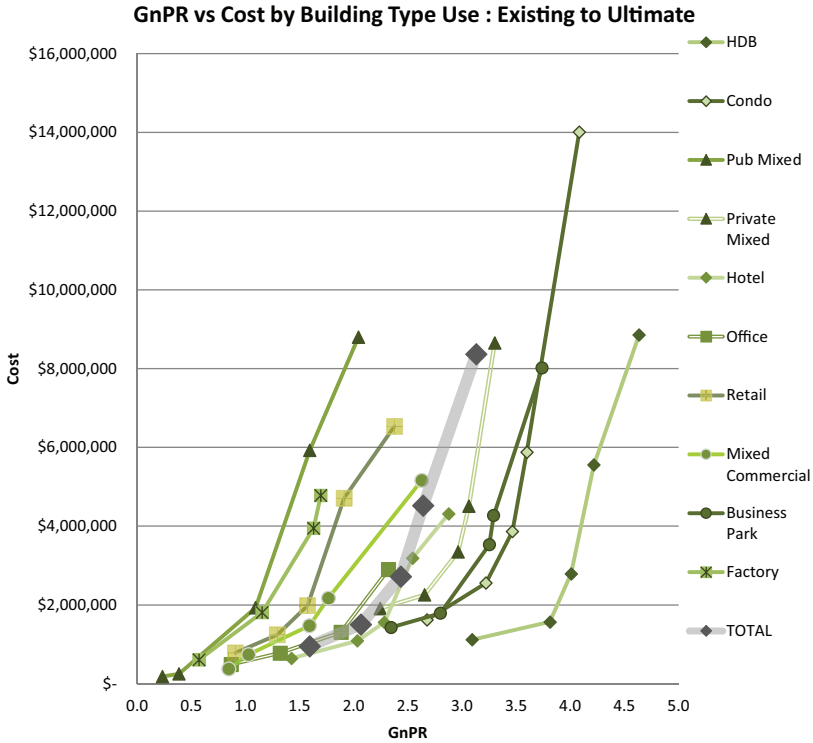


Fig. 2.5. GnPR vs. total cost

Source: Author, 2018

- Commercial — by 1.7 with total cost increase of S\$4.9 million;
- Factory — by 1.5 with total cost increase of S\$8.9 million;
- Business park — by 1.3 with total cost increase of S\$6.6 million.

The average increase of GnPR level from the ‘Maximum’ to the ‘Ultimate’ design scenario was observed as follows:

- Residential — by 0.5 with total cost increase of S\$5.9 million;
- Mixed (Residential-Commercial) — by 0.3 with total cost increase of S\$3.7 million;
- Commercial — by 0.6 with total cost increase of S\$2.0 million;
- Factory — by 0.4 with total cost increase of S\$4.8 million;
- Business Park — by 0.4 with total cost increase of S\$3.9 million.

A GnPR of 3.1 is achievable with the total cost of S\$8.4 million for the ‘Ultimate’ design scenario, while a GnPR of 2.6 with the total cost of S\$4.6 million is achievable for the ‘Maximum’ design scenario.

Marginal Cost Analysis (MCA)

The empirical data for the MCA model was obtained from the building audit of the 100 domestic buildings. The associated ‘Average Cost’ model, defined to be the total cost divided by GnPR level, was plotted in conjunction with the MCA model to generally validate the U-shape nature of the MCA model. The MCA model by the four land use categories was estimated and charted in a graph together with its approximated polynomial function, to indicate the narrow GnPR band around its minimum U-shaped point which is indicative of the optimal GnPR by land use and is highlighted as the lowest marginal cost band. The corresponding ‘Average Cost’ curves represent a more smoothened version of the MCA model’s curves and they broadly affirm the same pattern of the ‘Marginal Cost’ curves.

The lowest ‘Marginal Cost’ for the following five land uses (the ‘Industrial’ category was subdivided into ‘Factories’ and ‘Business parks’) was found to be at the following GnPR levels:

- Residential land use: the existing condition’s GnPR is 3.41 while the combined option’s is 3.67 with the total cost of S\$1,536,819.
- Mixed (residential-commercial) land use: the existing condition yields a GnPR of 1.03 while the combined option’s is 2.71 with the total cost of S\$5,125,360.
- Commercial land use: the GnPR for the existing condition is 0.56 while the combined option’s is 2.13 with the total cost of S\$425,440.
- Industrial land use — business parks: the existing condition’s GnPR is found to be 1.73 while the combined option’s is 1.97 with the total cost of S\$265,992.

- Industrial land use — factories: the existing condition's GnPR is calculated to be 0.25 while the combined option's is 1.66 with the total cost of S\$14,274,033.

The Optimal GnPR Values for Various Building Types in Singapore

To determine the optimal GnPR values, the heuristic algorithm previously described was used. The GnPR design and economic optimisation approaches for the model are shown below.

Part 1: The design optimisation

- The mean GnPR for the 'Existing' scenario is the low boundary of the optimal GnPR.
- The mean GnPR for the 'Ultimate' scenario is compared with GnPR values within the $+0.25SD$ and $+2.0SD$ boundary range.
- The lowest and closest GnPR value for an incremental SD to the mean for the GnPR of the 'Ultimate' scenario is chosen as the particular highest boundary for the optimal GnPR level.
- The 2 SD rule should hit at least the GnPR for the 'Enhanced 1' scenario.

Part 2: The economic optimisation

- The total cost (TC) for the 'Existing' and the 'Ultimate' design scenarios are provided for information. The TC comprises the green landscaping investment cost and the ten-year maintenance cost for both low and high GnPR values.
- The cost figures presented are the associated design cost of greenery (i.e. the cost that is nearest to the modelled optimum GnPR values).
- The optimal marginal GnPR values are compared with the optimal design GnPR values. The optimal value, derived by the economic

Table 2.7. Optimal GnPR, Singapore

Land use	Building type	Optimal GnPR (Design and Economic)	
		Low	High
Residential	Public	3.1	4.7
	Private	2.7	4.1
Mixed residential-commercial	Public	0.2	0.5
	Private	2.2	4.2
Commercial	Hotel	1.2	2.4
	Office	1.1	3.1
	Retail	0.9	2.6
	Mixed	0.8	2.6
Industrial	Business park	2.3	3.7
	Factory and warehouse	0.6	1.4

Source: Pomeroy & Broadway Malyan (2012); Author, 2018

approach, should be within the optimal GnPR range derived by the design approach. It would indicate that the optimal GnPR (design and economic) is conditioned by the returns to scale that are expected of greenery investing.

The results of the heuristically modelled ‘Optimal GnPR’ in the Singapore context for ten building types are presented in Table 2.7.

Concluding Remarks

To reiterate, the two main objectives of this book are:

- to provide the optimal levels of the green plot ratio (GnPR) for various land-use types; and
- to establish the capital and maintenance costs for various levels of greenery provision.

This book forms the basis of the development of a policy set of possible landscape guidelines, which can use this book’s ‘Optimal GnPR’

levels to facilitate a sustainable landscape for Singapore. A 'Landscape Guidelines' policy set can combine this book's building audit and its statistical analysis with the findings from a review of international best practices. Such landscape guidelines could provide the environmental, economic, aesthetic and social benefits of greenery for the urban built-up areas. This policy exercise could examine any current landscape strategies, the requirements, and technologies and underpin GnPR as an essential and modern tool for greenery measurement. The possible optimal GnPR levels for various land use categories in Singapore could help to illustrate greenery possibilities in a building, taking into consideration their corresponding installation and maintenance costs.

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03 Landscape Design Guidelines for Using GnPR in Singapore

Singapore's chronic and acute land scarcity means nature conservation and greenery replacement are very important. Provision of greenery has always been a key priority in Singapore's development and can be traced back to when the island state was undergoing rapid industrialisation and urbanisation. In 1968, the Singapore government started a strategy of integrating nature with urban development. This vision influenced subsequent urban development policies, with the first sustainability-oriented strategies developed under the Singapore Green Plan's concept of the 'garden city', which was introduced in 1992, reviewed in 1999 and a new plan developed in 2002. Known as the Green Plan 2012, it introduced a new set of strategies and targets for quality living in urban developments, as well as for sustaining economic prosperity (MEWR, 2019). One of the targets for 'conserving nature' was the expansion of parks and green linkages, which resulted in a substantial green cover expansion from 36 per cent to 47 per cent in the period from 1986 to 2007 (NParks, 2008).

The strategies and targets of the Green Plan 2012 were supported by various government policies and programmes. In 2009, initiative-based programmes like LUSH and the 'Skyrise Greenery Incentive Scheme' (URA, 2009; NParks, 2011) took the greening of Singapore to new heights of excellence. The programmes aimed to encourage building owners to retrofit their existing buildings and to design new developments with spaces for sky gardens and terraces. Skyrise greenery, like planting gardens on rooftops, terraces and balconies or along walls, form an important

and potential area for substantially enhancing the greenery in dense urban areas. Despite common misconceptions that rooftop and terrace gardens are complex to structure and need special structures to bear their weight, most modern green roof technologies are lightweight and require minimal maintenance. A variety of studies in Singapore have also shown their environmental benefits in dense urban areas, like the reduction of the urban heat island effect; increased biodiversity; thermal insulation and energy savings via the reduction of a building's cooling load; or the improvement of air quality due to their trapping of airborne dust particles, and the reduction of rainwater flow via the absorption and evaporation of rain water by the soil and vegetation.

Although skyrise greenery is deemed to be one of the most rapidly developing building features, it has yet to be regulated and implemented on an extensive scale; and needs to be tailored to specific national circumstances, especially in a tropical Asian country like Singapore, where forests and jungles prevail as part of our native habitat. This book introduces various sky rise landscaping systems and technologies that are implemented in Singapore, using the GnPR to calculate the amount of vegetation a real estate development should have. The resulting landscape guidelines can offer suggestions regarding the optimal levels of skyrise greenery for residential and mixed-residential private and public developments, hotels, offices, retail spaces, mixed commercial buildings, as well as business parks, factories and warehouses. The proposed landscape guidelines are not intended to replace existing regulatory guidelines and development procedures but to supplement them. The book also seeks to elaborate on the specific tools and recommendations to help the industry develop optimal greening strategies.

The landscape guidelines are intended to be used by building owners, real estate developers, architects, landscape architects, property managers and agencies and organisations involved in landscape related matters. They should set a new benchmark in the amount of vegetation cover for

several building types and could potentially help policy makers formulate, monitor and review new policies and standards on green space provision for real estate developments in Singapore and the Asian region.

Related Literature

In a dense tropical city like Singapore, urban greenery acts as a carbon sink, mitigates noise pollution and helps to reduce the urban heat island effect, while enhancing the quality of the urban ecosystem and bringing nature to the doorsteps of the urban dwellers (Wong & Chen, 2005; Wong, *et al.*, 2007; Wong, Tan, Tan, & Wong, 2009; Tan, Liao, Hwang, & Chua, 2019). These benefits have been validated through various studies undertaken for buildings in various parts of the world (Kohler, 1989; Mass, *et al.*, 2005). This book looks at several studies that examine the positive impacts of greenery on real estate developments from the economic, social and environmental viewpoints.

The Environmental Benefits

- Habitat preservation is an essential urban environmental benefit. Urban greenery contributes to a city's ecosystem and improves urban biodiversity by providing suitable habitats for wildlife, like native birds.
- Plants help to cleanse the air by producing oxygen and removing carbon dioxide, particulates and pollutants. A study conducted by (Minke & Witter, 1982) showed that a tree can produce enough oxygen every hour to support ten humans. Trees can also trap up to 85 per cent of airborne particles on leaf surfaces. A study conducted in 1991 for the Cook and DuPage counties in Chicago, USA (the study comprised a large total land area of 3,350 sq. km. and accounted for a relatively large population of approximately six million people) showed that about 5,575 mg of air pollutants were removed by the study area's urban forest (McPherson, 1994).

- Plants improve the climate and help mitigate the Urban Heat Island (UHI) Effect. Studies in many cities including Toronto, Chicago and Singapore have shown that skyscraper greenery significantly contribute to the urban thermal environment by reducing the ambient and surface temperatures of a building and its immediate surroundings. Buildings, roads and other sealed surfaces absorb and store heat in the city, creating a higher temperature than in the surrounding countryside. In particular, a study in Singapore highlighted that a maximum temperature difference of 4°C occurs between the southern ‘urban’ area to the northern ‘rural’ area, as shown in Fig. 3.1 (Wong & Chen, 2005). The difference in temperatures creates an air current where warm air rises over the city, while cooler, polluted air from the industrial areas is sucked in from the outer areas towards the central high-density areas (Arrau & Peña, 2011). A study of rooftop gardens in Singapore revealed that such a garden reduces the

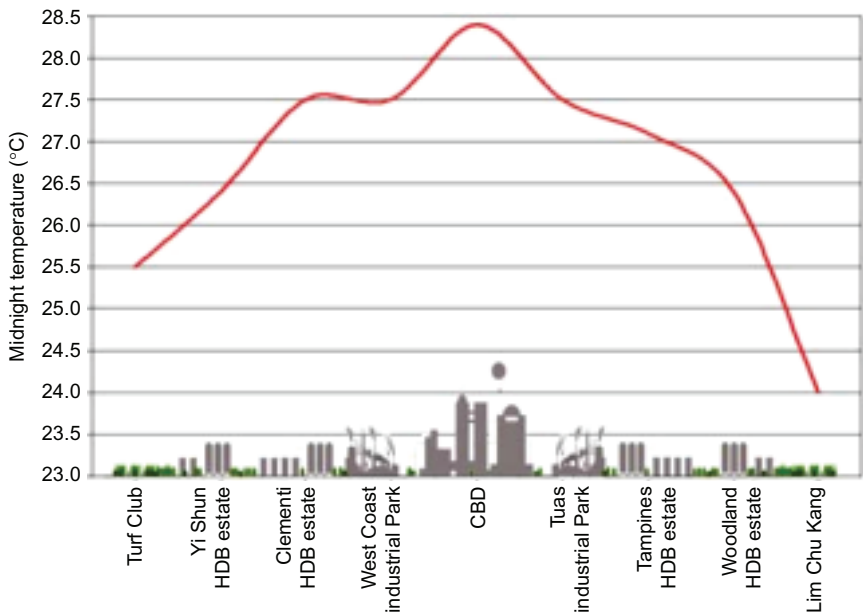


Fig. 3.1. Singapore's Urban Heat Island profile

Source: (Wong & Chen, 2005)

roof top ambient temperature by up to 3°C, significantly improving the thermal environment around the roofs. The roof top garden significantly benefitted not only the buildings that had them but also the surrounding areas (Wong, *et al.*, 2007).

- Vegetation on buildings slow down storm water runoff and absorb pollutants from the rain. Various studies have shown that green roofs absorb an average of 75 per cent of the prevailing rainfall. Plants also help to reduce storm water runoff (Kohler, 1989). In Portland, USA, green roofs are required and implemented for new real estate developments, to prevent storm water from overwhelming the city's sewer system.

Economic Benefits

- Rooftop gardens reduce energy consumption. They may act as rooftop insulators, cooling the building envelope and reducing the air-conditioning load. A study in Japan's capital city, Tokyo, showed that a reduction in the air temperature of between 0.11 and 0.84°C could be achieved if 50 per cent of rooftops are planted with roof gardens. The energy savings were estimated to be about S\$1.6 million a day based on the aggregate electricity bill (Hitoshi, 2000). All costs and building values are in S\$ terms.
- Green walls reduce energy consumption. Energy simulations were conducted for a hypothetical ten-storey building with a glass façade and findings highlighted that having a full vertical greenery system coverage on its façade could reduce the building's mean radiant temperature by about 10°C, which corresponds to reducing the energy consumption by 31.75 per cent (Wong, Tan, Tan, & Wong, 2009)
- Greenery increases property (real estate) value. Direct real estate commercial developments that incorporate greenery are more likely to be more attractive and may result in an increase in the building's property value, which can help firms as well as the community as

a whole. Households and firms are often more willing to pay more for eco-friendly buildings and neighbourhoods. Rooftop gardens can also provide garden-like facilities like spas, reading rooms, cafés and nurseries for the enjoyment of the buildings' occupants. A study by Truett (2003) reported that landscaping and landscape amenities have a value-add of up to 20 per cent of the building value.

Aesthetic and Social Benefits

- Sky gardens provide scenic views and access to outdoor spaces for building occupants. They can also be used for relaxation or as a community garden.
- Urban and semi urban environments with access to green spaces offer potential psychological and mental health benefits that can come from exposure to nature. (Seymor, 2003; Tan, Liao, Hwang, & Chua, 2019).
- Living near a green space can improve health by reducing stress levels and the rates of mental ill-health, as well as asthma and high blood pressure. It could also improve the recovery rate of sick patients. A study in the Netherlands found that for every 10 per cent increase in green spaces, there was a reduction in health complaints equivalent to a reduction of five years in age (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003).
- Another related study found that the annual prevalence in disease clusters is lower in environments that have more green spaces within a 1 km radius. The effects are stronger for people suffering from disorders such as anxiety and depression as well as for children and adults from lower socio-economic strata (Mass, *et al.*, 2005).
- According to Kua & Sia (2016) and Barton & Rogerson (2017), urban dwellers in a high-density environment who use a balcony or terrace garden are less vulnerable to illnesses.

Other Considerations

- Skyrise greenery is generally thought to be expensive to install and maintain. However, careful choice of plants and green wall systems and proper provision of storage spaces for maintenance equipment, as well as maintenance-centred building design, can help to achieve minimal maintenance and cost.
- Proper water proofing prior to the installation of a rooftop garden and/or a green wall can help to prevent the occurrence of leakages and the staining of walls.
- Concerns regarding the security of publicly accessible rooftop gardens and sky terraces need to be addressed at the design stage.
- Greening alone may not be an effective technique to achieve urban sustainability for the built environment but the effects of greening are cumulative. A rooftop garden alone may not be significant but the extensive greening of Singapore island-wide, may significantly improve the urban climate.

Policy Requirements and Programmes Stimulating Green Spaces Provision within a Real Estate Development in Singapore

Singapore's development into a 'Garden City' started four decades ago with the establishment of the government's greening programme (NParks, 2008). The driving force was Singapore's founding Prime Minister, the late Mr Lee Kuan Yew, who envisaged greenery as the city's key competitive and comparative advantage to attract foreign direct investments and global trade to Singapore. Since then, the provision of greenery within real estate developments have been popular in the high-density residential, retail and office sectors. With the rapidly expanding built-up areas in Singapore, the social and ecological benefits become equally important.

Greenery Provision for BCA's Green Mark Scheme

Singapore's 'BCA Green Mark Scheme' is a voluntary green building rating system for the development of high-performance sustainable buildings (BCA, 2017). Out of the 155 required points awarded by the 'Green Mark Certification Scheme' to promote environmental protection, residential and non-residential buildings can achieve one point for each level of GnPR in the provision of greenery, and one point for the restoration of trees on site.

Skyrise Greenery Awards

The skyrise greenery competition is open to architects, building owners, landscape architects and contract managers of real estate development projects (NParks, 2008). Winning projects receive an NParks 'Skyrise Greenery Award' and cash prizes of USD\$8,000 (1st prize), USD\$5,000 (2nd prize) and USD\$2,000 (3rd prize). In 2011, the 'SIA (Singapore Institute of Architects)-NParks Skyrise Greenery Awards' were given out to several local projects, like the hanging garden at 158 Cecil Street, the landscape installations in 'Helios Residences', the vertical garden in the hall of the office tower at 6 Battery Road and the landscaped deck in the 'Mapletree Business City' office-retail complex at the western end of Singapore (Lok, 2012).

NParks Skyrise Greenery Incentive Scheme

The 'Skyrise Greenery Incentive Scheme' (NParks, 2019) provides funding support for building owners undertaking the greening of roof tops and building façades. NParks provides cash incentives of up to half the cost of the installation capital of green roofs and green external walls.

Landscaping for Urban Spaces and High Rises (LUSH) Programme

In April 2009, an indirect financial initiative-based programme known as the 'Landscaping for Urban Spaces and High Rises (LUSH) Programme

was introduced by Singapore's URA (URA, 2009). It consolidates the existing, revised and new initiatives to encourage private real estate developers to provide more green spaces within their developments. Details of LUSH, like its guidelines and standards, can be found on URA's website, along with the main planning policies and requirements for the associated 'Gross Floor Area (GFA)' exemption which allows an increase in the building density (URA, 2017).

Landscape Replacement Policy for Strategic Areas

As more land is taken up by buildings in areas of high density, URA's innovative 'Landscape Replacement Policy for Strategic Areas' seeks to encourage the replacement of greenery lost to building footprints, with skyrise gardens and rooftop terraces on the first-storey and upper levels of a real estate development. Such a policy sets a minimum landscape area requirement in Singapore's Downtown Core, including the Marina Bay Central Business District (CBD), the nearby Kallang Riverside development and the Jurong Gateway at the western end of Singapore (URA, 2009). The policy requires the provision of landscape replacement areas on the ground or on the building that, in total, are at least equivalent in size to the real estate development site area. It calls for at least 40 per cent of the landscape replacement area to be allocated for permanent planting with sufficient soil depth.

Outdoor Refreshment Area on Landscaped Roof Tops

The Urban Redevelopment Authority (URA) of Singapore offers additional Gross Floor Area (GFA) beyond the 'Master Plan' gross plot ratio (GPR) control for existing buildings in the prime Orchard Road retail belt and the CBD, if building owners provide roof top landscaping for their real estate developments (URA, 2009).

GFA Exemption for Communal Sky Terraces

The 'Sky terrace GFA exemption guidelines' (URA, 2019) encourages high quality community spaces and greenery at sky terraces. The required

sky terrace, which is itself open to the public or to building occupants, stipulates the maximum area for GFA exemption. This maximum area is defined by the area under the 45-degree line, taken from the edge of the overhead projection.

Landscaped Deck

The 'Landscape Deck Guidelines' (URA, 2009) advise real estate developers to build car parks underneath a raised deck structure. The top surface of the deck, which is free from vehicular traffic, needs to be enhanced with landscaping and also be suitable for the provision of communal facilities. The guidelines require that a minimum of 60 per cent of the edges of the raised car park deck are landscaped with trees or shrubs.

Provision of Greenery within the Green Buffer and Peripheral Planting Strip

Since 2003, all new private real estate developments have been required to provide at-grade greenery between developments. The green buffer required is a two-metre peripheral tree planting strip (NParks, 2018). The technical requirements for the green buffer include a recommended distance of five to six metres between the trees, a minimum soil depth of two metres and a two-metre distance from any element to the centre of a tree.

GFA Incentive for Balconies in Residential and Hotel Developments

The 'Balcony Bonus Gross Floor Area (Balcony GFA) Scheme' (BCA, 2018) seeks to encourage real estate developers to incorporate balconies in their residential and hotel developments, and to facilitate planting and skyrise greenery. The ten per cent of additional GFA above the 'Master Plan' GPR control is granted if at least 40 per cent of the balcony's

perimeter is disclosed for skyrise gardening. However, the balconies are allowed to be screened to qualify for the GFA scheme.

GFA Exemption for Communal Landscaped Area at the 1st Storey

The ‘Gross Floor Area (GFA) Exemption for Covered Communal Ground Gardens’ (URA, 2014) policy seeks to encourage a more generous provision of covered landscaped communal areas and greenery on the first floor of new real estate developments. The maximum area to be exempted is defined by a 45-degree line taken from the edge of the overhead projection. The landscaped areas must be unenclosed, accessible and useable for communal activities.

GFA Exemption for Communal Planter Boxes

The ‘Bonus Gross Floor Area (GFA) Exemption for Communal Planter Boxes’ (URA, 2014) policy offers GFA exemption for planter boxes in real estate residential and non-residential buildings. Such a policy seeks to provide vertical greenery and to contribute to the greening of a high-density and sustainable urban environment.

Green Plot Ratio (GnPR) Definition

GnPR was originally defined by Ong (2002) as the ‘average leaf area index (LAI) of the greenery of a site’, where LAI is the area of a plant’s leaf per unit ground area that the leaf occupies. The current definition is developed and adopted by NParks, which is ‘the area weighted average leaf area index of a site’ (Tan & Sia, 2009), and is expressed in Eq. (3.1).

$$GnPR = \frac{\text{total leaf area}}{\text{site area}} = \frac{\sum LAI_1 \times \text{Canopy Area}_1 + \dots + LAI_n \times \text{Canopy Area}_n}{\text{Site Area}} \quad (3.1)$$

Table 3.1. Summary of the main plant groups and sub-categories, their LAI and canopy area

Category	Sub-category	LAI value (A)	Canopy area per unit (m ²)
Trees	Open	2.5	60
	Intermediate	3.0	60
	Dense	4.0	60
Palm	Solitary	2.5	20
	Cluster	4.0	17
Trellis	Horizontal	2.0	—
Roof planting	Extensive	2.0	—
	Intensive	varies	—
Soft scape of 0% landscape	Turf	2.0	1
	Shrub Mono	3.5	—
	Dico	4.5	—

Source: Author (2018)

The LAI values for different types of plants can be found in Tan & Sia (2009). The plants in the guidebook are categorised into several groups, like trees, palms, shrubs, ground covers and turf; and into several sub-groups defined by canopy density for trees, canopy type for palms, and by structure for shrubs. To calculate a real estate development’s GnPR, the plant’s group and its canopy type, as well as the number of plants and the area occupied by plants should be identified. Table 3.1 presents the summarised plant groups, their respective LAI values and the canopy areas to be utilised.

Optimal GnPR Values for Various Building Types

The GnPR study, which defines the optimal GnPR values for the various building types was conducted as a multi-agency joint research collaboration involving NUS, NParks, URA, HDB and JTC. The multi-agency research team selected 100 direct real estate developments from across the major land use types in Singapore, for an in-depth building audit of the existing greenery provisions and the parameters that influence GnPR levels. A consistent greening strategy with respect

Table 3.2. Optimal Green Plot Ratio (GnPR) values

Land use	Building type	Optimal GnPR (Design and Economic)	
		Low	High
Residential	Public	3.1	4.7
	Private	2.7	4.1
Mixed residential-commercial	Public	0.2	0.5
	Private	2.2	4.2
Commercial	Hotel	1.2	2.4
	Office	1.1	3.1
	Retail	0.9	2.6
	Mixed	0.8	2.6
Industrial	Business park	2.3	3.7
	Factory & warehouse	0.6	1.4

Source: Author (2018)

to cost and structural and urban design limitations was developed and extended to analyse the increase in and the amount of greenery in the direct real estate developments audited. Table 3.2 presents the optimal GnPR parameters for the various building types, which are ascertained via a rigorous statistical analysis of the data set from the building audit and the associated design simulation exercise.

Resulting Landscape Elements and Technologies

Extensive Green Roofs

Extensive green roofs have a thin growing medium, use succulents, indigenous herbs and grasses, require minimal maintenance, and in general do not require irrigation. Extensive green roofs are less costly to install than intensive green roofs.

