Calculating the Solar Potential of the Urban Fabric with SketchUp and HTB2

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Abstract

This paper introduces a new tool for analysing annual solar insolation potentials for façades and roofs at an urban scale using Trimble SketchUp and the dynamic simulation model HTB2. The tool is in the form of a plugin which 1) generates shading masks for every façade and roof in a model, 2) exports geometries to HTB2 for analysis, 3) invokes HTB2 from within SketchUp, and 4) returns outputs into SketchUp for review. Its capability to calculate the effects of complex terrain (imported from Google Earth) on façade and roof solar insolation levels is demonstrated. Case studies of the tool applied to both urban and rural areas of Wales and Europe are examined and results discussed. The simplicity of the tool in performing complex solar potential analyses is demonstrated, and its broader application as an analysis tool for calculating urban energy demands are presented.

Keywords: Solar, SketchUp, HTB2, Terrain

1. Introduction

As part of the Low Carbon Research Institute's work on energy supply and demand at an urban scale, we have developed a tool to calculate the solar potential of all urban roofs and façades in a model using HTB2 [1] as our thermal calculation engine and Trimble (previously Google) SketchUp [2] as the user interface. This paper is a technical review of the *Virvil for HTB2* plugin's capabilities, reviewing its findings of solar studies performed for urban areas across various regions.

2. Methodology

2.1 Shading Masks

HTB2 uses shading masks generated from each façade and roof to calculate the impact of solar radiation on a building; for the plugin to work effectively across an entire model, shading masks need to be generated automatically in SketchUp, and this procedure forms the backbone of the tool. Ray-casting is the basis of the shading mask generator in SketchUp. The centre point of each façade within a SketchUp model serves as the source of rays querying the surrounding urban and extra-urban fabric. Rays are generated at a user-defined angle separation of 10°, 5°, 2°, or 1°, are infinite in length, and are invisible to the user to speed up processing times.* The first object hit by a ray in the model is registered as an obstruction in the shading mask for that azimuth and altitude cell. If no object is struck, the cell is registered as unobstructed. For calculations in HTB2, the sky vault is divided into 324 cells (0°-360° azimuth and 0°-90° altitude) [3] and thus user-specified angle separations of less than

* A separate process within SketchUp allows for the visualisation of the rays and the view of the sky vault from the perspective of the centre point of a given façade, for illustrative purposes.

10° are aggregated to yield an obstruction percentage for the given cell (0%-100%). Shading masks are saved natively within the SketchUp model for analysis and comparison.

2.2 Terrain

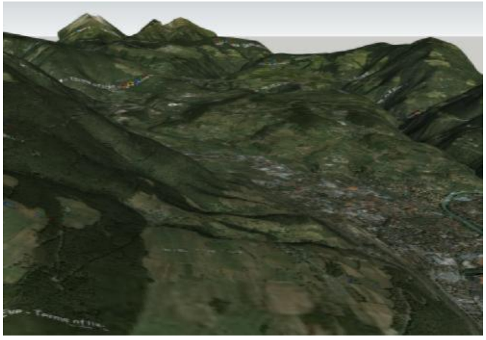

Figure 1: Imported Alpine terrain as seen in SketchUp

A significant amount of research has gone into calculating the effects of terrain solar radiation levels at urban, regional, and national scales using LiDAR, digital terrain model (DTM) and GIS data [5-8]. With the release of SketchUp 8 in 2010, terrain from Google Earth [9] can be imported directly into SketchUp for use in solar calculations (Figure 1). Terrain in Google Earth is generated from digital elevation model (DEM) data gathered by the Space Shuttle Endeavour in 2000 [10, 11]. For cases where structures, towns, or cities are located on hillsides or in deep valleys, the imposition of the terrain on solar access becomes necessary to calculate, and the import from Google Earth simplifies this process. Various existing software address terrain profiles in various ways, either via physical photographs of the site [12], drawings of the horizon profile into a model [13], or modelling terrain manually [14]. With SketchUp, DEM data of local terrain is imported from Google Earth as a component, and the models of a city are built within the terrain. The terrain can then be detected by the ray-casting from each façade when the plugin is invoked to generate shading masks.

