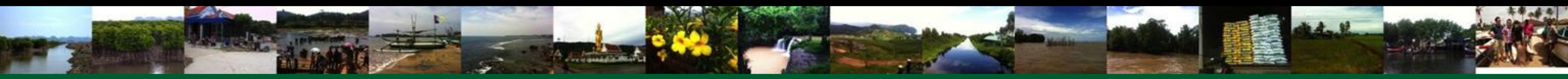

Evaluating Urban Facade Strategies for Solar and Heat Optimisation: A Remote Sensing and 3D Simulation Study of the Roppongi Hills

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Abstract: Tokyo's rapid urbanisation has intensified the urban heat island (UHI) effect, impacting environmental sustainability and liveability. This research evaluates Mori Building's 'Vertical Garden City' approach to mitigating UHI through vertical green infrastructure and photovoltaic (PV) technologies. Using remote sensing data—high-resolution thermal imagery from SatVu's HotSat-1 and NDVI from Landsat via Google Earth Engine—and 3D simulations in Rhino 8 with Grasshopper and Ladybug, the study quantifies direct sun hours and radiance across building facades during key seasonal periods.

Results show a clear inverse relationship between NDVI and land surface temperature (LST), underscoring vegetation's cooling role. Seasonal analysis reveals southern-facing, high-altitude facades receive prolonged sunlight and high radiance, making them optimal for PV integration. In contrast, northern-facing, lower-altitude facades—with limited sunlight—are ideal for vertical greenery, enhancing passive cooling through evapotranspiration. This dual-strategy development offers actionable recommendations for optimising building facades to balance energy generation and UHI mitigation.

Key Words: *Urban Heat Island (UHI), Vertical Green Infrastructure, Photovoltaic (PV) Integration, Remote Sensing, 3D Simulation*

I. Introduction

As global mega-cities confront rising temperatures and urban densification, sustainable design strategies are critical to improve thermal comfort and reducing environmental stress. While previous research has addressed rooftop greening or solar performance in isolation, few have integrated 3D simulations with high-resolution satellite-derived LST and NDVI data. This study bridges that gap by evaluating both solar and thermal dynamics on vertical facades of Mori Building's Roppongi Hills project, offering a novel hybrid approach to guide facade-specific strategies for energy generation and UHI mitigation.

世界の大都市が気温上昇や都市の高密化に直面する中、持続可能な設計戦略が不可欠です。これまでの研究では、屋上緑化や太陽光発電性能を個別に扱うものが多く、高解像度の衛星データ（LSTおよびNDVI）と3Dシミュレーションを統合した研究は限られていました。本研究では、森ビルの六本木ヒルズを対象に、垂直ファサードにおける太陽光および熱環境の動態を評価し、エネルギー創出およびヒートアイランド対策に向けたファサードごとの設計指針を導く新たなハイブリッド手法を提示します。