Main features:

- Lightweight in design, can be installed on most roofs without structural modifications



Fig. 3.2. Intensive roof on the top of a carpark



Fig. 3.3. Marina Barrage, Singapore

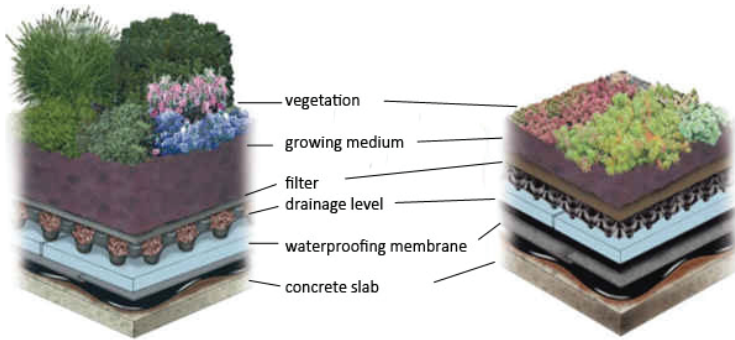


Fig. 3.4. Structure of an extensive vs intensive green roof

- Serve more environmental benefits than aesthetics
- Require 8–10 cm planting media
- Low installation cost
- Low maintenance
- Low water usage
- Self-sustaining
- Suitability of plants restricted to drought-tolerant plants
- Low wildlife potential

Applications:

- On slopes of up to 45 degrees
- Non-human trafficked areas
- Low load-bearing structures
- Relatively easy to install on existing roofs
- Rooftops, sky terraces, podium gardens

The Intensive Green Roof

Landscape possibilities with intensive green roofs are virtually limitless. Some examples of potential uses include recreation and sports.

Main features:

- Landscape design allows multiple possibilities to combine greenery with hardscapes and water features

- Usually designed to allow access by people
- Require high loading designs to accommodate various landscapes and tall trees
- Trees require a minimum of 1,000 mm of planting medium, while shrubs require a minimum of 450 mm of planting medium
- Require frequent maintenance; such as mowing, pruning, fertilising and watering
- High installation cost
- High maintenance cost
- Potential to enhance urban biodiversity

Applications:

- Flat roofs and sky terraces
- New buildings with appropriate weight loading capacity
- Rooftops, sky terraces, podium gardens



Fig. 3.5. Intensive green roof at a residential HDB estate



Fig. 3.6. Tampines Green Terrace, Singapore

Green Wall (Carrier System)

A Green Wall (Carrier System) can be either a free-standing structure or attached to a wall of a building, and covered with vegetation. The structure contains a series of modules with light weight planting media and plants fed by a drip irrigation system.

Main features:

- Lightweight and modular
- Robust and easy to assemble



Fig. 3.7. A green wall module



Fig. 3.8. Green wall installation at Hort Park, Singapore

- Modules can be easily replaced; allows for flexible design change
- Cater for a wide variety/selection of plants
- Requires an intensive fertigation system
- High installation cost
- High maintenance cost

Applications:

- Building façades
- Screen walls
- Walkways and linkways
- Feature walls and garden landscaping

Green Wall (Support System)

A Green Wall (Support System) allows plants to climb up on a vertical surface via a support structure such as wire cable system or wire mesh surface, and has a planter box at its top or bottom.

Main features:

- Plants could be grown directly from the ground or from the planter boxes
- Lightweight and modular
- Robust and easy to assemble
- Hosts only climbing plants or cascading groundcovers
- Requires a minimum of 300 mm of media depth

Applications:

- Building façades
- Walkways and linkways



Fig. 3.9. Mesh structural support for green wall support system



Fig. 3.10. Climbers planted into planter boxes at Singapore Management University

Cost of Landscape Elements

The installation capital cost of the landscape elements, their LAI and their illustrations are provided in Table 3.3, using the basis of a competitive and comparatively advantaged market in Singapore with the unit costs being achievable. The maintenance cost and the cost of the irrigation system are excluded. The associated values are from the end of 2012, subject to changes and merely used as a reference guide.

Table 3.4 compares the relative strengths and weaknesses of the various landscape elements and technologies.

Table 3.3. Installation capital costs and LAI of landscape elements

Element (<i>Landscape Element</i>)	LAI	Cost in S\$	Illustration
Tree	2.5–4.0	300–400	
Tree planter	2.5	550–750	
Palm	2.5–4.0	60–90	
Palm planter	2.54.0	300–500	
Shrub	3.5–4.5	60–90	
Shrub planter	3.5–4.0	450–700	
Turf	2	25–35/m ²	
Green wall (Carrier system)	2	850–1100/m ²	

(Continued)

Table 3.3. (Continued)

Element (Landscape Element)	LAI	Cost in S\$	Illustration
Green wall (Support system)	2	550–800/m ²	
Horizontal Trellis	2	550–800/m ²	
Extensive roof	2	250–500/m ²	
Intensive roof	3.5	500–900/m ²	

Source: Author (2018)

Table 3.4. Strengths and weaknesses of various landscape elements

Kit of parts (landscape elements)	Planting on the ground					Skyrise greenery				
	Ground					Extensive roof	Intensive roof	Green wall	Planter box	Trellis structure
	Turf	cover	Shrub	Tree	Palm					
Lightweight						√	χ	√	√	√
Shallow planting medium			χ			√ (80–100 mm)	χ (450– 1,000 mm)	√	√	√
Low installation cost			√			√	χ	χ	√	√
Low maintenance			√			√	χ	χ	χ	χ
Low water usage			χ			√	χ	√	√	√
Self-sustaining			χ			√	χ	χ	χ	χ
Wide variety of species			√			χ	√	√	√	χ
High wildlife potential			√			χ	√	χ	χ	χ
Accessible for use			√			χ	√	χ	χ	χ
Flexible for design change			√			χ	χ	√	√	χ
Easy to assemble			√			χ	χ	√	√	χ

Source: Author (2018)

Design Considerations

Retrofit and Redevelopment

The incorporation of green spaces in buildings can use two design approaches. In scenarios involving the retrofitting of an existing building, greenery can be optimised from the ground level to the upper and top horizontal levels and the vertical surfaces respectively. The GnPR level can then be estimated and designed on the 'drawing board' for a redevelopment or for a new development. The support structures can be designed as an internal part of the façade and horizontal levels. While existing buildings may not be as efficient as newly constructed facilities, green building retrofitting can improve their GnPR levels. The amount of greenery and the energy efficiency of these improvements can provide the environmental, economic and social benefits of interest.

Step-by-Step Design Guide

The following steps are suggested for retrofitting an existing real estate development, with the purpose of providing more green spaces and the optimal GnPR level:

- Contact a local planning authority if necessary;
- Contact experts as needed;
- Identify the possible areas for greenery application;
- Conduct a structured survey in the majority of cases to determine a building's roof load bearing capacity before designing a building retrofit to enhance its greenery. The weight of the green roof system has to be considered when determining the retrofit potential;
- Identify the area of greenery application, the strength and durability of the existing waterproofing and the material requirements, as suggested by the experts;
- Prepare landscape plans, taking into consideration sunlight, the position of surrounding buildings, the shaded areas, the visible areas from ground level, accessibility, pedestrian walkways and shading;

- Select the drainage and irrigation methods;
- Choose the type of planting medium and the plant species;
- Calculate the amount of soil and the number of plants needed;
- Prepare a maintenance plan;
- Obtain quotes for the required materials, professional fees, the cost of structural changes, the greenery installation capital cost and the maintenance cost.

Design Aspects for the Audit of a Building's Green Space

Six design aspects are suggested for consideration in conjunction with the real estate development site audit. Although they are not exhaustive, they can provide a starting point for the various dimensions of traditional greenery and skyrise greenery.

Spatial Design

Questions to ask:

- Are there areas on the ground plane that have little or no planting?
- Are there visible service (i.e. operational) areas from the public view point that are not landscaped?
- Does the existing circulation pattern support increased planting and activity on the ground plane?
- Is there an opportunity to green the rooftop? Greening of the rooftops can help to lower the temperature between the outside and the top floor of the building; and provide recreational spaces.
- Will vertical planting improve the design integrity of the building?

Environmental Design

Questions to ask:

- Does the ground plane lack an established planting strategy?
- Does the ground plane continue an established landscape style or character as defined by the street wall?

- Can the western or eastern façade of the building benefit from vertical greening?
- Is the existing microclimate uncomfortable?

Social Design

Questions to ask:

- Are there underutilised areas that could be turned into passive or active recreational spaces?
- Can the quality of the existing communal areas be improved with increased planting?
- Is the rooftop easily accessible?
- Are there good views from the rooftop?

Cultural Design

Questions to ask:

- Will intensifying the existing greening on the site contribute to its unique character?
- Will incorporating vertical greening on the building reinforce its identity?
- Will increased planting (horizontal or vertical) improve how the building integrates with its surroundings?

Technological Design

Questions to ask:

- Is the rooftop flat?
- Is the building façade continuous?
- Do punctuations and variations in the façade provide planting opportunities?
- Are there opportunities to synthesise with existing greening technologies on site, like solar power to manage irrigation?
- Is there an existing irrigation or maintenance strategy?

Landscape Design

Questions to ask:

- What is the existing planting strategy?
- Does the planting provide a diversity of plant types? How intensive is this?
- Are there any predominant species or groups of plants onsite?
- Are native plants used?
- Does the choice of plants offered enhance urban biodiversity?

Figure 3.11 illustrates the various parts of a building where the greenery landscape elements can be added onto the horizontal and vertical planes.

The following suggested steps, while not exhaustive, seek to offer an appropriate starting point, when considering the various aspects of greenery provision for a real estate development.

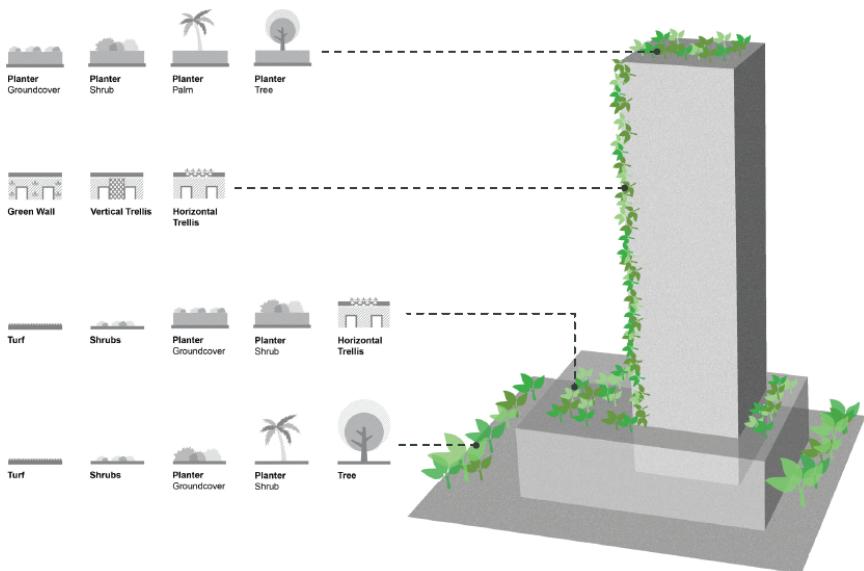
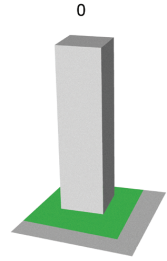


Fig. 3.11. Spatial categorisation of landscape elements

Source: Author (2018)

Existing Greenery

- Identify the areas that are important to retain. Keep the mature trees, retain and enhance valuable wildlife habitats and spaces valued by the local community.
- Maximise opportunities for new planting. Plant on the ground level whenever possible; use vegetation as buffers for buildings against wind and rain.
- Minimise sealed surfaces using paving systems which incorporate vegetation and use plants as alternatives to hard landscaping such as fences, barriers and walls.
- Plan for long-term management of the green areas. Determine the objectives, management agency and funding.
- Consider community involvement in the planning and management of green areas.



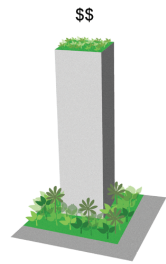
Enhancing Greenery on the Ground Level

- Enhance the existing vegetation on the ground with various landscape elements, such as trees, palms, shrubs, turf, and ground covers applied to the ground level, including link way shelters and boundary walls.
- Turf can be installed at large areas exposed to heat gain that are infrequently trafficked.
- Trees and/or palms can be installed either in planter boxes or as part of the 'soft scape' in pedestrian-intensive areas to provide shade.
- Horizontal trellises with creeper plants can be installed to provide cover in public areas.
- Design the green spaces to screen the service areas.



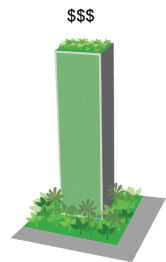
Enhancing the Greenery on the Upper Horizontal Levels

- Apply various greenery systems to the roof tops, podiums, terraces, and balconies (subject to the horizontal levels having the load bearing capacity).
- An extensive green roof should be installed if the load-bearing capacity permits, while keeping a one metre perimeter to the edge of the roof structure.
- Greenery can be enhanced around the service areas.



Applying Vegetation Systems on Vertical Surfaces

- Maximise greenery by applying vertical systems on façades, such as green walls (subject to the building's walls having the load bearing capacity needed).
- Green walls can be installed in car park structures where there is a minimum setback of ten metres from the nearest structure.
- Green walls can be installed on east- and west-facing building façades provided there is a minimum setback of ten metres from the nearest structure.
- The installation of a green wall would reduce heat gain on a building's façade and help create a greener sky rise environment, thereby enhancing the visual aesthetics at street level.
- Planter boxes can also be installed on the building's façade provided there is a minimum setback of ten metres from the nearest structure.



Further Greenery Enhancements

Consider the structural adaptations of roofs and walls for incorporating sky gardens, terraces and green walls:

- Sky terraces can be incorporated in building designs in accordance with the URA guidelines for GFA exemption and NParks' 'Skyrise Greenery Scheme'.



- While providing additional spaces in the building for greenery, access to outdoor spaces for building occupants and the opportunities for social interaction should also be considered.

Results and Findings

Illustration of GnPR Application for the Calculation of the Amount of Greenery in a Real Estate Development

Example 1: Calculation of GnPR for the existing green space

Figure 3.12 depicts a mixed use residential-commercial development with a site area of 14,700 sq. m., inclusive of a free-standing multi-level car park. The main building comprises a large podium, retail space and a residential tower in the middle of the podium.

The 3,150 sq. m. area in front of the building is landscaped with 13 solitary palms and is planted with turf, occupying about 23 per cent of the site area. The existing landscape at ground level is poorly integrated but future enhancement may be difficult owing to limited space. The space between the main building and the car park can potentially be filled with plants that do not require much sunlight. The top of the car park

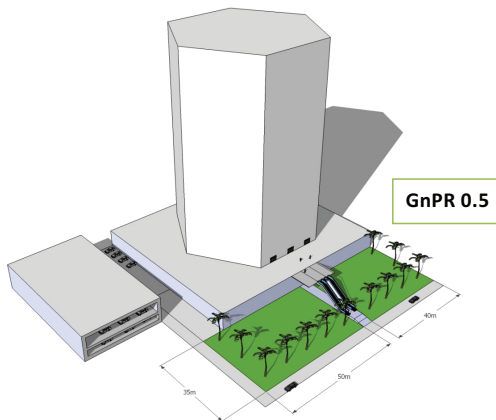


Fig. 3.12. A mixed commercial-residential building with GnPR of 0.5

Source: Author (2018)

and the larger portion of the podium top are flat and accessible and offer potential space for either high-volume public usage or private residential recreational facilities. Access to the rooftop is restricted while the roof is occupied with existing services that limit greenery possibilities. The south façade of the residential tower faces the main road and can be enhanced with vertical vegetation that should be visible to the public and should also reinforce the building's identity.

The simulated model is drawn to scale and serves for merely illustration purposes. For convenience, the calculation of GnPR of the site is presented in Table 3.5.

Example 2: Enhanced green space at ground level and the resulting GnPR of 0.7

The abandoned paved areas between the carpark and the main building could benefit from real estate redevelopment that can create an additional landscaped area of about 800 sq. m. via the planting of a green buffer along the road. The greenery is intensified with a GnPR of 0.2 with the addition of 21 solitary palms, 3,950 sq. m. of turf and 275 sq. m. of dicotyledon (dicot) shrubs (see Fig. 3.13 and Table 3.6). Dicot shrubs are preferred as they contribute to a higher leaf area and are known to be more durable and suitable for screening from roads.

Example 3: Retrofitting of the upper horizontal levels

The tops of the podium and the car park are to be accessible, visible from the surrounding areas, open and flat. This presents a good opportunity for the integration of the intensive green roof system with a variety of landscape elements including trees, palms and shrubs. The accessible garden can also be used as a recreational deck for the building's occupants that can benefit the community. Such retrofitting may be reflected in the value placed on the building. The recreational deck can even be

Table 3.5. Calculation of existing GnPR

Example 1: Existing green space											
	Category		Sub-category				LAI value (A)	Canopy area per unit (m²)	No./ Area	Leaf area	% of GnPR
Green Area 3150	Trees		Open				2.5	60	0	0	0%
			Intermediate				3.0	60	0	0	0%
			Dense				4.0	60	0	0	0%
Ground	Palm		Solitary				2.5	20	13	650	9%
			Cluster				4.0	17	0	0	0%
	Trellis		Horizontal				2.0	1	0	0	0%
	Softscape of landscape	0%	Turf	0%	—		2.0	1	3150	6300	91%
			Shrub	0%	Mono	0%	3.5	1	0	0	0%
					Dico	0%	4.5	1	0	0	0%
Podium and Car park	Trees		Open				2.5	60	0	0	0%
			Intermediate				3.0	60	0	0	0%
			Dense				4.0	60	0	0	0%
	Palm		Solitary				2.5	20	0	0	0%
			Cluster				4.0	17	0	0	0%
	Trellis		Horizontal				2.0	1	0	0	0%
	Roof planting		Extensive				2.0	1	0	0	0%
			Intensive				4.5	1	0	0	0%

(Continued)

Table 3.5. (Continued)

Example 1: Existing green space											
	Category		Sub-category				LAI value (A)	Canopy area per unit (m²)	No./ Area	Leaf area	% of GnPR
	Softscape of landscape	0%	Turf	0%	—		2.0	1	0	0	0%
			Shrub	0%	Mono	0%	3.5	1	0	0	0%
					Dico	0%	4.5	1	0	0	0%
Roof top and Terrace	Trees		Open				2.5	60	0	0	0%
			Intermediate				3.0	60	0	0	0%
			Dense				4.0	60	0	0	0%
	Palm		Solitary				2.5	20	0	0	0%
			Cluster				4.0	17	0	0	0%
	Trellis		Horizontal				2.0	1	0	0	0%
	Green roof		Extensive				2.0	1	0	0	0%
Intensive				4.5	1	0	0	0%			
Balcony	Tree planter		Open				2.5	0	0	0	0%
	Green roof		Extensive				2.0	1	0	0	0%
			Intensive				4.5	1	0	0	0%
Façade	Green wall		Support				2.0	1	0	0	0%
			Carrier				2.0	1	0	0	0%
							Total Leaf Area			6,950	
							Site Area			14,700	
							GnPR			0.5	

Source: Author (2018)

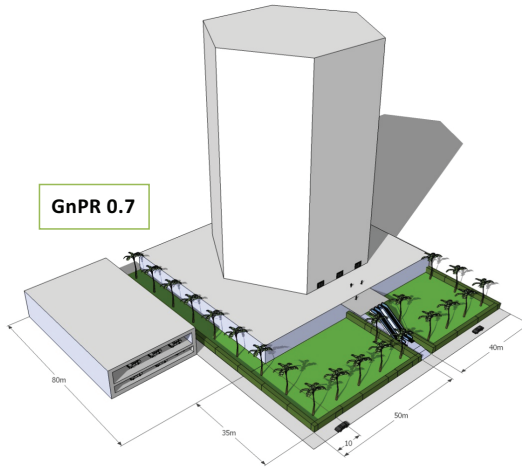


Fig. 3.13. Enhanced green space at ground level raises building GnPR to 0.7

Source: Authors (2018)

consolidated with a rooftop pool, a spa, a playground or a gymnasium. The lush vegetation can serve as a habitat for small birds.

Since the roof is usually partially occupied with heavy service equipment that limit possibilities for intensive rooftop greenery, an extensive system can be installed on the residential tower top. Drought-tolerant and self-sustaining native plant species are proposed to be planted in this extensive system. It will allow for minimal maintenance and could also serve as an acoustic and thermal barrier that can decrease the building's air-conditioning load. The extensive system can even serve as a storage site and filter for rainwater. Rooftop gardens can contribute at large to reducing the urban heat island effect. Six additional trees with open canopies can be installed in planter boxes in front of the residential entrance on the podium top to shade the pedestrian path. As shown in Fig. 3.14 and Table 3.7, the GnPR of the site increases to 3.4 with the suggested improvements.

Table 3.6. GnPR calculation for a building with enhanced green space at ground level

Example 2: Building retrofit — enhanced green space at ground level											
	Category			Sub-category			LAI value (A)	Canopy area per unit (m²)	No./ area	Leaf area	% of GnPR
Green area 3950	Trees			Open			2.5	60	0	0	0%
				Intermediate			3.0	60	0	0	0%
				Dense			4.0	60	0	0	0%
Ground	Palm			Solitary			2.5	20	21	1,050	9%
				Cluster			4.0	17	0	0	0%
	Trellis			Horizontal			2.0	1	0	0	0%
	Softscape of landscape	0%	2.0	0%	—		2.0	1	3,950	7,900	78%
			3.5	0%	Mono	0%	3.5	1	0	0	0%
			4.5		Dico	0%	4.5	1	275	1,238	12%
Podium and Car park	Trees			Open			2.5	60	0	0	0%
				Intermediate			3.0	60	0	0	0%
				Dense			4.0	60	0	0	0%
	Palm			Solitary			2.5	20	0	0	0%
				Cluster			4.0	17	0	0	0%
	Trellis			Horizontal			2.0	1	0	0	0%
	Roof planting			Extensive			2.0	1	0	0	0%
				Intensive			4.5	1	0	0	0%

	Softscape of landscape	0%	2.0	0%	—		2.0	1	0	0	0%
3.5			0%	Mono	0%	3.5	1	0	0	0%	
4.5				Dico	0%	4.5	1	0	0	0%	
Rooftop and Terrace	Trees		Open			2.5	60	0	0	0%	
			Intermediate			3.0	60	0	0	0%	
			Dense			4.0	60	0	0	0%	
	Palm		Solitary			2.5	20	0	0	0%	
			Cluster			4.0	17	0	0	0%	
	Green roof		Extensive			2.0	1	0	0	0%	
			Intensive			4.5	1	0	0	0%	
Balcony	Tree Planter		Open			2.5	0	0	0	0%	
	Green roof		Extensive			2.0	1	0	0	0%	
			Intensive			4.5	1	0	0	0%	
Façade	Green wall		Support			2.0	1	0	0	0%	
			Carrier			2.0	1	0	0	0%	
Total Leaf Area								10,088			
								14,700			
								0.7			

Source: Author (2018)

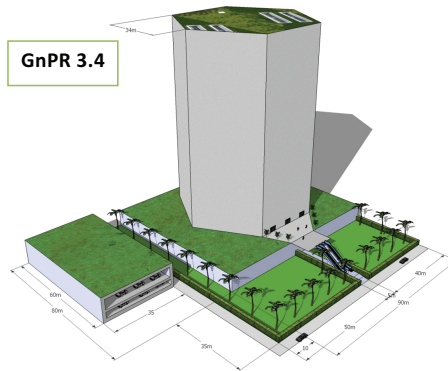


Fig. 3.14. Building retrofit increases the site's GnPR to 3.4

Source: Author (2018)

Example 4: Building redesign for the application of vertical green systems

In the fourth example, the design of the building was modified to facilitate sky terraces and the installation of the extensive green roof system with planters for small trees. Sky terraces are unique aesthetic amenities that provide green spaces at the doorstep for the building's occupants.

The front façade has a blank area where the vertical green wall with its support system can be installed to improve the building identity, with the potential to increase the direct real estate asset value. Another benefit is that the vertical green wall with its support system can be aesthetically pleasing to the occupants or residents entering the building, and could also well serve to functionally reduce the solar gain. The building redesign increases the GnPR of the development site to 4.5 (see Fig. 3.15 and Table 3.8).

Concluding Remarks

Singapore's nature conservation and greenery provision strategies to address the country's chronic and acute land scarcity, are supported in synergy with various government policies and programmes. Initiative-based

Table 3.7. GnPR calculation for additional greenery at the upper horizontal levels

Example 3: Building retrofit — enhanced upper horizontal levels													
	Category		Sub-category			LAI value (A)		Canopy area per unit (m²)		No./ Area	Leaf area	% of GnPR	
Green area 3950	Trees		Open			2.5		60		0	0	0%	
			Intermediate			3.0		60		0	0	0%	
			Dense			4.0		60		0	0	0%	
	Palm		Solitary			2.5		20		21	1050	2%	
Ground			Cluster			4.0		17		0	0	0%	
	Trellis		Horizontal			2.0		1		0	0	0%	
	Soft scape of landscape	0%	Turf	0%	—		2.0		1		3,950	7,900	16%
			Shrub	0%	Mono	0%	3.5		1		0	0	0%
					Dico	0%	4.5		1		275	1,238	2%
Podium & Carpark	Trees		Open			2.5		60		6	900	2%	
			Intermediate			3.0		60		0	0	0%	
			Dense			4.0		60		0	0	0%	
	Palm		Solitary			2.5		20		0	0	0%	
			Cluster			4.0		17		0	0	0%	
	Trellis		Horizontal			2.0		1		0	0	0%	
	Roof planting		Extensive			2.0		1		0	0	0%	
			Intensive			4.5		1		7,700	3,4650	70%	

(Continued)

Table 3.7. (Continued)

Example 3: Building retrofit — enhanced upper horizontal levels											
	Category		Sub-category			LAI value (A)		Canopy area per unit (m²)	No./ Area	Leaf area	% of GnPR
	Softscape of Landscape	0%	Turf	0%	—	2.0		1	0	0	0%
			Shrub	0%	Mono	0%	3.5	1	0	0	0%
					Dico	0%	4.5	1	0	0	0%
Rooftop	Trees		Open			2.5		60	0	0	0%
			Intermediate			3.0		60	0	0	0%
			Dense			4.0		60	0	0	0%
	Palm		Solitary			2.5		20	0	0	0%
			Cluster			4.0		17	0	0	0%
	Green Roof		Extensive			2.0		1	2,000	4,000	8%
Intensive			4.5		1	0	0	0%			
Balcony	Tree Planter		Open			2.5		60	0	0	0%
	Green Roof		Extensive			2.0		1	0	0	0%
			Intensive			4.5		1	0	0	0%
Façade	Green wall		Support			2.0		1	0	0	0%
			Carrier			2.0		1	0	0	0%
Total area of podium, sq. m. =				7,200		Total Leaf Area Site Area GnPR				4,9738	
Total area of carpark, sq. m. =				2,800						14,700	
Total area of roof, sq. m. =				2,200						3.4	
Podium green area, sq. m. =				4,900							
Roof green area, sq. m. =				2,000							

Source: Author (2018)

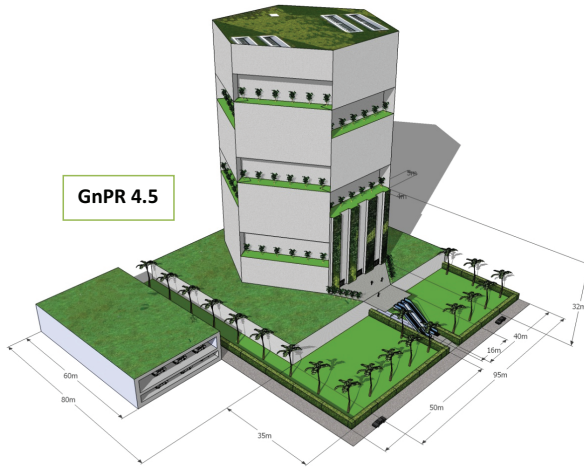


Fig. 3.15. Redesigned building with new GnPR of 4.5

Source: Author (2018)

programmes like LUSH and the' Skyrise Greenery Incentive Scheme took the greening of Singapore to new heights of excellence, encouraging building owners to retrofit their existing buildings and to redesign them, or to design new direct real estate developments with space for sky gardens and terraces. Skyrise greenery like the planting of gardens on roof tops, terraces and balconies or along the walls, form an important potential area for enhancing greenery in dense urban areas. Despite common notions that roof top and terrace gardens may be complex and need special structures to bear their weight, most modern green roof technologies are lightweight and require minimal maintenance. Their environmental benefits in dense urban areas include the reduction of the urban heat island effect; increased biodiversity; thermal insulation and energy savings; and the improvement of air quality. Although skyrise greenery is readily deemed to be one of the most rapid and developing building feature, it has yet to be regulated and implemented on an extensive planning scale in Singapore. However, it is tailored to specific national circumstances in Singapore where forests prevail as part of our native habitat.

