# Detecting shadow for direct radiation using CityGML models for photovoltaic potentiality analysis.

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ABSTRACT: Photovoltaic method is very popular for generating electrical power. Its energy production depends on solar radiation on that location and orientation. Shadow rapidly decreases performance of the Photovoltaic system. In this research, it is being investigated that how exactly real-time shadow can be detected. In principle, 3D city models containing roof structure, vegetation, thematically differentiated surface and texture, are suitable to simulate exact real-time shadow. An automated procedure to measure exact shadow effect from the 3D city models and a long-term simulation model to determine the produced energy from the photovoltaic system is being developed here. In this paper, a method for detecting shadow for direct radiation has been discussed with its result using a 3D city model to perform a solar energy potentiality analysis.

## 1 INTRODUCTION

The main source of energy for photovoltaic cell is sun. Sunlight comes to the earth as a form of electromagnetic radiation. Power emitted from the sun is composed of many wavelengths and this is constant. Solar radiation incident on earth's atmosphere is also relatively constant but the radiation at earth's surface varies due to absorption, scattering, reflection, change in spectral content, diffuse component, water vapor, clouds and pollution etc. Photovoltaic cells experience daily variation in light intensity. The incident power varies from 0 and 1 $kW/m^2$.

Energy production from photovoltaic system depends of incident solar energy and photovoltaic efficiency. Efficiency of photovoltaic cell depends on spectrum and intensity of incident light and temperature of the cell. Solar energy incident upon a surface depends on longitude, latitude, sun angles, surface tilt, surface orientation, contribution of direct and diffuse radiation, absorption, reflectance, shadow caused by surrounding objects etc.

3D models are most realistic options for detecting shadow and other parameters. Buildings are the largest consumers of energy in cities. For large scale implementation in the urban areas building integrated photovoltaic system is an appropriate option. (Reisa, 2011) in her research has experimented with partial shadow on a photovoltaic array. She found that the size and position of the shadow caster has an impact on energy production. For a thin linear object like a pipe or wire (diameter 0.63 inch) lying horizontally across the array will have nearly no impact but if the pipe is placed diagonally then it will produce around 2 percent less energy than non-shadow condition. If the diameter of the pipe is increased to 1.7 inch then it will produce around 14 percent less energy than non-shadow condition. For a horizontal of 2 inch by 4 inch the array will decrease energy production up to 39 percent. So, clearly the size, shape and position of the shadow have different impact on energy production by photovoltaic array.

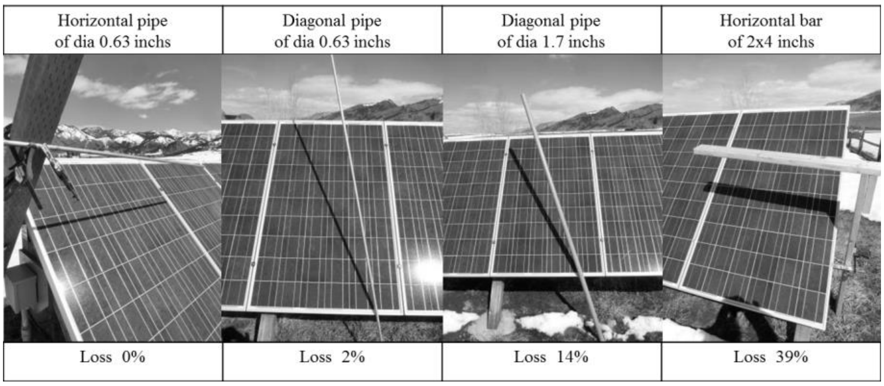


Figure 1. Partial Shadow on PV array (Reisa 2011).

Former military area Scharnhauser Park shown in figure 2 has been choosen as the case study area for this research. It is an urban conversion and development area of 150 hecta res in the community of Ostfildern on the southern border near Stuttgart with 7000 inhabitants. About 80% heating energy demand of the whole area is supplied by renewable energies and a small portion of electricity is delivered by existing roof top photovoltaic system (Tereci et al, 2009). This has been selected as the study area for this research because of availability CityGML and LIDAR data, building footprints and existing photovoltaic cells on roofs and façades. Land Survey Office Baden-Wüttemberg provides the laser scanning data with a density of 4 points per square meter at a high resolution of 0.2 meter.

