CityGML and Solar Potential Analysis for Buildings in Singapore

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Solar Energy System Cluster

Solar Energy Research Institute of Singapore (SERIS)
National University of Singapore (NUS)

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Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Motivation and Background
- Methodology
- Case studies
  - Rooftop PV potential
  - Solar Insolation for Buildings with full 3D implementation
  - Automatically Modelling LoD from 2 to 3

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SERIS

Solar Energy Research Institute of Singapore

- Founded in 2008; focuses on applied solar energy research
- Part of the National University of Singapore (NUS)
- Rapid growth (now ~160 people and > 6000 m^2 of space)
- > USD 30 million investments for labs
- R&D focus is on PV (cells, modules, systems) and solar energy efficient buildings
- Specialised in professional services for the PV industry
- ISO 9001 & ISO 17025* certified
  (* PV Module Testing Lab)

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Overview

- Introduction of SERIS
- Capabilities from SES cluster

SES cluster

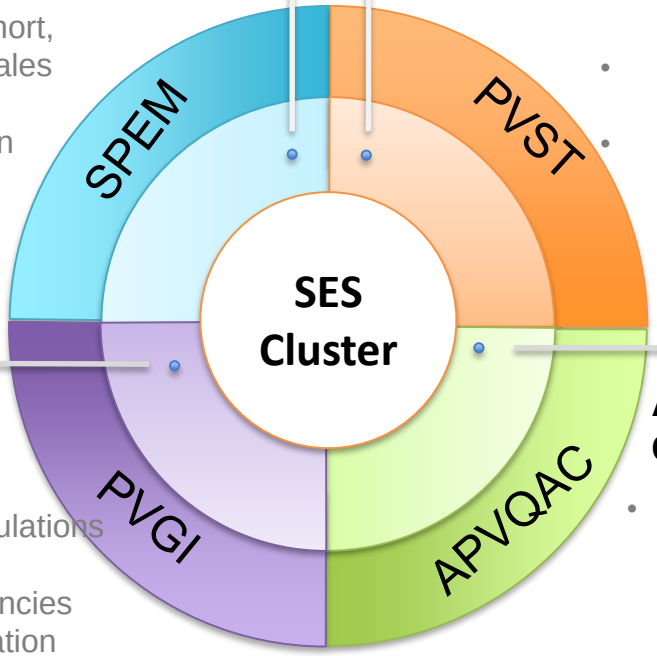
Research Groups

Solar Potential & Energy Meteorology Group

- Solar potential analysis for buildings
- Solar Irradiance forecasting: short, medium and long term time scales
- Sky image and GPS acquisition
- Weather Research and Forecasting
- Cloud analysis and forecasting

PV System Technology Group

- Long-term PV module performance testing and monitoring
- PV system optimization
- First floating PV test bedding in Singapore



PV Grid Integration

- Power grid operations and regulations
- Multiple levels of interdependencies between the distributed generation
- Variability of the resource and demand
- Integrations between grid control, PV systems and energy storage solutions

Asia PV Quality Assurance Center

- Third part evaluation of system design, implementation and economic variability
- Feasibility studies and full due diligence evaluations
- National Solarisation Center (NSC)

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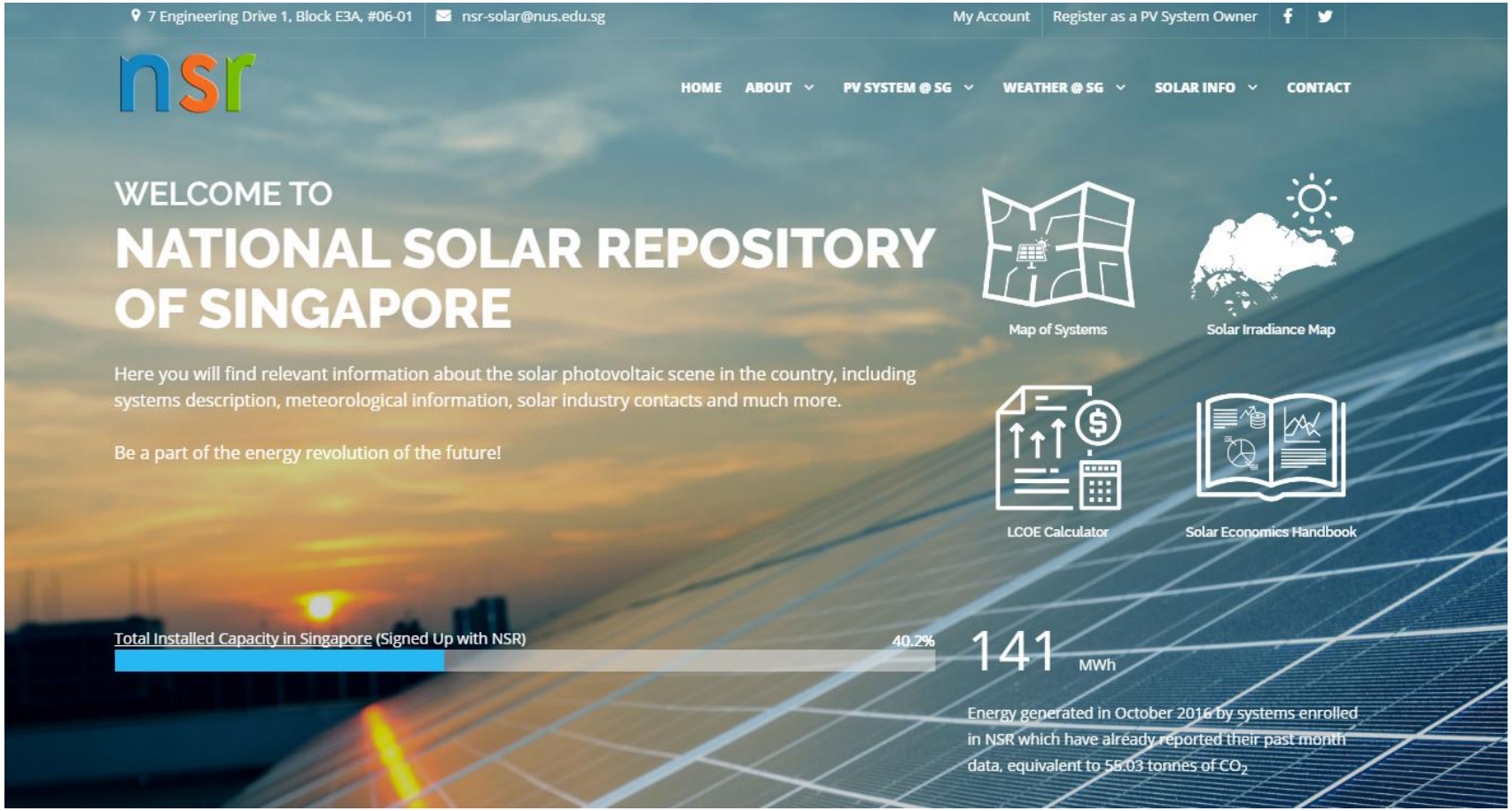
National Solar Repository (NSR)