2.3 Reflections

Ray-casting allows for the generation of reflection masks for affected façades. The impact of solar reflection from neighbouring buildings in terms of glare and increased cooling loads can be a significant issue in the urban environment, and has been discussed widely [15, 16]. The *Virvil for HTB2* plugin allows for visualisation and calculation of this phenomenon in SketchUp. Using the same ray-casting process to calculate shading masks, the plugin uses one bounce off an opposing façade; if the reflected ray strikes another object in the model, the cell is registered as obstructed. Otherwise, the reflected angle is aggregated in a reflection mask for the façade, with the angle and altitude of the reflected ray compiled as the cell of the sky which the façade actually 'sees.' The solar radiation received from this cell of the sky is tempered by the angle of incidence and by the reflective properties of the façade which initiated the reflection. This amount of received solar radiation is calculated and compiled with every reflected ray in an additive manner to calculate the effects of reflected radiation onto a façade. Work by Roos, et. al. [17] and the Berkeley National Laboratory [18] has defined reflection properties of glazing at various angles, properties which have been used in the calculations here, and research is on-going to refine these values. The *Virvil for HTB2* plugin allows for the illustration of the portions of the sky a façade actually 'sees' via reflection off neighbouring façades. For instance, Figure 2 illustrates the southwest segment of the sky vault an east facing façade on a neighbouring building 'sees' via reflection off the face of the tall skyscraper positioned to the east.

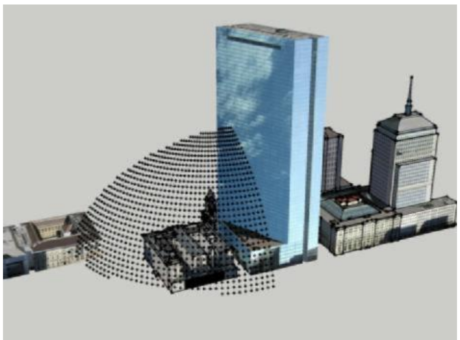

Figure 2: Segment of sky as viewed by a hotel façade in Boston, USA due to skyscraper reflection.

3. Results

As the tool is in its inception phase, several tests and subsequent results are presented here to demonstrate the versatility and accuracy of the tool and its outputs.

3.1 Terrain

Figure 3: Modelled houses without terrain

Obstructions to the sky vault limit the amount of solar radiation received by a façade or roof. In dense urban areas, neighbouring buildings provide the greatest obstructions to a structure's façades or roof, but in areas of aggressive terrain, the surrounding environment can occlude a significant portion of the view of the sky from a façade or roof. In terms of building physics, this can have a detrimental effect on the heating loads for a broad swath of existing and proposed structures. To test the percentage of obstruction landscapes can impose, houses in New Tredegar, a village in the Welsh Valleys north of Cardiff, Wales was modelled. The structures were modelled using photographs, Google StreetView and Google Earth images. Two tests were then run: one leaving the geography flat (as seen by a satellite, for instance) with the modelled houses all resting on the horizontal plane and one by importing the terrain into the model from Google Earth and modifying the positions of the modelled houses to represent reality. Only the houses in the immediate vicinity which would obstruct the view of the sky vault from the tested structures were modelled. The terrain – hills to the southwest and northeast – were objects providing the greatest obstruction. The roofline rotation of the modelled houses was 44.8° west of north, and the roof tilt was 35°. Results are presented in Table 1, and demonstrate a reduction due to terrain in solar insolation for tested roofs to be 10% for the southeast-facing (down valley) roofs, and 25% for the southwest-facing (hill-facing) roofs. This is significant, as many modern calculations by domestic solar companies for solar potential are made using satellite images. If the terrain is not considered, a considerable portion of promised solar radiation will not be delivered. Similar tests can be carried out using the tool for virtually any location on the globe if local climate data is also available.