II. Methodology

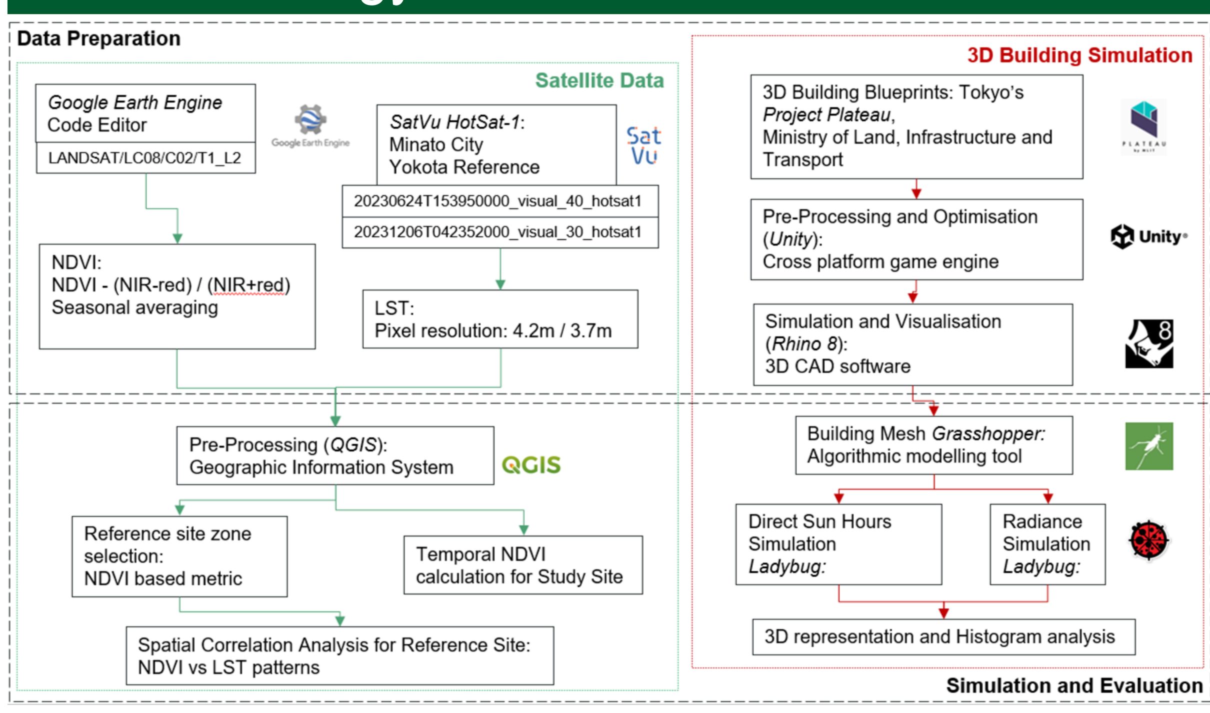

Fig1. Research Framework.

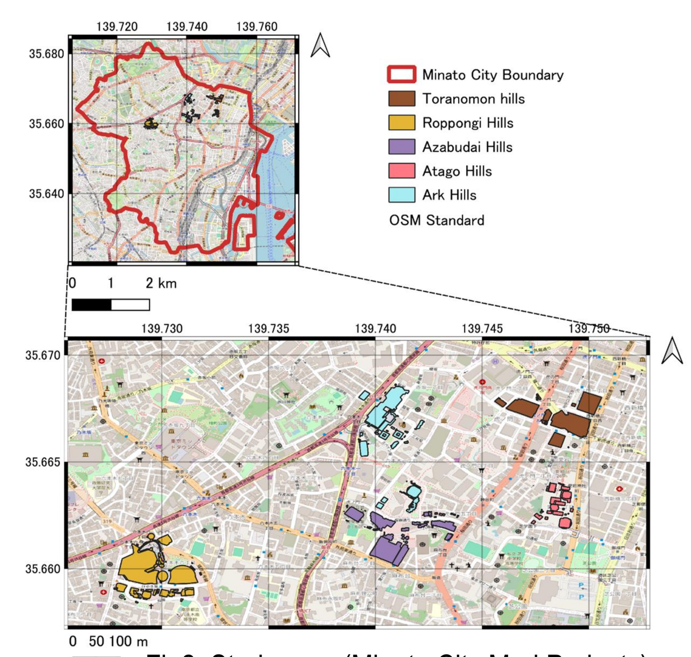

Fig2: Study area (Minato City Mori Projects)

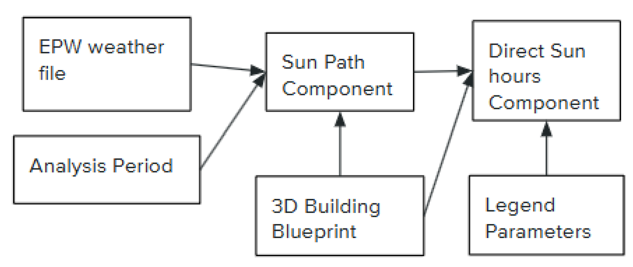

Fig3a. Simulation Workflow for Direct Sun Hours.