One-step information for solar PV in Singapore



http://www.solar-repository.sg

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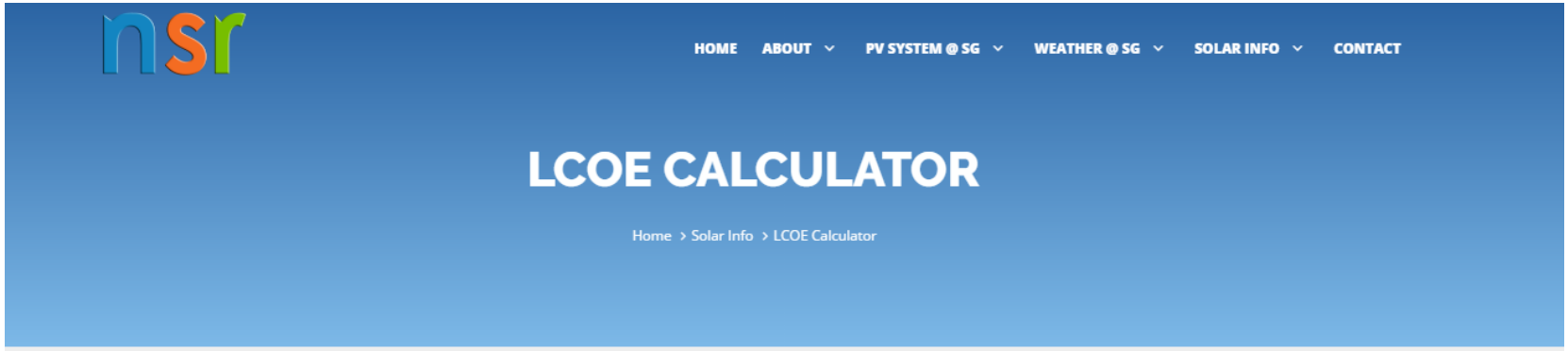
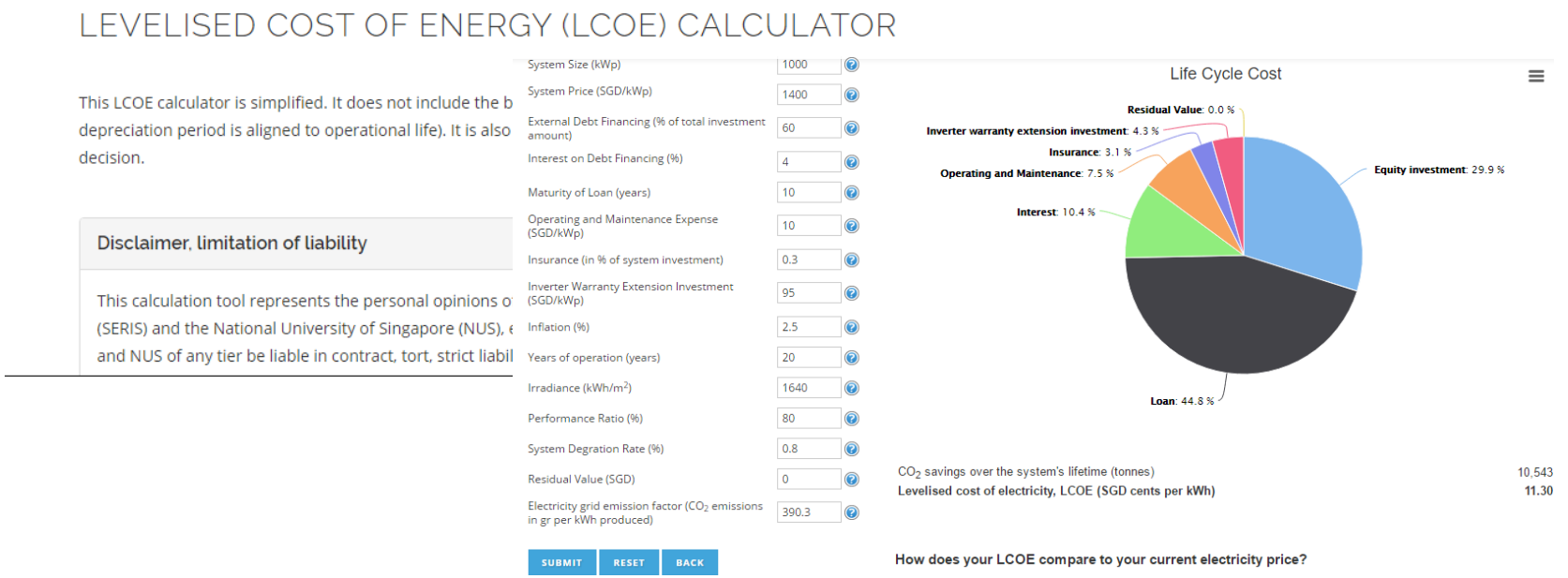
National Solar Repository (NSR)

LCOE calculator





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Overview

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- Background and Motivation

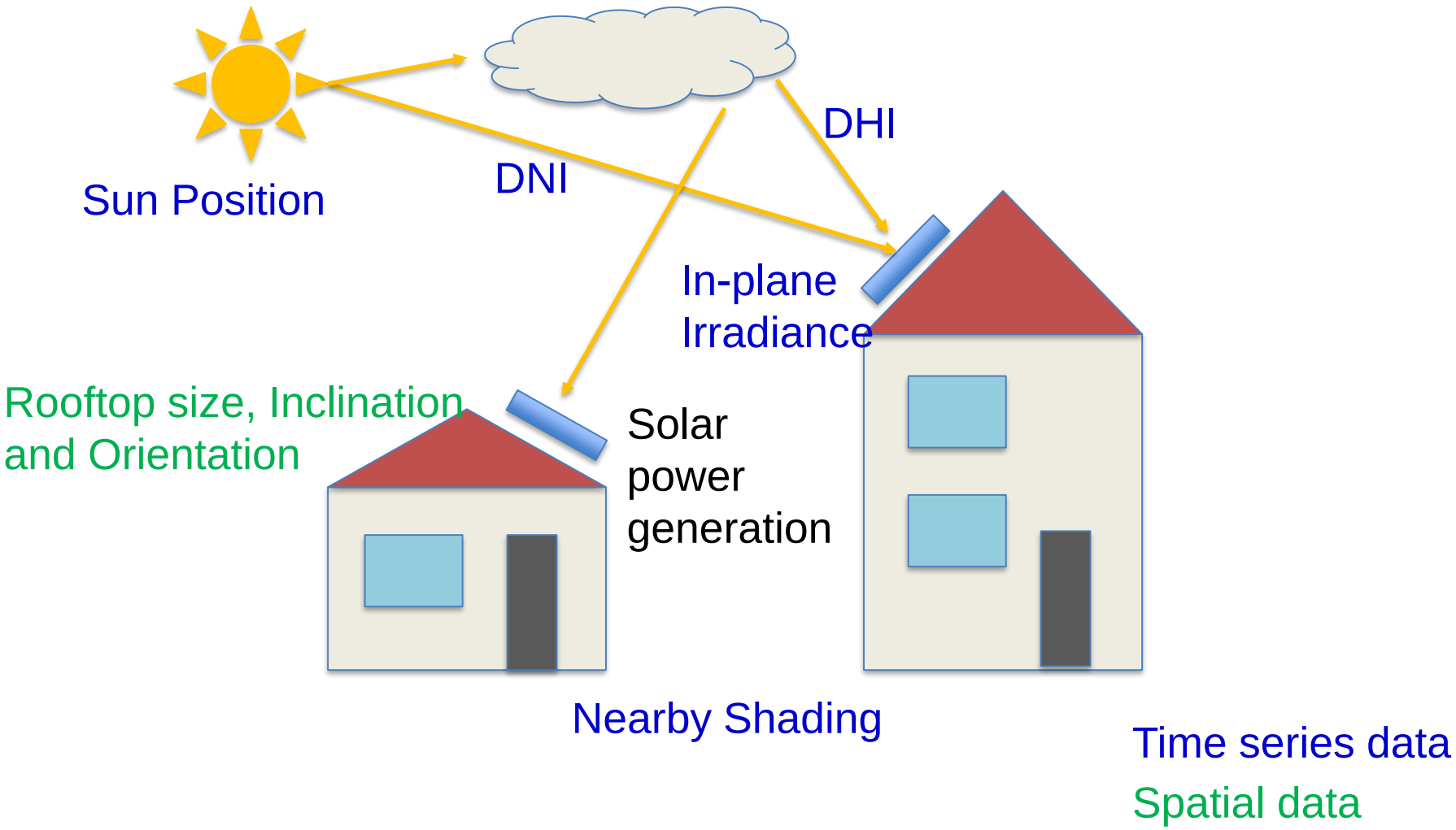
Vision

Deploying Solar Energy in Singapore

- Adopting of solar power from 87.8 MWp in Q3-2016 to 350 MWp by 2020
- Reducing greenhouse gas emissions by 16% by 2020
- Reducing the ratio of carbon emissions to each dollar of the GDP by 36% from 2005 levels by 2030