Table 3.8. Calculation of GnPR for the redesign scenario

Example 4: Building redesign and vegetation systems on vertical surfaces											
	Category		Sub-category				LAI value (A)	Canopy area per unit (m²)	No./ Area	Leaf area	% of GnPR
Green area 3950	Trees		Open				2.5	60	0	0	0%
			Intermediate				3.0	60	0	0	0%
			Dense				4.0	60	0	0	0%
Ground	Palm		Solitary				2.5	20	21	1,050	2%
			Cluster				4.0	17	0	0	0%
	Trellis		Horizontal				2.0	1	0	0	0%
	Softscape of landscape	0%	Turf	0%	—		2.0	1	3,950	7,900	12%
			Shrub	0%	Mono	0%	3.5	1	0	0	0%
					Dico	0%	4.5	1	275	1,238	2%
Podium & Carpark	Trees		Open				2.5	60	18	2700	4%
			Intermediate				3.0	60	0	0	0%
			Dense				4.0	60	0	0	0%
	Palm		Solitary				2.5	20	0	0	0%
			Cluster				4.0	17	0	0	0%
	Trellis		Horizontal				2.0	1	0	0	0%
	Green roof		Extensive				2.0	1	0	0	0%
			Intensive				4.5	1	7,700	34,650	52%

	Softscape of landscape	0%	Turf	0%	—		2.0	1	0	0	0%
			Shrub	0%	Mono	0%	3.5	1	0	0	0%
					Dico	0%	4.5	1	0	0	0%
Rooftop	Trees		Open			2.5	60	0	0	0%	
			Intermediate			3.0	60	0	0	0%	
			Dense			4.0	60	0	0	0%	
	Palm		Solitary			2.5	20	0	0	0%	
			Cluster			4.0	17	0	0	0%	
	Green roof		Extensive			2.0	1	0	0	0%	
			Intensive			4.5	1	0	0	0%	
Balcony	Tree planter		Open			2.5	60	90	13500	20%	
	Green roof		Extensive			2.0	1	2250	4500	7%	
			Intensive			4.5	1	0	0	0%	
Façade	Green wall		Support			2.0	1	0	0	0%	
			Carrier			2.0	1	612	1224	2%	
Total area of podium, sq. m.				7,200			Total Leaf Area Site Area GnPR			66,762	
Total area of carpark, sq. m.				2,800						14,700	
Total area of roof, sq. m.				2,200						4.5	
Podium green area, sq. m.				4,900							
Roof green area, sq. m.				2,000							
Balcony area, sq. m.				170*15 = 2,250							

Source: Author (2018)

This book clearly demonstrates the methodology for calculating the amount of vegetation for a direct real estate development using GnPR. Optimal levels of skyrise greenery for residential and mixed-residential private and public developments, hotels, offices, retail areas, and mixed commercial building types, business parks, factories and warehouses were suggested in the guidelines. This book also introduces various skyrise landscaping systems and technologies for implementation in Singapore.

The information within the potential landscape guidelines hopes to supplement existing regulatory guidelines and development procedures, and to elaborate on the specific tools and recommendations needed for the industry to develop optimal greening strategies. The guidelines are meant to be used by stakeholders involved in landscape related matters in Singapore, should set a new benchmark in the amount of vegetation cover of several building types, and potentially help policy makers develop new policies and standards.

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04 Statistical Analysis and Optimisation of the GnPR Urban Planning Metric

The statistical analysis and optimisation of GnPR form an integral part of this book meant to ascertain the optimal GnPR levels for the major land use categories via an in-depth investigation of the various factors that influence the GnPR levels in a building.

This book's statistical analysis and the subsequent GnPR optimisation were meant to evaluate the audit and design scenario data, and to recommend the optimal GnPR level for the four land uses and the 'Public spaces' use via the study of the key factors which influence GnPR level and through the MCA model. The most economic Optimal GnPR levels for each land use (also known by the label 'Optimal GnPR (design and economic)') were defined to be a range, with low and top boundaries. The statistical analysis and the GnPR optimisation determined the five main factors that influenced GnPR levels are:

- Land use
- Year/period of building construction (before or after 2000)
- Building site coverage (below or more than 50 per cent) and location
- Building density (GPR level)
- Installation, maintenance and total (installation and maintenance) costs.

GnPR Factors

Land Use

Land use refers to five land use groups that can be divided into various sub-uses:

1. Residential land use with the following sub-uses:
 - a. Public housing (HDB flats),
 - b. Private (Condominiums), and
 - c. Strata landed housing;
2. Mixed residential-commercial; divided into:
 - a. Public, and
 - b. Private;
3. Commercial land use:
 - a. Hotels,
 - b. Offices,
 - c. Retail, and
 - d. Mixed commercial;
4. Industrial land use:
 - a. Business parks and
 - b. Factories;
5. Public (social) space

As depicted in Fig. 4.1 which plots the mean GnPR+1SD (standard deviation) against land use, the residential land use category was found to have the highest existing GnPR and SD values; followed by the mixed-residential, industrial and commercial land uses. The commercial land use has its SD value nearly as large as its mean value. From Table 4.1, the associated values of the mean GnPRs, medians and SDs are distinctly unique.

Residential Land Use — Public (HDB Flat) and Private (Condominium)

The lowest standard deviation of GnPR by residential land use is 0.34 for the strata landed housing sub-use while the highest mean GnPR

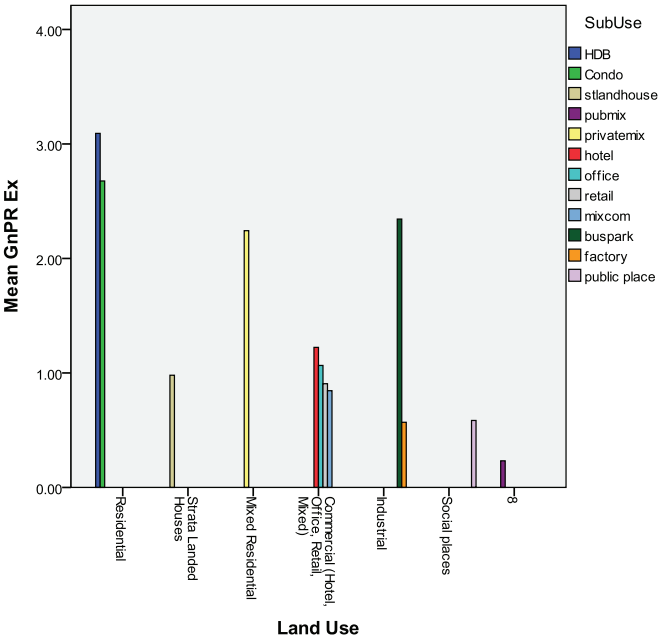


Fig. 4.1. GnPR vs. Land use

Source: Author (2012; 2018)

Table 4.1. The 12 Land sub-use types, their mean GnPRs, medians and SDs

Sub-use	Mean	N	Std. deviation	Grouped median
HDB flat	3.0923	13	1.61416	2.6200
Condominium	2.6767	15	1.36903	2.4900
Strata landed housing	0.9800	2	0.33941	0.9800
Public mixed	0.2325	4	0.10966	0.2150
Private mixed	2.2425	8	1.19791	1.8850
Hotel	1.2233	6	0.77120	1.1050
Office	1.0656	9	1.17932	0.6100
Retail	0.9060	15	0.57765	0.7400
Mixed commercial	0.8450	10	1.00972	0.6550
Business park	2.3440	5	0.64493	2.3400
Factory	0.5691	11	0.40488	0.4500
Public space	0.5850	2	0.13435	0.5850
Total	1.5930	100	1.38433	1.2250

Source: Author (2012; 2018)

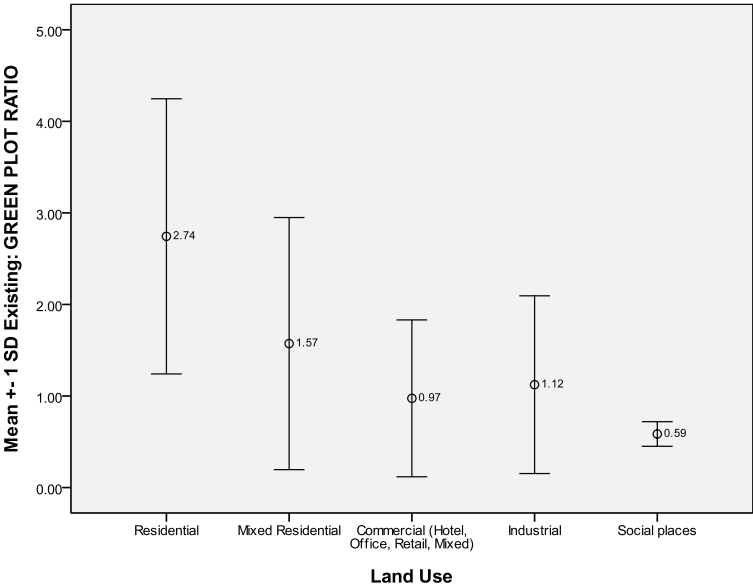


Fig. 4.2. Mean GnPRs for five land uses

Source: Author (2012; 2018)

Table 4.2. Residential land use: Mean, median and SD

Residential use	Mean	Median	N	Std. deviation
HDB flat	3.0923	2.6200	13	1.61416
Condominium	2.6767	2.4900	15	1.36903
Strata landed housing	0.9800	0.9800	2	0.33941
Total	2.7437	2.4800	30	1.50275

Source: Author (2012; 2018)

is 3.1 for the HDB sub-use, as shown in Table 4.2 and illustrated in Fig. 4.3.

Strata Landed Housing

The sample size for the strata landed housing building type is small (i.e. only two such buildings were audited) and the buildings were similar in terms of the scale, site coverage, plot ratio, location and age. Therefore,

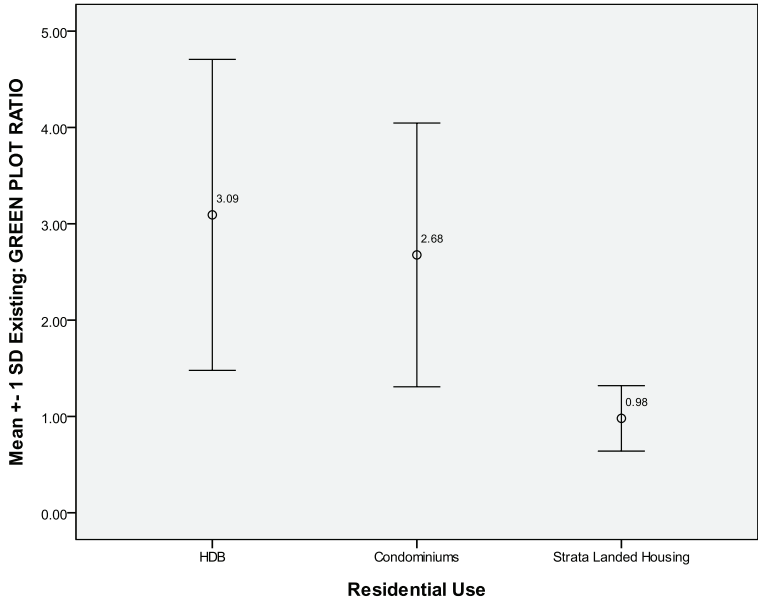


Fig. 4.3. Mean GnPR for each residential land use sub-type

Source: Author (2012; 2018)

Table 4.3. Mixed residential: GnPR and mean

Mixed(Residential) Commercial Land Use)	Mean	Median	N	Std. deviation
HDB–commercial flat	0.2325	0.2150	4	0.10966
Condominium–commercial	2.2425	1.8850	8	1.19791
Total	1.5725	1.3550	12	1.37691

Source: Author (2012; 2018)

the value of this sub-use type’s GnPR was not influenced by any factor. The mean GnPR value of 0.98 is accepted as empirically close to the mean value of GnPR for this building type.

Private and Public Mixed Residential Type

From the analysis of the mean-standard-deviation relationship (see Table 4.3 and Fig. 4.4), it is observed that all samples of the private and

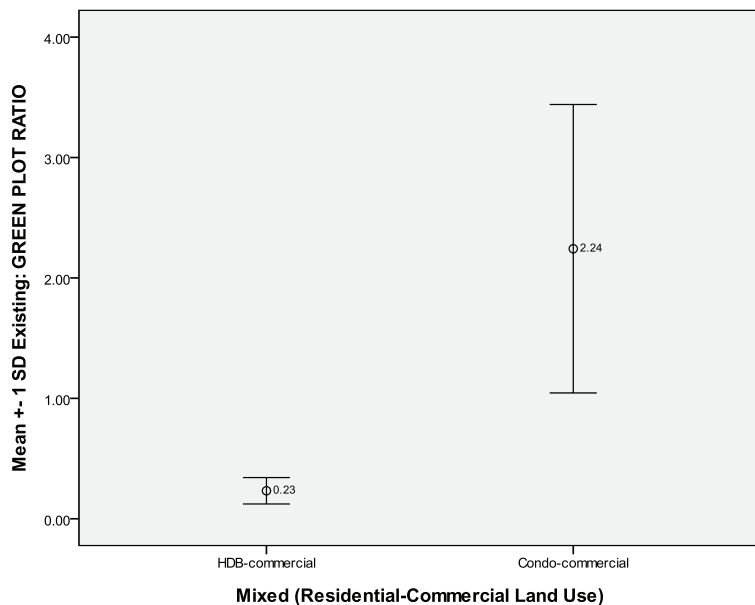


Fig. 4.4. Mixed residential: GnPR and mean

Source: Author (2012; 2018)

public mixed residential (MR) sub-use groups belong to two different typologies: all public MRs were built before 2000 whereas all private MRs were built thereafter. Most of public MRs had medium density whereas private MRs' densities were very high. As the other factors did not seem to have an impact on the buildings' GnPR levels, the mean value of 0.2 for all old MR buildings and 2.24 for all new MR buildings with very high diversity, were accepted as the optimal GnPR values for the mixed residential land use.

Commercial Land Use

The highest mean GnPR of 1.2 for the commercial land use type is not correlated with the lowest standard deviation (see Table 4.4 and Fig. 4.5). The mean GnPR value of 1.0 is accepted as the mean GnPR value for all commercial buildings.

Table 4.4. Commercial land use: Mean and median GnPRs and SDs

Commercial land use	Mean	Median	N	Std. deviation
Hotel	1.2233	1.1050	6	0.77120
Office	1.0656	0.6100	9	1.17932
Retail	0.9060	0.7400	15	0.57765
Mixed commercial	0.8450	0.6550	10	1.00972
Total	0.9742	0.7000	40	0.85682

Source: Author (2012; 2018)

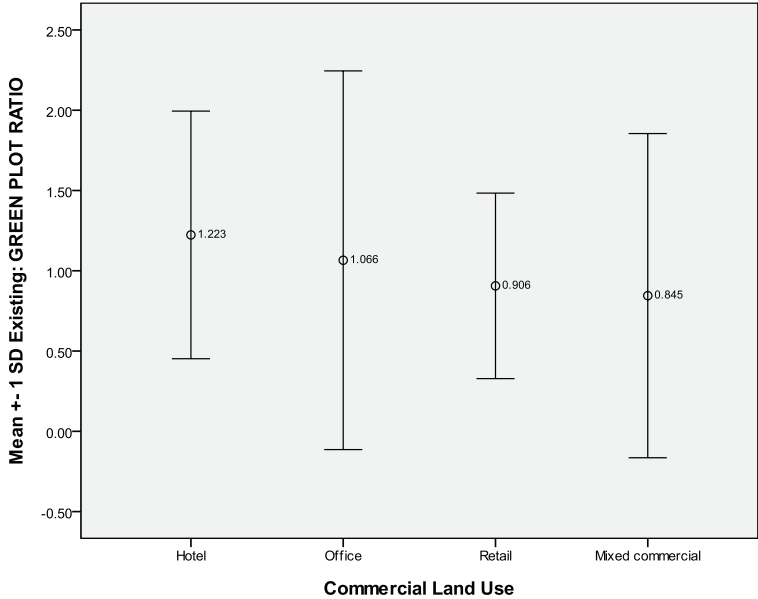


Fig. 4.5. Commercial land use: GnPR and Means

Source: Author (2012; 2018)

Business Parks and Factories

Values of the mean, median and standard deviation for industrial land use are shown in Table 4.5 and depicted in Fig. 4.6. The lowest standard deviation of 0.4 was observed for the factory sub-use type

Table 4.5. Industrial land use: mean and median GnPRs and SDs

Industrial land use	Mean	Median	N	Std. deviation
Business park	2.3440	2.3400	5	0.64493
Factory	0.5691	0.4500	11	0.40488
Total	1.1238	0.8650	16	0.97064

Source: Author (2012; 2018)

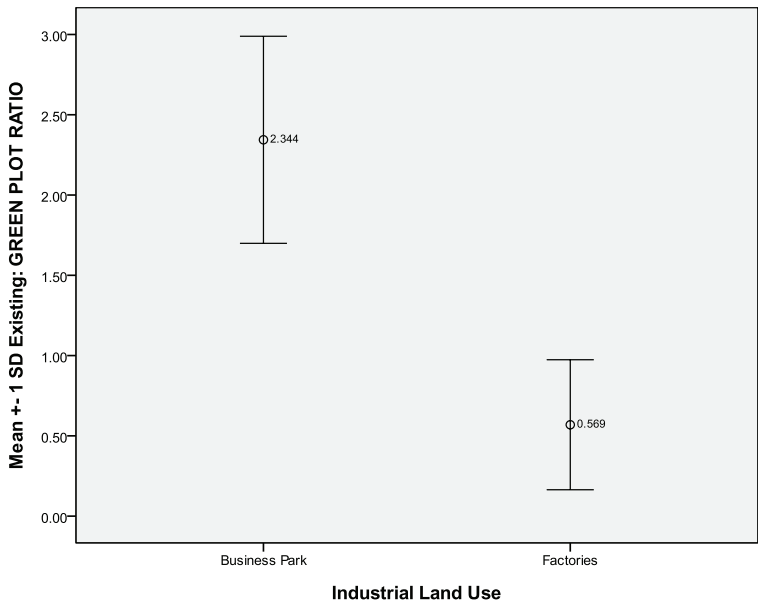


Fig. 4.6. Industrial land use: Sub-uses’ mean GnPRs

Source: Author (2012; 2018)

while the highest mean GnPR of 2.3 was observed for the business park sub-use type.

Public Space

Based on the limited sample size, the mean GnPR value of the public space land use type is presented in Table 4.6 and depicted in Fig. 4.7.

Table 4.6. Public space: Mean and median GnPR and SD

	Mean	Median	N	Std. deviation
Public space	0.5850	0.5850	2	0.13435
Total	0.5850	0.5850	2	0.13435

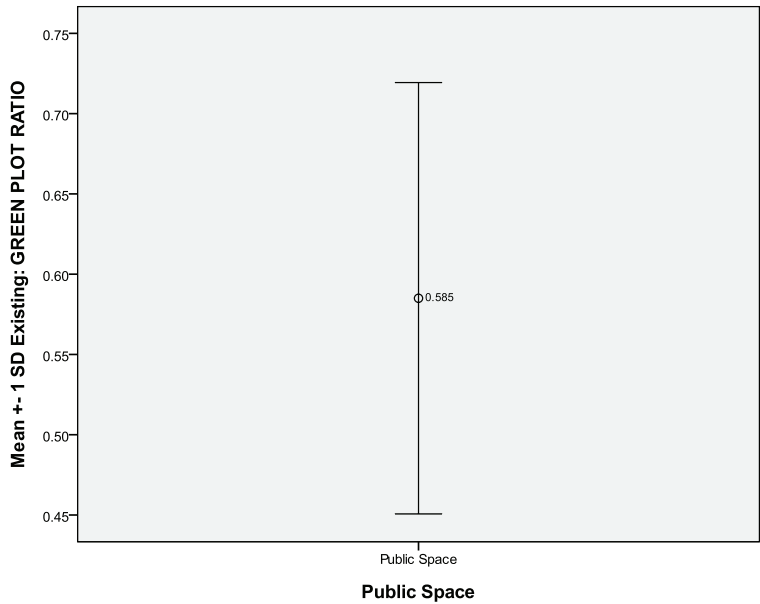


Fig. 4.7. Public space: Mean GnPR

Source: Author (2012; 2018)

The mean GnPR was estimated to be low at 0.6 with the standard deviation of 0.1.

Implications of Analysis

Residential and Industrial Land Uses

The analysis of the mean GnPRs for the residential and industrial land uses did not show a conclusive relationship between the mean and standard

deviation. Therefore, the mean GnPR could be subject to further statistical analysis to evaluate the impact from other factors.

Mixed Residential Land Use

During a preliminary study on the optimal GnPR value for the mixed residential land use, several key observations were observed:

- For a retrofitted building built before 2000, the mean GnPR was found to be 0.2;
- For new developments built after 2000 and new retrofitted buildings with medium density, the mean GnPR was found to be 0.2;
- For new developments built after 2000 and new retrofitted buildings with very high density, the mean GnPR was found to be 1.9.

Period of Building Construction

Building age was another factor influencing the GnPR levels of the audited buildings. In the audited sample, the average age of the residential and industrial buildings was 14 years, whereas the mixed-residential and commercial buildings were much older at 21 years, as shown in Fig. 4.8. It generally was observed that the newer the building, the higher the GnPR, which confirms the growing skyrise greenery trend in Singapore

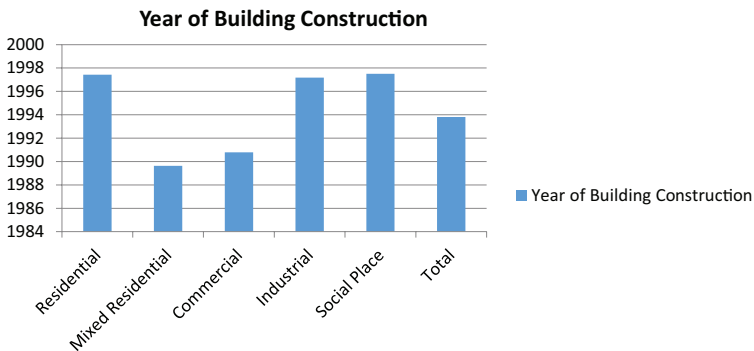


Fig. 4.8. Mean year of building construction for five land uses

Source: Author (2012; 2018)

supported by various green policies, initiatives and schemes introduced by the government, such as the gross floor area (GFA) development control policy introduced by URA in 1989. The policy exempts some additional areas, particularly covered public spaces and landscaped decks from the GFA calculation, thereby permitting real estate developers to build higher buildings. However, there was no drastic change observed in buildings' GnPR levels immediately after 1989, as it probably took some time for real estate developers and investors to bring green features into their new development projects. The change in GnPR was more noticeable after 2000.

The buildings' years of construction, shown in Fig 4.9, were organised into two time periods:

1. Before 2000 with a mean GnPR of 1.13;
2. After 2000 with a mean GnPR of 2.7.

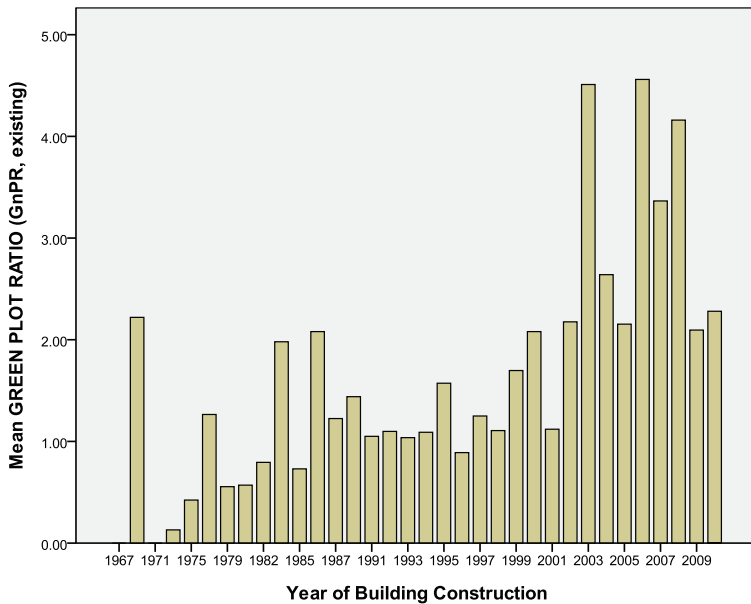


Fig. 4.9. Year of construction vs. GnPR

Source: Author (2012; 2018)

The distribution of the GnPR across land uses and divided by the old and new developments is shown in Fig. 4.10. The new public and private residential buildings shown in Fig. 4.11 to Fig. 4.14 were found to have significantly higher GnPR levels than old residential buildings. Additionally, all the public residential buildings audited fell under the “old” category and the mean GnPR for new private mixed residential buildings was almost two times higher than that of the “old” private mixed residential buildings.

Density of Development

The density of a development is defined by its gross plot ratio (GPR). The GPR distribution across land uses and their associated GnPRs are presented in Figs. 4.15 and 4.16.