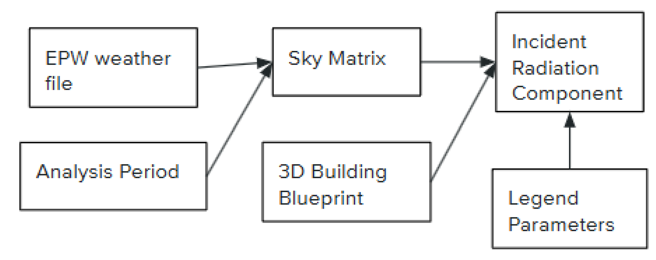

Fig3b. Simulation Workflow for Radiance.

III. Results and Discussion

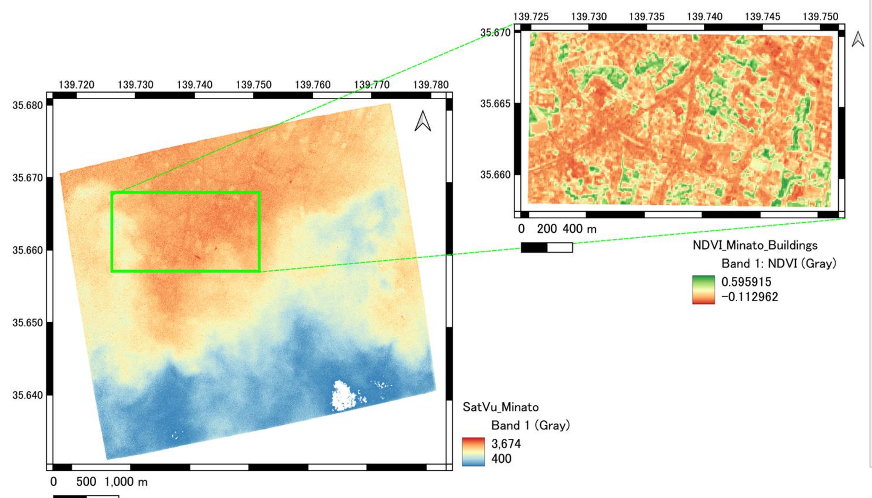

Fig4. Minato City LST map (left), Study site NDVI map (right)