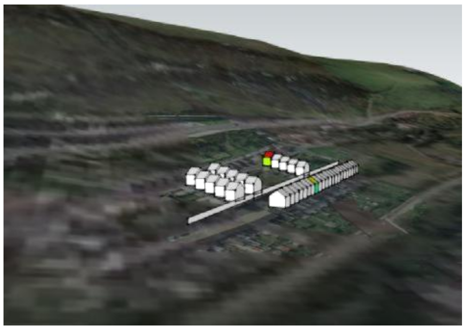

Figure 4: Modelled houses with terrain

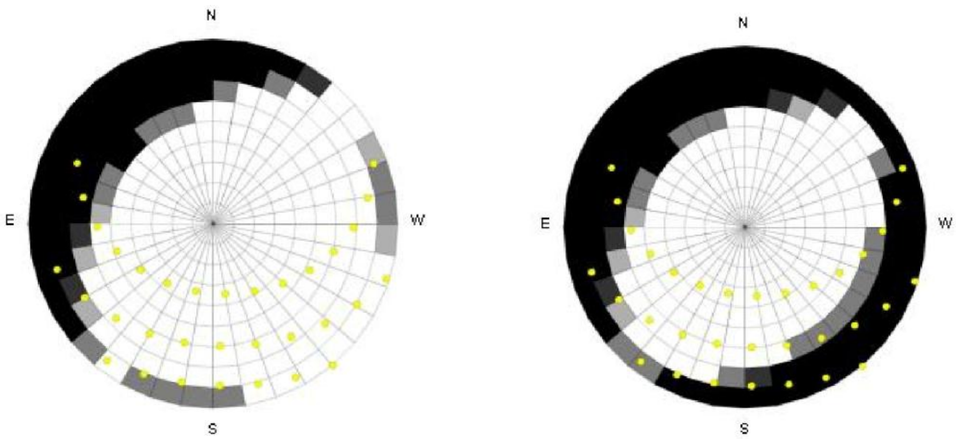

Figure 5: SW-facing roof shading mask showing no terrain (L) and imposition of terrain to the southwest (R)

Table 1: Imposition of terrain on annual solar potential calculations

Roof Orientation	**No Terrain (kWh/m²)**	**With Terrain (kWh/m²)**	**Difference (%)**
South West	1056	847	- 25
South East	1023	932	- 10

3.2 Solar Radiation

In another test of the plugin, levels of available façade solar radiation in an urban environment were queried on a model in Cardiff, Wales. Streets in a Cardiff neighbourhood were modelled with the assistance of Google StreetView, photographs, Google Building Maker, and Google Earth. Foliage was added to the back gardens by importing 3-D trees into the model from Google's 3D-Warehouse, and chimneys were modelled to maximise accuracy. Tests were run to identify the solar potential of the roofs and façades in an urban environment using a ubiquitous Cardiff house type (terraced properties) and neighbourhood layout, as seen in Figure 6. The results of this test are shown in Table 2, and demonstrate a difference between east- and west- facing roofs of terraced housing in the neighbourhood, compared with a level of solar potential of terraced housing for the south-facing roofs in the neighbourhood. Façades can be divided into smaller faces in SketchUp for a more detailed analysis of solar insolation, as shading masks are generated for each face and can be averaged over the entire façade. The roofs in Cardiff were divided into 8 even faces and the total roof solar insolation results were compared with the previous test. The results can also be seen in Table 2; dips in insolation by 1.4% – 2.9% can be attributed to the chimneys on the houses. A greater division of the roof will analyse the impact of the chimneys in more detail, and the results of this test demonstrate models can be analysed in fine detail using the tool.

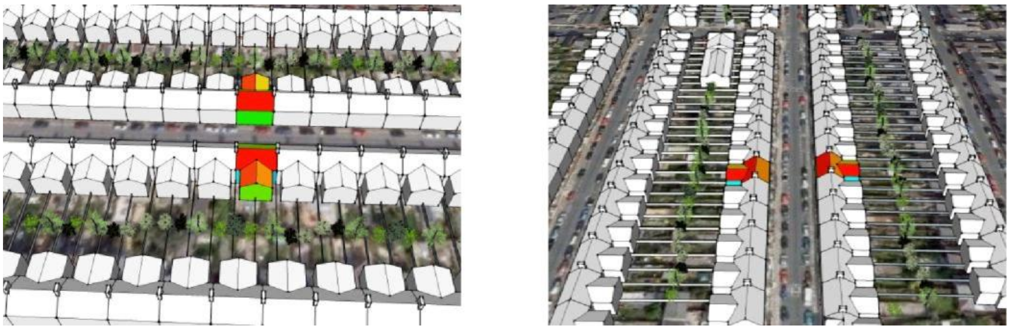

Figure 6: Views of the Cardiff radiation models

Table 2: Solar Radiation Results of divided facades in Cardiff

	Undivided Roof (kWh/m²)	**Divided Roof (kWh/m²)**	**Difference (%)**
South	1038	1023	- 1.4
West	947	927	- 2.2
North	703	683	- 2.9
East	830	810	- 2.5

4. Conclusions

This paper has introduced a new solar calculation tool for use with Trimble SketchUp. The *Virvil for HTB2* plugin provides a diverse platform for investigating the solar potential of structural skins. Entire neighbourhoods and cities can be modelled according to their basic form, and the creation of shading masks for every façade enables accurate analysis in HTB2. Examples in this paper demonstrated a significant imposition of terrain on solar radiation levels received by existing façades and roofs, as well as the effects surrounding landscaping and urban fabric have on solar potentials. This link between modelled buildings in SketchUp with HTB2 can also provide a suite of building energy performance data, including annual operational energy requirements, heating and cooling demands, and other data relevant to the ongoing energy demands of the urban environment. Future work within the LCRI will refine the reflections calculations and provide faster calculation times.

4.1 Footnotes

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