The density of a development refers to the intensity of the residential, commercial and industrial developments in accordance



Fig. 4.10. Period of building construction vs GnPR of 100 existing buildings
Source: Author (2012; 2018)

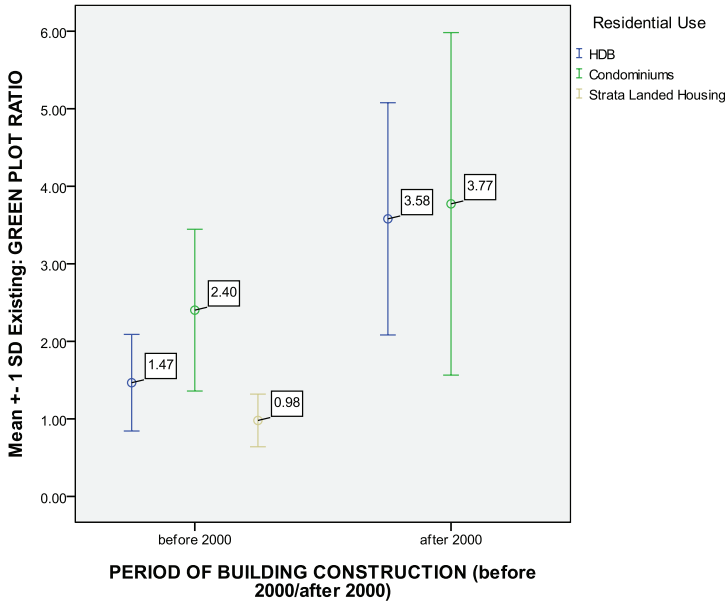


Fig. 4.11. Period of building construction vs. Mean GnPR for residential use

Source: Author (2012; 2018)

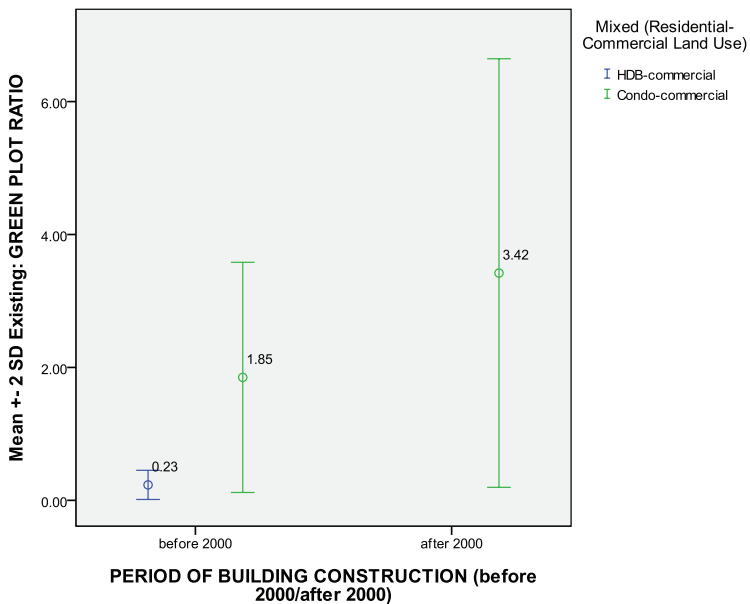


Fig. 4.12. Period of building construction vs. Mean GnPR for mixed residential use

Source: Author (2012; 2018)

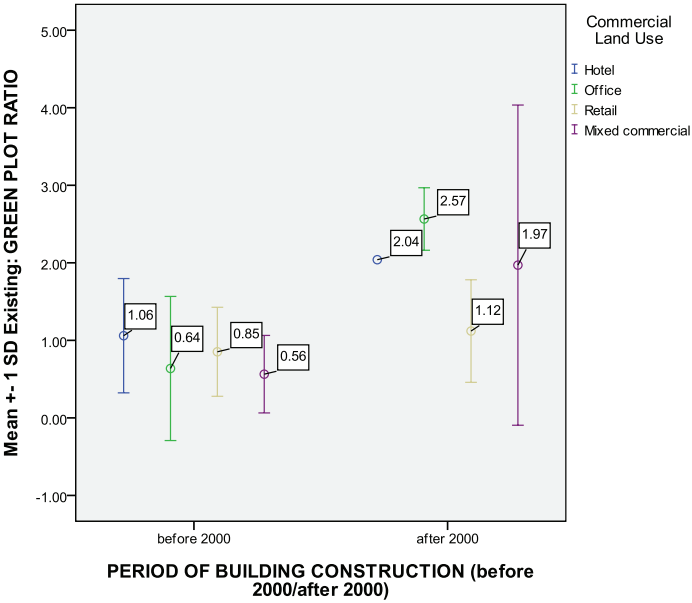


Fig 4.13. Period of building construction vs. Mean GnPR for commercial use

Source: Author (2012; 2018)

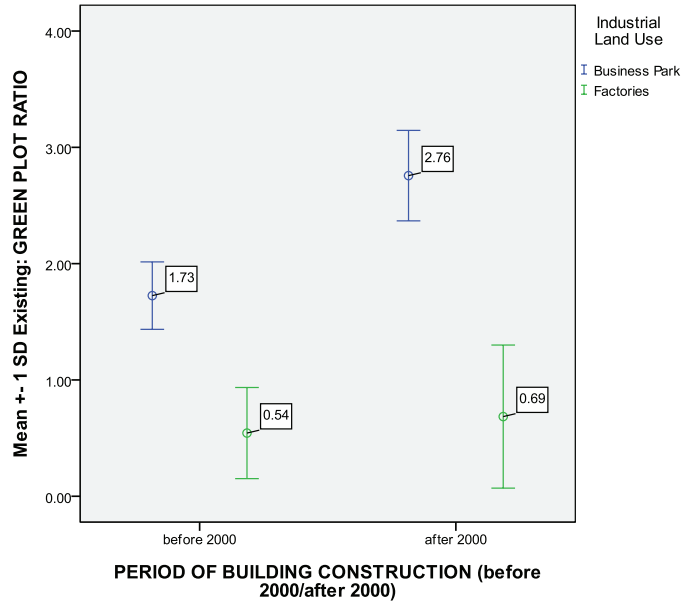


Fig. 4.14. Period of building construction vs. Mean GnPR for industrial use

Source: Author (2012; 2018)

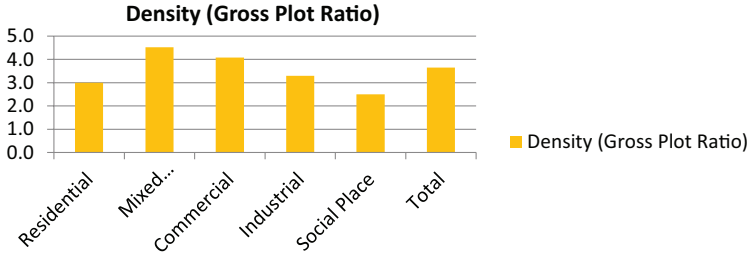


Fig. 4.15. Mean GnPRs for five land uses

Source: Author (2012; 2018)

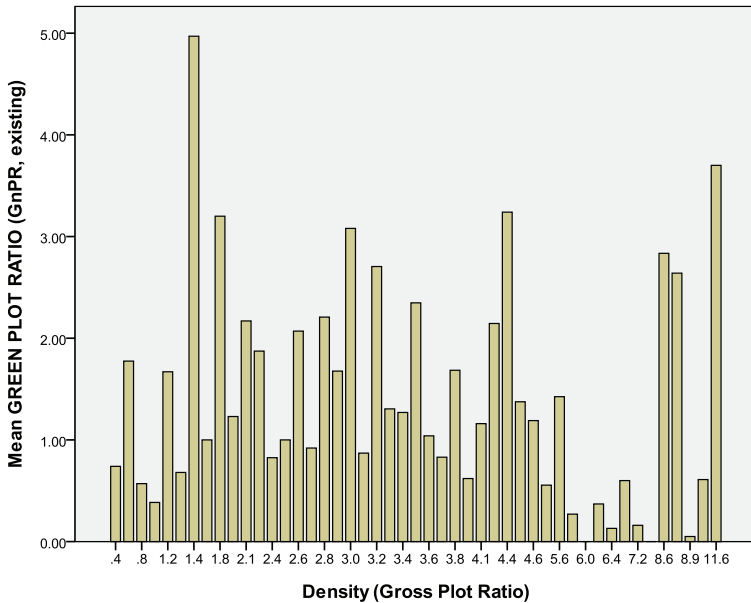


Fig. 4.16. Density of development vs. Mean GnPRs for five land uses

Source: Author (2012; 2018)

with the Singapore Master Plan 2008 (URA, 2008). It is categorised by different GPR levels:

1. Low density: GPR of 1.4, 5-storey height control;
2. Medium density: GPR of 1.6, 12-storey height control;
3. Medium-high density: GPR of 2.1, 24-storey height control;

Table 4.7. Mean and median GnPRs vs. density of development

Density	Mean	Median	Std. deviation	N
Low (<1.4)	1.9910	1.5100	1.71240	21
Medium (up to 1.6)	0.7380	0.3700	0.83718	5
Medium-high (up to 2.1)	2.4400	2.4950	0.94676	6
High (up to 2.8)	1.2575	1.0550	0.74833	16
Very high (>2.8)	1.5202	1.1500	1.41430	52
Total	1.5931	1.2250	1.38428	100

Source: Author (2012; 2018)

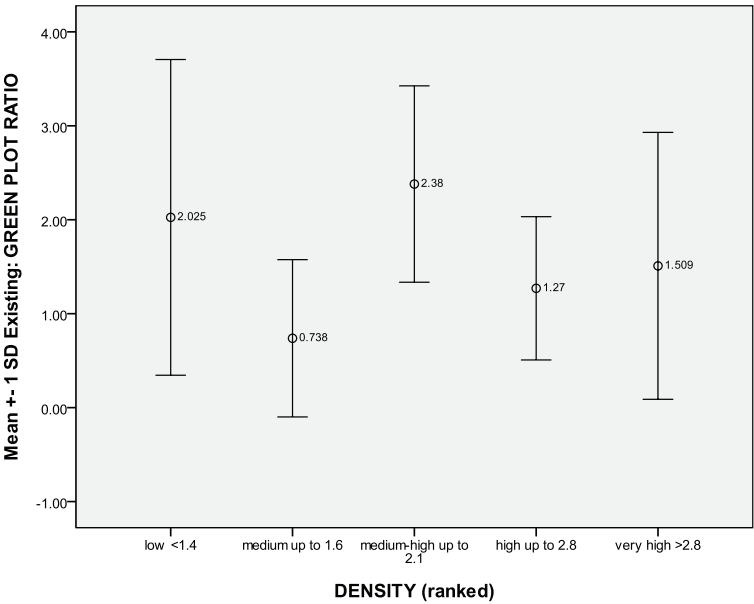


Fig. 4.17. Mean GnPR vs. Density of development

Source: Author (2012; 2018)

- 4. High density: GPR of 2.8, 36-storey height control;
- 5. Very high density: GPR of above 2.8 and height above 36 storeys.

The mean GnPRs for the different land uses categorised by density of development are shown in Table 4.7 and depicted in Fig. 4.17. On the whole, the highest mean GnPR of 2.44 was observed for medium-to-high

density developments, followed by a lower GnPR of 1.99 for low density developments. Very high- and high-density developments had much lower mean GnPRs of 1.52 and 1.26 respectively.

As shown in Figs. 4.18 to 4.21, the GnPR levels for the public and private residential sub-types were generally found to be higher for the low and very high-density developments than for medium-, medium-high- and high-density developments.

Site Coverage

Site coverage is the area occupied by all the buildings or structures within a development site, as measured along the outer most external walls, where the roof projection is equal to or less than two metres. It is expressed as a percentage of the net site area (excluding roads and drainage reserve, if any) and is a planning parameter that determines the extent of the

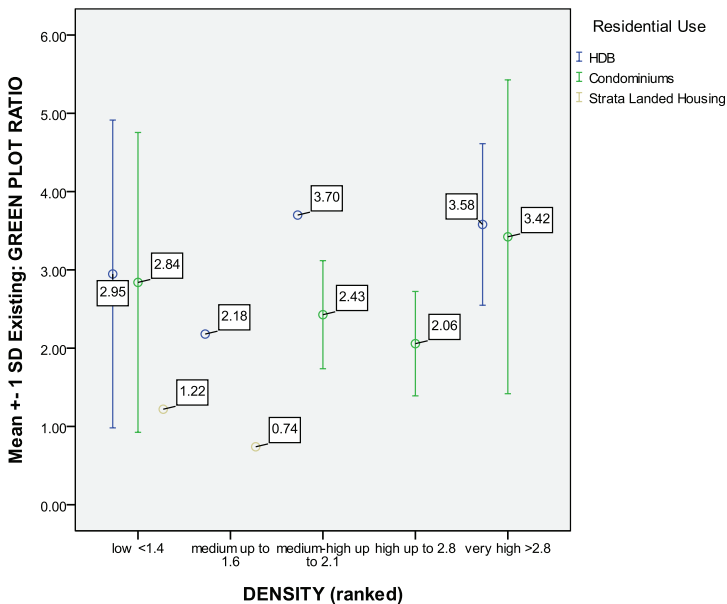


Fig. 4.18. Mean GnPR for residential land use categorised by density of development
Source: Author (2012; 2018)

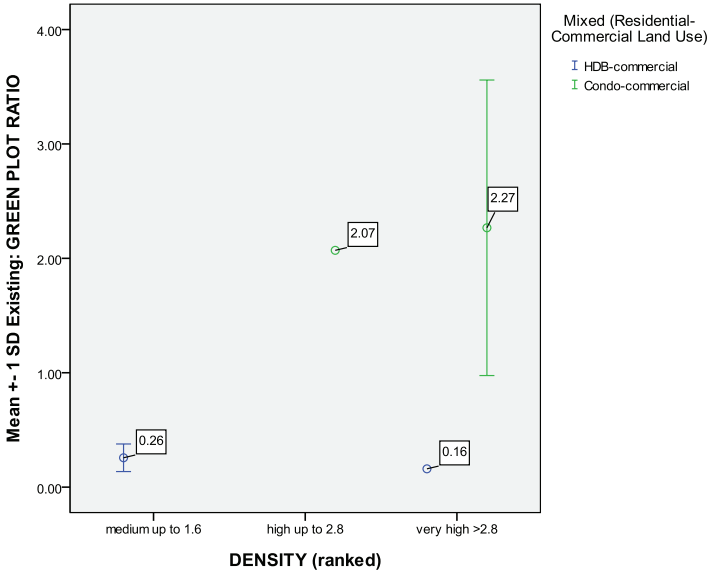


Fig. 4.19. Mean GnPR for mixed residential land use categorised by density of development

Source: Author (2012; 2018)

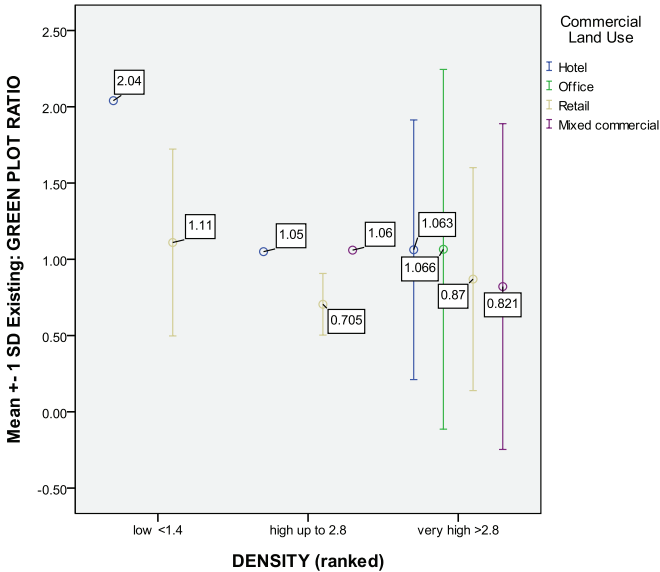


Fig. 4.20. Mean GnPR for mixed commercial land use categorised by density of development

Source: Author (2012; 2018)

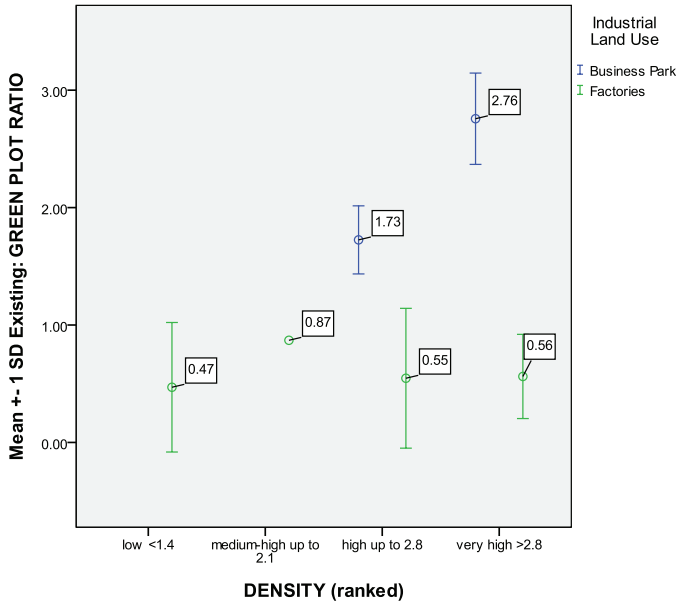


Fig. 4.21. Mean GnPR for industrial land use categorised by density of development
 Source: Author (2012; 2018)

“built-up ness” of a particular site. The primary objective of site coverage control is to ensure that the development site is not over-built and has adequate areas devoted to greenery and landscaping, to achieve high environmental quality (URA, 2019). The distribution of site coverage across the five land uses is presented in Fig. 4.22 while the mean GnPRs across the land uses is presented in Fig. 4.23.

Site coverage was divided into two categories:

1. Low: 0–50 per cent, with a mean of 1.97;
2. High: 51–100 per cent, with a mean of 1.02.

As presented in Table 4.8 and depicted in Figs. 4.24 to 4.29, it was generally found that the mean and standard deviation (SD) of the GnPR for the low site coverage category, tended to be higher than that of the high site coverage category.

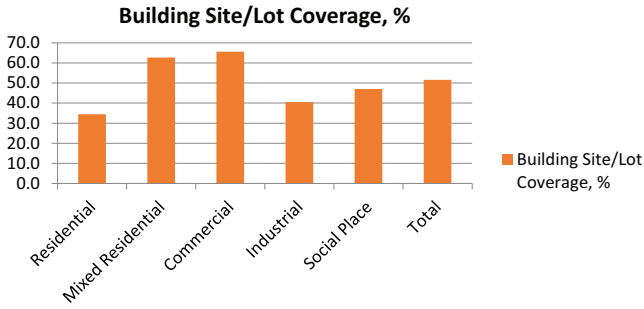


Fig. 4.22. Mean site coverage for the five land uses

Source: Author (2012; 2018)

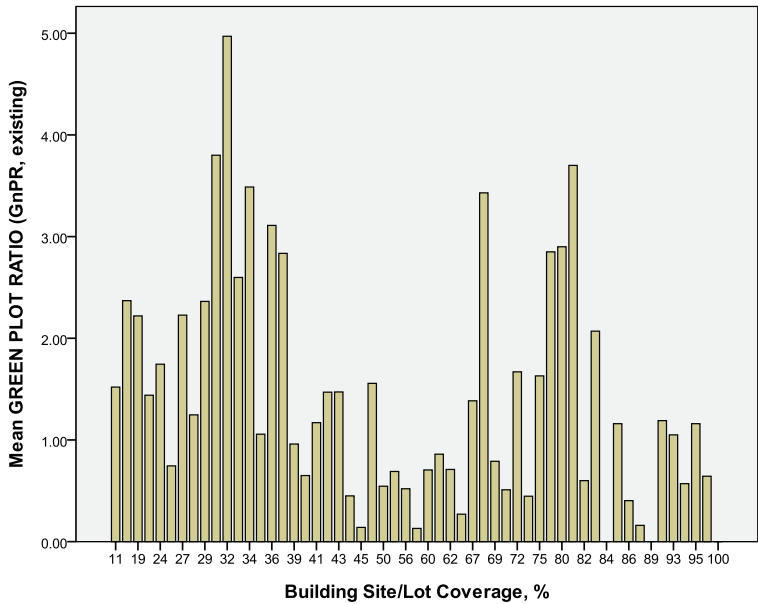


Fig. 4.23. Mean GnPR vs. site coverage

Source: Author (2012; 2018)

Table 4.8. GnPR vs. Site coverage

Site Coverage (ranked)	Mean	Median	N	Std. Deviation
Low: 10–50%	1.9727	1.6100	60	1.42765
High: 51–100%	1.0235	0.6050	40	1.10763
Total	1.5930	1.2250	100	1.38433

Source: Author (2012; 2018)

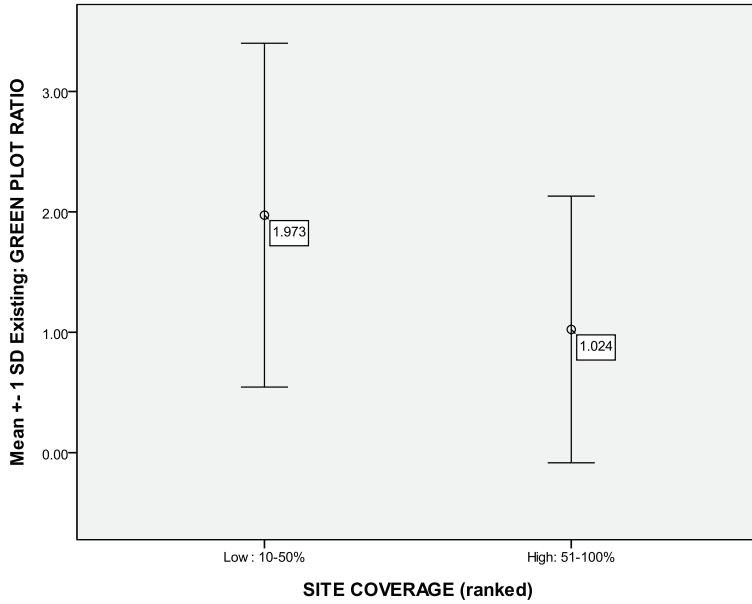


Fig. 4.24. Mean GnPRs categorised by level of site coverage

Source: Author (2012; 2018)

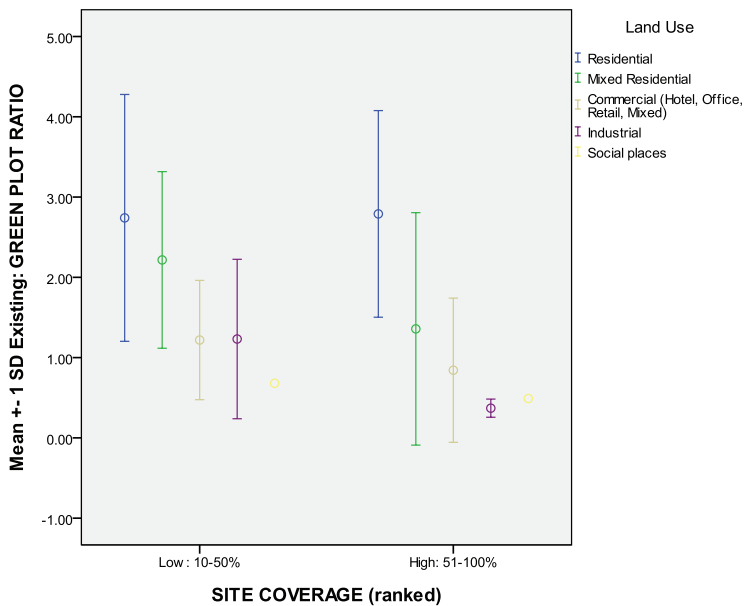


Fig. 4.25. Mean GnPRs for different land uses categorised by level of site coverage

Source: Author (2012; 2018)

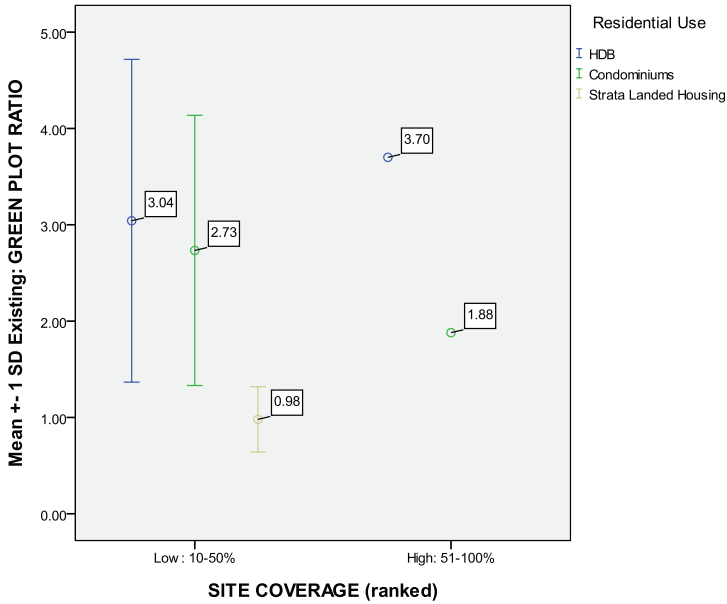


Fig. 4.26. Mean GnPRs for residential land use categorised by level of site coverage
Source: Author (2012; 2018)

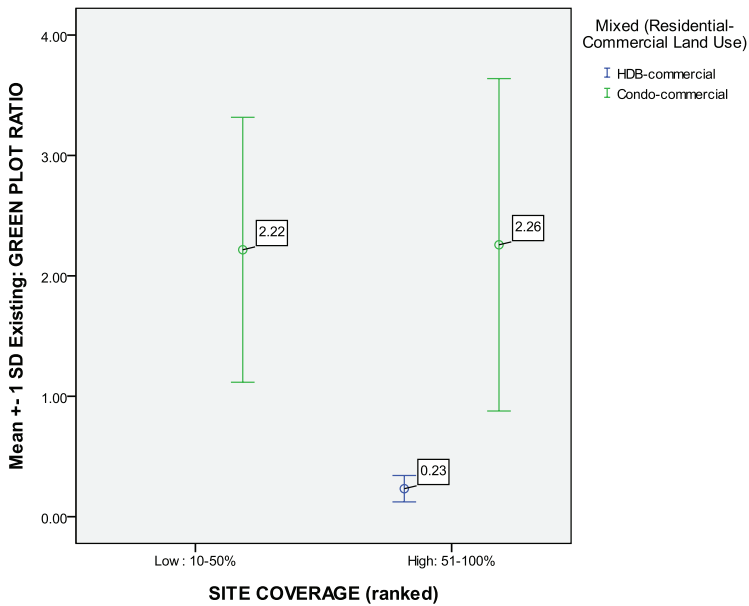


Fig. 4.27. Mean GnPRs for mixed residential land use categorised by level of site coverage
Source: Author (2012; 2018)

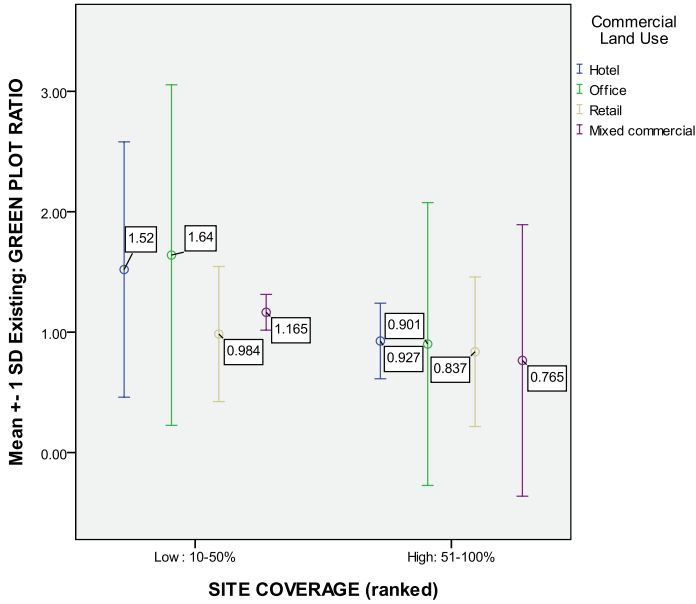


Fig. 4.28. Mean GnPRs for commercial land use categorised by level of site coverage

Source: Author (2012; 2018)

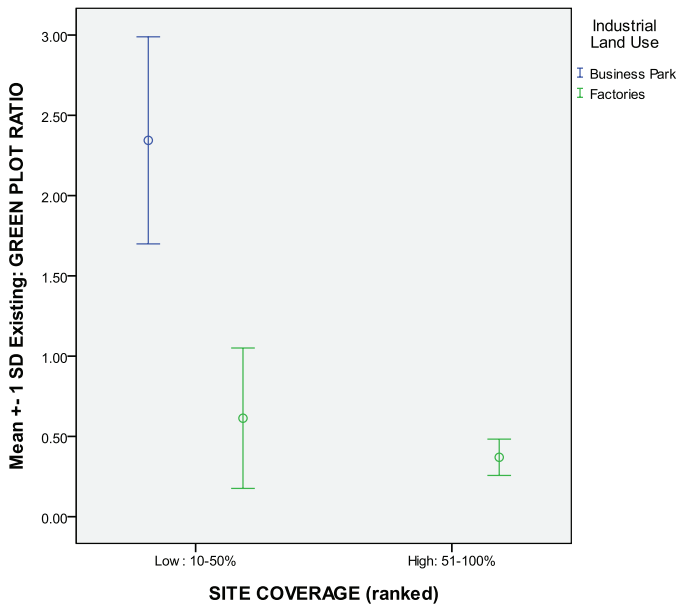


Fig. 4.29. Mean GnPRs for industrial land use categorised by level of site coverage

Source: Author (2012; 2018)

Gross Floor Area

Gross Floor Area (GFA) is the total area of the covered floor space measured between the centre line of property walls, including the thickness of external walls but excluding voids (BCA, 2010; URA, 2011). The GFA in square metres (sq. m.) is categorised as follows:

- 1. Low: 1–50,000 sq. m.;
- 2. Medium: 50,000–100,000 sq. m.;
- 3. Medium-high: 100,001–200,000 sq. m.;
- 4. High: 200,001–1,000,000 sq. m.

