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Dense and Green Building Typologies: Architecture as Urban Ecosystem

Overview

Contemporary architecture and urban design practice in Singapore and beyond is increasingly exploring the integration of green spaces in buildings, producing innovative building types for high-density urban environments that include public spaces, extensive sky terraces, sky bridges, vertical parks, roof gardens and other 'green' components. Combinations of all these, often applied to mixes of residential, civic and commercial programmes, conjoin at times to produce 'vertical cities', in which the built sections become part of larger urban ecosystems, such as parks, gardens and river networks. Density and sustainability here are not seen as contradictory but rather as mutually dependent and synergistic.

The Dense and Green Building Typologies research group explores these developments through a systematic study of the urban, architectural, environmental, social and economic benefits of such building types in high-density urban contexts. As such, the project contributes to the Future Cities Laboratory (FCL) High-Density Mixed-Use Cities scenario, which develops new integrated planning approaches, research methodologies and implementation processes to support higher population densities, higher standards of environmental sustainability and enhanced liveability.

The Dense and Green Building Typologies project is organised in five work packages:

- Urban Design and Architecture Benefits explores design strategies that mitigate the negative effects of high density;
- Environmental Benefits studies the performance of dense and green building types in terms of thermal comfort, heat gain, urban heat island effects, air quality and noise pollution;
- Social Benefits investigates dense and green building types in terms of use and appropriation as well as psychological comfort;
- Economic Benefits examines the role of dense and green building types in land value appreciation; and
- Design Strategies integrates all work packages to develop innovative approaches to future high-density urban design and architecture.

The research on dense and green building typologies is conducted by a multidisciplinary team that brings together expertise in planning, urban design, architecture, landscape architecture, building technology, social science and ecology and that works synergistically with other teams at FCL. Beyond FCL, the Dense and Green Building Typologies team has established a number of important collaborations with Singapore government agencies, including the Urban Redevelopment Authority, the Housing and Development Board, the Building and Construction Authority, the National Parks Board and the National Environment Agency, as well as dense and green building project clients and practitioners. In addition, the team works closely with a number of academic institutions, including the Politecnico di Milano in Italy and the University of New South Wales in Australia, on some of its case studies.

Case Studies

At the core of the research on dense and green building typologies are a number of in-depth case studies from Singapore and beyond in which the research team investigates recently completed dense and green buildings and their urban contexts. These in-depth case studies were chosen from over 400 national and international cases that the team reviewed in the first phase of the project. They include:

Fig. 1 Dense and green building typologies case study, Punggol Waterway Terraces I, Singapore, 2015, aerial view.
Fig. 2 Punggol Waterway Terraces I, view from the northeast.

Punggol Waterway Terraces I, a large-scale public housing project located adjacent to a linear park with a canal in the newly developed Punggol district in the north of Singapore. The project features cascading roof gardens and a series of lush green spaces at ground level that are accessible to the public.

Architect	group8asia / Aedas
Landscape	ICN Design International Pte Ltd
Developer	Housing and Development Board, Singapore
Building type	Residential (public)
Climate zone	Tropical forest
Location	308B Punggol Walk, Singapore 822308
Coordinates	1°24'28.4"N 103°54'00.3"E
Site area	44,802 sq m
Gross floor area	146,000 sq m
Gross plot ratio	3.26
Green plot ratio	4.33
Number of units	1,072

Oasia Hotel Downtown, located in Singapore's central business district. Designed as a 'living tower', the project features a series of large sky gardens on multiple levels as well as an extensive green façade.

Architect	WOHA
Landscape	Tropical Environment Pte Ltd
Developer	Far East SOHO Pte Ltd
Building type	Mixed-use
Climate zone	Tropical forest
Location	100 Peck Seah Street, Singapore 079333
Coordinates	1°16'33.4"N 103°50'40.0"E
Site area	2,311 sq m
Gross floor area	19,416 sq m
Gross plot ratio	8.4
Green plot ratio	11.1
Programme	Commercial › Office, Hospitality + Sport › Hotel

Solaris, an office building located in Fusionopolis, a research and development district in the south of Singapore. The project features a number of green atria as well as a continuous spiralling green space that connects the project's ground level with its roof gardens.