PV Energy Harvesting

Process



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Challenging Issues

Solar Potential Analysis for Urban Environment

- Limited rooftops for PV installation
- Variability of Solar Irradiance
- Complexity of building geometry
- Shading impacts on solar irradiation
- PV system performance

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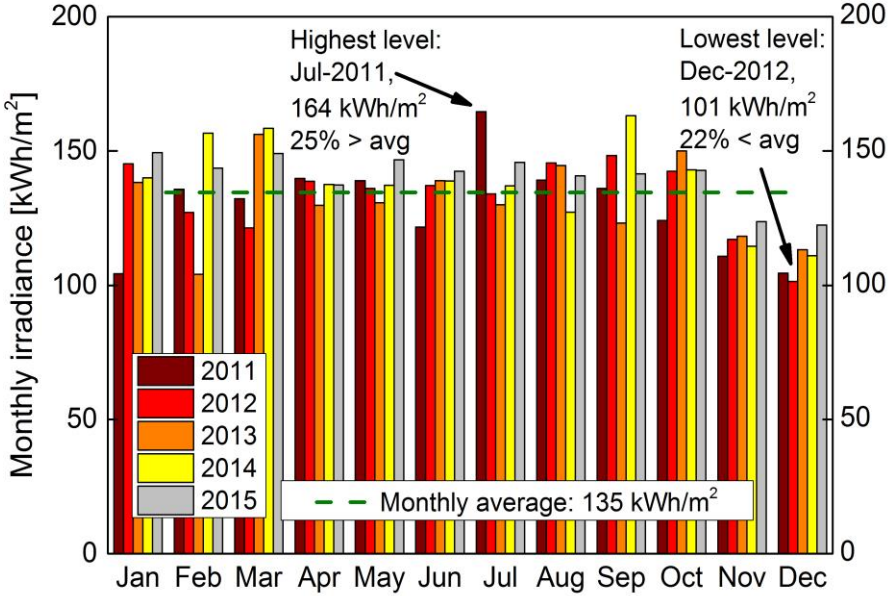
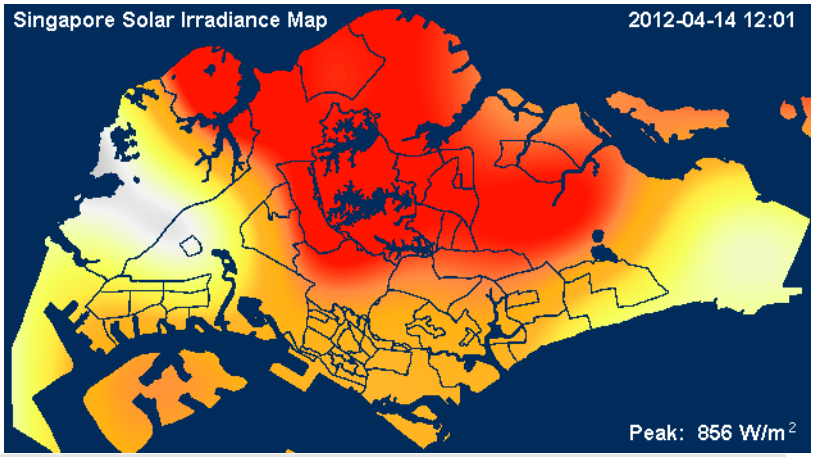
Solar Radiation in Singapore

Using SERIS' 25 irradiance stations, assessing time-spatial variability



Year-on-year comparison of the monthly solar irradiance



Spatial distribution of the solar irradiance across Singapore

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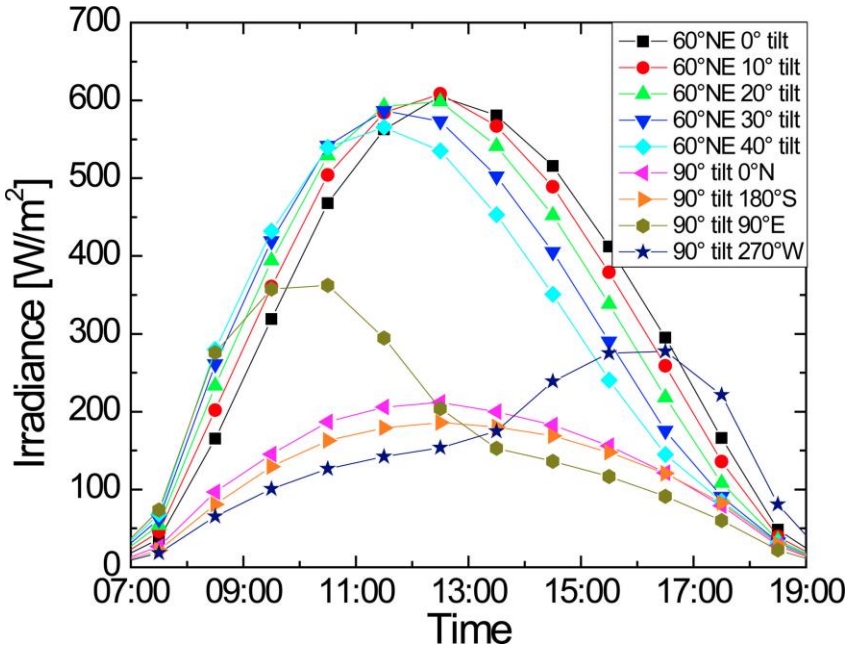
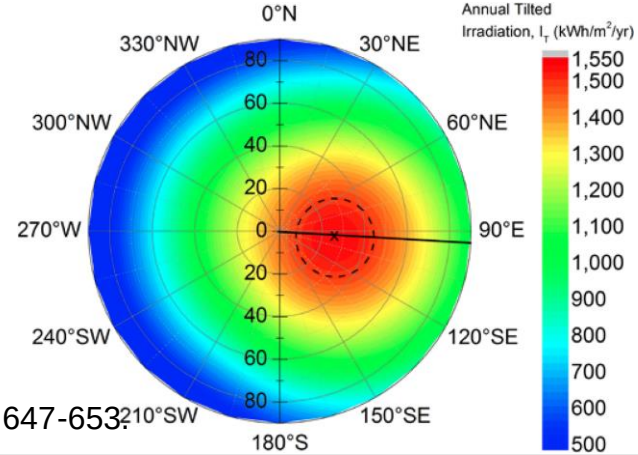
In-Plane Solar Irradiation Variability

Impact factors: surface inclination and orientation



Irradiance distributions for a typical day in Singapore from June 2011 to may 2012



Highest annual irradiation is 1562 kWh/m2 when a surface facing 97°SE with tilt angle of around 26°

[2] Yong Sheng Koo, et. al, IEEE Journal of Photovoltaics, Vol. 4, 647-653.

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Key Indicators

Solar Potential Analysis

- Solar Irradiation
  - Direct, diffuse and ground reflected irradiation
  - Able to represent weather (clear sky, cloudy and heavy sky)
- Rooftop profile
  - Size, shape, inclination and orientation
- Shading from near by buildings
  - Irradiation reduction due to shading effect
- PV system performance
  - Suitable area
  - PV technology
  - Performance Ratio
  - Solar power generation

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Solar Potential Analysis for Buildings

Procedure

- Procedure

[1] Pieter Gagnon, Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment, NREL/TP-6A20-65298, Jan. 2016, http://www.nrel.gov/docs/fy16osti/65298.pdf

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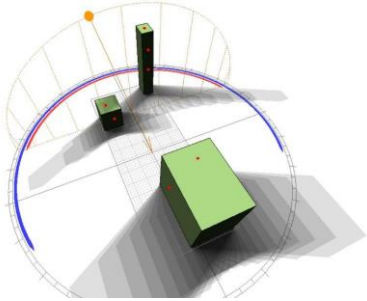
Solar Potential Analysis for Buildings

Quantify Solar Irradiation Received by Buildings

1. 3D building models (Sample data from SLA)