In general, there is a rising trend between the GFA and the GnPR factors up to the ‘Medium-high GFA’ category where the mean GnPR and standard deviation (SD) peak. After this, the peak falls off, as shown in Table 4.9 and readily observed in Figs. 4.30–4.32. This trend is due to the high concentration of commercial buildings within the audit of 100 buildings that have high GFA and low GnPR. The only reverse trend is in the case of the mixed residential land use, with its highest mean GnPR and greatest GnPR variability falling under the relatively small ‘Low GFA’ category, shown in Fig. 4.32

Cost Elements

The total cost is the sum of installation capital cost and the maintenance cost over a ten-year period. The factors contributing to the installation

Table 4.9. GnPR vs. GFA

GFA (sq. m)	Mean	N	Std. Deviation
1–50,000	1.2390	48	1.31802
50,000–100,000	1.7252	25	1.17882
100,001–200,000	2.3900	19	1.52877
200,001–1,000,000	1.4112	8	1.40756
Total	1.5930	100	1.38433

Source: Author (2012; 2018)

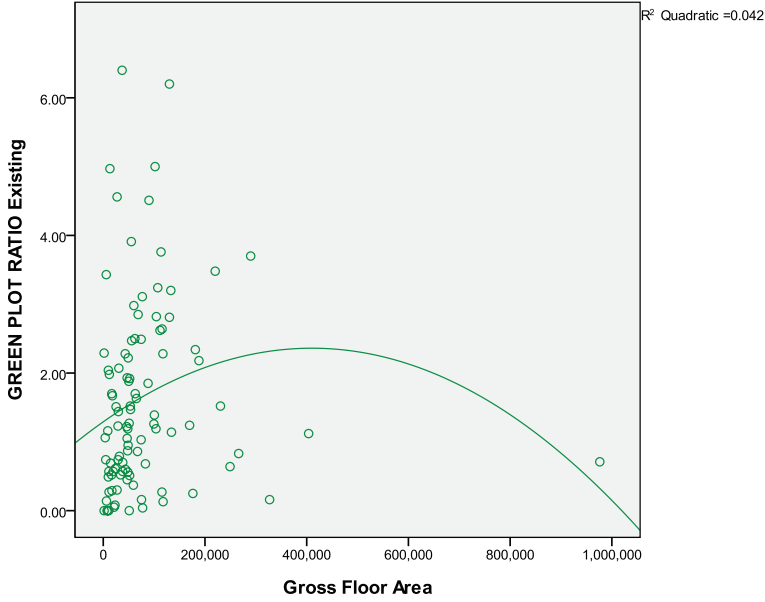


Fig. 4.30. GnPR vs. GFA

Source: Author (2012; 2018)

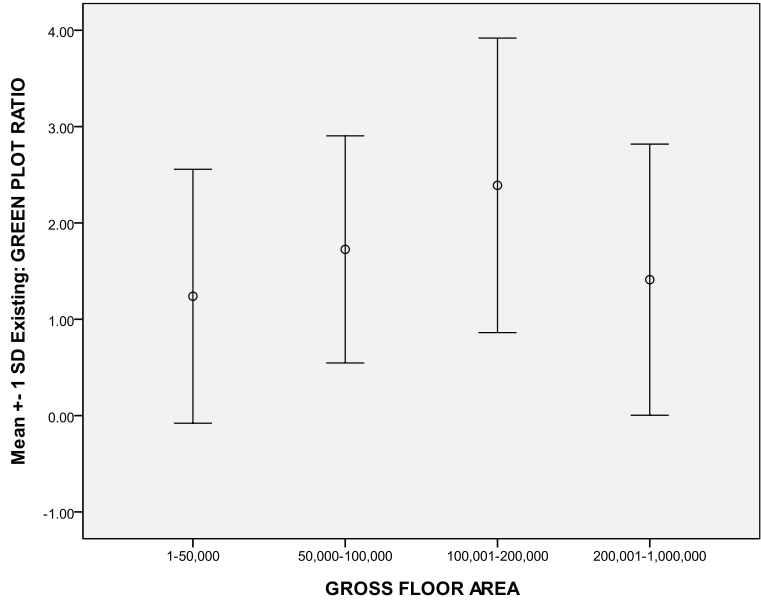


Fig. 4.31. Mean GnPRs categorised by GFA of site

Source: Author (2012; 2018)

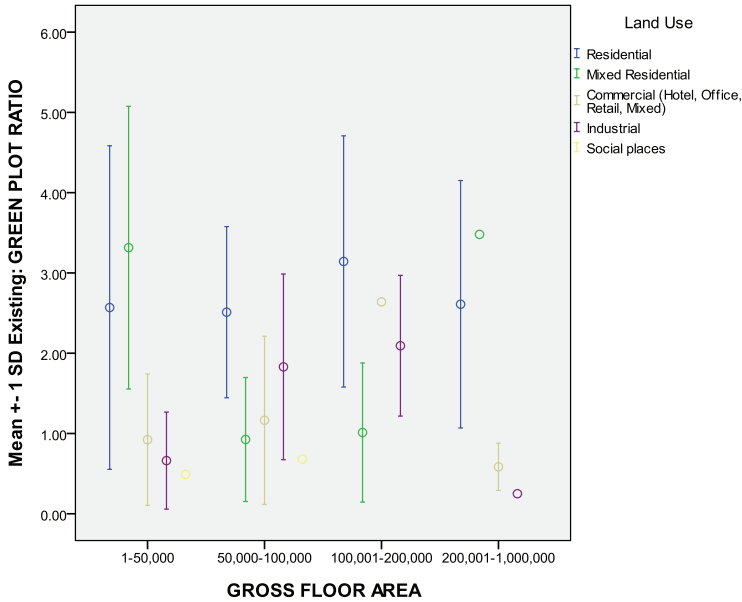


Fig. 4.32. Mean GnPRs of five land uses categorised by site GFA

Source: Author (2012; 2018)

capital cost and the maintenance cost and their limitations are presented below. The total cost was estimated for the five landscape design scenarios — Existing’, ‘Enhanced 1’, ‘Enhanced 2’, ‘Maximum’ and ‘Ultimate’ — to determine the limit of the incremental GnPR by land use. This analysis offers comprehensive insights on the total cost for the Existing condition (the origin of the design scenarios). The following section also briefly describes the cost estimation basis.

Factors considered in installation capital cost

The costing for the ‘Kit of Parts’ is concerned with the following factors:

- Horizontal on ground
 - Planting on existing earth ground;
 - No alterations required;
 - No irrigation system;
 - No services diversion.

- Horizontal
 - Construction of planters on existing ground level hard standing;
 - Minor or no alterations required;
 - No irrigation system;
 - No services diversion.
- Vertical
 - Minor or localised alterations;
 - No irrigation system;
 - No services diversion.
- Horizontal
 - Above ground;
 - Minor or localised alterations;
 - No irrigation system;
 - Extensive roof assumed to be turf only, no allowance for connecting planting from ground level to roof level;
 - No services diversion.

Basis of maintenance cost

- The cost was based on the annual maintenance requirement of a consistent scope of landscaping to be maintained throughout a period of ten years.
- Maintenance includes the trimming of turf and shrubs and tree-pruning to maintain acceptable reach and coverage to reasonable standards.
- The costs were based on an extrapolation of a known existing site's likely landscape maintenance awarded contract cost and applied across various bands of site areas.
- There are limited economies of scale applied owing to the wide range of site areas. However, there are three bands of site areas created across each type of property over the 100 buildings studied. These three bands allow the site areas to be separately grouped within definitive quantities to provide economies-of-scale by using

a different (\$/sq. m.) rate when transiting beyond or under a certain site area.

- The usually large or small site maintenance cost is worked out by unit rates of maintenance for each specific landscape item and is adjusted against its band of site area for a customised approach.

List of exclusions

The following factors are not included in cost calculations for maintenance and capital costs:

- Works outside of the site boundary;
- Variations to the planting location;
- Future changes in the quantity of landscaping;
- Replacement of new landscape items;
- Abnormal cost premiums due to significant natural disasters and similar catastrophic events;
- Consequential loss of profit and/or rent and cost of alternative accommodation during maintenance;
- Fluctuating market conditions such as but not limited to economic climate shift, labour and material costs fluctuation;
- Cost premiums associated with new work methods required by future codes of practice or legislation
- Prevailing Goods and Services Tax;
- Cost escalation beyond May 2011.

Cost analysis

The distribution of the mean existing installation capital cost and maintenance cost factors across land uses, with the lowest mean total cost for the commercial and social space land uses are presented in Fig. 4.33. The existing GnPR rises in general with the total cost, up to S\$3,000,000 and S\$4,000,000, beyond which outliers are sparingly observed.

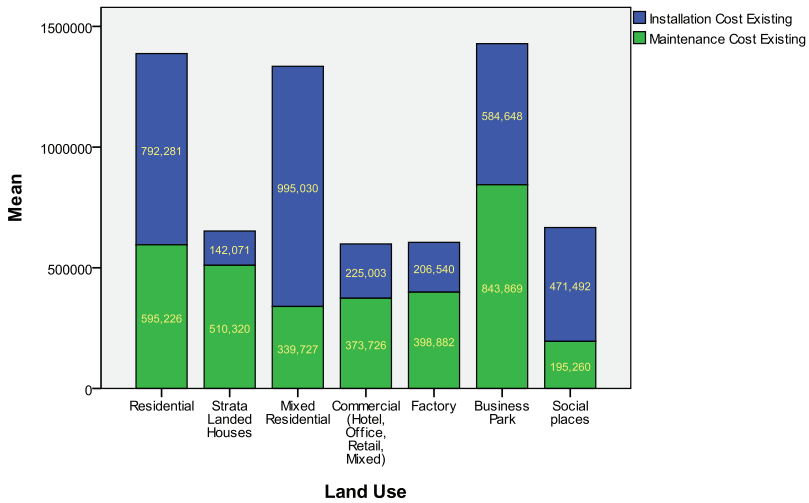


Fig. 4.33. Average installation and maintenance costs vs. land use

Source: Author (2012; 2018)

On the whole, most of the audited buildings have GnPR values lower than 2.0 and the total cost of greenery not exceeding S\$1,000,000. In addition, the GnPR distribution across the total cost for the ‘Existing’ condition (i.e. the original design scenario) is presented in Fig. 4.34. One of the audited buildings, ‘Fusionopolis’ — a ‘Business park’ building type at ‘One-North, Singapore’ — shows a typical example of the rising GnPR-cost trend, with approximately 46 per cent of the GnPR attributable to greenery on the building and approximately 34 per cent of the GnPR attributable to the greenery on the ground level. The corresponding one-time installation cost of greenery for the aforementioned building is S\$1,722,315 and the maintenance cost is S\$68,201 per year.

A low GnPR of 0.8 was achievable with total cost (including maintenance over ten years) of less than S\$500,000. A higher GnPR of 1.6 was achievable at a higher investment cost of less than S\$1.0 million, while a much higher GnPR of 2.6 was achievable at the much higher investment cost of S\$1–\$2.5 million, as shown in Fig. 4.35.

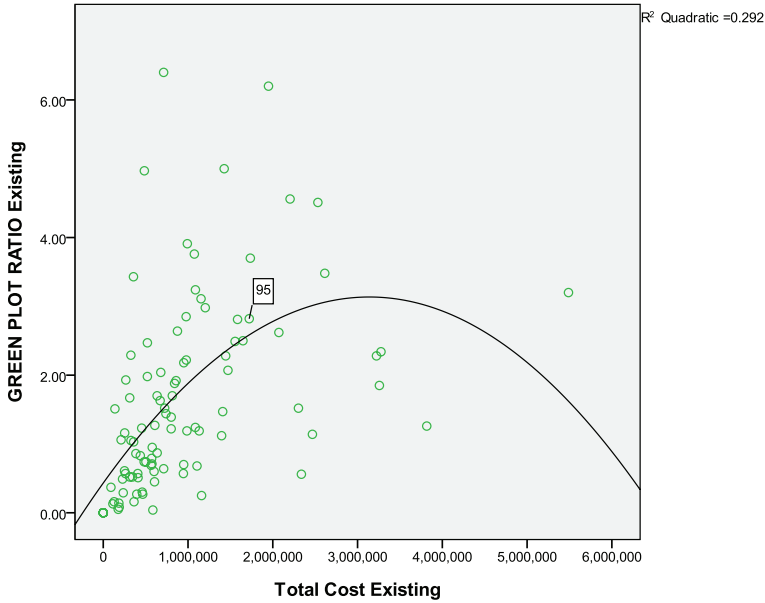


Fig. 4.34. GnPR vs. total cost

Source: Author (2012; 2018)

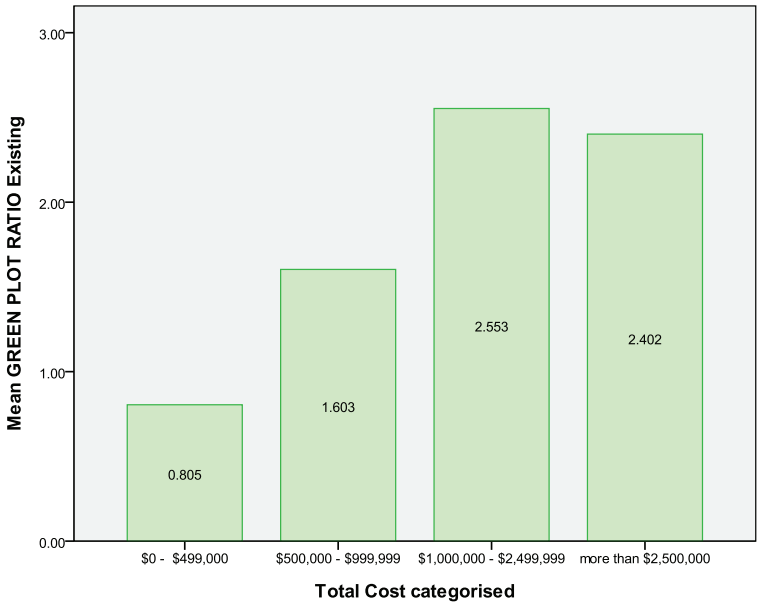


Fig. 4.35. Mean GnPR vs. total cost

Source: Author (2012; 2018)

From Fig. 4.35, the total cost is divided into four bands, namely,

- Up to S\$499,999
- S\$500,000–S\$999,999
- \$1,000,000–\$2,499,999
- S\$2,500,000 and above.

The total cost frequency, categorised by the above bands and by land use is shown in Fig. 4.36. The total cost of greenery for most of the commercial buildings audited was found to be less than S\$750,000. The total cost of greenery for business parks was mostly in excess of S\$1,500,000 whereas that of factories was found to be in the first three cost bands of up to S\$2,500,000. The residential and mixed residential land uses tended to have relatively higher levels of mean GnPR at 2.2–3.3 and at 1.7–2.9 respectively. The same trend was observed for the business

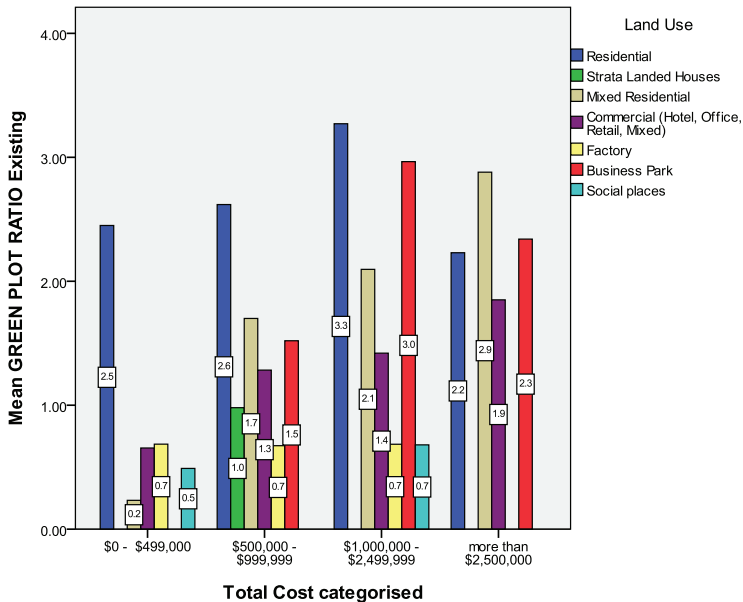


Fig. 4.36. GnPR vs. total cost categorised by land use

Source: Author (2012; 2018)

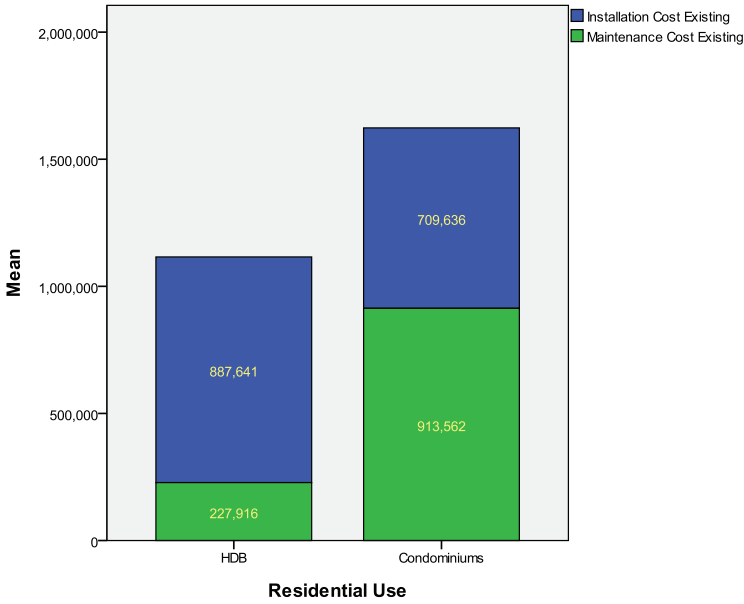


Fig. 4.37. Total cost by residential land use

Source: Author (2012; 2018)

park land use, with its mean GnPR at 1.5–3.0. The other land uses tended to have their mean GnPRs more or less evenly distributed and at much lower levels across the total cost categories.

Figures 4.37 to 4.40 show the further total cost breakdown by the respective sub-land uses to facilitate cost understanding.

For information purposes, summaries are provided in Tables 4.10 and 4.11 for the existing mean GnPRs and their standard deviations (SDs), categorised by total cost, land use, as well as sub-land uses.

GnPR Means by Land Use and Cost

The mean GnPR for the land uses, the sub-uses and the five design scenarios are presented in Table 4.12. In this book, the strata landed housing land use type is envisaged to be distinct and separate from the residential land use in Table 4.10.

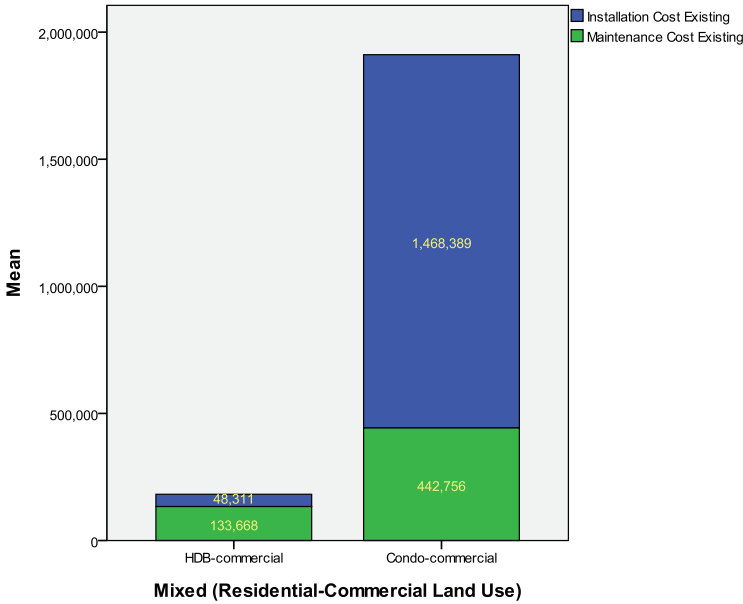


Fig. 4.38. Total cost by mixed land use

Source: Author (2012; 2018)

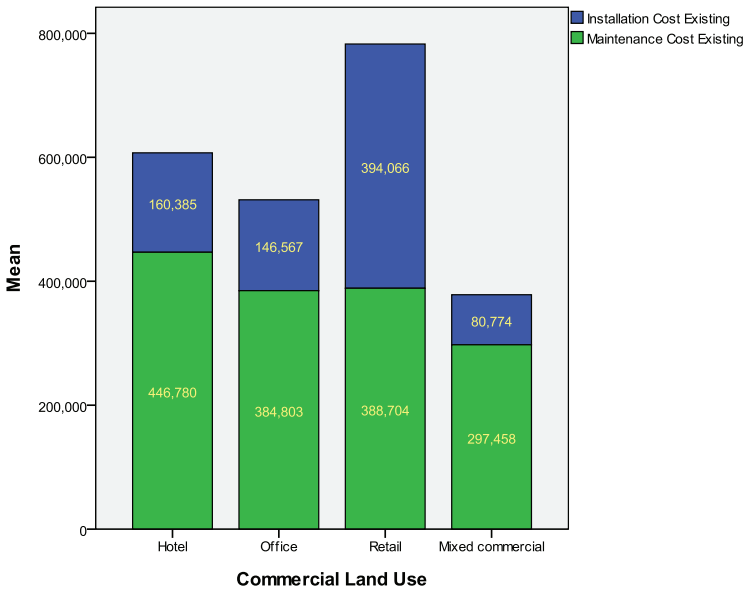


Fig. 4.39. Total cost by commercial land use

Source: Author (2012; 2018)

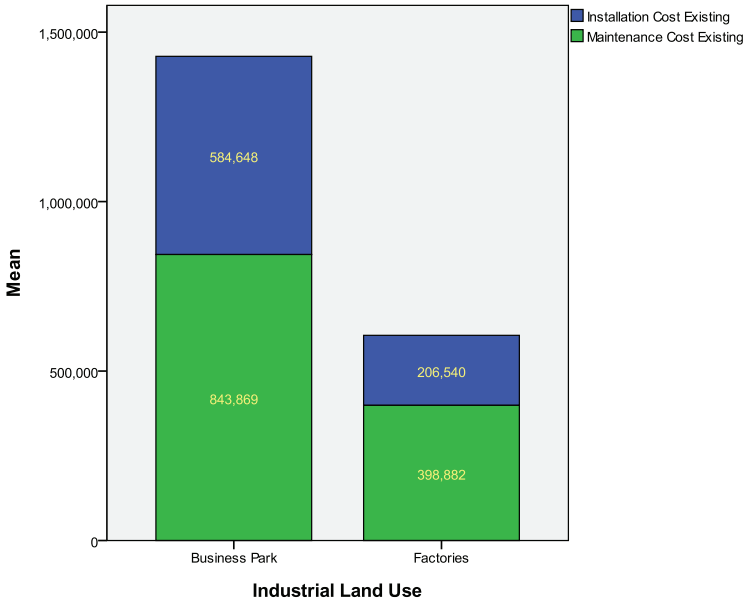


Fig. 4.40. Total cost by industrial land use

Source: Author (2012; 2018)

Tables 4.13 and 4.14 provide the summary of the means of the various greenery costs for the 100 audited buildings, calculated for the five design scenarios per building (namely, ‘Existing’, ‘Enhanced 1’, ‘Enhanced 2’, ‘Maximum’ and the ‘Ultimate’) by land use and by sub-use respectively.