Architect	T. R. Hamzah & Yeang Sdn Bhd / CPG Consultants Pte Ltd
Landscape	Tropical Environment Pte Ltd
Developer	Soilbuild Group Holdings Ltd
Building type	Commercial
Climate zone	Tropical forest
Location	1 Fusionopolis Walk, Singapore138628
Coordinates	1°17'53.8"N 103°47'24.5"E
Site area	7,734 sq m
Gross floor area	51,282 sq m
Gross plot ratio	6.63
Green plot ratio	12.2
Programme	Office

The Interlace, a large-scale private housing development located adjacent to Singapore's Southern Ridges, a series of parks and nature reserves in the south of the island state. The project features an extensive eco-deck as well as sky gardens on multiple levels.

Architect	OMA / Buro Ole Scheeren / RSP Architects, Planners & Engineers
Landscape	OMA/ICN Design International Pte Ltd
Developer	CapitaLand Singapore Pte Ltd
Building type	Residential (private)
Climate zone	Tropical forest
Location	180–226 Depot Road, Singapore 109684–109707
Coordinates	1°16'55.3"N 103°48'09.2"E
Site Area	81,000 sq m
Gross floor area	170,000 sq m
Gross plot ratio	2.09
Green plot ratio	1.12
Number of units	1,040

Skyville@Dawson, a recent public housing development along Singapore's Alexandra Canal, a linear park and waterway that connects the central and eastern parts of the city. The project features publicly accessible sky gardens on multiple levels.

Architect	WOHA
Landscape	ICN Design International Pte Ltd
Developer	Housing and Development Board, Singapore
Building type	Residential (public)
Climate zone	Tropical forest
Location	86 Dawson Rd, Singapore 141086
Coordinates	1°17'45.7"N 103°48'35.7"E
Site area	29,392 sq m
Gross floor area	114,793 sq m
Gross plot ratio	3.9
Green plot ratio	1.1
Number of units	960

Khoo Teck Puat Hospital, located in Singapore's Yishun Central area, adjacent to an urban park and Yishun Pond. The project features extensive green spaces on multiple levels as well as a community garden for urban farming on its rooftop.

Architect	RMJM / CPG Consultants Pte Ltd
Landscape	Peridian Asia Pte Ltd
Developer	Ministry of Health / Alexandra Health Pte Ltd
Building type	Healthcare
Climate zone	Tropical forest
Location	90 Yishun Central, Singapore 768828
Coordinates	1°25'26.3"N 103°50'19.2"E
Site area	34,000 sq m
Gross floor area	108,000 sq m
Gross plot ratio	3.18
Green plot ratio	6.18
Number of beds	590

Bosco Verticale, a private residential development located in the Porta Nuova Isola district of Milan. The project consists of two towers and features extensive greenery, including about 800 trees, on large cantilevering balconies.

Architect	Boeri Studio
Landscape	LAND Srl
Developer	Hines Italia Srl
Building type	Residential (private)
Climate zone	Mediterranean forest
Location	20124 Milan, Italy
Coordinates	45°29'08.4"N 9°11'26.0"E
Site area	N.A.
Gross floor area	40,000 sq m
Gross plot ratio	n/a
Green plot ratio	n/a
Number of units	113

One Central Park, a large-scale mixed-use development located in Chippendale, a suburb of Sydney. The project features extensive green façades planted with 250 species of Australian flowers and plants.

Architect	Ateliers Jean Nouvel/PTW Architects
Landscape	Aspect | Oculus
Developer	Frasers Property Australia/ Sekisui House Australia
Building type	Mixed-use
Climate zone	Temperate forest
Location	28 Broadway, Chippendale NSW 2008, Australia
Coordinates	33°53'04.5"S 151°12'02.0"E
Site area	7,734 sq m
Gross floor area	67,626 sq m
Gross plot ratio	6.63
Green area	4,000 sq m
Number of units	623

Fig. 3 Punggol Waterway Terraces I, urban design and architecture benefits, urban-scale study area.