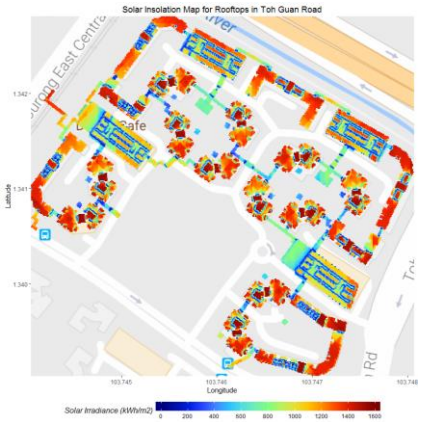
Building Geometry

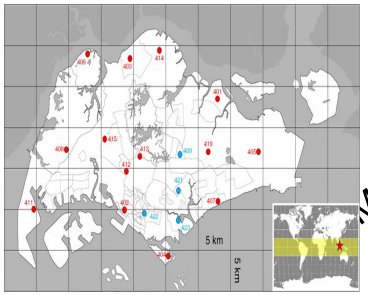
Shading analysis



2. Shading analysis at spatial and temporal scales

Solar insolation for rooftop / facades



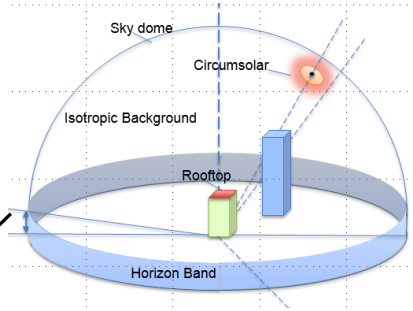


3. Measurement Data from SERIS Stations

Measured Irradiance

5. In-plane solar insolation for any surface using four input

Sky Model



4. Calibrated Perez diffuse irradiance model to transpose measurement data to any inclined surface

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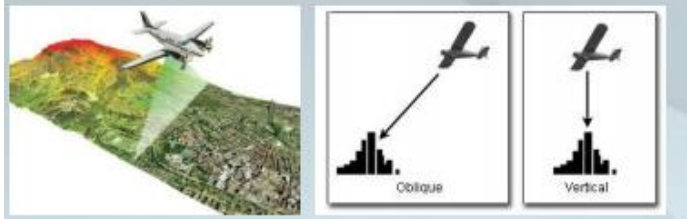
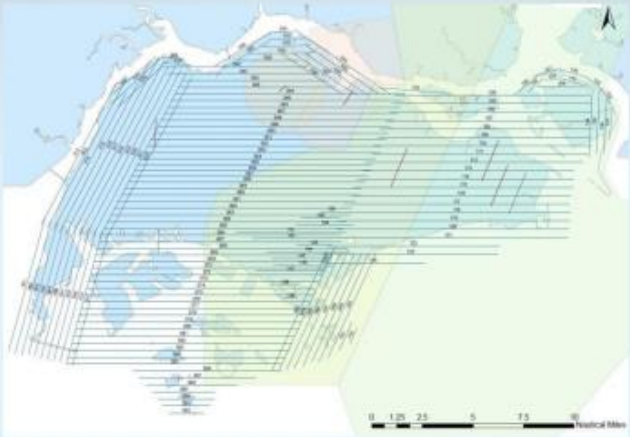
Mapping Singapore in 3D

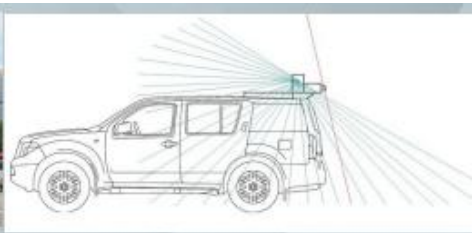
Technology of Reconstructing Singapore in 3D

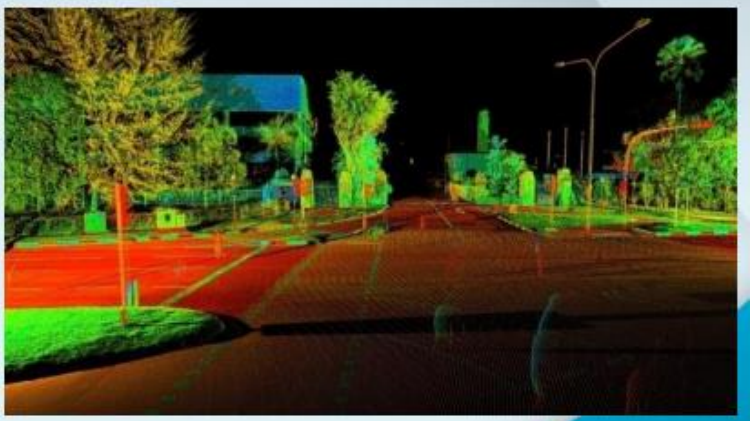
Airborne Laser Scanning & Imaging





Mobile Laser Scanning & Imaging





[3] Mapping Singapore in 3D, http://www.clc.gov.sg/documents/books/Mapping%20Singapore%20in%203D.pdf.

Mapping Singapore in 3D

Demo of 3D Singapore in Downtown Delivered by SLA

[4] https://asmmag.com/features/feature/10733-innovation-in-3d-is-putting-singapore-land-authority-on-the-map.html.

Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Project Objectives
- Methodology
- Case studies

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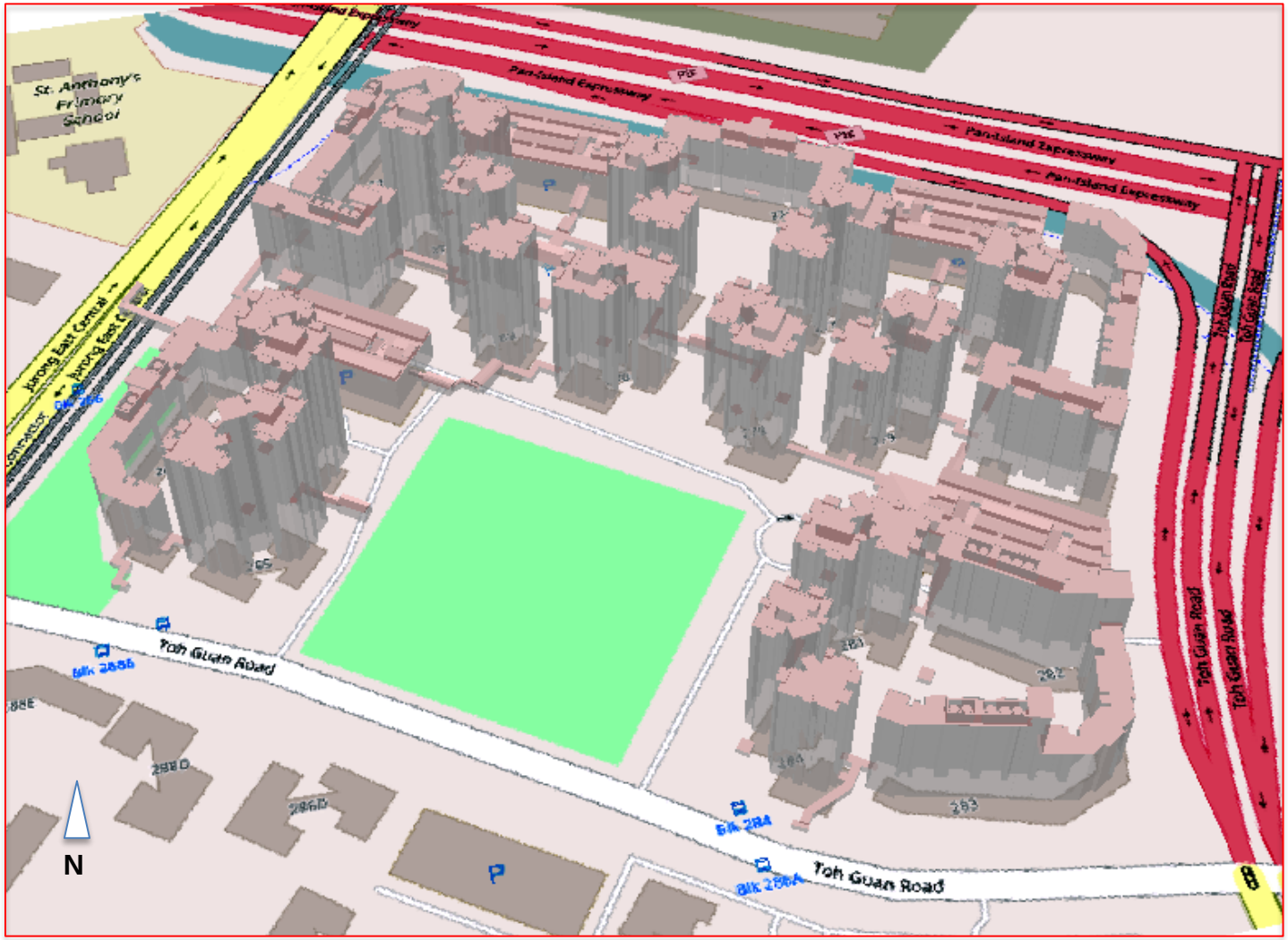
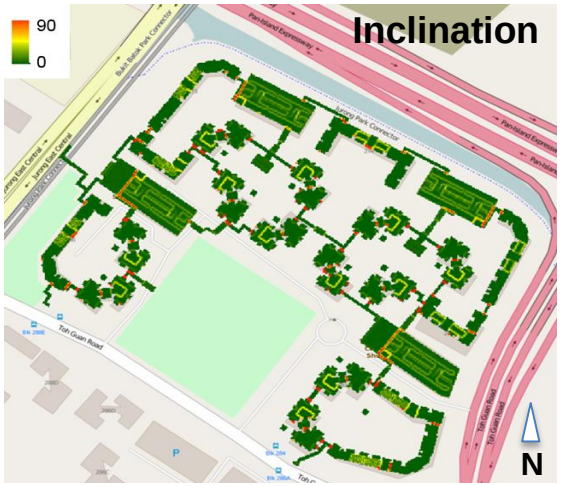
Case Study I

