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Urban solar potential analysis through semantic 3D city models

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Extended Abstract

Currently, approximately 60% of the global population lives in urban areas (UN. Population Division, 2018). Incorrect quantification of the current and expected energy demands of buildings can lead to erroneous decisions and misguided planning for energy supply. Additionally, society is transitioning to adopting more sustainable energy sources to reduce environmental impacts. Solar gains play a major role in energy demand simulations. Therefore, it is important to perform precise calculations of the solar radiation for a given area of interest. However, this energy source faces challenges, such as shadowing, which rapidly decreases the performance of any solar panel, and it is constantly changing owing to the movement of the sun across the sky. Figure 1 shows a sketch of the considerations for computing shadowing calculations and the components of the solar irradiance.

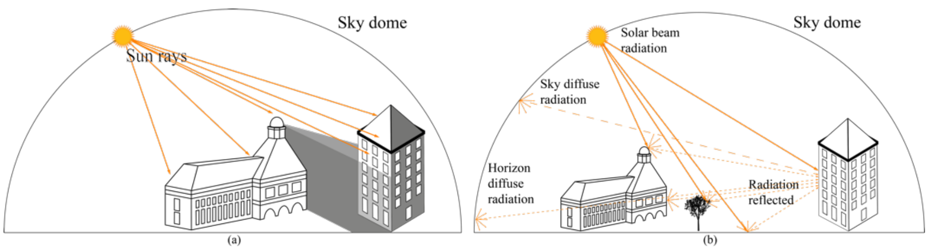

Figure 1. Shadowing computation sketch (a) and solar irradiance components (b).

Shadowing analysis is crucial in urban planning (Palme *et al.*, 2020), especially for assessing the solar potential (Figure 1(a)). It helps identify suitable locations in urban areas by considering existing structures and future developments. This analysis is relevant for policymakers, as they encourage the population to adopt solar energy while ensuring efficient utilisation of available resources for a given location.

To perform solar potential analysis, it is essential to consider the geographical location and its surroundings. These include factors such as topography, construction, and vegetation (De Sá *et al.*, 2022). These city objects can be represented using semantic 3D city models [3DCM] (Agugiaro *et al.*, 2020), which provide datasets that allow for a coherent geometrical and semantic representation of urban features in a well-defined data structure. The solar irradiance received on a tilted surface can be categorised as direct beam irradiance, sky diffuse irradiance, and (ground)reflected irradiance. Figure 1(b) illustrates these, with the diffuse components further divided into diffuse sky and diffuse horizon components.

We present the development of a solar potential analysis tool based on 3DCM. Our work uses the 3DBAG (Peters *et al.*, 2022), an open dataset containing 3D models of all buildings in the Netherlands. This dataset is available for downloading in several formats and multiple levels of detail (LoD) (0, 1.2, 1.3, 2.2) (Biljecki *et al.*, 2016). We used the pvGIS database (EU Science Hub, 2022) as the input weather data for our computations.

The hourly solar irradiance values were calculated using the Python package pvlib (Holmgren *et al.*, 2018). These values are aggregated for each surface. Additionally, we aggregated the solar irradiance values for each month, as shown in Figure 2. The final values were compared according to the statistical parameters defined by Dutch standard NTA8800:2024 (NEN, 2024), which specifies a method for assessing the energy performance of buildings in the Netherlands. The statistical values provided by the standard were categorised based on the orientation and inclination of the boundary surfaces enclosing a building. Our simulations were conducted in the municipality of Rijssen-Holten, located in the eastern part of the Netherlands. The municipality has approximately 38000 inhabitants, corresponding to approximately 23000 buildings.

Figure 2 shows a scatter plot comparison for each boundary surface of buildings in the study area, with the red line representing the computed correlation coefficient. Figure 3 shows aggregated values per month for better comparison with norm values. Additionally, we include some statistical metrics such as MAE, n-RMSE, R, RMSE.

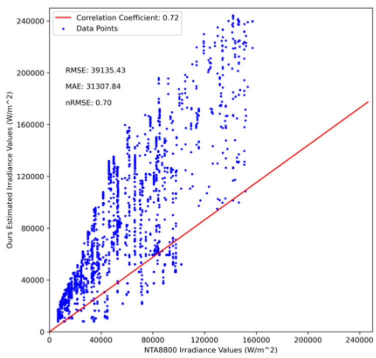

Figure 2. Scatter plot of monthly solar irradiance values.