Table 4.15 provides another version of the summary for the various mean greenery costs per sq. m. of the existing 100 audited buildings for four design scenarios per building, namely, the ‘Enhanced 1’, ‘Enhanced 2’, ‘Maximum’ and the ‘Ultimate’ design scenarios by land use (Karlik & Winer, 2001; Jones, 1992; Ho & Orlenko, 2012; 2014; Ong B. , 1996; Ong B. , 1999; Ong B. L., 2003; Ong, Ho, & Ho, 2012; Wall, 1994) (Whitford, Ennos, & Handley, 2001). On the whole, the mean maintenance costs, installation capital costs and the total costs rose sharply between the ‘Maximum’ and the ‘Ultimate’ design scenarios across all land use types. However, the mean maintenance cost, installation capital cost and the

Table 4.10. Existing mean GnPRs by existing costs (in SGD)

Total cost	Land Use	GnPR	Installation	Maintenance	Total cost
			cost	cost	
\$0–\$499,000	Residential	2.45	\$138,570	\$188,165	\$326,735
	Mixed residential	0.23	\$48,311	\$133,668	\$181,979
	Commercial (hotel, office, retail, mixed)	0.65	\$32,924	\$222,588	\$255,512
	Industrial	0.69	\$81,581	\$229,749	\$311,330
	Public space	0.49	\$148,709	\$78,940	\$227,649
	Total	0.80	\$58,343	\$206,726	\$265,069
\$500,000–\$999,999	Residential	2.62	\$439,867	\$330,899	\$770,766
	Strata landed housing	0.98	\$142,071	\$510,320	\$652,391
	Mixed residential	1.70	\$301,782	\$512,630	\$814,412
	Commercial (hotel, office, retail, mixed)	1.28	\$259,248	\$462,250	\$721,498
	Industrial	0.89	\$219,780	\$508,865	\$728,645
	Total	1.60	\$299,119	\$435,713	\$734,832
\$1,000,000–\$2,499,999	Residential	3.27	\$1,143,983	\$494,640	\$1,638,623
	Mixed residential	2.10	\$1,263,319	\$464,366	\$1,727,685
	Commercial (hotel, office, retail, mixed)	1.42	\$926,778	\$964,150	\$1,890,928
	Industrial	1.83	\$767,177	\$590,836	\$1,358,013
	Public space	0.68	\$794,275	\$311,580	\$1,105,855
	Total	2.55	\$1,076,197	\$534,215	\$1,610,412
more than \$2,500,000	Residential	2.23	\$1,399,509	\$3,252,635	\$4,652,144
	Mixed residential	2.88	\$2,564,368	\$353,795	\$2,918,163
	Commercial (hotel, office, retail, mixed)	1.85	\$2,307,205	\$950,400	\$3,257,605
	Industrial	2.34	\$676,282	\$2,600,000	\$3,276,282
	Total	2.40	\$1,818,540	\$1,793,877	\$3,612,417
Total	Residential	2.87	\$792,281	\$595,226	\$1,387,508
	Strata landed housing	0.98	\$142,071	\$510,320	\$652,391
	Mixed residential	1.57	\$995,030	\$339,727	\$1,334,757
	Commercial (hotel, office, retail, mixed)	0.97	\$225,003	\$373,726	\$598,729
	Industrial	1.12	\$324,699	\$537,940	\$862,639
	Public space	0.59	\$471,492	\$195,260	\$666,752
	Total	1.59	\$495,467	\$457,103	\$952,570

Source: Author (2012; 2018)

Table 4.11. Existing mean GnPRs for the sub-uses (in SGD)

Total cost	Sub-use	GnPR	Installation	Maintenance	Total cost
			cost	cost	
\$0–\$499,000	HDB flat	1.27	\$143,315	\$104,880	\$248,195
	Condominium	3.63	\$133,824	\$271,450	\$405,274
	Public mixed	0.23	\$48,311	\$133,668	\$181,979
	Hotel	0.84	\$20,892	\$325,570	\$346,462
	Office	0.24	\$19,209	\$135,164	\$154,373
	Retail	0.60	\$33,843	\$271,888	\$305,731
	Mixed-commercial	0.97	\$49,298	\$186,433	\$235,731
	Business park	1.93	\$265,992	\$0	\$265,992
	Factory	0.48	\$50,846	\$268,040	\$318,886
	Public space	0.49	\$148,709	\$78,940	\$227,649
	Total	0.80	\$58,343	\$206,726	\$265,069
\$500,000–\$999,999	HDB flat	3.38	\$649,459	\$157,314	\$806,773
	Condominium	1.67	\$177,877	\$547,880	\$725,757
	Strata land housing	0.98	\$142,071	\$510,320	\$652,391
	Private mixed	1.70	\$301,782	\$512,630	\$814,412
	Hotel	1.87	\$330,137	\$539,610	\$869,747
	Office	1.75	\$328,859	\$516,470	\$845,329
	Retail	1.16	\$276,291	\$391,440	\$667,731
	Mixed-commercial	0.66	\$127,988	\$463,995	\$591,983
	Business park	1.52	\$268,384	\$456,000	\$724,384
	Factory	0.67	\$203,578	\$526,487	\$730,065
	Total	1.60	\$299,119	\$435,713	\$734,832
\$1,000,000–\$2,499,999	HDB flat	3.46	\$1,334,235	\$327,763	\$1,661,998
	Condominium	3.11	\$980,910	\$637,677	\$1,618,587
	Private mixed	2.10	\$1,263,319	\$464,366	\$1,727,685
	Office	2.28	\$144,425	\$1,300,000	\$1,444,425
	Retail	0.56	\$1,709,131	\$628,300	\$2,337,431
	Business park	2.97	\$856,290	\$581,673	\$1,437,963

(Continued)

Table 4.11. (Continued)

Total cost	Sub-use	GnPR	Installation cost	Maintenance cost	Total cost
more than \$2,500,000	Factory	0.69	\$678,064	\$600,000	\$1,278,064
	Public Space	0.68	\$794,275	\$311,580	\$1,105,855
	Total	2.55	\$1,076,197	\$534,215	\$1,610,412
	Condominium	2.23	\$1,399,509	\$3,252,635	\$4,652,144
	Private mixed	2.88	\$2,564,368	\$353,795	\$2,918,163
	Retail	1.85	\$2,307,205	\$950,400	\$3,257,605
	Business park	2.34	\$676,282	\$2,600,000	\$3,276,282
	Total	2.40	\$1,818,540	\$1,793,877	\$3,612,417
	HDB flat	3.09	\$887,641	\$227,916	\$1,115,557
	Condominium	2.68	\$709,636	\$913,562	\$1,623,198
Total	Strata landed housing	0.98	\$142,071	\$510,320	\$652,391
	Public mixed	0.23	\$48,311	\$133,668	\$181,979
	Private mixed	2.24	\$1,468,389	\$442,756	\$1,911,146
	Hotel	1.43	\$197,604	\$447,879	\$645,482
	Office	0.87	\$112,273	\$376,095	\$488,368
	Retail	0.91	\$394,066	\$388,704	\$782,769
	Mixed commercial	0.85	\$80,774	\$297,458	\$378,232
	Business park	2.34	\$584,648	\$843,869	\$1,428,517
	Factory	0.57	\$206,540	\$398,882	\$605,422
	Public Space	0.59	\$471,492	\$195,260	\$666,752
	Total	1.59	\$495,467	\$457,103	\$952,570

Source: Author (2012; 2018)

total cost were found to rise more gradually, stagnate or decline between the 'Enhanced 2' and the 'Maximum' design scenarios.

The highest mean total cost of about S\$315 per sq. m. was observed for the 'Ultimate' design scenario for the factory land-use type with a high mean installation capital cost of about S\$232 per sq. m., and a much lower mean maintenance cost of about S\$83 per sq. m, as shown in Table 4.16. The lowest mean total cost of about S\$14 per sq. m. was

Table 4.12. Mean GnPRs for the five design scenarios by land uses

Land use/Scenario	Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
Residential	2.9	3.5	3.7	3.9	4.3
Strata landed Housing	1.0	1.5	2.2	2.2	3.0
Mixed residential	1.6	1.9	2.3	2.6	2.9
Commercial (hotel, office, retail, mixed)	1.0	1.4	1.8	2.1	2.7
Industrial	1.1	1.7	2.1	2.2	2.6
Public space	0.6	0.9	1.1	1.2	1.6
Total	1.6	2.1	2.4	2.6	3.1

Source: Author (2012; 2018)

observed for the ‘Existing’ scenario of the business park land-use type which had the third-lowest mean installation cost of about S\$7 per sq. m., and the second-lowest mean maintenance cost of about S\$7 per sq. m. The factory land-use type had the lowest mean installation capital cost of about S\$3 per sq. m. for the ‘Existing’ scenario but a relatively high mean maintenance cost of S\$13 per sq. m. and a mean total cost of about S\$16 per sq. m. The mixed residential land-use type had the lowest mean maintenance cost of about S\$5.6 per sq. m. for the ‘Existing’ scenario but a mean maintenance cost of S\$14 per sq. m. and a mean total cost of about S\$20 per sq. m.

Figure 4.41 depicts the hyperbolic slow-to-sharp rising trend of the GnPR with the assigned total cost (S\$) from the ‘Existing’ to the ‘Ultimate’ design scenarios. The average increase of GnPR per land-use type was observed as follows:

- Public residential buildings — by 1.5 with an increase of S\$7.7 million in total cost;
- Private residential buildings — by 1.4 with an increase of S\$12.3 million in total cost;

Table 4.13. Mean GnPRs for the five design scenarios by sub-uses

Sub-use		Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
HDB flat	Mean	3.0923	3.8115	4.0077	4.2177	4.6346
	Std. Deviation	1.61416	1.60818	1.56088	1.62125	1.53055
Condominium	Mean	2.6767	3.2200	3.4647	3.5980	4.0820
	Std. Deviation	1.36903	1.44079	1.40175	1.42636	1.37851
Strata landed housing	Mean	0.9800	1.5000	2.1500	2.1500	2.9650
	Std. Deviation	0.33941	0.00000	0.24042	0.24042	0.53033
Public mixed	Mean	0.2325	0.3850	1.0925	1.5925	2.0425
	Std. Deviation	0.10966	0.25723	0.35929	0.29579	0.60846
Private mixed	Mean	2.2425	2.6538	2.9638	3.0625	3.3012
	Std. Deviation	1.19791	1.22219	1.38578	1.38393	1.49180
Hotel	Mean	1.2233	1.7867	2.0033	2.2567	2.5500
	Std. Deviation	0.77120	1.07202	0.96736	1.19580	1.30180
Office	Mean	1.0656	1.5633	2.1111	2.5356	3.3089
	Std. Deviation	1.17932	1.42585	1.24561	1.18417	1.25508
Retail	Mean	0.9060	1.2933	1.5727	1.9113	2.3760
	Std. Deviation	0.57765	0.70957	0.66893	1.19970	1.20250
Mixed commercial	Mean	0.8450	1.0270	1.5910	1.7660	2.6280
	Std. Deviation	1.00972	0.99490	0.99845	1.01488	1.40723
Business park	Mean	2.3440	2.8000	3.2520	3.2920	3.7400
	Std. Deviation	0.64493	0.76443	0.67559	0.64913	0.62598
Factory	Mean	0.5691	1.1536	1.6282	1.6955	2.0182
	Std. Deviation	0.40488	0.74462	1.05432	1.06925	1.22446
Public space	Mean	0.5850	0.9250	1.1200	1.1900	1.5850
	Std. Deviation	0.13435	0.34648	0.38184	0.38184	0.88388
Total	Mean	1.5930	2.0662	2.4338	2.6415	3.1306
	Std. Deviation	1.38433	1.51744	1.44952	1.49055	1.52355

Source: Author (2012; 2018)

- Strata landed housing — by 2.0 with an increase of S\$7.7 million in total cost;
- Public mixed buildings — by 1.8 with an increase of S\$8.6 million in total cost;

Table 4.14. Cost of Greenery for five design scenarios by land use (in SGD)

Land use	Installation cost existing	Installation cost enhanced 1	Installation cost enhanced 2	Installation cost maximum	Installation cost ultimate (structural changes)
Residential	\$792,281	\$1,393,954	\$2,466,613	\$4,368,598	\$9,720,114
Strata landed Housing	\$142,071	\$343,284	\$2,949,909	\$2,949,909	\$6,518,806
Mixed residential	\$995,030	\$1,193,742	\$2,222,433	\$3,949,818	\$7,326,761
Commercial (hotel, office, retail, mixed)	\$225,003	\$415,452	\$959,582	\$2,413,739	\$4,300,230
Industrial	\$324,699	\$696,507	\$2,399,114	\$3,053,738	\$7,132,886
Public space	\$471,492	\$735,975	\$3,255,750	\$4,621,200	\$9,435,900
Total	\$495,467	\$832,763	\$1,849,148	\$3,302,702	\$6,781,291
Land use	Maintenance cost existing	Maintenance cost enhanced 1	Maintenance cost enhanced 2	Maintenance cost maximum	Maintenance cost ultimate
Residential	\$595,226	\$703,975	\$898,305	\$1,357,961	\$1,894,476
Strata landed housing	\$510,320	\$604,708	\$1,162,177	\$1,162,178	\$1,787,768
Mixed residential	\$339,727	\$394,959	\$652,069	\$1,029,263	\$1,373,246
Commercial (hotel, office, retail, mixed)	\$373,726	\$582,561	\$686,262	\$1,034,899	\$1,172,070
Industrial	\$537,940	\$1,105,715	\$1,419,880	\$1,565,744	\$2,078,529
Public space	\$195,260	\$313,148	\$894,644	\$1,442,064	\$2,836,384
Total	\$457,103	\$672,804	\$872,596	\$1,220,304	\$1,589,119
Land use	Total cost existing	Total cost enhanced 1	Total cost enhanced 2	Total cost maximum	Total cost ultimate
Residential	\$1,387,508	\$2,097,929	\$3,364,918	\$5,726,559	\$11,614,590
Strata landed housing	\$652,391	\$947,992	\$4,112,086	\$4,112,087	\$8,306,573
Mixed residential	\$1,334,757	\$1,588,701	\$2,874,502	\$4,979,081	\$8,700,007
Commercial (hotel, office, retail, mixed)	\$598,729	\$998,013	\$1,645,843	\$3,448,639	\$5,472,300
Industrial	\$862,639	\$1,802,222	\$3,818,995	\$4,619,482	\$9,211,415
Public space	\$666,752	\$1,049,123	\$4,150,394	\$6,063,264	\$12,272,284
Total	\$952,570	\$1,505,567	\$2,721,743	\$4,523,006	\$8,370,410

Source: Author (2012; 2018)

Table 4.15. Total cost of greenery for five design scenarios by sub-use (in SGD)

Sub-use	Installation cost existing	Installation cost enhanced 1	Installation cost enhanced 2	Installation cost maximum	Installation cost ultimate (structural changes)
HDB	\$887,641	\$1,302,276	\$2,335,785	\$4,603,695	\$7,388,652
Condo	\$709,636	\$1,473,408	\$2,579,998	\$4,164,848	\$11,740,713
Strata landed housing	\$142,071	\$343,284	\$2,949,909	\$2,949,909	\$6,518,806
Public mixed	\$48,311	\$72,760	\$1,291,837	\$4,527,544	\$6,996,449
Private mixed	\$1,468,389	\$1,754,234	\$2,687,731	\$3,660,955	\$7,491,917
Hotel	\$197,604	\$348,622	\$757,615	\$2,146,947	\$3,153,058
Office	\$112,273	\$217,693	\$665,087	\$1,950,180	\$3,925,787
Retail	\$394,066	\$726,860	\$1,360,066	\$3,521,412	\$5,170,964
Mixed commercial	\$80,774	\$153,331	\$735,828	\$1,309,833	\$4,096,703
Business park	\$584,648	\$800,689	\$2,274,989	\$2,900,474	\$6,196,491
Factory	\$206,540	\$649,151	\$2,455,535	\$3,123,403	\$7,558,520
Public Space	\$471,492	\$735,975	\$3,255,750	\$4,621,200	\$9,435,900
Total	\$495,467	\$832,763	\$1,849,148	\$3,302,702	\$6,781,291
Sub-use	Maintenance cost existing	Maintenance cost enhanced 1	Maintenance cost enhanced 2	Maintenance cost maximum	Maintenance cost ultimate
HDB	\$227,916	\$266,085	\$455,146	\$950,303	\$1,467,103
Condo	\$913,562	\$1,083,481	\$1,282,376	\$1,711,264	\$2,264,867
Strata landed housing	\$510,320	\$604,708	\$1,162,177	\$1,162,178	\$1,787,768
Public mix	\$133,668	\$180,134	\$635,372	\$1,397,640	\$1,801,985
Private mix	\$442,756	\$502,371	\$660,417	\$845,075	\$1,158,877
Hotel	\$447,879	\$740,798	\$799,689	\$1,037,141	\$1,159,887
Office	\$376,095	\$561,118	\$640,026	\$948,152	\$944,567
Retail	\$388,704	\$518,536	\$625,122	\$1,192,145	\$1,367,613
Mixed commercial	\$297,458	\$584,986	\$735,560	\$866,860	\$1,069,287
Business park	\$843,869	\$989,513	\$1,252,182	\$1,368,438	\$1,823,736
Factory	\$398,882	\$1,158,534	\$1,496,107	\$1,655,429	\$2,194,344
Public Space	\$195,260	\$313,148	\$894,644	\$1,442,064	\$2,836,384
Total	\$457,103	\$672,804	\$872,596	\$1,220,304	\$1,589,119

(Continued)

Table 4.15. *(Continued)*

Sub-use	Total cost existing	Total cost enhanced 1	Total cost enhanced 2	Total cost maximum	Total cost ultimate
HDB	\$1,115,557	\$1,568,361	\$2,790,931	\$5,553,998	\$8,855,755
Condo	\$1,623,198	\$2,556,889	\$3,862,373	\$5,876,111	\$14,005,580
Strata landed housing	\$652,391	\$947,992	\$4,112,086	\$4,112,087	\$8,306,573
Public mix	\$181,979	\$252,894	\$1,927,210	\$5,925,184	\$8,798,434
Private mix	\$1,911,146	\$2,256,605	\$3,348,148	\$4,506,030	\$8,650,794
Hotel	\$645,482	\$1,089,420	\$1,557,304	\$3,184,088	\$4,312,945
Office	\$488,368	\$778,811	\$1,305,113	\$2,898,332	\$4,870,354
Retail	\$782,769	\$1,245,396	\$1,985,188	\$4,713,556	\$6,538,577
Mixed commercial	\$378,232	\$738,316	\$1,471,389	\$2,176,693	\$5,165,990
Business park	\$1,428,517	\$1,790,202	\$3,527,170	\$4,268,911	\$8,020,227
Factory	\$605,422	\$1,807,686	\$3,951,642	\$4,778,832	\$9,752,865
Public space	\$666,752	\$1,049,123	\$4,150,394	\$6,063,264	\$12,272,284
Total	\$952,570	\$1,505,567	\$2,721,743	\$4,523,006	\$8,370,410

Source: Author (2012; 2018)

- Private mixed buildings — by 1.1 with an increase of S\$6.7 million in total cost;
- Hotels — by 1.5 with an increase of S\$3.7 million in total cost;
- Offices — by 2.2 with an increase of S\$4.4 million in total cost;
- Retail buildings — by 1.5 with an increase of S\$5.8 million in total cost;
- Mixed commercial buildings — by 1.8 with an increase of S\$4.8 million in total cost;
- Business parks — by 1.4 with an increase of S\$6.6 million in total cost;
- Factories — by 1.4 with an increase of S\$9.1 million in total cost.

Table 4.16. Total cost of greenery per sq. m. for five design scenarios

		Existing	Enhanced 1	Enhanced 2	Maximum	Ultimate
Maintenance cost (\$\$ per sq. m., 10-year)						
Residential	Mean	13.61	15.34	18.35	27.03	35.38
	Std. Deviation	27.87	28.58	30.71	34.98	36.63
Strata landed housing	Mean	13.25	16.40	30.84	30.84	46.31
	Std. Deviation	1.78	2.33	0.23	0.23	6.86
Mixed residential	Mean	5.55	6.51	10.10	14.76	19.46
	Std. Deviation	6.08	6.90	9.72	10.50	15.47
Commercial (hotel, office, retail, mixed)	Mean	15.14	22.38	25.64	36.01	40.99
	Std. Deviation	18.12	25.75	26.44	33.29	36.39
Factory	Mean	13.00	53.75	64.62	69.26	82.93
	Std. Deviation	11.42	67.33	82.74	82.75	105.09
Business park	Mean	7.15	9.30	13.97	15.02	20.86
	Std. Deviation	5.16	3.86	4.91	5.63	8.37
Installation cost (\$\$ per sq. m.)						
Residential	Mean	10.93	18.31	34.78	27.03	120.11
	Std. Deviation	9.49	12.56	26.05	34.98	108.82
Strata landed housing	Mean	4.03	9.89	74.32	30.84	164.33
	Std. Deviation	1.65	5.02	24.52	0.23	53.63
Mixed residential	Mean	14.45	16.11	30.91	14.76	85.57
	Std. Deviation	18.30	18.51	29.64	10.50	33.49
Commercial (hotel, office, retail, mixed)	Mean	5.37	13.27	31.89	36.01	124.08
	Std. Deviation	7.99	30.46	38.54	33.29	105.49
Factory	Mean	2.87	18.49	76.65	69.26	232.23
	Std. Deviation	2.20	23.80	115.80	82.75	329.60
Business park	Mean	6.63	9.12	34.37	15.02	78.72
	Std. Deviation	2.62	2.68	22.44	5.63	34.70
Total Cost (\$\$ per sq. m.)						
Residential	Mean	24.53	33.66	53.13	92.68	155.49
	Std. Deviation	35.60	38.30	53.67	82.11	128.09
Strata landed housing	Mean	17.27	26.29	105.17	105.17	210.63
	Std. Deviation	0.13	7.34	24.29	24.29	60.49
Mixed residential	Mean	20.00	22.62	41.01	66.76	105.04
	Std. Deviation	23.78	24.54	38.52	43.42	46.82
Commercial (hotel, office, retail, mixed)	Mean	20.51	35.65	57.52	107.27	165.07
	Std. Deviation	21.70	50.99	59.24	112.95	135.37
Factory	Mean	15.87	72.24	141.26	166.42	315.16
	Std. Deviation	11.44	72.42	187.59	186.92	422.20
Business park	Mean	13.78	18.42	48.34	55.02	99.58
	Std. Deviation	4.83	2.32	25.44	26.46	42.13

Source: Author (2012; 2018)

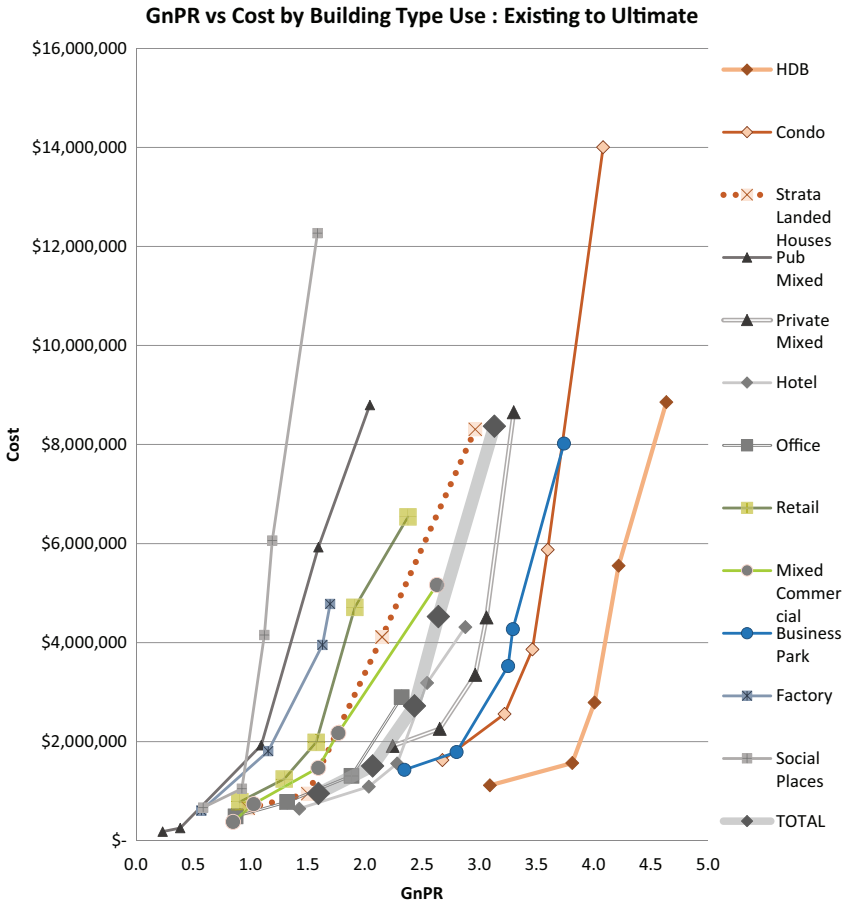


Fig. 4.41. GnPR vs total cost

Source: Author (2018)

The average increase of GnPR from the ‘Maximum’ to ‘Ultimate’ design scenarios was observed as follows:

- Public residential buildings — by 0.4 with an increase of S\$3.3 million in total cost;
- Private residential buildings — by 0.5 with an increase in total cost of S\$8.1 million;

- Strata landed housing — by 0.8 with an increase in total cost of S\$4.2 million;
- Public mixed buildings — by 0.5 with an increase in total cost of S\$2.9 million;
- Private mixed buildings — by 0.2 with an increase in total cost of S\$4.1 million;
- Hotels — by 0.3 with an increase in total cost of S\$1.1 million;
- Offices — by 0.8 with an increase in total cost of S\$2.0 million;
- Retail buildings — by 0.5 with an increase in total cost of S\$1.8 million;
- Mixed commercial buildings — by 0.9 with an increase in total cost of S\$3.0 million;
- Business parks — by 0.4 with an increase in total cost of S\$3.8 million;
- Factories — by 0.3 with an increase in total cost of S\$5.0 million.

The ultimate GnPR of 3.1 is achievable with the total cost of S\$8.4 million for the ‘Ultimate’ design scenario while the maximum GnPR of 2.6 with the total cost of S\$4.6 million is achievable for the ‘Maximum’ design scenario. The increase in cost from the ‘Maximum’ to the ‘Ultimate’ design scenarios (in percentages) for the 11 sub-uses is summarised below:

- Public residential buildings — by 43 per cent;
- Private residential buildings — by 66 per cent;
- Strata landed housing — by 55 per cent;
- Public mixed buildings — by 33 per cent;
- Private mixed buildings — by 61 per cent;
- Hotels — by 31 per cent;
- Offices — by 45 per cent;
- Retail buildings — by 32 per cent;
- Mixed commercial buildings — by 62 per cent;
- Business parks — by 57 per cent;
- Factories — by 54 per cent.

In general, the total cost of greenery doubled if the design scenario was enhanced from the 'Maximum' to the 'Ultimate' design scenarios, while GnPR increased only by 0.5.

The Approach

This book adopts a multi-prong approach involving the analysis of variance, the general linear model, the marginal cost analysis model and GnPR heuristic optimisation models, which in turn comprise the design and economic optimisation models.