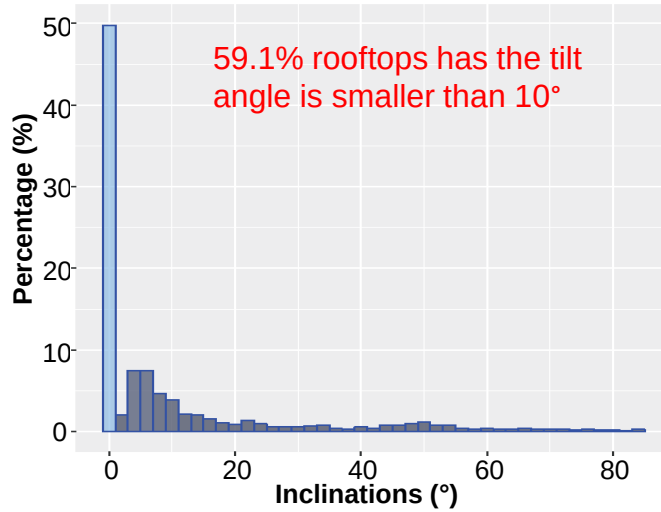
Rooftop PV Potential



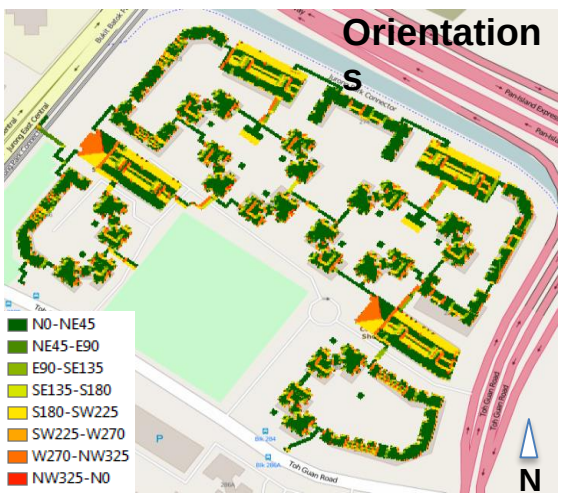
Case Study I

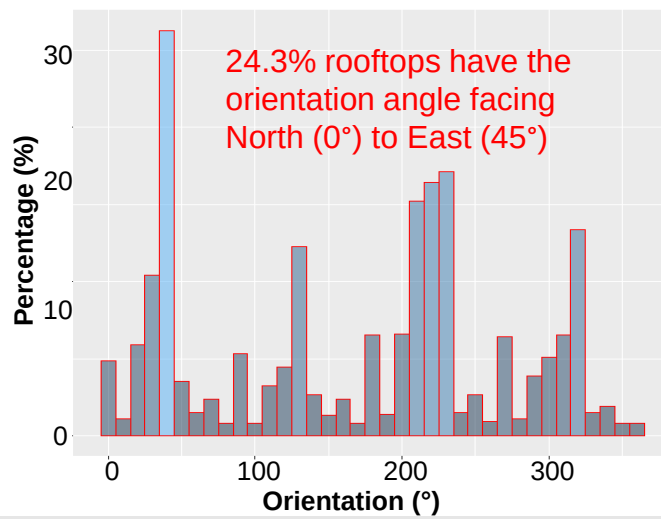
Rooftop analysis – inclinations and orientations





- Total rooftop size
  - 36,645 m^2
- Inclination distribution
  - Flat surfaces: 40.4%
  - Slope <= 10° (59.1%)





- Orientation distribution
  - N0~NE45: 24.3%

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Case Study I

Shading analysis – annual shaded hours for rooftops

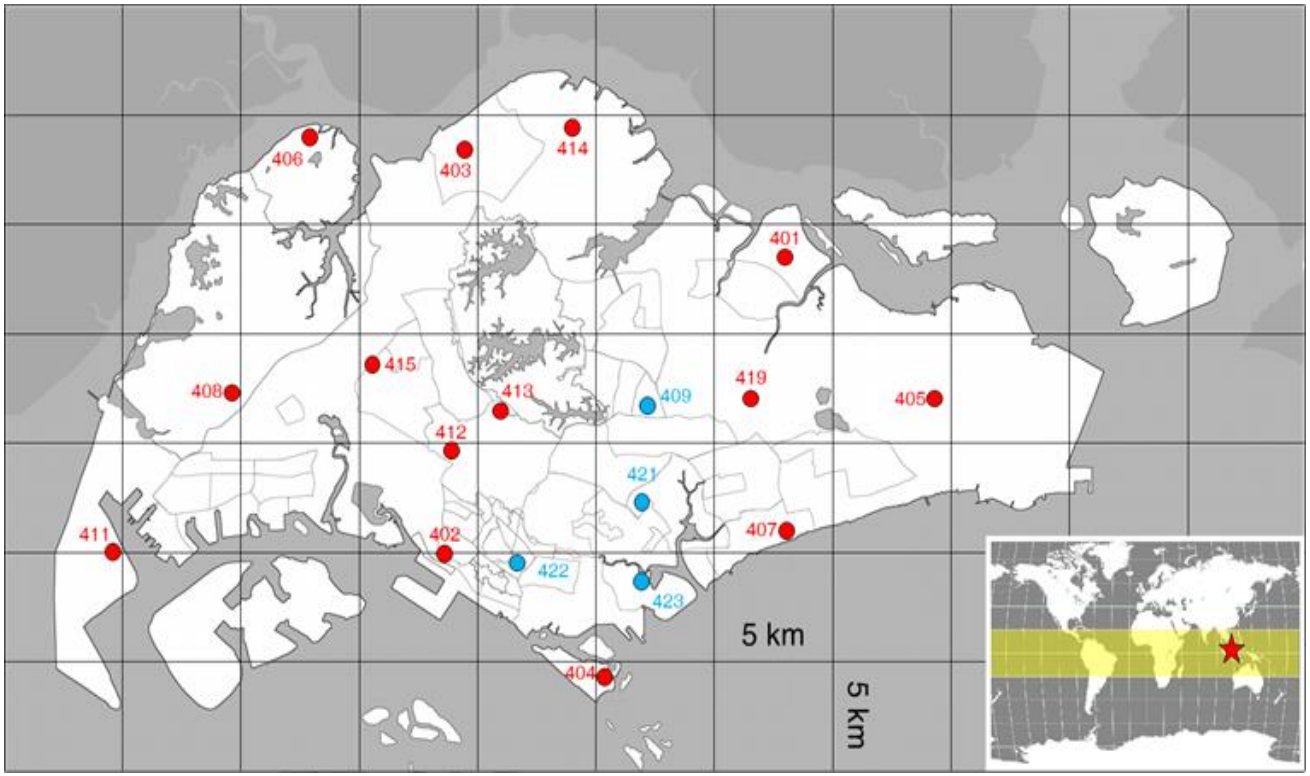
Annual shaded hours (hrs) 0 876 1752 2628 3504 4380