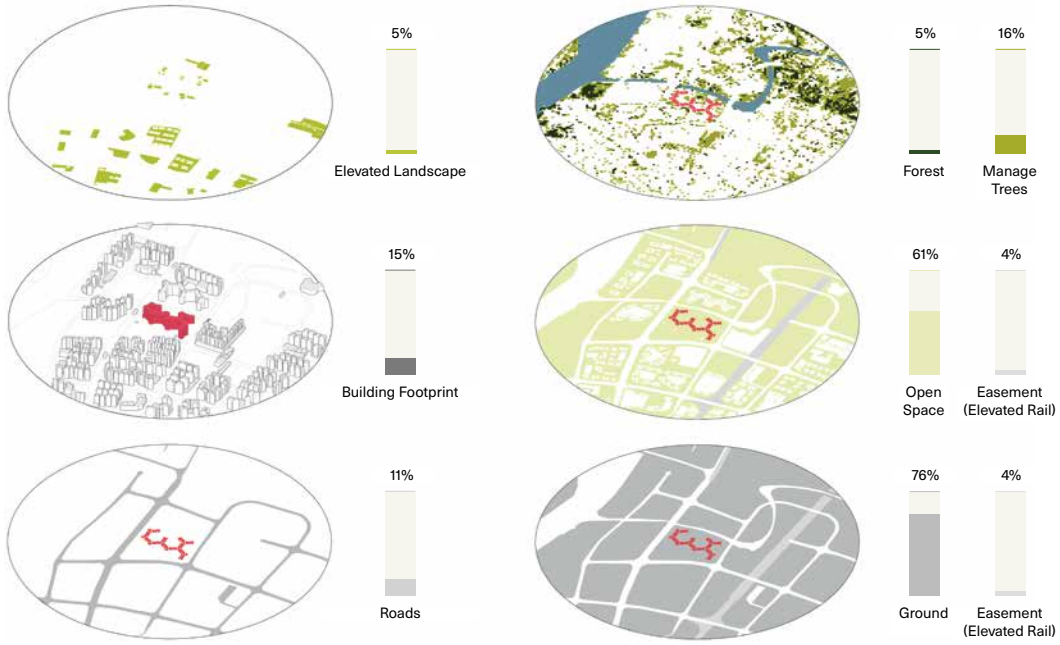


Fig. 4 Punggol Waterway Terraces I, urban design and architecture benefits, urban density and space coverage analysis (excerpt).

Research Methodologies

Urban Design and Architecture Benefits

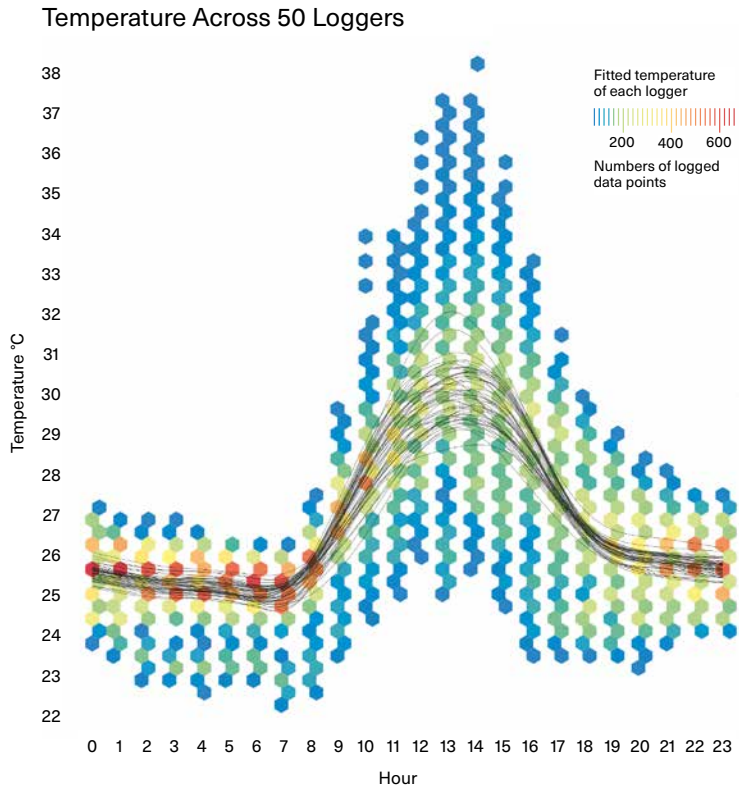
The urban design and architecture benefits work package introduces each in-depth case study through a discussion of its particular context and project background, based on a literature review as well as interviews with its various stakeholders. The work package subsequently analyses the respective project on the urban scale in terms of density, greenery, landscape provisions as well as contributions to larger urban systems, such as blue and green networks.