ANOVA (Analysis of Variances)

The fieldwork data of the audited 100 buildings was subjected to the ANOVA model and the general linear model (GLM) estimations, which ascertained the correlation coefficients and the means associated with a dependent factor GnPR, for its explanatory factors. The dependent GnPR factor in turn depends on the explanatory factors in combination, as expressed in Eq. (4.1).

$$\text{GnPR} = f(\beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + c), \quad (4.1)$$

where $\beta_1, \beta_2, \dots, \beta_n$ are the regression coefficients, $x_1, x_2, \dots, x_n$ are the independent or explanatory variables (whereby the given values of the explanatory factors significantly influence the GnPR of a certain building), and c is a constant (the intercept). The values of β , x and c are obtained from the GLM analysis.

The ANOVA model tests the hypothesis of the relationship between the dependent GnPR factor and its explanatory factors, in order to estimate the various related factors that may explain the GnPR value for different land uses.

The General Linear Model (GLM)

The purpose of the GLM estimation is to quantitatively establish the primary factors from among the related factors that influence GnPR for

the assigned land uses and their sub-types. First, land use is examined as a fixed factor in a univariate analysis for the dependent GnPR factor. The related factors, including density, gross floor area, site coverage, year, total cost and the maintenance cost were collated and calculated for all 100 buildings.

The Marginal Cost (MC) Analysis Model

The MC analysis model was conducted to establish the returns to scale for GnPR investing that are expected of a profit seeking private real estate developer-investor. This would correspond to the minima turning point at the margin per additional GnPR level, beyond which there are no returns to scale. In other words, the marginal cost (MC) is defined as the change in total cost per unit change in GnPR level. The MC analysis model is expected to be U-shaped, reaching a minimum MC for a certain GnPR level and rising thereafter. Given that the landscaping construction industry in Singapore has a highly competitive market structure, with limited prevailing monopoly power, the returns to scale for a minima MC function would not originate from the landscaping unit-cost (same across all design scenarios) economies-of-scale but mainly from two other principal sources:

- Innovation in architectural landscaping design, based on the simulated designs per existing building audited, and the
- Innovation in the “Kit of Parts”.

The empirical data for the MC analysis model was obtained from the building audit of 100 buildings. The associated average cost (AC) model, defined to be the total cost divided by the building's GnPR level, was plotted in conjunction with the MC analysis model to generally validate the U-shaped nature of MC analysis model.

The MC analysis model by four land uses were estimated and graphed accordingly, together with the approximated polynomial function, to indicate the narrow GnPR band around its minimum U-shaped point

that reflects the optimal GnPR by land use. The narrow band is indicative of the optimal GnPR and is denoted by the lowest MC band in the MC analysis model. The corresponding AC curves represent a smoothened version of the MC analysis model curves and broadly affirm the same pattern of the MC curves. The MC analysis model was estimated using the building audit data on MS Excel spreadsheet software. The specific buildings that made up the narrow GnPR band were uniquely accountable for the two principle sources of innovation. These specific buildings were readily detailed and obtained from the MC analysis spreadsheet model.

The Heuristic GnPR Optimisation Model

The heuristic optimisation model was able to determine the range of optimal GnPR values for selected land uses. In practice and for an observed normal distribution, approximately 95 per cent of the data should fall within the spread of $\pm 1.96SD$ from its mean. The parameters necessary for this model are the distribution of the existing GnPR, the mean and standard deviation (SD) that define the 'Existing GnPR' as well as the optimal GnPR range that is linked to the mean GnPR, which in turn are derived from the five GnPR design scenarios. The model is further extended to the cost differences between landscape designs within the optimal GnPR range, and confirms the 'Optimal GnPR' to be estimated by the MC analysis model, within the 'Optimal GnPR' range observed from the design options (Santamouris, 2001; Jusuf & Wong, 2009).

Design optimisation

The mean existing GnPR defines the lower boundary of the optimal GnPR for each building type. To determine the upper boundary of the optimal GnPR, the mean GnPR of the 'Ultimate' scenario is highlighted under the 'Ultimate' column and is then compared with the corresponding $+0.25SD$ to $+2SD$ values. The closest value to the mean GnPR of the 'Ultimate'

design scenario for each building type is chosen as the upper boundary of the optimal (design) GnPR.

Economic optimisation

The ‘optimal (economic) GnPR’, obtained from the marginal cost (MC) analysis model, was found to be within the range of that ‘Optimal GnPR’, derived from the ‘Design optimisation’ model for the public residential, public and private mixed use, office and business park building types. However, for the public residential, strata landed housing, hotels, retail, mixed commercial and factory building types, the highest boundary of the GnPR defined by the design optimisation method is out of the ‘Optimal (economic) GnPR’ range found by the MC analysis model. Because the optimum GnPR (economic) values for all building types are within the 95 per cent GnPR distribution confidence level, the ‘Optimal GnPR’ range is adjusted accordingly.

Data Analysis

The results of the ANOVA analysis are presented in Table 4.17.

The ANOVA model’s results determine if Eq. (4.1) explains a statistically significant portion of the variability in the dependent variable from the variability in the explanatory variables. Taken individually, the results show that only the following two factors are significant:

1. Gross Floor Area; and
2. Site coverage.

In GLM estimation, land use is examined as a fixed factor in a univariate analysis for the dependent GnPR factor. The related factors that influence the GnPR for the assigned land uses and their sub-types include density (GPR), gross floor area (GFA), site coverage (S Coverage), year of construction, total cost (TCex) and the maintenance cost (MCex), and are generated in Table 4.18 for all buildings.

Table 4.17. ANOVA model and the Significance of explanatory factors influencing GnPR

		Sum of squares	df	Mean square	F	Sig.
Land use	Between Groups	240.740	85	2.832	1.762	0.117
	Within Groups	22.500	14	1.607		
	Total	263.240	99			
Density (Gross Plot Ratio)	Between Groups	397.273	85	4.674	1.286	0.310
	Within Groups	50.875	14	3.634		
	Total	448.147	99			
Gross Floor Area	Between Groups	1.285E12	85	1.511E10	3.490	0.006
	Within Groups	6.063E10	14	4.331E9		
	Total	1.345E12	99			
Location (central area/outside)	Between Groups	18.826	84	0.224	1.272	0.319
	Within Groups	2.467	14	0.176		
	Total	21.293	98			
Building site coverage, %	Between Groups	52845.083	85	621.707	2.103	0.060
	Within Groups	4139.667	14	295.690		
	Total	56984.750	99			
Year of building construction	Between Groups	8855.793	85	104.186	1.179	0.384
	Within Groups	1236.967	14	88.355		
	Total	10092.760	99			
Building form	Between Groups	4957.443	85	58.323	0.659	0.878
	Within Groups	1239.467	14	88.533		
	Total	6196.910	99			

(NB. * denotes significance at the 5 per cent level, ** denote moderate significance.)

Source: Authors (2012; 2017)

Analysis clearly shows that the following five explanatory factors do not have an influence on GnPR itself:

1. Gross Plot Ratio (GPR)
2. Site coverage (SCoverage)
3. Year of building construction (Year)

Table 4.18. General liner model: Full factor list test

Dependent Variable: GnPR, Existing design scenario						
Parameter	Beta coefficient, B	Std. error	t-statistic	Sig.	95% Confidence interval	
					Lower bound	Upper bound
Intercept	-96.872	24.870	-3.895	0.000	-146.272	-47.471
GPR	0.121	0.061	1.995	0.049	0.001	0.242
GFA	-1.243E-6	9.798E-7	-1.269	0.208	-3.189E-6	7.031E-7
Location	-0.140	0.261	-0.538	0.592	-0.658	0.377
S Coverage	-0.017	0.006	-3.019	0.003	-0.028	-0.006
Year	0.050	0.013	3.956	0.000	0.025	0.074
TCex	6.923E-7	2.003E-7	3.456	0.001	2.944E-7	1.090E-6
MCex	-5.453E-7	2.726E-7	-2.001	0.048	-1.087E-6	-3.897E-9

Source: Author (2012; 2018)

4. Total cost (TCex)
5. Maintenance cost (MCex)

The GLM estimation was then conducted, deploying these five related factors to ascertain that they are among the related ones that significantly influence GnPR.

The results of the GLM estimation, presented in Table 4.19, affirmed that only five primary factors are found to be significant:

1. Year (i.e. Year of building construction) with 0 per cent error;
2. Total cost with 1 per cent error;
3. Site coverage with 0.4 per cent error;
4. Gross Plot Ratio with 5.7 per cent error;
5. Maintenance cost with 5.9 per cent error

In accordance with Eq. (4.1), it was affirmed that the GLM estimation for GnPR is expressed by the explanatory-based Eq. (4.2) and presented in Table 4.19.

Table 4.19. Parameter estimates of the GLM analysis for the existing GnPR design scenario

Parameter	Beta coefficient, B	Std. error	t-statistic	Sig.	95% Confidence interval	
					Lower bound	Upper bound
Intercept	−92.120	24.203	−3.806	0.000	−140.176	−44.065
GPR	0.114	0.060	1.923	0.057	−0.004	0.233
S Coverage	−0.016	0.005	−2.980	0.004	−0.027	−0.005
Year	0.047	0.012	3.871	0.000	0.023	0.071
TCex	6.539E-7	1.951E-7	3.351	0.001	2.664E-7	1.041E-6
MCex	−5.098E-7	2.671E-7	−1.909	0.059	−1.040E-6	2.046E-8

Source: Author (2012; 2018).

$$GnPR = 0.114 \text{ GPR} - 0.16 \text{ Site Coverage} + 0.47 \text{ Year} + 6.359E - 7 \text{ Total Cost} - 5.098E \text{ Maintenance Cost} \quad (4.2)$$

Equation (4.2), however, is not detailed enough to be a prediction model.

The Correlation Coefficients

The estimated Pearson correlations are broadly consistent with the GLM estimation results, as the corresponding correlations are found to be significant between GnPR and three explanatory factors, namely, land use, building site coverage and year of building construction. This is because the Pearson correlation is merely indicative of the pair-wise strength of association between only two factors, i.e. GnPR and another explanatory factor while the other factors are not taken into account. As shown in Table 4.20, only three related factors that are each taken to correlate individually with the GnPR factor are found to have significant Pearson coefficients.

From Table 4.20, three key observations can be inferred:

1. The correlation coefficient for site coverage of −0.335 indicates a negative medium-to-strong linear relationship with GnPR: as the site coverage increases, GnPR decreases.

Table 4.20. The Pearson correlation coefficients for GnPR and explanatory factors

		Existing green plot ratio
Density (Gross Plot Ratio)	Pearson Correlation	−0.074
	Sig. (2-tailed)	0.464
	N	100
Gross Floor Area	Pearson Correlation	0.028
	Sig. (2-tailed)	0.784
	N	100
Location (central area/ outside)	Pearson Correlation	0.168
	Sig. (2-tailed)	0.097
	N	99
Building site coverage, %	Pearson Correlation	−0.355**
	Sig. (2-tailed)	0.000
	N	100
Year of building construction	Pearson Correlation	0.492**
	Sig. (2-tailed)	0.000
	N	100
Existing: Green Plot Ratio	Pearson Correlation	1
	Sig. (2-tailed)	
	N	100
Existing: Total cost	Pearson Correlation	0.457**
	Sig. (2-tailed)	0.000
	N	100
Existing: Maintenance cost	Pearson Correlation	0.168
	Sig. (2-tailed)	0.096
	N	100

NB. Correlation is significant at the 0.01 level (2-tailed)**.

Source: Authors (2012; 2017)

2. The correlation coefficient for year of building construction of 0.494 defines a positive strong linear relationship with GnPR: the newer a building, the higher the GnPR.
3. The correlation coefficient for the total cost of −0.457 indicates that there is a negative strong relationship: as the total cost increases, GnPR decreases.

The Marginal Cost (MC) Analysis Model

The MC analysis model for the four land uses were estimated and graphed accordingly, as shown in Figs. 4.42–4.46, together with its approximated polynomial function, to indicate the narrow GnPR band around its minimum U-shaped point that reflects the optimal GnPR for each land use. The optimal GnPR, highlighted as the lowest MC band in the figures’ captions of the respective MC analysis model, is indicated by the U-shaped point in each graph. The corresponding average cost (AC) curves represent a smoothened version of the MC analysis model curves and broadly affirm the same pattern of the MC curves.

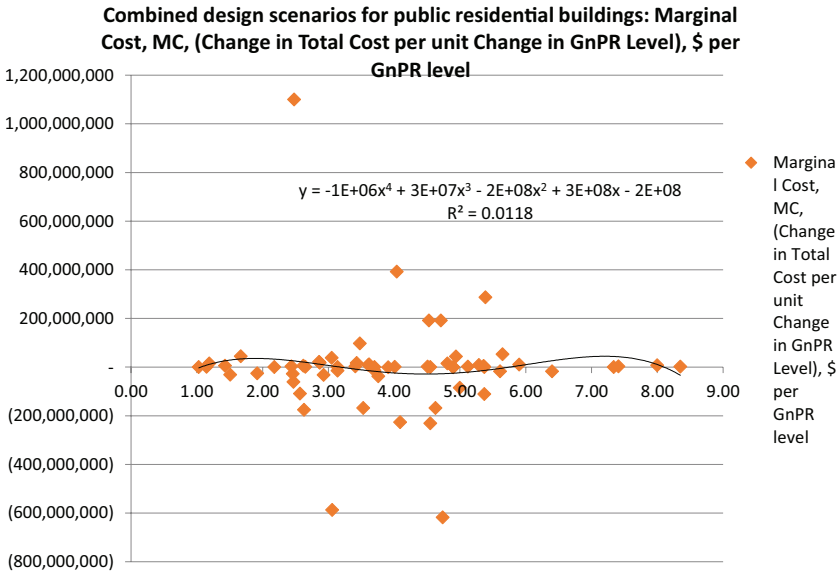


Fig. 4.42. Combined MC for public residential buildings; lowest MC band is between 3.2 and 5.0, min MC at 4.7

Source: Author (2012; 2018)

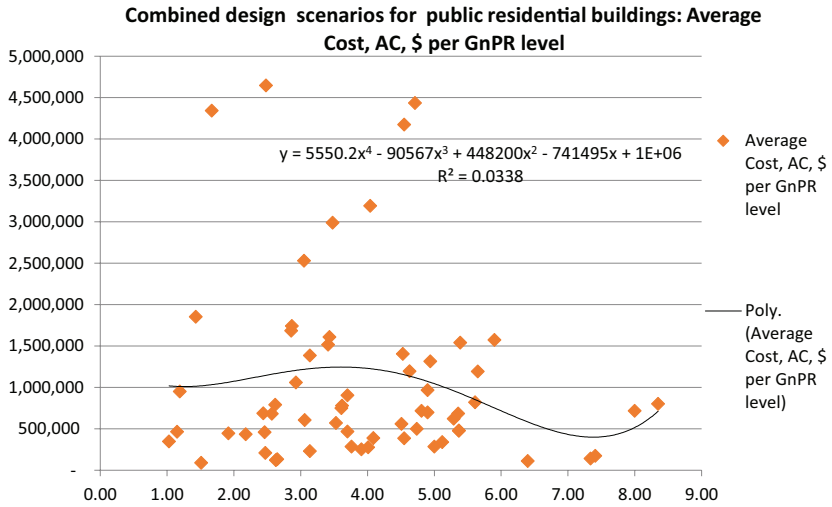


Fig. 4.43. Combined Average Cost (AC) for public residential buildings

Source: Author (2012; 2018)

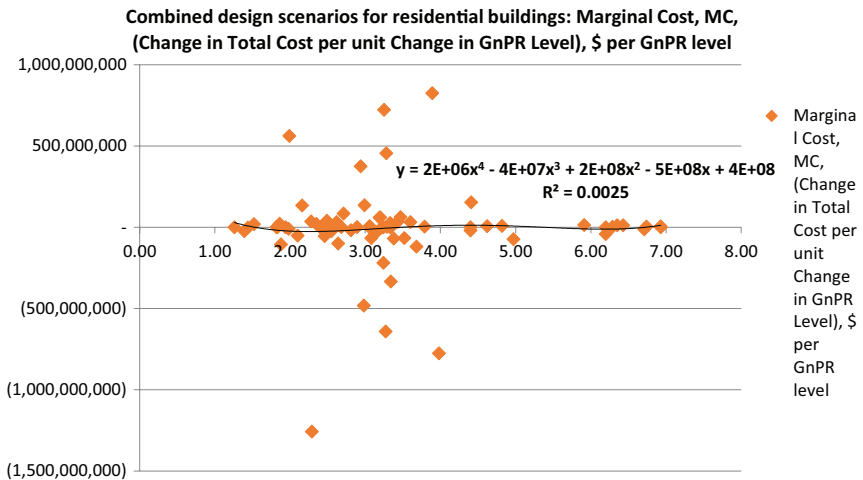


Fig. 4.44. Combined MC for private residential buildings; Lowest MC band is between 1.5 and 3.5, min MC at 2.3

Source: Author (2012; 2018)

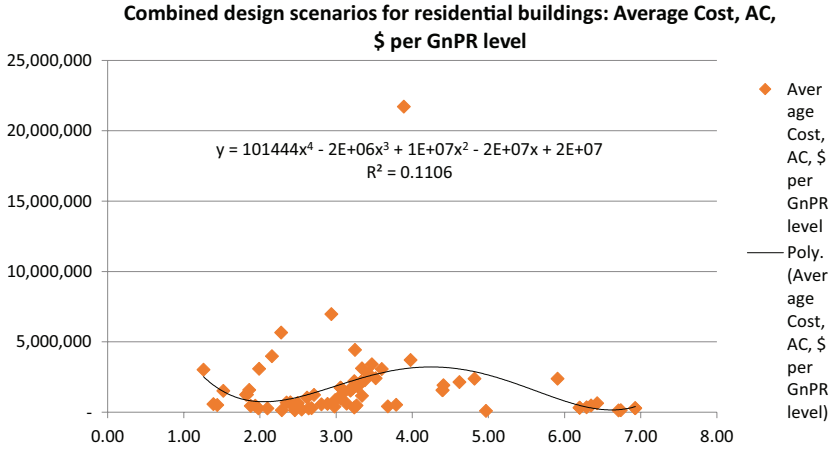


Fig. 4.45. Existing combined cost for private residential buildings

Source: Author (2012; 2018)

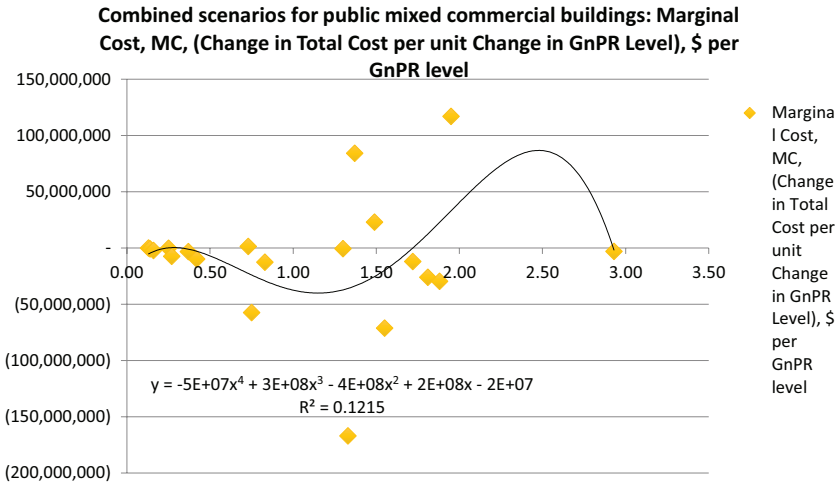


Fig. 4.46. Combined MC for public mixed commercial buildings; lowest MC band is between 0.3 and 1.6, min MC at 1.3

Source: Author (2012; 2018)

Implications

The lowest marginal cost is found to be at the following GnPR levels for the following land uses:

- Public residential: the combined option is 4.7 with the total cost of S\$2,376,191
- Private residential: the combined option is 2.3 with the total cost of S\$325,771
- Public mixed commercial: the combined option is 1.3 with the total cost of S\$7,612,063
- Private mixed commercial: the combined option is 4.2 with the total cost of S\$4,789,357
- Hotels: the combined option is 1.3 with the total cost of S\$1,666,747
- Offices: the combined option is 0.9 with the total cost of S\$364,344

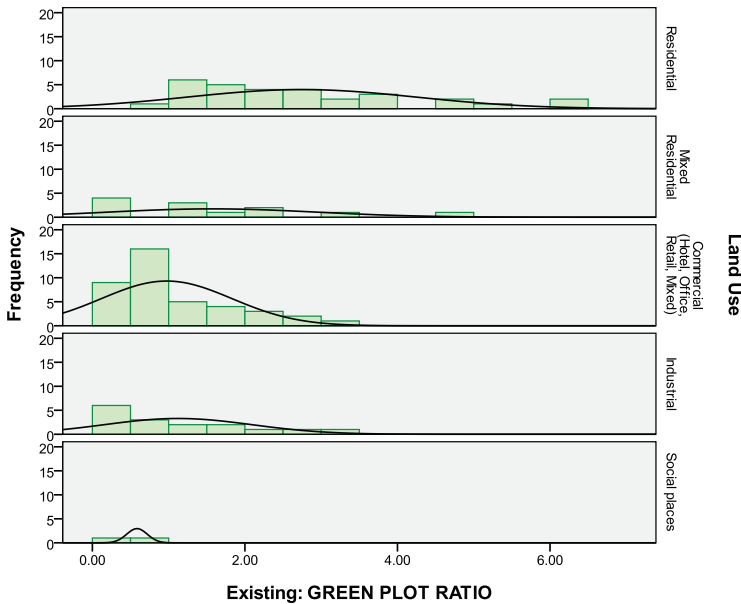


Fig. 4.47. Normal distribution of GnPR values

Source: Author (2012; 2018)

- Retail: the combined option is 2.5 with the total cost of S\$1,137,304
- Mixed commercial: the combined option is 1.6 with the total cost of S\$624,423
- Business parks: the combined option is 1.97 with the total cost of S\$265,992
- Factories: the combined option is 1.23 with the total cost of S\$453,529.

The GnPR Heuristic Optimisation Models

The one-sample Kolmogorov-Smirnov test was adopted to test that the GnPR is normally distributed, as shown in Table 4.21 and Fig. 4.48. Figure 4.47 plots all data in a symmetrical trend and demonstrates that most of the results are situated normally around the mean. The supporting Q-Q plots are provided in Figs. 4.49–4.51 for added information.

To test for normality, a parametric statistical Kolmogorov-Smirnov analysis was conducted, and the results are presented in Table 4.21 and illustrated in Figs. 4.49–4.51.

Table 4.21. Normality tests

		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
Land use		Statistic	df	Sig.	Statistic	df	Sig.
Existing: GnPR	Residential	0.133	30	0.187	0.915	30	0.020
	Mixed residential	0.147	12	0.200*	0.899	12	0.153
	Commercial (hotel, Office, Retail, Mixed)	0.167	40	0.007	0.893	40	0.001
	Industrial	0.166	16	0.200*	0.889	16	0.053
	Public spaces	0.260	2				

^aLilliefors Significance Correction.

*This is a lower bound of the true significance.

Source: Author (2012; 2018)

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Existing: GREEN PLOT RATIO is normal with mean 1.593 and standard deviation 1.384.	One-Sample Kolmogorov-Smirnov Test	.061	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Fig. 4.48. One sample non-parametric test

Source: Author (2012; 2018); SPSS V7 (2012)

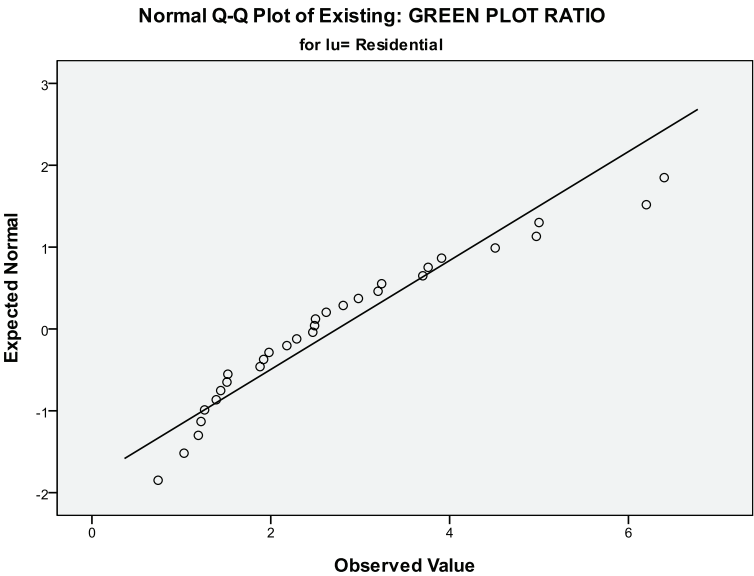


Fig. 4.49. Expected normal distribution of GnPR for residential use

Source: Author (2012; 2018); SPSS V7 (2012)

GnPR Optimisation Model

The GnPR optimisation model, as shown in Table 4.22 adopts a heuristic algorithm that conforms to the usual practice of imposing constraints on a maximising objective function. Such an increasing function for the GnPR is represented by incrementing the standard deviation from the mean GnPR (+SD) within the boundary range of between +0.25SD and +2.0SD. The 95 per cent confidence interval represents the extreme

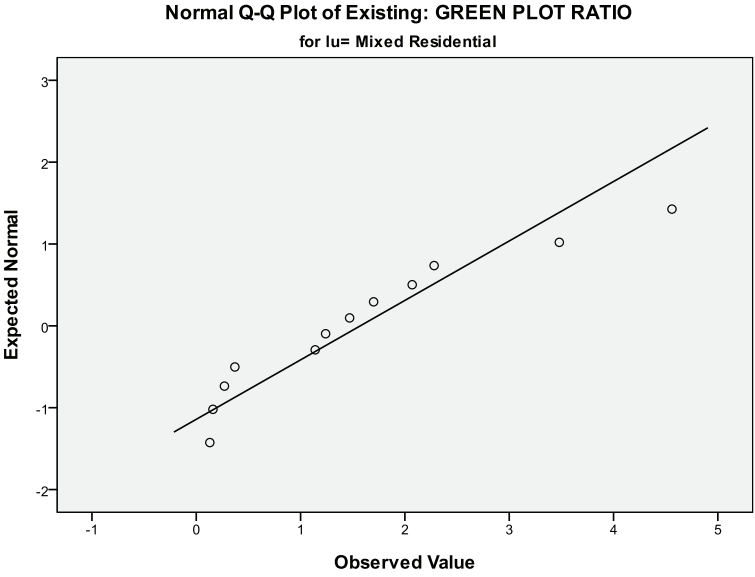


Fig. 4.50. Expected normal distribution of GnPR for mixed commercial use

Source: Author (2012; 2018); SPSS V7 (2012)

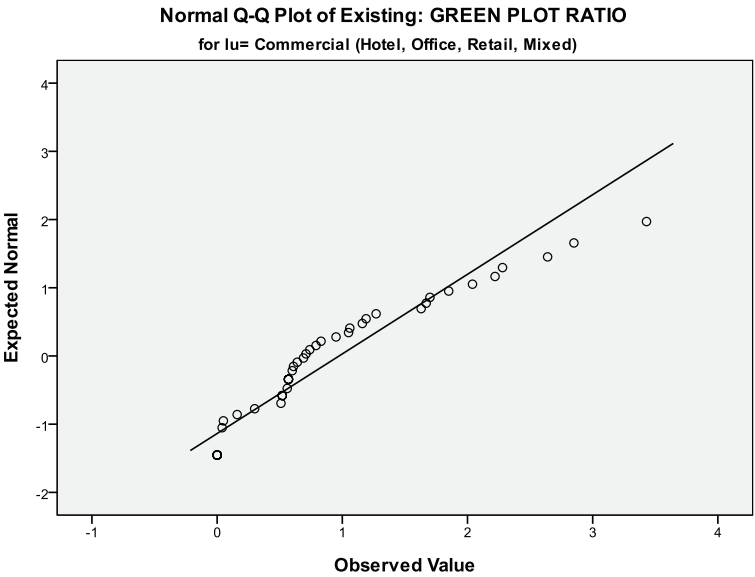


Fig. 4.51. Expected normal distribution of GnPR for commercial use

Source: Author (2012; 2018); SPSS V7 (2012)

Table 4.22. Optimal GnPR (design and economic) by land use and building type

Land use	Building type	Optimal GnPR (design and economic)	
		Low	High
Residential	Public	3.1	4.7
	Private	2.7	4.1
	Strata landed housing	1.0	1.7
Mixed residential-commercial	Public	0.2	0.5
	Private	2.2	4.2
Commercial	Hotel	1.2	2.4
	Office	1.1	3.1
	Retail	0.9	2.6
	Mixed	0.8	2.6
Industrial	Business park	2.3	3.7
	Factory and warehouse	0.6	1.4
Public space		0.6	0.9

Source: Author (2012; 2018)

+2SD boundary condition for the GnPR, to which the extended GnPR can realistically achieve. The four-step rules of the GnPR heuristic optimisation model are spelt out in two parts — ‘Design optimisation’ and ‘Economic optimisation’, shown in Tables 4.23 and 4.24 respectively.