- Simulation period
  - From 7.00 am to 7.00 pm, 1st Jan – 31th Dec. 2015, UT+8
  - 4380 hours in total
  - Rooftop colored dark blue: no shading over a whole year
- Shading pattern
  - fisheye images for every square meter

[5] XU Le, et. al, ”Modelling solar potentials for urban rooftops”, PVSEC-26, Singapore, Oct. 2016

SERIS 25 Weather Stations

Data acquisition



Sensors: irradiance, temperature, humidity, pressure, wind speed, sky image

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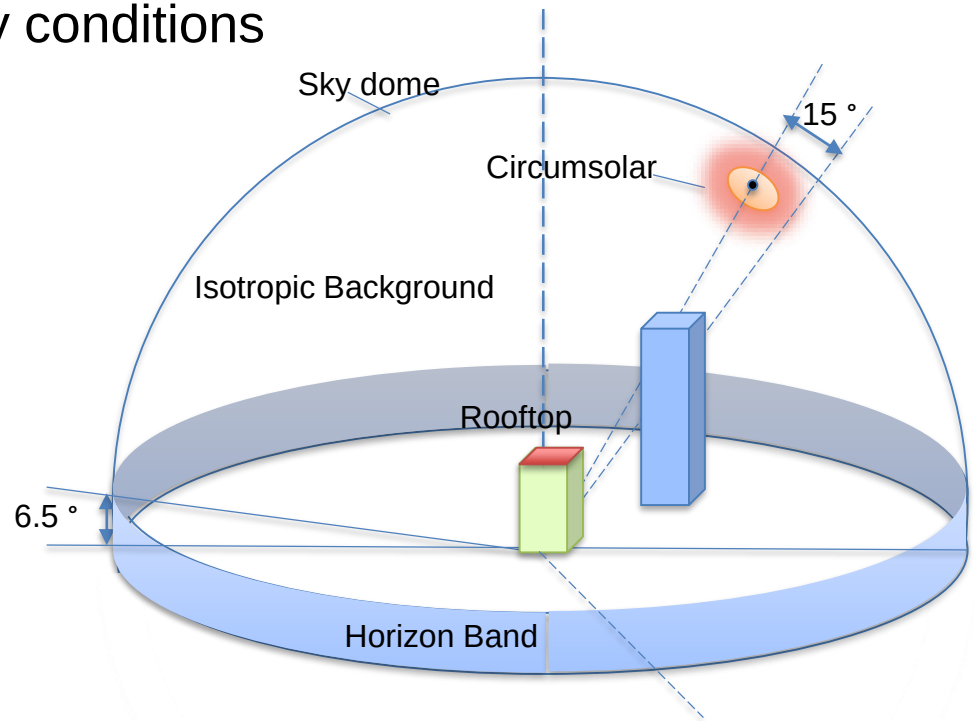
Solar Radiation Modelling

Perez Diffuse Irradiance Model

- Well represent different sky conditions
  - Circumsolar
  - Isotropic background
  - Horizon brightening



- Adapted Perez model to tropic weather

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Case Study I

Solar Insolation map for rooftops

Solar Insolation (kWh/m²)

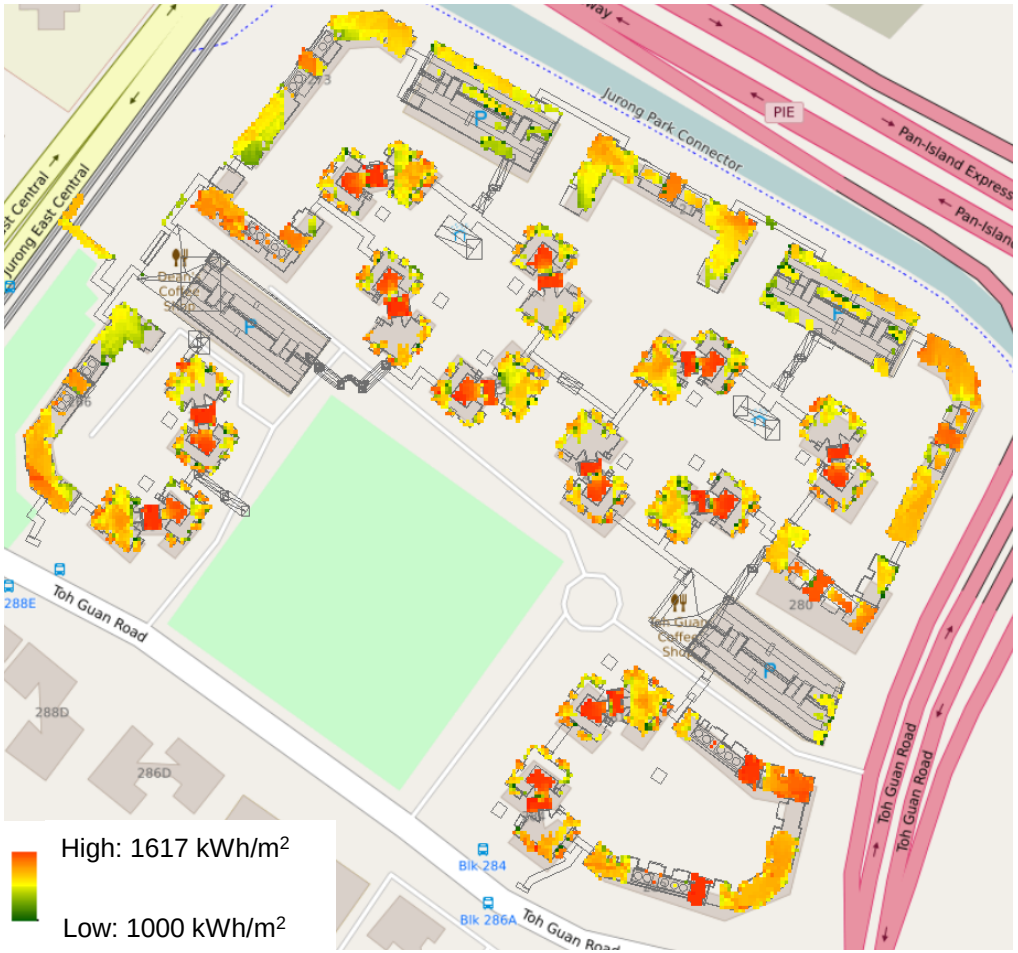
0 200 400 600 800 1000 1200 1400 1600

- Simulation configuration
  - Considered **rooftop profiles** (inclination, orientation and shading)
  - Applied **Perez diffuse irradiance model** for in-plane global, direct, diffuse and reflected irradiation
  - Simulated **hourly in-plane irradiances** over a whole year for every square meter based on measured irradiance data
- Significant Irradiance loss caused by nearby shading

[5] XU Le, et. al, ”Modelling solar potentials for urban rooftops”, PVSEC-26, Singapore, Oct. 2016

Case Study I

Classify suitable rooftop area



- Classify suitable rooftop area
  - Annual solar irradiation
    - >= 1000 kWh/m^2
- Suitable rooftop area
  - 13,323 m^2

[5] XU Le, et. al, ”Modelling solar potentials for urban rooftops”, PVSEC-26, Singapore, Oct. 2016

Case Study I

PV potential analysis for suitable rooftop area

- PV assumptions
  - PV configuration: follow rooftop structure
  - Area factor: 126 Wp/m2 (260Wp PV, 1.65 m × 1 m)
  - Average Performance Ratio (PR): 80% for unshaded rooftop area, linear response to the irradiance loss
  - CO_2 grid emission factor: 0.4313 kg/kWh

