Solar World Congress 2025

Digitalizing Solar Energy Integration for Sustainable Urban Precinct Redevelopment

Summary

This study presents a digital twin-enabled workflow developed to support the integration of solar energy in sustainable urban precinct redevelopment. With a case study of the Sunshine Precinct redevelopment project in Victoria, Australia, the workflow combines 3D geospatial modeling, solar potential mapping, and dynamic PV system simulation to assess rooftop photovoltaics (PV) and building-integrated photovoltaics (BIPV) potential at precinct scale. The workflow enables precise, scalable, and scenario-based evaluation of solar opportunities across complex urban environments. Preliminary results highlight significant gains in total energy capture and generation stability when rooftop PV and BIPV are integrated strategically. The digital twin approach offers an effective decision-support tool for urban planners, architects, and policymakers, facilitating data-driven design interventions and accelerating the transition toward net-zero energy urban precincts.

Keywords: Digital twin, urban solar potential, photovoltaic, building-integrated photovoltaics, renewable energy transition.

1. Introduction

Urban environments offer substantial opportunities for distributed solar energy deployment. Unlocking this potential requires a transition from isolated building-level analyses toward integrated, precinct-scale planning that considers architectural form, urban morphology, and evolving energy demands. Digitalization technologies, combining high-precision data, simulation, and 3D geospatial modeling, provide a powerful framework to bridge architectural design, urban planning, and renewable energy integration.

This study applies a digital twin-enabled workflow to the Sunshine Precinct in metropolitan Melbourne, with a study area of 4000 meter by 5000 meter, focusing on the integrated assessment of rooftop photovoltaics (PV) and building-integrated photovoltaics (BIPV) at the urban scale. The digitalization approach enables evidence-based planning, supports architectural interventions for solar energy adoption, and advances the transition toward net-zero urban precincts.

2. Methods

2.1 Digital Twin Development

A digital twin model of the Sunshine Precinct was developed by integrating high-resolution Light Detection and Ranging (LiDAR), building footprints of the redevelopment scheme, zoning information, and urban built form information. The digital twin captures key urban attributes, including building geometries, surrounding terrain, vegetations, traffic network, and capacity modelling of the new precinct. These datasets were processed through a geospatial platform (QGIS) and a MATLAB-based simulation environment, enabling dynamic spatial-temporal analyses of solar potential and energy generation across the precinct.

2.2 Solar Potential Assessment and PV/BIPV simulation workflow

The solar potential mapping and simulation consists of the following steps:

- Solar potential mapping and shading intensity

Hourly raster layers (size: 4000 m by 5000 m, resolution: 1 m) were generated to capture:

  - Shading height on wall surfaces (meter)
  - Shading pattern on roof surfaces (logical indices)
  - Plane-of-array (POA) solar irradiance on wall surfaces (W/m²),

- POA solar irradiance on roof surfaces (W/m²).

Simulations were conducted only during daylight hours, when the solar altitude angle exceeded 0° and global irradiance was above 0 W/m². The weather input was based on the Commonwealth Scientific and Industrial Research Organization (CSIRO)'s 2050 projected Typical Meteorological Year (TMY) dataset for Melbourne Airport Weather Station (CSIRO 2022).

- PV and BIPV performance simulation

Using the generated shading and irradiance layers, PV system performance was simulated for both rooftop PV and BIPV systems. The Sandia National Laboratories' PVLIB toolbox (Anderson et al., 2023) was employed to evaluate hourly PV module temperatures and operating power outputs, considering location-specific irradiance and thermal conditions from the CSIRO 2050 TMY dataset.

The simulation process allowed for high-resolution temporal and spatial assessment of energy yields under projected future weather conditions. The overall workflow of the simulation process is summarized within Figure 1.