A larger-scale analysis covers an area of 200 hectares around the project, which allows for the capturing of at least one urban system it is part of. This larger-scale analysis also allows for a meaningful quantification of the greenery contribution of the project to its urban context and provides the basis for a comparison with the other case studies.

The documentation of each project on the urban scale further includes a detailed review of the respective master plan and the development guidelines it is part of. The case study's density analysis is comprised of various project mappings, 3D modelling and quantification of land based on documentation through drone videography, Google Earth Pro satellite images, Singapore government ArcGIS/QGIS data and OpenStreetMap (OSM) vector components. Each case study also includes detailed information on roads, plots, open spaces, building footprints and elevated landscape spaces that allows for a cross-case comparison of the urban morphology of the project and its context.

On the architectural scale, each case study documents research-relevant building regulations and analyses the spatial organisation of the respective project based on information provided by its various stakeholders, including building owners, clients, architects, landscape architects and contractors, as well as onsite documentation. All of this information is subsequently translated into detailed analytical drawings that serve as a basis for mappings, such as that of green components. Each case study further provides detailed building area calculations, green plot ratios and greenery typology quantifications, which allow for comparisons with the other case studies.

Fig.5 Punggol Waterway Terraces I, urban design and architecture benefits, architectural-scale green space integration.



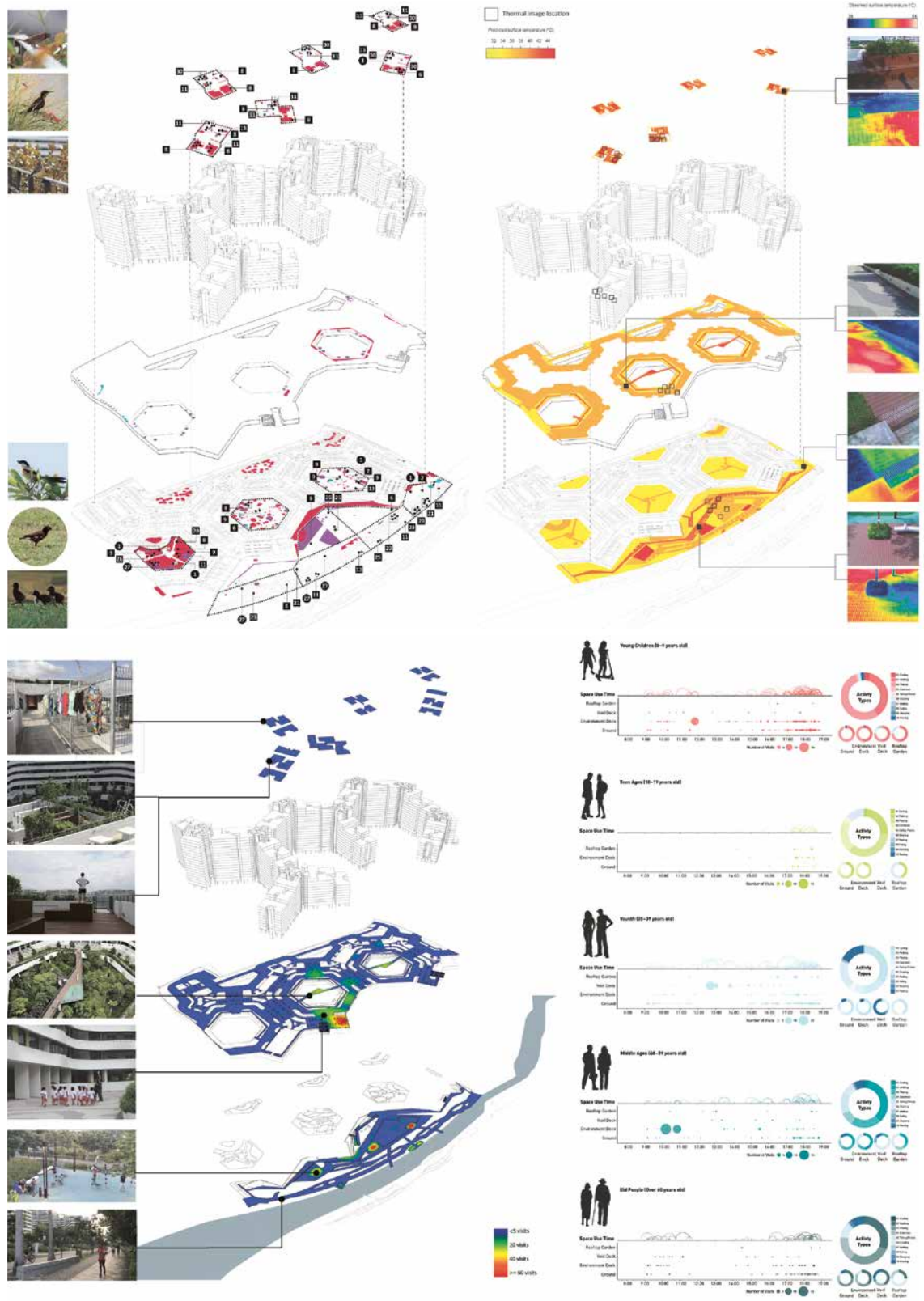


Fig. 6 Punggol Waterway Terraces I, urban design and architecture benefits, building layout and spatial organisation. (bottom left)
Fig. 7 Punggol Waterway Terraces I, integrated green space. (top)
Fig. 8 Punggol Waterway Terraces I, environmental benefits, temperature sensor data. (bottom right)
Fig. 9 Punggol Waterway Terraces I, environmental benefits, distribution of biodiversity surface heat maps. (right page, top)
Fig. 10 Punggol Waterway Terraces I, social benefits, space use and pedestrian movement analysis and heat maps. (right page, bottom)