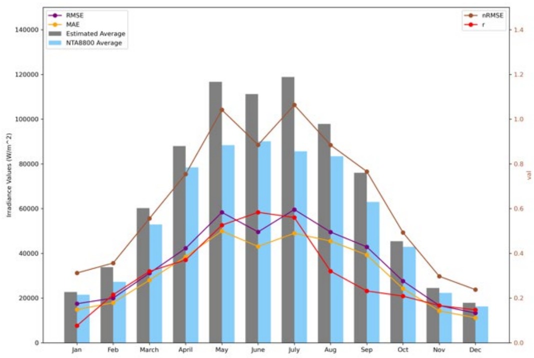

Figure 3. Bar plot of monthly solar irradiance values.

Figure 4 shows the solar irradiance per surface in May for Rijssen-Holten. Both images used the same colour palette, ranging from blue (lowest value) to orange (highest value).

(a) (b)

Figure 4. Rijssen-Holten solar irradiance output visualisation in May for NTA880 (a) and our computation (b).

The comparison of irradiance values between the NTA8800 standard and our method highlights the significant differences between purely statistical approaches and analytical methods that account for urban morphology. The correlation coefficient for the study area was 0.72, indicating a moderately linear relationship between the two values. This suggests that there is still a fundamental alignment in the irradiance patterns captured by both the datasets.

Error metrics in the bar plot in Figure 3 indicate that discrepancies between the NTA8800 values and our computed values were higher during warmer months. This divergence may be attributed to clearer skies during warmer seasons as opposed to predominantly overcast skies during colder skies. During colder seasons, the shadowing effect is not the primary source of energy loss, as overcast skies largely block direct beam solar irradiance, thereby reducing its impact (Tuononen *et al.*, 2019). One limitation of our approach is the inadequate treatment of light-ray diffusion and reflection, as illustrated in Figure 1(b). Our analysis simplifies the complex interactions between diffusion and reflection, which may affect the precision of our findings.

References

Agugiaro, G., González, F.G.G., Cavallo, R. (2020). The City of Tomorrow from... the Data of Today. *ISPRS International Journal of Geo-Information, 9*, 554. https://doi.org/10.3390/ijgi9090554

Biljecki, F., Ledoux, H., Stoter, J. (2016). An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*, *59*, 25–37. https://doi.org/10.1016/j.compenvurbsys.2016.04.005

De Sá, B.A., Dezuo, T., Ohf, D. (2022). Shadow Modelling Algorithm for Photovoltaic Systems: Extended Analysis and Simulation. *Journal of Control, Automation and Electrical Systems, 33*, 1507–1518. https://doi.org/10.1007/s40313-022-00905-2

EU Science Hub (2022) PVGIS Online Tool [WWW Document]. Photovolt. Geogr. Inf. Syst. URL https://joint-research-centre.ec.europa.eu/pvgis-online-tool_en (Last accessed 31 May 2024)

Holmgren, W.F., Hansen, C.W., Mikofski, M.A. (2018). pvlib python: a python package for modeling solar energy systems. *Journal of Open Source Software, 3*(29), 884. https://doi.org/10.21105/joss.00884

Nederlands Normalisatie Instituut (2024). *Energy performance of buildings – Determination method* (NTA 8800:2024 nl). https://www.nen.nl/en/nta-8800-2024-nl-320123

Palme, M., Privitera, R., Rosa, D.L. (2020). The shading effects of Green Infrastructure in private residential areas: Building Performance Simulation to support urban planning. *Energy Build*. *229*, 110531. https://doi.org/10.1016/j.enbuild.2020.110531

Peters, R., Dukai, B., Vitalis, S., van Liempt, J., Stoter, J. (2022). Automated 3D Reconstruction of LoD2 and LoD1 Models for All 10 Million Buildings of the Netherlands. *Photogrammetic Engineering & Remote Sensing, 88*(3), 165–170. https://doi.org/10.14358/PERS.21-00032R2

Tuononen, M., O'Connor, E.J., Sinclair, V.A. (2019). Evaluating solar radiation forecast uncertainty. *Atmospheric Chemistry and Physics, 19*(3), 1985–2000. https://doi.org/10.5194/acp-19-1985-2019

UN. Population Division (2018). The World's Cities in 2018. United Nations, New York, USA.