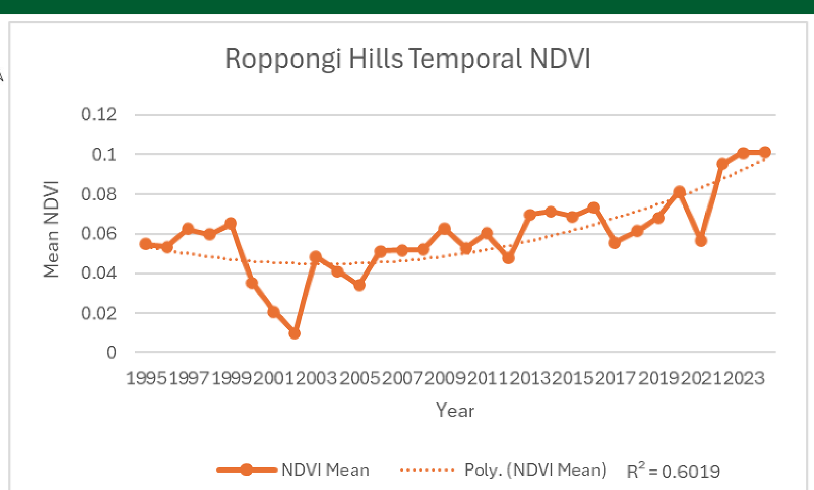

Fig5. Temporal NDVI for Roppongi Hills Project

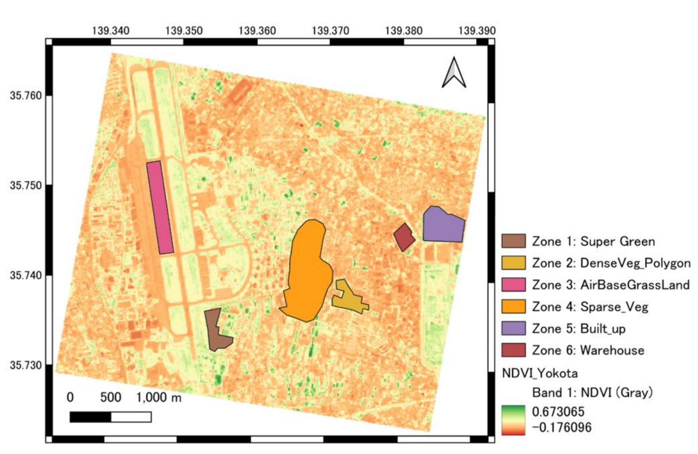

Fig6. Reference Site Study Zones on NDVI map

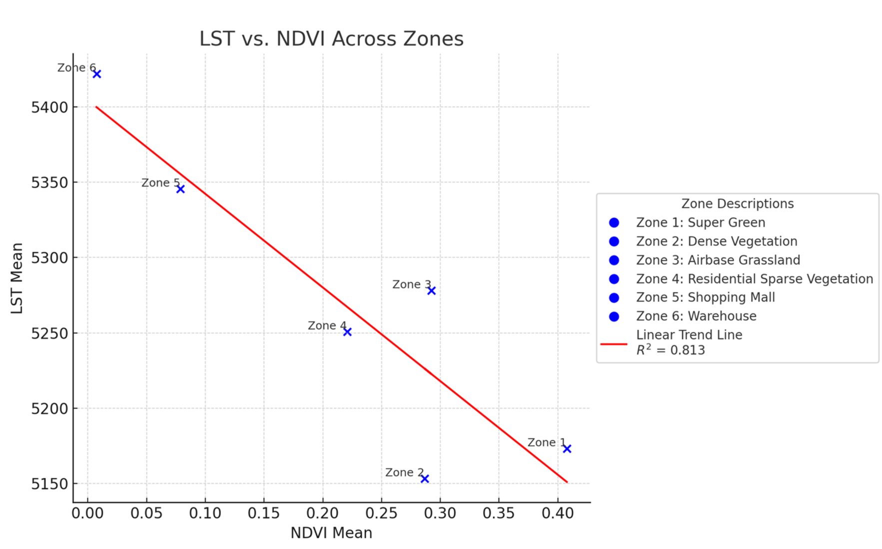

Fig7. Reference site Study Zone LST vs NDVI correlation graph

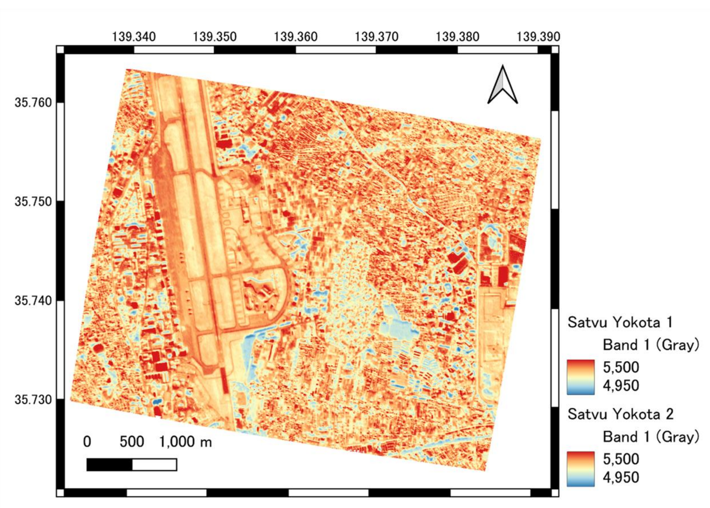

Fig8. Reference site LST map

- Despite a sharp drop during the early-2000s construction phase, Roppongi Hills' mean NDVI has risen consistently afterwards, nearly doubling since the mid-1990s and reaching ~0.10 by 2023—evidence of significant long-term greening (trend $R^2 \approx 0.60$). (Fig5.)
- Due to high cloud coverage (80%) over Minato City (Fig4.), the Yokota site was used as a reference for NDVI analysis (Fig8.). Six polygons were selected for spatial correlation analysis between NDVI and LST values. (Fig6.)
- The results reveal a strong inverse relationship between vegetation and surface temperature, with an R^2 value of 0.813, highlighting the significant cooling effect of vegetated areas in urban environments. (Fig7.)