The lowest and closest GnPR value for the incrementing SD to the ‘Ultimate GnPR’ is chosen as the highest boundary for the optimal GnPR level. On practical grounds, the ‘Optimal GnPR’ is appropriately presented as a range between two values — the ‘High Optimum GnPR’ and the ‘Low Optimum GnPR’. The high optimum GnPR does not exceed the ‘Ultimate GnPR’ value.

Rules of the GnPR heuristic optimisation model

Part 1: Design optimisation

1. ‘Existing GnPR’ is the low boundary of ‘Optimal GnPR’.
2. ‘Ultimate GnPR’ is compared with those GnPR values within the +0.25SD and +2.0SD boundary range.

Table 4.23. Heuristic optimisation model, Part 1: Design optimisation

(Part 1: Heuristically modelled optimum GnPR by land use: Design optimisation)																		
Land use	Building type	Mean GnPR					GnPR distribution (< 2SD = 95% confidence)										Optimal GnPR	
		Existing	Enhance-	Enhance-	Maximum	Ultimate	Mean	StDev	mean	mean	mean	mean	mean	mean	mean	mean	low	high
			ment 1	ment 2					+0.25SD	+0.5SD	+0.75SD	+1SD	+1.25SD	+1.5SD	+1.75SD	+2SD		
Residential	Public	3.09	3.81	4.01	4.22	4.63	3.09	1.61	3.50	3.90	4.30	4.71	5.11	5.51	5.92	6.32	3.1	4.3
	Private	2.68	3.22	3.46	3.60	4.08	2.68	1.37	3.02	3.36	3.70	4.05	4.39	4.73	5.07	5.41	2.7	4.1
	Strata landed housing	0.98	1.50	2.15	2.15	2.97	0.98	0.34	1.06	1.15	1.23	1.32	1.40	1.49	1.57	1.66	1.0	1.7
Mixed resi- dential- com- mercial	Public	0.23	0.39	1.09	1.59	2.04	0.23	0.11	0.26	0.29	0.31	0.34	0.37	0.40	0.42	0.45	0.2	0.5
	Private	2.24	2.65	2.96	3.06	3.30	2.24	1.20	2.54	2.84	3.14	3.44	3.74	4.04	4.34	4.64	2.2	3.1
Commercial	Hotel	1.22	1.79	2.00	2.26	2.55	1.22	0.77	1.42	1.61	1.80	1.99	2.19	2.38	2.57	2.77	1.2	2.4
	Office	1.07	1.56	2.11	2.54	3.31	1.07	1.18	1.36	1.66	1.95	2.24	2.54	2.83	3.13	3.42	1.1	3.1
	Retail	0.91	1.29	1.57	1.91	2.38	0.91	0.58	1.05	1.19	1.34	1.48	1.63	1.77	1.92	2.06	0.9	2.1
	Mixed	0.85	1.03	1.59	1.77	2.63	0.85	1.01	1.10	1.35	1.60	1.85	2.11	2.36	2.61	2.86	0.8	2.6
Industrial	Business park	2.34	2.80	3.25	3.29	3.74	2.34	0.64	2.51	2.67	2.83	2.99	3.15	3.31	3.47	3.63	2.3	3.6
	Factory and ware- house	0.57	1.15	1.63	1.70	2.02	0.57	0.40	0.67	0.77	0.87	0.97	1.08	1.18	1.28	1.38	0.6	1.4
Public spaces		0.59	0.93	1.12	1.19	1.59	0.59	0.13	0.62	0.65	0.69	0.72	0.75	0.79	0.82	0.85	0.6	0.9

Source: Author (2012; 2018)

Table 4.24. Heuristic optimisation model, Part 2: Marginal cost
 (Part 2: Heuristically modelled optimal GnPR by land use: Economic optimisation)

Land use	Building type	Existing design scenario		Ultimate design scenario		Marginal cost optimisation		Optimal GnPR (design)		Optimal GnPR (design and economic)		Comments
		GnPR	TC	GnPR	TC	GnPR	MC	low	high	low	high	
Residential	Public	3.092	1,115,557	4.635	8,855,755	4.70	2,376,191	3.1	4.3	3.1	4.7	The high GnPR is changed
	Private	2.677	1,623,198	4.082	14,005,580	2.30	325,771	2.7	4.1	2.7	4.1	
	Strata landed housing	0.98	652,391	2.965	8,306,573			1.0	1.7	1.0	1.7	
Mixed residential-commercial	Public	0.233	181,979	2.043	8,798,434	1.30	7,612,063	0.2	0.5	0.2	0.5	No. of buildings is too small
	Private	2.243	1,911,146	3.301	8,650,794	4.2	4,789,357	2.2	3.1	2.2	4.2	The high GnPR is changed
Commercial	Hotel	1.223	645,482	2.55	4,312,945	1.30	1,666,747	1.2	2.4	1.2	2.4	
	Office	1.066	488,368	3.309	4,870,354	0.90	364,344	1.1	3.1	1.1	3.1	
	Retail	0.906	782,769	2.376	6,538,577	2.50	1,137,304	0.9	2.6	0.9	2.6	
	Mixed	0.845	378,232	2.628	5,165,990	1.60	624,423	0.8	2.6	0.8	2.6	
Industrial	Business park	2.344	1,428,517	3.74	8,020,227	1.97	265,992	2.3	3.6	2.3	3.7	No. of buildings is too small
	Factory and warehouse	0.569	605,422	2.018	9,752,865	1.23	453,529	0.6	1.4	0.6	1.4	
Public spaces		0.585	666,752	1.585	12,272,284			0.6	0.9	0.6	0.9	

Source: Author (2012; 2018)

3. The lowest and closest GnPR value for an incrementing SD to the 'Ultimate GnPR' is chosen as that particular highest boundary for the 'Optimal GnPR' level.
4. The 2SD rule should hit at least the GnPR for the 'Enhanced 1' design scenario.

Part 2: Economic optimisation

1. The total cost (TC) for the 'Existing' and 'Ultimate' design scenarios are provided for information. The TC comprises the green landscaping investment cost and the ten-year maintenance cost for the low and high GnPR values, for a private real estate developer-investor.
2. The cost figures presented denote the associated design cost of greenery, nearest to the modelled optimal GnPR values.
3. The optimal marginal GnPR values are compared with the optimal design GnPR values: the optimal (economic) GnPR defined by marginal cost analysis (MCA) should be within the optimal (design) low-high GnPR range, indicating that the 'Optimal GnPR' (design and economic) is conditioned by the returns to scale that are expected of greenery investing.

Optimal GnPR values for five land uses and 11 building types

Five land use types were chosen for the GnPR design optimisation in Table 4.24:

1. Residential: public, private, and strata landed housing;
2. Mixed residential-commercial: public and private;
3. Commercial including hotels, offices, retail and mixed commercial buildings;
4. Industrial: Business parks, factories and warehouses; and
5. Public spaces.

Optimal GnPR values

The corresponding 'Optimal GnPRs (design and economic)' for the five land use types are presented in Table 4.22.

Concluding Remarks

This book's statistical analysis and the subsequent GnPR optimisation aim to evaluate the audit and design scenario data, and to recommend the optimal GnPR level for the four land uses and 'public spaces' use via the study of the key factors which influence GnPR level and through the Marginal Cost (MC) Analysis model. The 'optimal GnPR (design and economic)' is defined to be a range, with low and top boundaries for each land use.

An important result from the statistical analysis and the GnPR optimisation is the importance of five main factors which influence the GnPR level like the period of building construction (before or after 2000), the building site coverage (below or more than 50 per cent), the building density (GPR level) and the cost. The following conclusions can be inferred:

- The greenery innovation trend indicates that new developments tend to yield a higher GnPR than older developments;
- The lower the site coverage, the higher the GnPR as there is more greenery at the ground level as well as available space for the application of the 'Kit of Parts';
- The higher the GPR, the higher the GnPR as it is observed in practice that taller buildings allow for more greenery provision;
- The higher the GnPR level, the higher the total cost; albeit dependent on the architectural design and building scale. In theory, the GnPR of 2.0 is achievable with a budget of less than S\$2 million. However, in practice, the 'Total Cost' of landscape installation and maintenance can be lower, for example the Pinnacle@Duxton public housing complex was developed at the estimated cost of S\$1,735,082 with a relatively high GnPR of 3.7.

Nevertheless, the coefficients of significance that are found in the statistical modelling cannot be readily extended to the estimation of the GnPR level for a specific building type, owing to the small building sample within each category and the unequal distribution of samples in the various land use categories. For example, all public mixed-use buildings in the study that were built before 2000 had relatively low GnPR values, and were of medium-high density and high site coverage; whereas the private mixed-use buildings in the study were more recently constructed buildings that have high GnPR values and were of high site coverage and very high density. However, a concerted attempt was made to determine the correlation between the buildings built before 1989 (the year when the first public policy initiatives for the greening of buildings were first launched) and their GnPR levels. The review found that it had taken more time than expected for private real estate developers in Singapore to respond to such initiatives. Therefore, a slight increase in GnPR was observed much later, around 2000, rather than in the immediate years following the first greening initiative. From the slow-to-sharp rising trend of GnPR with the assigned 'Total Cost' (in S\$) of the 'Existing' to the 'Ultimate' design scenarios, the average increase in GnPR levels observed were as follows:

- Public residential buildings — by 1.5 with an increase in total cost of S\$7.7 million;
- Private residential buildings — by 1.4 with an increase in total cost of S\$12.3 million;
- Strata landed housing — by 2.0 with an increase in total cost of S\$7.7 million;
- Public mixed — by 1.8 with an increase in total cost of S\$8.6 million;
- Private mixed — by 1.1 with an increase in total cost of S\$6.7 million;
- Hotels — by 1.5 with an increase in total cost of S\$3.7 million;
- Offices — by 2.2 with an increase in total cost of S\$4.4 million;

- Retail — by 1.5 with an increase in total cost of S\$5.8 million;
- Mixed commercial — by 1.8 with an increase in total cost of S\$4.8 million;
- Business parks — by 1.4 with an increase in total cost of S\$6.6 million;
- Factories — by 1.4 with an increase in total cost of S\$9.1 million.

The average increase in GnPR level (in percentage) from the 'Maximum' to the 'Ultimate' design scenario was observed to be:

- For public residential buildings — by 43 per cent;
- For private residential buildings — by 66 per cent;
- For strata landed housing — by 55 per cent;
- For public mixed — by 33 per cent;
- For private mixed — by 61 per cent;
- For hotels — by 31 per cent;
- For offices — by 45 per cent;
- For retail — by 32 per cent;
- For mixed commercial — by 62 per cent;
- For business parks — by 57 per cent; and
- For factories — by 54 per cent.

For the 'Ultimate' design scenario, a maximum GnPR of 3.1 is achievable at the total cost of S\$8.4 million, while a maximum GnPR of 2.6 with the total cost of S\$4.6 million is achievable for the 'Maximum' design scenario. The lowest marginal cost is found to be at the following GnPR levels for ten building types:

- Public residential: the combined option is 4.7 with the total cost of S\$2,376,191
- Private residential: the combined option is 2.3 with the total cost of S\$325,771

- Public mixed commercial: the combined option is 1.3 with the total cost of S\$7,612,063
- Private mixed commercial: the combined option is 4.2 with the total cost of S\$4,789,357
- Hotels: the combined option is 1.3 with the total cost of S\$1,666,747
- Offices: the combined option is 0.9 with the total cost of S\$364,344
- Retail: the combined option is 2.5 with the total cost of S\$1,137,304
- Mixed commercial: the combined option is 1.6 with the total cost of S\$624,423
- Business parks: the combined option is 1.97 with the total cost of S\$265,992
- Factories: the combined option is 1.23 with the total cost of S\$453,529

The ‘Optimal (design and economic) GnPRs’, obtained from the MC analysis model were found to be within the range of the optimal GnPR obtained from the design optimisation model for the medium and high-rise residential, strata landed housing and commercial building types. Since the ‘Optimal (design and economic) GnPR’ values for all building types are within the 95 per cent GnPR distribution confidence level, the optimum GnPR range was adjusted accordingly. Finally, the ‘Optimal GnPRs (design and economic)’ for the twelve building types are summarised in Table 4.22.

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05 Conclusion

This book has essentially achieved two main objectives, namely, to determine the optimal levels of the green plot ratio (GnPR) for the various land-use types; and to establish the capital and maintenance costs for various levels of greenery provision. Subsequently, the book also helps to complete the potential landscape guidelines for the application of optimal GnPR levels, to facilitate a sustainable landscape for Singapore and other similar cities.

This forms the basis of further studies that could look into the development of a policy set of possible landscape guidelines, which could use the 'Optimal GnPR' levels to determine a sustainable landscape. A 'Landscape Guidelines' policy set can combine the findings from a review of international best practices, this book's building audit as well as its statistical analysis, to provide the environmental, economic, aesthetic and social benefits of greenery for urban built-up areas. This policy exercise should examine any current landscape strategies, the requirements, and technologies, as well as underpin GnPR as an essential and modern tool for greenery measurement. The possible optimal GnPR levels for various land use categories in Singapore could help to illustrate greenery possibilities in a building, taking into consideration their corresponding installation and maintenance costs.

Singapore's nature conservation and greenery provision strategies, owing to chronic and acute land scarcity, are supported in synergy with various government policies and programmes such as LUSH and the

‘Skyrise Greenery Incentive Scheme’ which encourage building owners to retrofit their existing buildings and to redesign them, or to design new direct real estate developments with space for sky gardens and terraces.

Skyrise greenery, like the planting of gardens on roof tops, terraces and balconies or along the walls, form an important potential area for enhancing greenery in dense urban areas. Despite notions that rooftop and terrace gardens may be complex to structure and need special structures to bear their weight, most modern green roof technologies are lightweight and require minimal maintenance. A variety of local and overseas systems studied in Singapore over the years have measured their environmental benefits in dense urban areas. These include the reduction of the urban heat island effect, increased biodiversity, thermal insulation and energy savings, improvement of air quality, as well as the reduction of rainwater flow.

Although skyrise greenery is readily deemed to be one of the most rapid and developing building feature, it has yet to be regulated and implemented on an extensive planning scale in Singapore. Instead, it is tailored to specific national circumstances, such as the prevalence of forests in the Singapore native habitat. This book clearly demonstrates the methodology for calculating the amount of vegetation for a direct real estate development and introduces various skyrise landscaping systems and technologies for implementation in Singapore. Guidelines developed can offer the optimal levels of skyrise greenery for various building types.

The potential landscape guidelines are meant to supplement the existing regulatory guidelines and development procedures, and to elaborate on the specific tools and recommendations to help the industry develop optimal greening strategies. They are meant to be used by the various stakeholders involved in landscape related matters in Singapore. The guidelines should also set a new benchmark in the amount of the vegetation cover of several building types, as well as potentially help policy

makers develop new policies and standards on the provision of green spaces for real estate developments and redevelopments.

The statistical analysis and the subsequent GnPR optimisation evaluated the audit and design scenario data, and through the study of the key factors which influence GnPR level and the Marginal Cost Analysis (MCA) model, recommended the optimal GnPR levels for each of the four land uses and the public spaces use. The 'Optimal GnPR (design and economic)' was defined as a range, with high and low boundaries for each land use.

An important result from the statistical analysis and GnPR optimisation is the importance of five main factors which influence GnPR level. These are the period of building construction (before or after 2000), the building site coverage (less than or more than 50 per cent), the building density (GPR level) and cost. The following conclusions were inferred:

- New developments tend to yield higher GnPRs than older developments;
- The lower the site coverage, the higher the GnPR;
- The higher the GPR, the higher the GnPR;
- The higher the GnPR level, the higher the total cost.

Owing to the small sample size within each building category and the unequal distribution of samples between the various land use categories, the coefficients of significance that were found in the statistical modelling cannot be readily extended to GnPR level estimation for a specific building type. For example, all public mixed-use buildings in the study that were built before 2000 had relatively low GnPR values, and were of medium-high density and high site coverage; whereas the private mixed-use buildings in the study were more recent buildings that have high GnPR values and were of high site coverage and very high density.

From the slow-to-sharp rising trend of GnPR with the assigned total cost (in S\$) of the 'Existing' to the 'Ultimate' design scenarios, the average increase of the GnPR levels was observed to be as follows:

- For public residential buildings — by 1.5 with total cost increase of S\$7.7 million;
- For private residential buildings — by 1.4 with total cost increase of S\$12.3 million;
- For strata landed housing — by 2.0 with total cost increase of S\$7.7 million;
- For public mixed — by 1.8 with total cost increase of S\$8.6 million;
- For private mixed — by 1.1 with total cost increase of S\$6.7 million;
- For hotels — by 1.5 with total cost increase of S\$3.7 million;
- For offices — by 2.2 with total cost increase of S\$4.4 million;
- For retail — by 1.5 with total cost increase of S\$5.8 million;
- For mixed commercial — by 1.8 with total cost increase of S\$4.8 million;
- For business parks — by 1.4 with total cost increase of S\$6.6 million;
- For factories — by 1.4 with total cost increase of S\$9.1 million.

The average increase in GnPR level from the 'Maximum' to the 'Ultimate' design scenarios (in percentage) was observed to be:

- For public residential buildings — by 43 per cent;
- For private residential buildings — by 66 per cent;
- For strata landed housing — by 55 per cent;
- For public mixed — by 33 per cent;
- For private mixed — by 61 per cent;
- For hotel — by 31 per cent;
- For offices — by 45 per cent;
- For retail — by 32 per cent;
- For mixed commercial — by 62 per cent;

- For business parks — by 57 per cent; and
- For factories — by 54 per cent.

The maximum GnPR of 3.1 was found to be achievable with the total cost of S\$8.4 million for the ‘Ultimate’ design scenario while the maximum GnPR of 2.6 with the total cost of S\$4.6 million was found to be achievable for the ‘Maximum’ design scenario.

The lowest marginal cost was found to be at the following GnPR levels for the following ten building types:

- Public residential: the combined option is 4.7 with the total cost of S\$2,376,191
- Private residential: the combined option is 2.3 with the total cost of S\$325,771
- Public mixed commercial: the combined option is 1.3 with the total cost of S\$7,612,063
- Private mixed commercial: the combined option is 4.2 with the total cost of S\$4,789,357
- Hotels: the combined option is 1.3 with the total cost of S\$1,666,747
- Offices: the combined option is 0.9 with the total cost of S\$364,344
- Retail: the combined option is 2.5 with the total cost of S\$1,137,304
- Mixed commercial: the combined option is 1.6 with the total cost of S\$624,423
- Business parks: the combined option is 1.97 with the total cost of \$265,992
- Factories: the combined option is 1.23 with the total cost of \$453,529

The ‘Optimal (design and economic) GnPR’, obtained from the MCA model was found to be within the range of the optimal GnPR obtained from the design optimisation model for the medium and high-rise residential, strata landed housing and commercial building types. Since the ‘Optimal (design and economic) GnPR’ values for all

building types were within the 95 per cent GnPR distribution confidence level, the optimum GnPR range was adjusted accordingly. Finally, the ‘Optimal GnPRs (design and economic)’ for the twelve building types are summarised in Table 5.1.

Table 5.1. The Optimal GnPR

Land use	Building type	Optimal GnPR (design and economic)	
		Low	High
Residential	Public	3.1	4.7
	Private	2.7	4.1
	Strata landed housing	1.0	1.7
Mixed residential-commercial	Public	0.2	0.5
	Private	2.2	4.2
Commercial	Hotel	1.2	2.4
	Office	1.1	3.1
	Retail	0.9	2.6
	Mixed	0.8	2.6
Industrial	Business park	2.3	3.7
	Factory and warehouse	0.6	1.4
Public spaces		0.6	0.9

Source: Author (2012; 2018)

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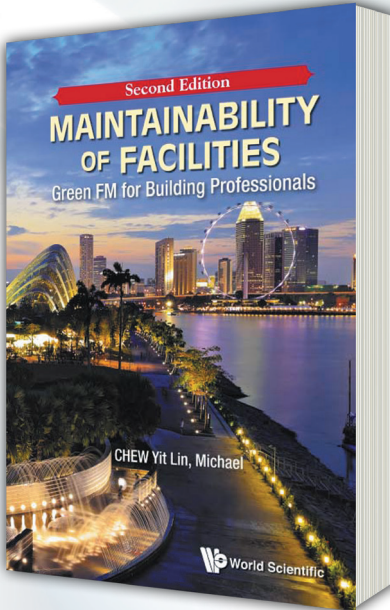
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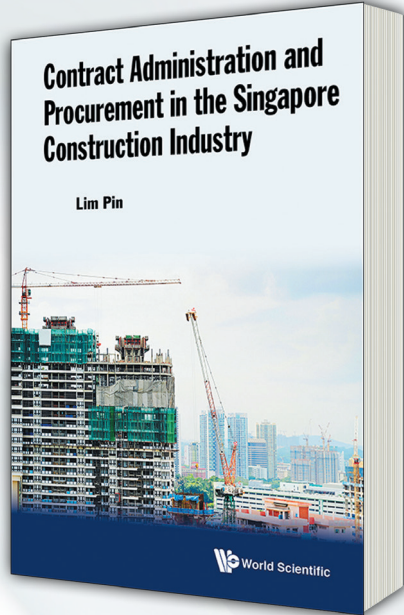
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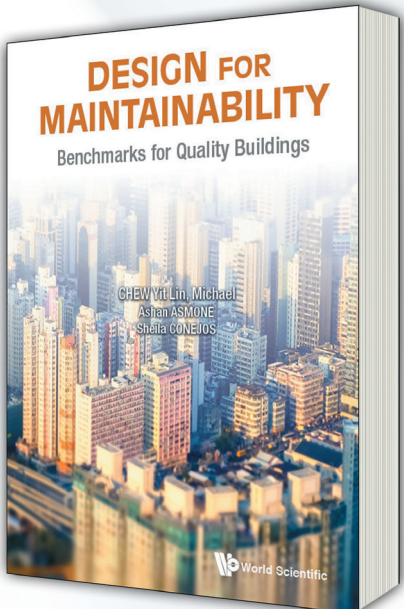
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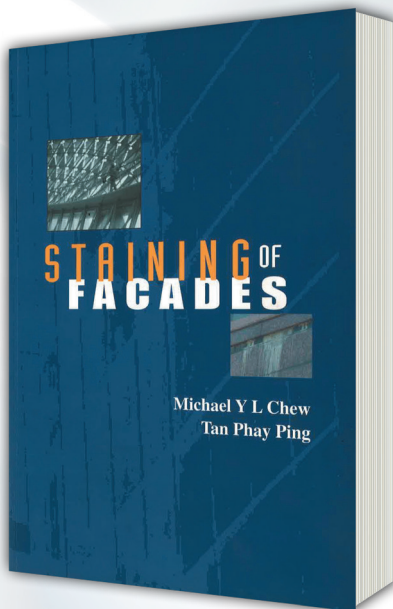


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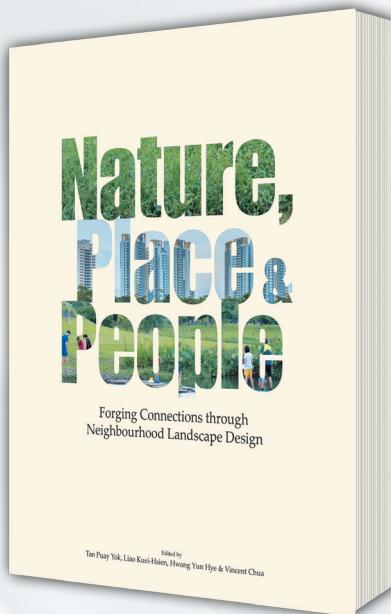


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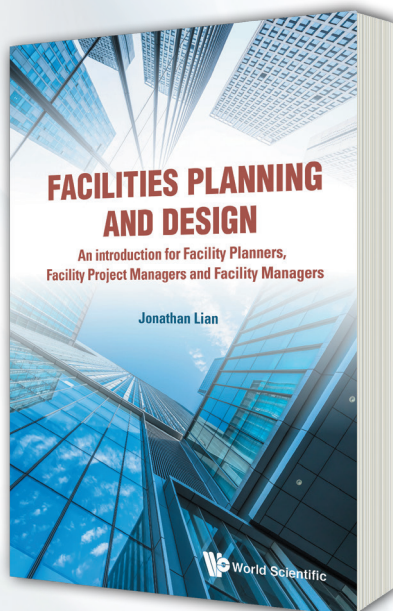
Titles of Interest



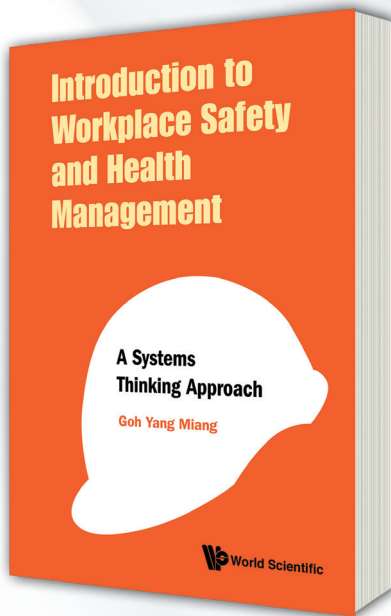
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