The paper has been organized with a brief introduction at the beginning explaining background of photovoltaic energy and motivation for this research in. Then the effect of shadow on photovoltaic cells and a methodology for detecting shadow from direct radiation. Then result has been shown applying the methodology and some brief idea about the future work of this research has been presented.

## 2 METHODOLOGY

CityGML models are used for the simulation of the shadow detection. Firstly only direct radiation is being considered. For photovoltaic potentiality analysis effectiveness of a cell depends on amount of incident sunlight and its intensity. The weakest link cell in the chain limits the amount of energy production. 3D models are mostly consisting of polygons. First step is to read these sets of polygons and then triangulate each of them. Each surface of the city model is subdivided into triangles. The triangles extracted from potential surfaces are further subdivided into smaller triangles. Shadow will be calculated for specific points distributed over the surface, which will represent the whole surface.

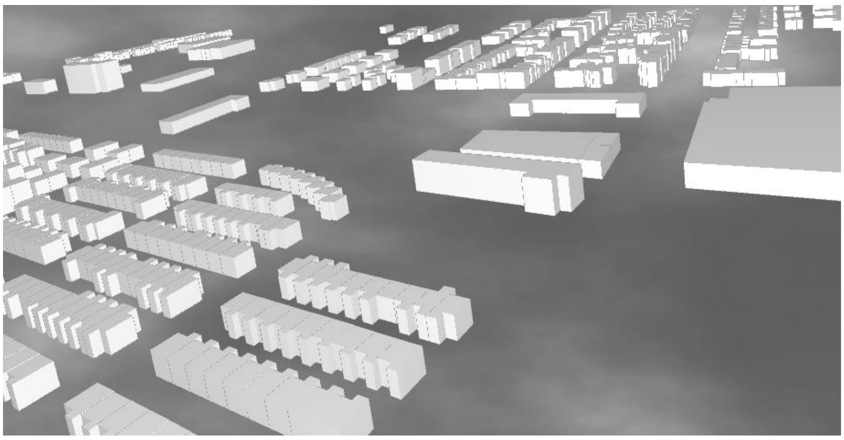

Figure 2. Residential area Scharnhauser Park.

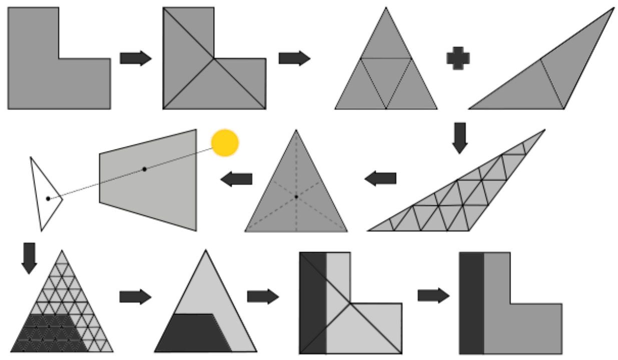

Figure 3. Workflow of shadow detection (Alam et al, 2011)

So to achieve a fine resolution each triangle is further triangulated as shown in figure 3. This resolution represents the maximum distance between two points. Then the centroid of the triangle is measured and a line towards the sun's direction is calculated representing the sun's ray. Here the real time sun information is used. Sun's azimuth and zenith are calculated with the simulation engine INSEL (Schumacher, 1991) at any specific time. The next step is to look if the sun's ray intersects any of the surfaces.

For this purpose it is checked if the line intersects with any of the triangles found in the second step. Then tilt and orientation are calculated from the surface by extracting the surface normal. Angular distance of surface normal from the ground and north were measured. An additional filtering for surface dimension is applied to avoid the narrow surface not suitable for PV installation. So, for surface dimension filtering, requirements for minimum length and width of a PV array must be fulfilled.