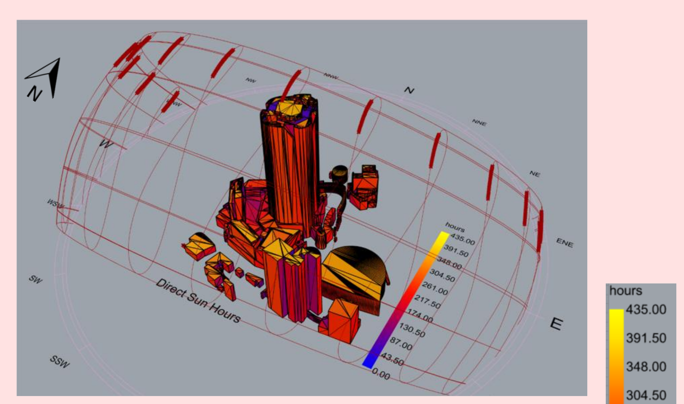

Fig 9a. South facing DSH Simulation May

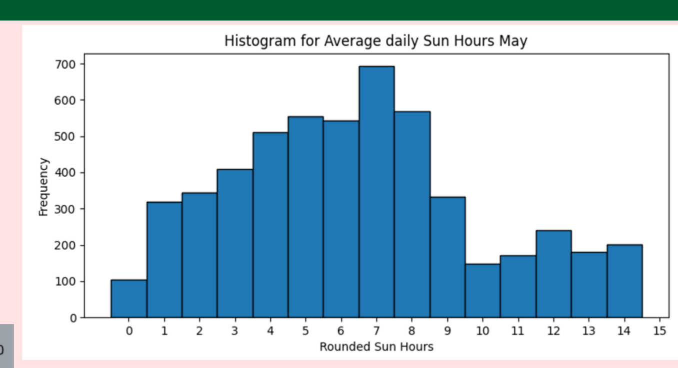

Fig 11a. Histogram, Direct Sun Hours May

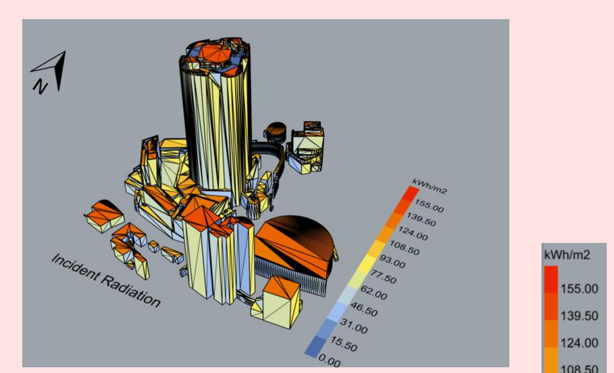

Fig 13a. South facing Radiance May

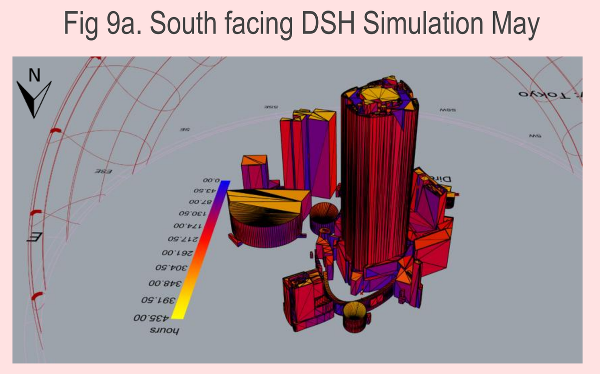

Fig 9b. North facing DSH Simulation May

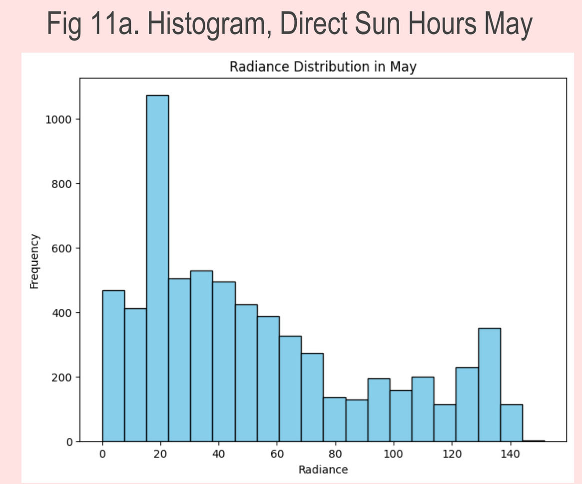

Fig 11b. Histogram, Radiance May

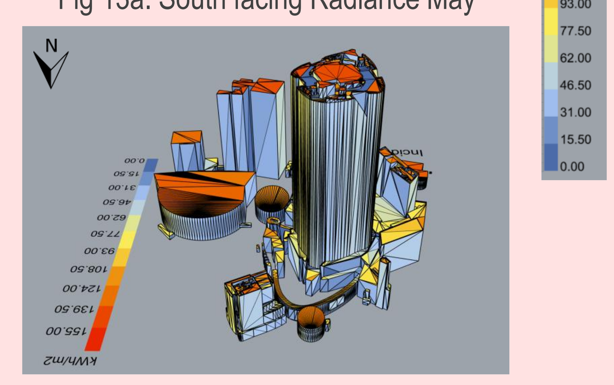

Fig 13b. North facing Radiance May

The 3D simulations using Rhino and Ladybug reveal clear seasonal and directional differences in solar exposure. South-facing facades consistently receive higher Direct Sun Hours (DSH) and radiance, especially in May, with peak daily sun hours reaching over 7 hours and radiance exceeding 140 kWh/m². High PV (photovoltaic) potential facades receive over 10 hours of sun hours.