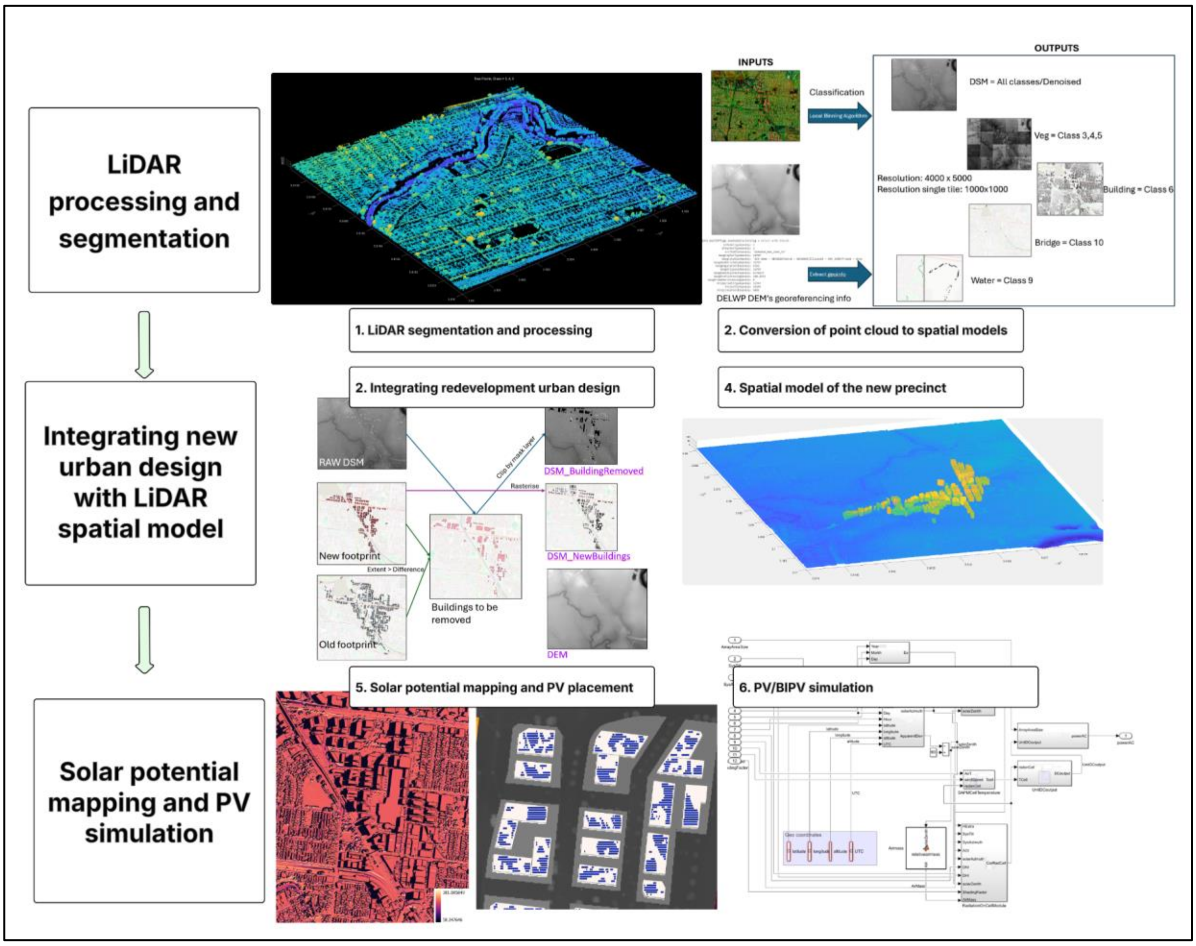

Fig. 1: Workflow of the digitalization process

3. Results and key findings

3.1. Solar potential mapping

The solar potential mapping of the Sunshine Precinct was developed using high-resolution digital layers capturing shading intensity and POA solar irradiance on both rooftops and building facades (Figure 2). The analysis reveals that the relatively uniform building heights across the precinct result in minimal overshadowing between structures, creating favorable conditions for rooftop solar deployment. Most rooftops demonstrate high solar potential, with additional opportunities identified on the north- and west-facing podium areas of mixed-use developments.

Compared to the current lower-density, detached housing forms, the Sunshine Precinct offers superior rooftop solar performance due to flatter roofs, better orientation, and the ability to optimize panel tilt angles. However, complex vertical shading patterns are observed on building facades, caused by a combination of self-shading and distant shading from neighboring structures, leading to stronger temporal variations in façade irradiance. The redevelopment design, characterized by expansive flat roofs, significantly increases hosting capacity for rooftop PV systems while also enhancing the potential for BIPV, particularly on west-facing walls.