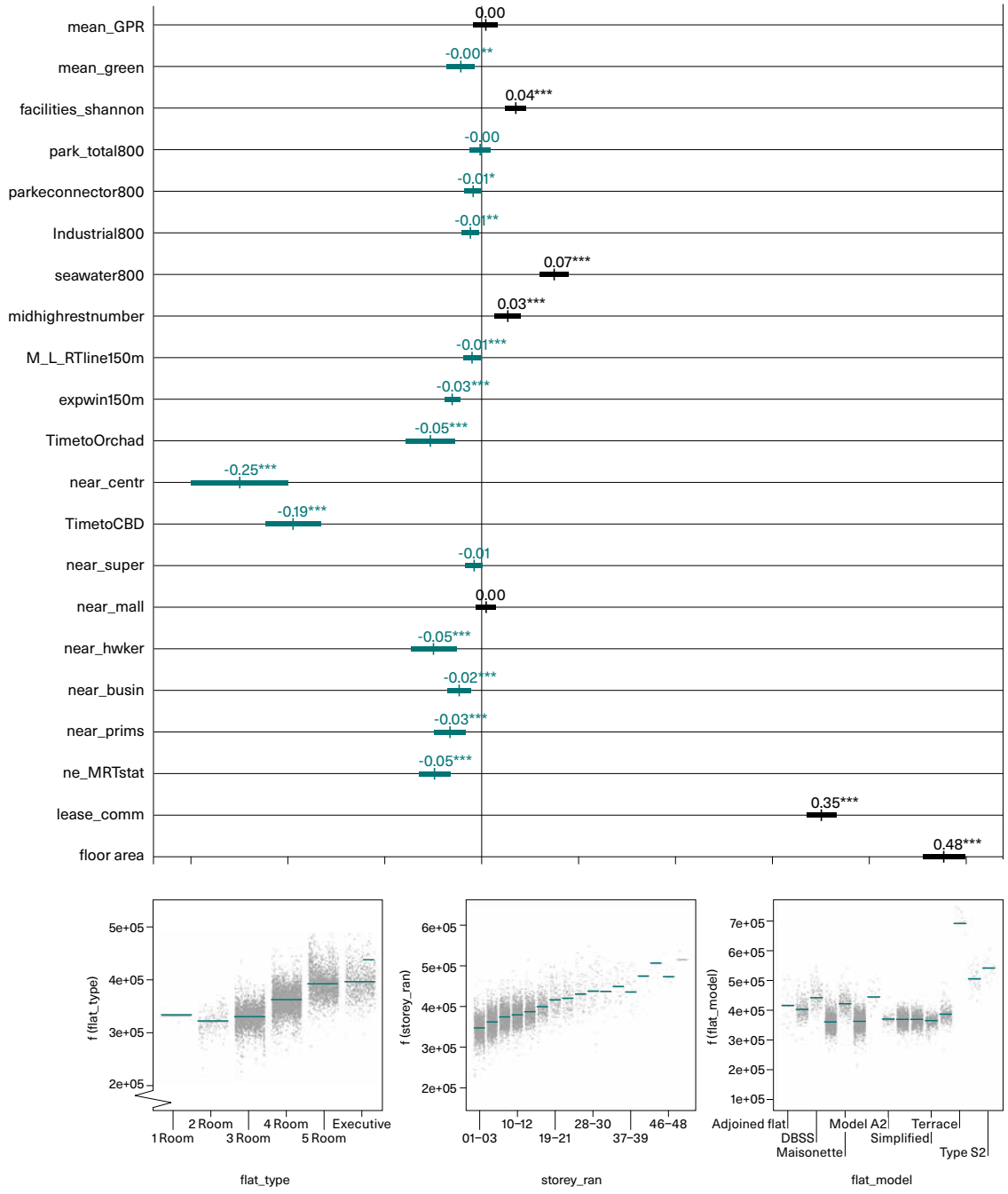


Fig. 11 Punggol Waterway Terraces I, economic benefits.

Environmental Benefits

Each case study includes a thorough analysis of plant and animal biodiversity in the project and its urban context. For the study of plant biodiversity, the vegetation of all landscaped areas is surveyed. Plants are identified to the species level and mapped onto the drawings provided by the Urban Design and Architecture Benefits work package. Plant species identifications are cross-referenced with landscape plans provided by contractors, Flora Fauna Web and plant identification reference books. For the capturing of trees, canopy radii are measured with laser rangefinders. The vertical and horizontal vegetation structure of each area in the project site is then assessed and recorded qualitatively to capture spatial complexity and thus the ability of a larger variety of biodiversity to use the vegetation.

Methodologies for the analysis of animal biodiversity include bird point-count surveys for which patches of 250–1,000 sq m visible from accessible viewpoints are identified and subsequently surveyed using the Active Search Point Method. For the analysis across case studies, a statistical model, correlating the abundance of birds found with different green elements around each case study at each survey patch, is applied.

To study General Taxa Diversity, researchers walk transects around each project over the course of a day to provide a general backdrop to the types of animals, aside from birds, that are found in different parts of the respective site. Methodologies to study animal biodiversity connections with larger ecosystems include the application of Circuit Theory as a basis for modelling how animals move in the surrounding urban environment.

For the study of the effect of greenery on surface temperatures in outdoor spaces, the research identifies areas that are highly frequented by the respective projects' residents and visitors. Surface temperatures are documented through the use of thermal images taken with an FLIR E8 infrared camera. The surfaces in the digital images are subsequently categorised based on surface types and whether or not they are shaded, through a two-step image classification process. This includes first mainly identifying green and non-green elements at a broad scale, and then using computer software to automatically classify the shaded and unshaded parts of each image. Subsequently, the thermal images are superimposed with corresponding categorised digital images, and the mean temperatures for shaded and unshaded surface types are determined in each image pair.