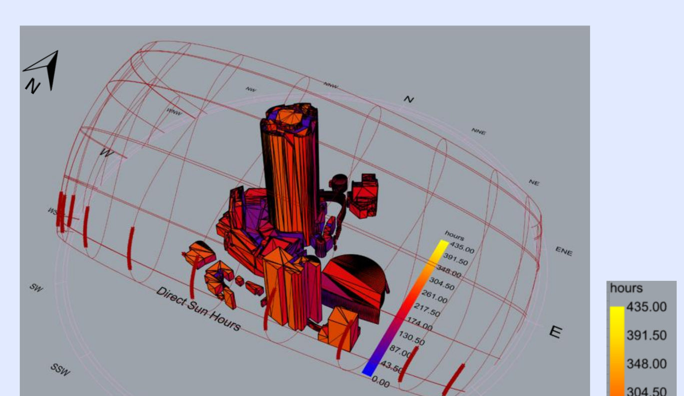

Fig 10a. South facing DSH Simulation November

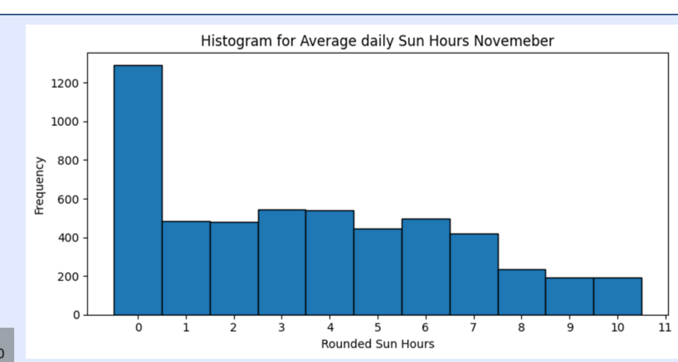

Fig 12a. Histogram, Direct Sun Hours November

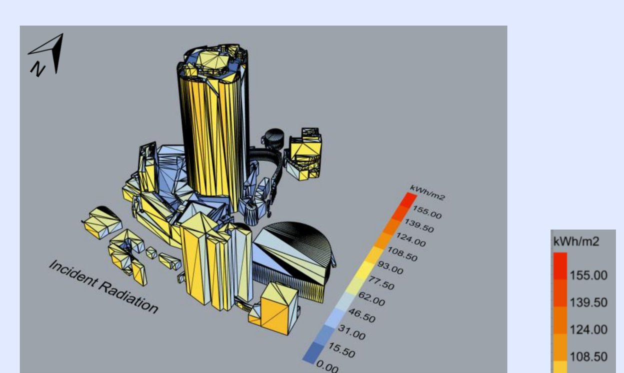

Fig 14a. South facing Radiance November

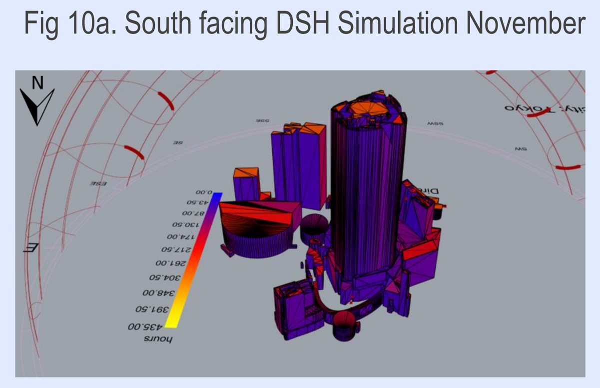

Fig 10b. North facing DSH Simulation November

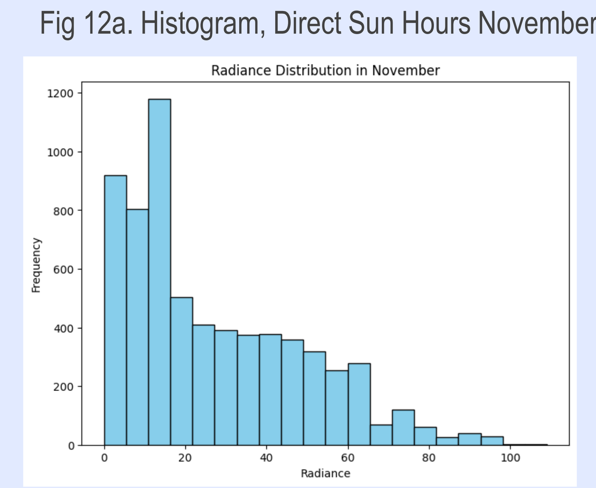

Fig 12b. Histogram, Radiance November

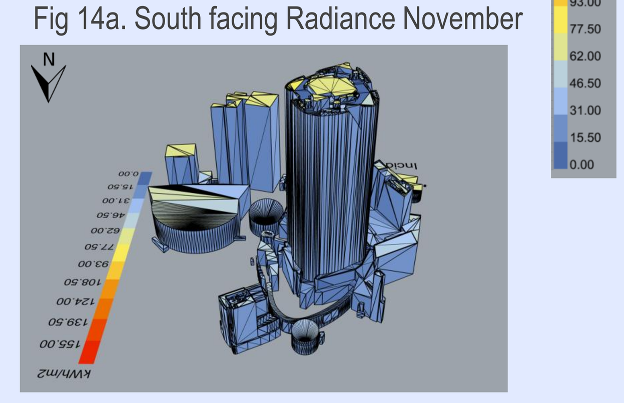

Fig 14b. North facing Radiance November

In contrast, north-facing facades receive significantly less sunlight, particularly in November, with average sun hours below 5 and radiance under 60 kWh/m². These findings confirm the suitability of south-facing facades for PV integration and north-facing surfaces for green infrastructure, supporting a dual-strategy for facade optimisation.

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