Summary of results	Value
Total rooftop area (km^2)	0.037
Suitable rooftop area (km^2)	0.013
Installed capacity potential (MWp)	1.72
Annual electricity generation (GWh)	1.65
Annual CO_2 emission savings (Ton)	710

Source: CO_2 gird emission factor: Singapore energy statistics 2015, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES2015_Final_website_2mb.pdf

Case Study I

Strengths and Weakness

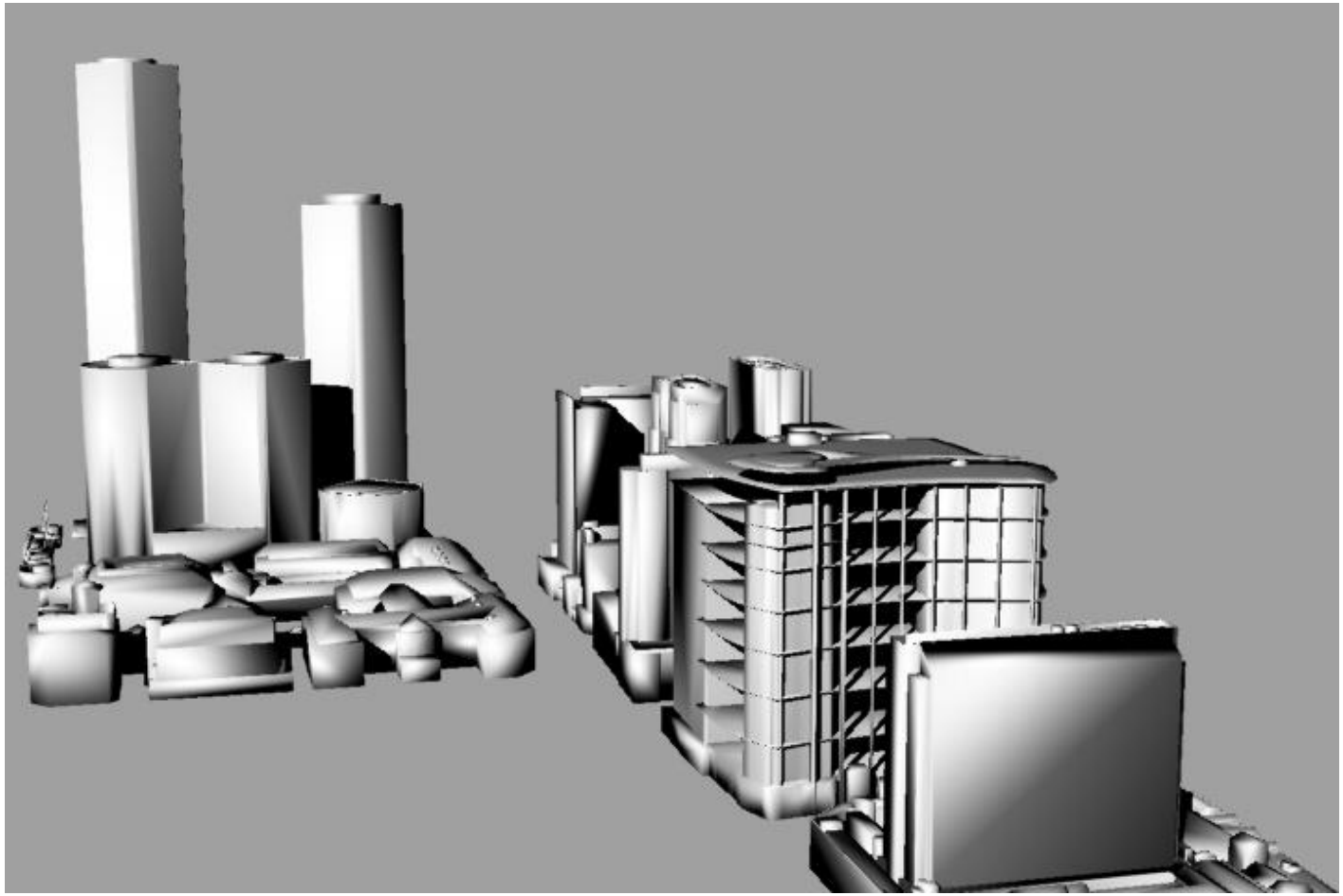
- Strengths
  - Solving 3D problem by 2D graphics (like DEM, fish-eye photography)
  - Modelling solar potential analysis for LoD2 Buildings
  - 1 spare meter for spatial resolution
  - Minutely or hourly temporal resolution
  - 3D building model could be CityGML, .shp, .sketchup, .obj.
  - Could be applied in other countries.

- **Weakness**
  - Lost details in facades during meshing buildings as square meter
  - Only good for Rooftop PV analysis

Case Study II

Solar Potential Analysis for Buildings with full 3D implementation

- Visualization of 3D buildings in CBD.



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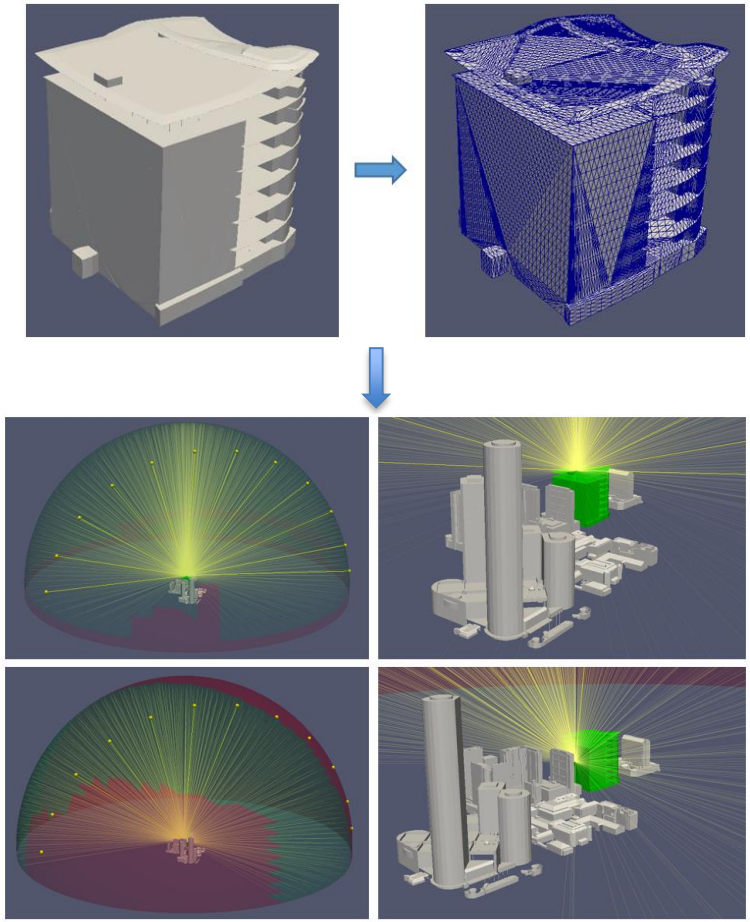
Case Study II

3D computer graphics modelling



- Mesh a building into pixels representing a small surface area (e.g. 1 square metre)
- Represent a sky dome that becomes the source of incident radiation
- Mesh the sky dome into pixels
- Ray tracing is implemented for each building pixel and sky pixel

[6] Martin Reed, et. al, ”A full 3D ray tracing algorithm with a Perez sky model for solar insolation studies of urban areas”, PVSEC-26, Singapore, Oct. 2016