To allow for an analysis of projects across case studies, the researchers generate a linear mixed-effects model that is based on mean temperatures of shaded and unshaded surfaces in all analysed images. This allows for predictions regarding the surface temperatures in each project. In this model, mean surface temperature is the response variable, whereas surface type, shading condition, air temperature, relative humidity, wind speed and solar radiation are explanatory variables. The thermal image (nested in the case study) and time (nested in the date) are the random effects, which are used to account for temporal and spatial differences across the images.

Social Benefits

Each case study investigates the relationships among greenery provisions, space uses and pedestrian movements in the respective project, featuring two main components: post-occupancy space-use analysis, which analyses the influence of greenery provisions on space dwelling, and pedestrian movement analysis, which investigates the influence of greenery on pedestrian flows in selected project areas.

The research methodologies for the former include onsite observations with a focus on public and shared spaces. The researchers collect data, including space users' estimated age, ethnic group and gender, the start and end time of the use, activity types and context information, such as weather conditions at the time of the data collection. The data is subsequently mapped onto the spatial drawings provided by the Urban Design and Architecture Benefits work package through space-use heat maps. The data is further analysed in terms of the relationships between space types and use, and time and age groups. Additional methodologies include onsite interviews, in which the researchers enquire about space-use preferences and perceived space qualities in the respective project.

Methodologies for the study of the latter include onsite observations as a basis for environmental image mappings to categorise spatia elements and features. The collected data is subsequently analysed using the Spearman rank-order correlation, which measures the strength and direction of

association between two ranked variables, such as the number of occupants and the spatial elements in an investigated area of the project.

Economic Benefits

Each case study includes a detailed analysis of maintenance costs affiliated with greenery that are derived from government agency plant classification data and information provided by various project stakeholders. In addition, each case study features a detailed cost analysis for integrated landscape design components.

The economic benefits work package further investigates the investment and maintenance costs in the case study building, compared to traditional high-density buildings with minimal or no greenery, through detailed cost tabulations, based on breakdowns of landscape components, such as plant materials, planting media, irrigation, structure and safety costs. The costs of investments during the design and implementation phase and maintenance costs in the post-completion stage are derived for each case study as well. The data is subsequently analysed to determine relative costs for each greenery component for the various dense and green building case studies.

In addition, the work package includes an analysis of the land value appreciation of residential dense and green building typologies, based on a correlation of individual condominium selling price with its density of greenery. During this analysis, other factors are controlled for, including environmental conditions nearby (such as the distance to train stations) and the structural characteristics of each apartment (such as floor area and storey).

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The Waterfront Tanjong Pagar Project: A Transdisciplinary Approach Towards Urban Planning

> ‘To face the complexity of concrete situations,
> research for societal problem solving has to transcend
> disciplinary boundaries and laboratories.’
> (van den Daele and Krohn 1998; Hadorn et al. 2006)

The contemporary urban condition poses various challenges for urban research, theory and practice. Addressing concrete urban challenges like urbanisation, population growth, advanced forms of mobility, climate change and rising sea levels, a global economy and digitalisation, the development of spatially anchored responses is at the very core of the Future Cities Laboratory (FCL) agenda. The complexity and dynamics that define the urban condition have, therefore, determined the selection of different research projects which form FCL.

In the Waterfront Tanjong Pagar project, expertise in various disciplines comes together with the common goal of a sustainable urban development scenario and a shared research agenda to be tested at the aforementioned waterfront in Singapore. Due to its port activities, the large Tanjong Pagar Container Terminal in the south of the island has always been strategically important to the city-state. Dominated by industrial and port activities, the area has been cut off from urban life for decades. This has inhibited a direct connection from the Central Business District, the Marina Bay and the Marina South area to the southwestern part of the Greater Southern Waterfront.

The Waterfront Tanjong Pagar project brings together the disciplines of ecology (Ecosystem Services), engineering (Multi-Scale Energy Systems, Cyber Civil Infrastructure, Engaging Mobility), architecture and planning (The Grand Projet, Dense and Green Building Typologies), computer science (Big Data-Informed Urban Design and Governance), psychology (Cognition, Perception and Behaviour) and economy. The project aims to formulate sustainable development guidelines for high-density, mixed-use developments that speak both