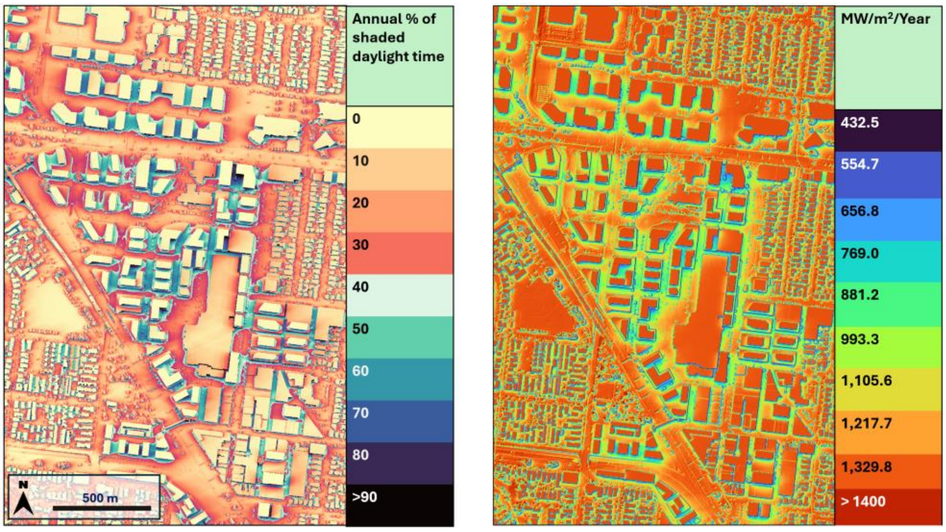

Fig. 2: Summary digital layer of shading intensity (Left) and solar potential mapping (Right) for Sunshine Precinct, Melbourne

3.2. Rooftop PV and BIPV system simulation

To further explore the complementary nature of rooftop PV and building-integrated photovoltaics (BIPV), hourly energy outputs from both systems were simulated and compared over a full year. As shown in Figure 3, BIPV and rooftop PV exhibit distinct generation patterns, with rooftop PV output peaking during summer months (December to February), while BIPV, benefiting from diverse wall orientations, contributes more generation during the winter season (June – August) when the sun altitude is generally lower.

This indicates that integrating BIPV alongside rooftop PV not only increases total solar energy capture but also helps mitigate seasonal fluctuations, providing a more balanced and resilient solar generation profile for urban precincts. Such complementary integration supports better alignment with local energy demand patterns and enhances the value of distributed solar energy systems within urban planning frameworks.

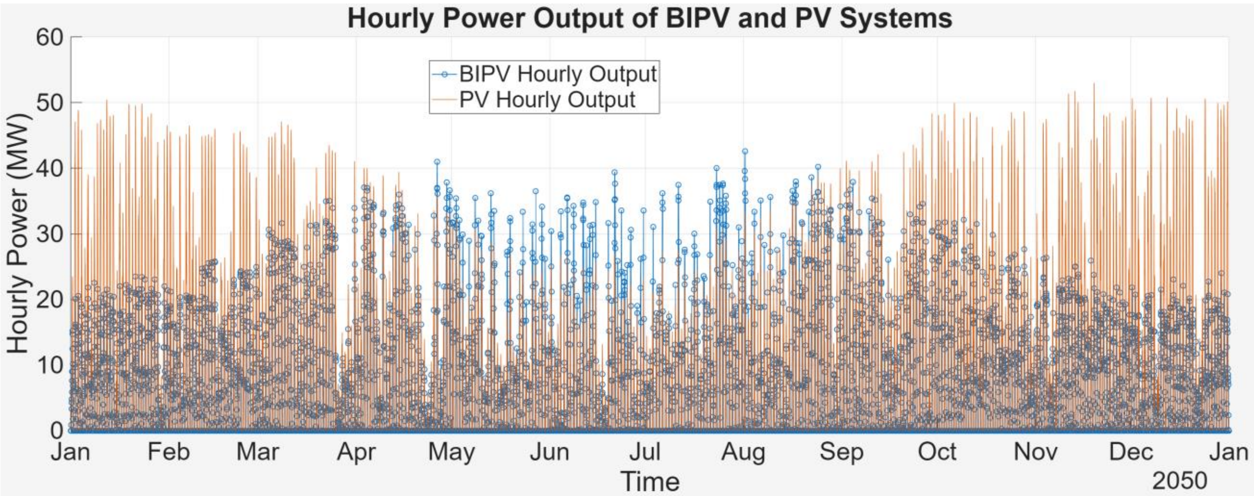

Fig. 3: Hourly power output of BIPV and rooftop PV systems in the precinct

4. References

Anderson, K., Hansen, C., Holmgren, W., Jensen, A., Mikofski, M., Driesse, A. 2023 “pvlib python: 2023 project update.” Journal of Open Source Software, 8(92), 5994, (2023). https://doi.org/10.21105/joss.05994

CSIRO., 2022. Projected weather files for building energy modelling. Commonwealth Scientific and Industrial Research Organization. Irl: https://ahd.csiro.au/other-data/predictive-weather-files-for-building-energy-modelling/