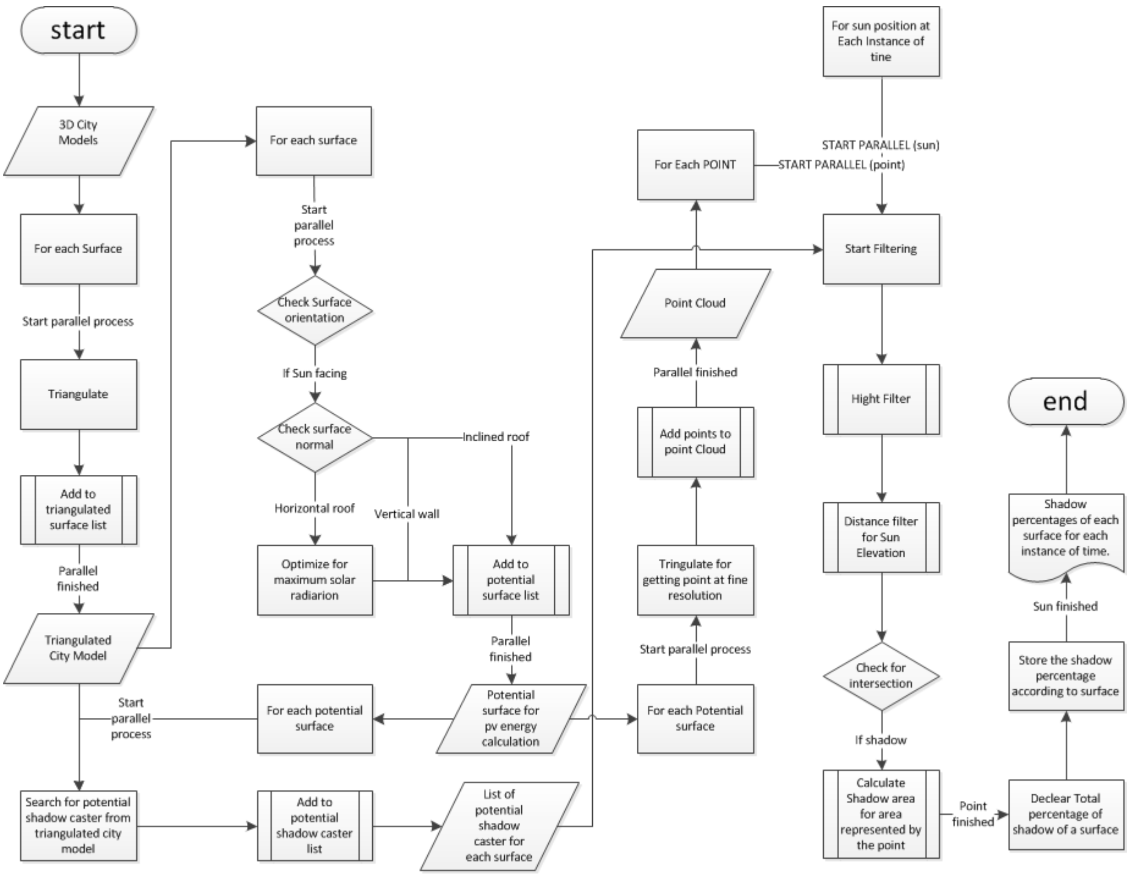


Figure 4. Flow chart of complete shadow detection process.

Irregular shaped surface are placed in a bounding box determined by south-west and north-east corner or upper-left and bottom-right corner. For each point, the whole city models are divided into four quadrants, divided by the north-south and east west axis. The quadrant, which contains the sun, is marked as active quadrant and surfaces, which have at least one vertex in this area, are selected as potential shadow caster surface. Surfaces, which are below the target point, are further filtered from the selection by comparing the elevation or height of each vertex of the surface with the target point. Only the surfaces where at least one subdivided triangle is shadowed are considered for surface regeneration. This is only necessary when a visual output for real time shadow is required for an instance of time. If the calculation is carried out for any longer time period like and hourly or minutely shadow calculation then this step might be excluded. Neighboring subdivided triangles with same shadow status are joined together to form shadow and non-shadow region. These regions are further merged with other neighboring region with similar shadow status. The whole process produces result for an instance of time. To get hourly or minutely shadow calculation this has been repeatedly applied and the result has been presented in a tabular form. More details about the methodology can be found in Alam et. at., 2012.