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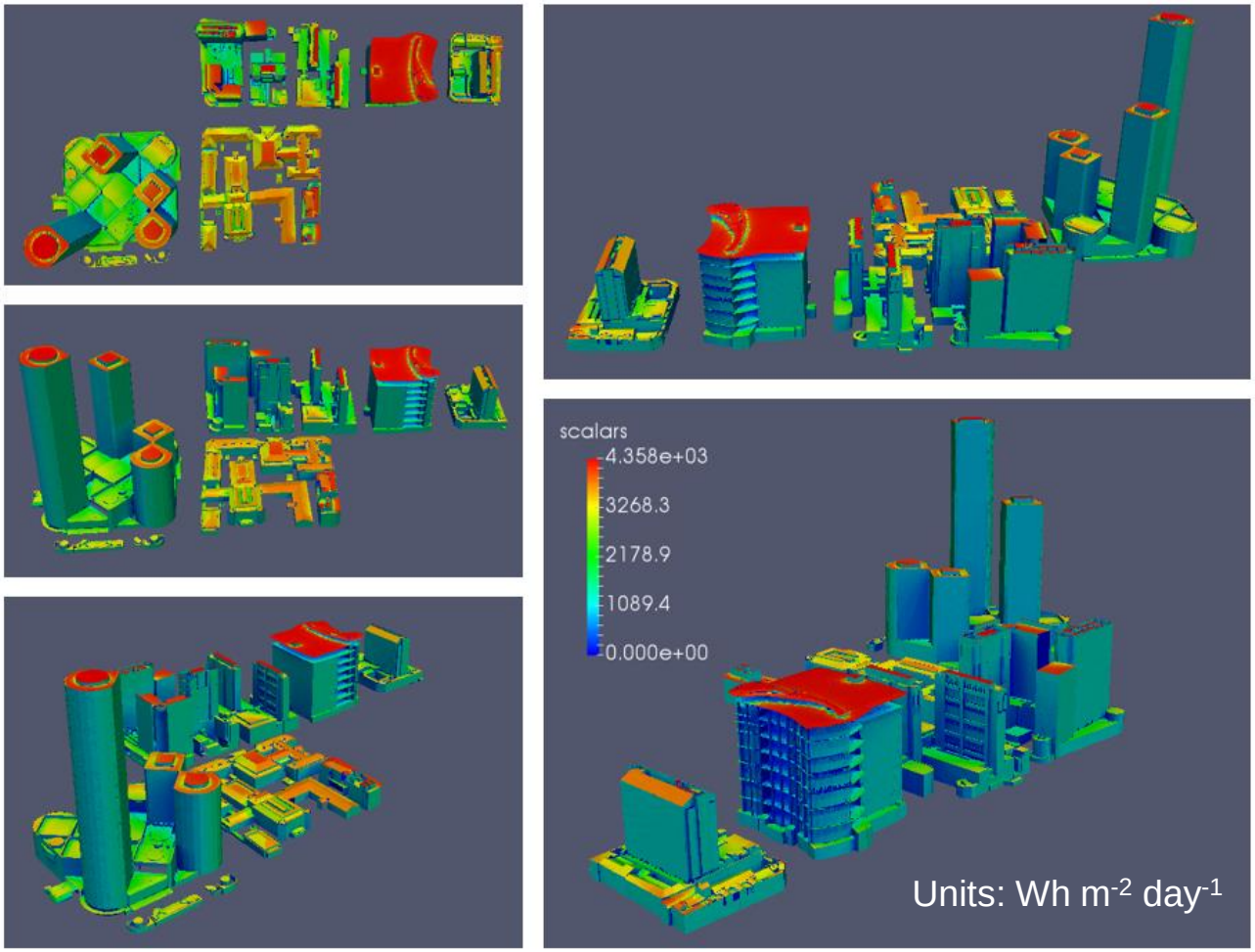
Case Study II

Full solar insolation profile of a downtown area in Singapore



[6] Martin Reed, et. al, ”A full 3D ray tracing algorithm with a Perez sky model for solar insolation studies of urban areas”, PVSEC-26, Singapore, Oct. 2016

Case Study II

Strengths and Weakness

- Strengths
  - Perfect solution to mesh LoD3 buildings in 3D
  - Analysing building geometries through vertices, e.g. surface normal, surface area, surface tilt and surface orientation
  - Well rendering each surface based on weights
  - 3D building model could be CityGML, .shp, .sketchup, .obj.
  - Could be applied in other countries.

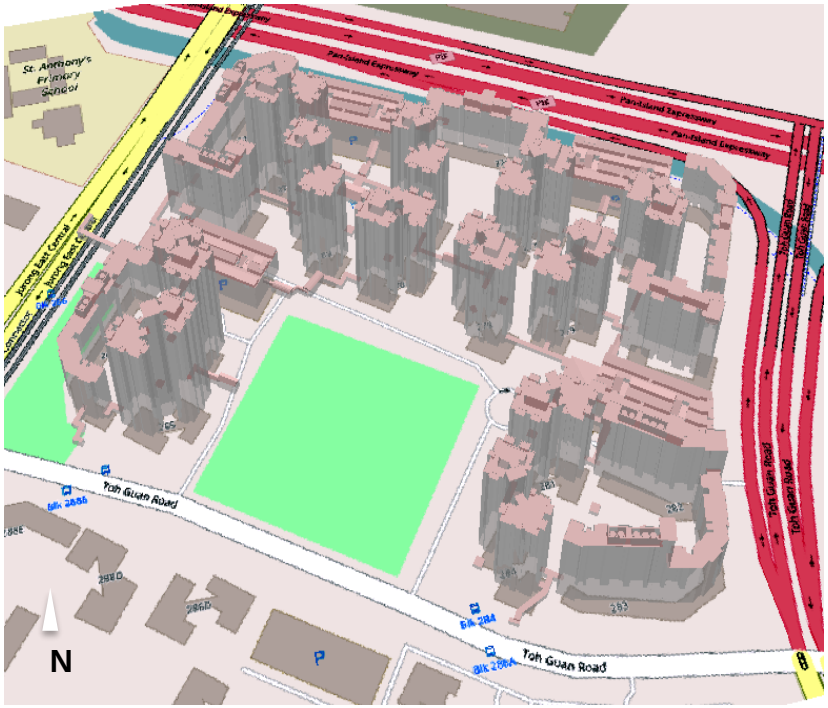
- **Weakness**
  - Time-consuming
  - Over-meshing issue
  - Need to use HPC for speeding up computation
  - Need to find a online solution

Case Study III

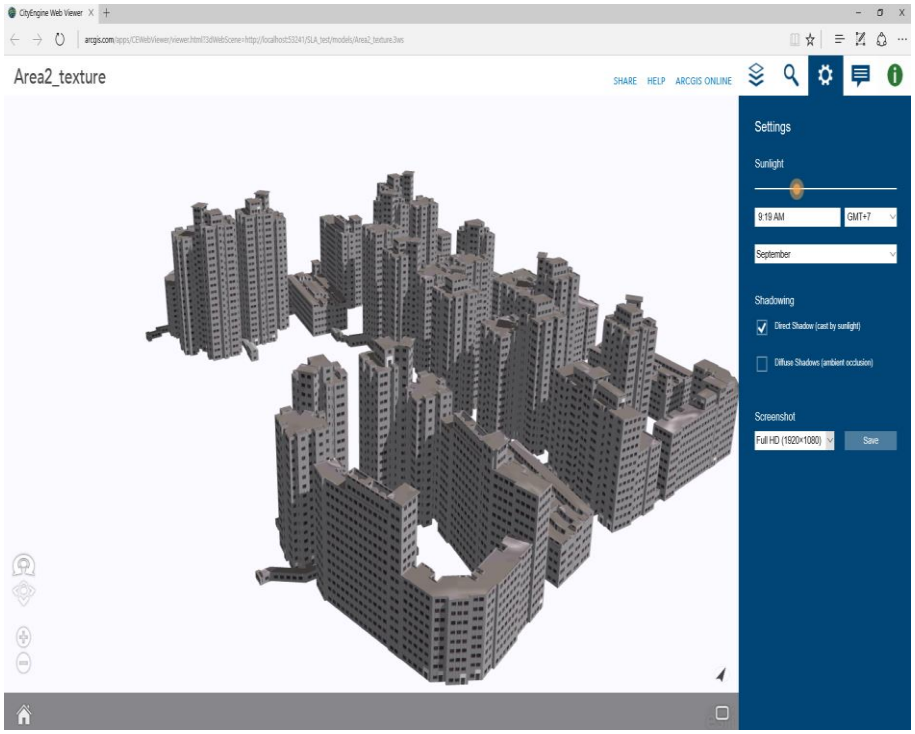
Automatically Modelling LoD from 2 to 3

- Computer generated architecture (CGA)
  - Texture 3D buildings

Before



After



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