This approach is only applied for direct or beam radiation. For diffuse radiation surrounding buildings and objects should also be considered. Any reflective surface in surrounding area would cause an increase in diffuse radiation. The procedure has to be applied for every time step of the simulation due to the changing solar position. The complete process has been illustrated in Figure 4.

## 3 RESULT

Initially to check the algorithm a test model with two buildings blocks have been tested, one of which has a photovoltaic module on its roof. The model has been tested for each daylight hour of the year, which means nearly 4520 times. The test has given correct tabular result. Then the method was applied for actual city models. The information of shadow is obtained for the whole model where the surface is potential for energy production. As energy production of a photovoltaic module is determined by the weakest link, the position of shadow will affect the result. Shadow caused by the linear object partially blocks the array and will cause significant difference in energy production than unshadowed module at same condition. The linear objects might be electric or telephone wire, or antenna, which are only present in detail city models. This is a temporary object and might not always be present within the city model. But it has also significant impact on energy production. Terrain has also big impact on shadow calculation. Photovoltaic modules that have been installed beside a hill will suffer from daily reduction of sun hour. But if the terrain is not included in the city model then the result will be very different from the reality.

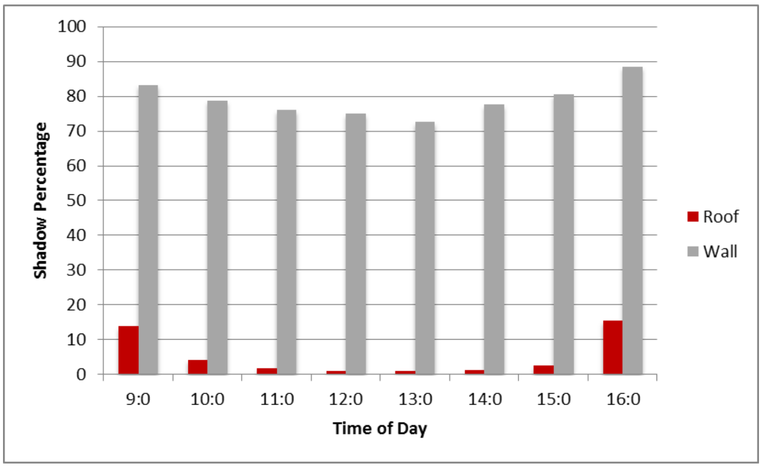


Figure 5. Comparison of shadow on roof and wall surfaces during
The whole day at hourly basis on 22nd December.

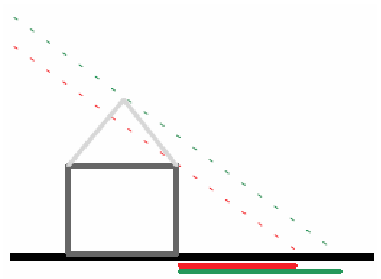

Figure 6. Effects of usage of different LoDs (Biljecki et al, 2013).

Figure 5 shows a result of shadow calculation carried on Scharnhauser Park for 22nd December when it get lowest amount of sunlight hours during the day and elevation of sun is also very low which will cause more shadow. Clearly the wall surfaces are 70 to 90 percent shaded during whole day and Roof surfaces are getting 0 to 15 percent shadow. And in the middle of the day roof surfaces doesn't get any shadow at all. The calculation was carried out for 698 buildings. As most of the buildings had flat roof and because the geometry was almost similar, so the LOD1 model was used for this purpose. But buildings with saddle roof will have different result if LOD1 models are used. Figure 6 shows LOD1 and LOD2 model of a building and their respective shading which is different for the same building.

## 4 CONCLUSION AND FUTURE WORK

The test implementation on a study area for beam radiation has also been presented. Future work of this research will focus on detection of diffuse radiation, impact of reflection, utilization of programmable rendering pipeline of modern graphics hardware or GPU. This research will also focus the data quality of 3D city models, which is minimum for solar energy potentiality estimation. The city models are validated using the CityDoctor (Pouliot et al., 2013) validation tool before using it for shadow calculation and is the model contains error then the model is healed by the CityDoctor healing tool and then used for shadow calculation. Both of the tools are being developed in parallel with this research. Future work of this research also includes development of soft shadow algorithm will consider the indirect radiation also.

## REFERENCE


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