Shadow effect on Photovoltaic potentiality analysis using 3D city models.

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ABSTRACT: Three dimensional city models are presently being used in many sectors. The potentiality of three dimensional data has been exploited by many researchers and applications. It has been realized that 3D data are not only for visualization or navigation but to support solving more complex problems in urban planning, disaster management, facility management etc. In this paper a 3D city model is used to perform a solar energy potentiality analysis. In contrast to existing methods shadowing effects on the roof surface and façades are taken into account to achieve better simulation results. Of course, geometric details of the building geometry directly effect the calculation of shadows. In principle, 3D city models or point clouds, which contain roof structure, vegetation, thematically differentiated surface and texture, are suitable to simulate exact real-time shadow. Solar radiation data during the whole day and around the year and photovoltaic cells response to the radiation can be modeled using available simulation environment. However, the real impact on geometric details has to be investigated in further research.

1 INTRODUCTION

Advancement in geo-information processing is improving and helping to produce fully automated 3D urban model. These 3D models are very high quality, realistic and include high geometric detail. Urban planning, cultural heritage, navigation, gaming, disaster management, architecture and other sectors are using 3D models to solve their problems. 3D models are very appropriate in solar energy analysis as well. Our present living standard is fully dependent on electricity and other forms energy. Photovoltaic electricity is still more expensive than other renewable energy resources. Special importance should be given to lower energy losses from inappropriate inclination, orientation and effect of shading. A good basis for automatic detection of best fitting roof and façade surface for photovoltaics in terms of energy performance and integration possibilities is 3D city models. These models can be used for attribute extraction such as geographical position and orientation, roof area and pitch as well as shadow effects based on roof structures and neighborhoods (Eicker et al, 2010).

Urbanization leads to a very high increase of energy use. 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. A web based approach for solar energy prediction using 2D map has been done earlier (Alam, 2009). Researches has been presented to measure the potential building roofs for photovoltaic cells. However, limited 3D city models are also being used for this purpose. Presently most of the major cities have started 3D city modeling and some of the cities already have those. Still, 3D models are being used for visualization purpose only. Geographic location, orientation, tilt, climate condition, roof area, vegetation, neighbor buildings and shadow, which are the important parameters for predicting the energy production from the photovoltaic cells, can also be derived from these 3D models.

Among all these factors shadow is most difficult to determine. People spend a lot of money for photovoltaic cells and if it is placed at a wrong place where due to shadow, the production is much lower than it was measured from potentiality analysis, they will lose money. Therefore it is of great importance to be investigated is to measure exact shadow effect and sunlight intensity on each surface. The computation should also include the direct and diffuse component of light after reflection and absorption by surrounding objects and at real time automatically from the 3D city models. During this research, the quality of the current city models will be checked. It will also be determined how detailed data is the minimum for calculating exact shadows. Cloud, Air quality, humidity, vegetation, color, material and other weather related and geographical aspects which causes, effects and controls shadow will also be investigated.

This paper has been organized with a brief introduction at the beginning. Then some related works has been mentioned and drawback has been used to identify the gap in the literature and the good things have been integrated. A case study area has been selected for availability of data. The types of data suitable for the research have been discussed. Then the system architecture has been presented. The effect of shadow on photovoltaic cells and a methodology for detecting shadow caused by blocking of direct beam radiation have been explained. Finally the result has been shown applying the methodology on a small sample city model to have a idea of the final result.

2 RELATED WORKS

Solar energy potentiality research is a very hot topic and many researchers as well as companies are very much interested to work with it. Researches carried out in this direction have been mentioned here and thoroughly analyzed which helps to understand the necessity of this research, improve the poor approaches and taking advantages of good approaches. (GTA Geoinformatik Gmbh, 2010) produced a solar map for showing the potential roofs for solar energy. They use a 3D city model, DTM and DSM of a particular area. The factors they consider are azimuth, tilt and size of the roof, neighboring buildings or vegetation, solar radiation on that position. But the whole process for shadow consideration is roof oriented, façades in this case have not been considered. They do not consider things like electric wire, antenna, cloud information, surrounding objects color, texture and transparency etc.

(Baum, 2009) developed Shadow Analyzer tool for the analysis of the shadow effect on installation of solar energy equipment. It analyzes shadows from external objects as well as self-shadowing or sun tracking solar collector systems. It also allows texture but only for visualization purpose. It uses the algorithm of *simplified clear sky model for direct and diffuse insolation on horizontal surface* by Bird & Hulstrom, which is a very old model using low quality data. It claims to consider climate data but uses only ready to use solar data without considering atmospheric data. This faces problem for lack of sufficiently detailed and uniformly represented solar database. It proposes to construct users own climate model for a particular site. This is suitable for very small area but for larger area it might not work. It also provides bad results for worst variant which is normal for any *bird* model (Bird & Hulstrom, 1981). But it gives an approximate result when the user doesn't have information about climate or irradiance, by considering default settings and monthly probabilities of clear sky.

(Joachem et al., 2009) considers shadowing effects by calculating the horizon of each point, which uses full 3D information for both feature extraction and solar potential analysis based on input LIDAR point clouds. The process has two main disadvantages: loss of information and roof planes are not separated. There are two predominant approaches: model driven and data driven for automatic building reconstruction. The orthophotos used here were taken in different year which produced error. The main problem of this method is that small objects (mentioned as in earlier works) are not considered and excluded from the profile line for computing the horizon. Here shadow has been pointed out as more influential during winter and clouds from spring till fall. Usage of DSM leads to deviation at roof overhangs, chimneys, dormers etc. due to rasterization process and thus shadows are not represented here properly.

(Hofierka et al., 2009) present a methodology for assessment of photovoltaic potential in urban area using open-source solar radiation tools and 3D city models. The radiation model includes a shadowing algorithm which has been used in the analysis of shadow cast by buildings or other objects. The model was a 2D model and was unable to be used for vertical façades. The suggested for a more complete model with trees, city infrastructure and intra urban structures etc. (Memar Consultants Inc., 2008) offers in their words, some of the most accurate exterior Sun-Shadow Study and Interior Day Light calculations available in the industry. It helps to determine how far natural light penetrates inside the building the winter or summer. The services they provide mainly are exterior sun shadow study, interior day light calculation, natural light penetration and sun angle calculation. This is a good example of what this research work is going to present except the effect of shadow on the PV modules. The data used for this purpose seems more suitable for interior architecture where distant objects have less effect.

(Izquierdo et al., 2008) describe a method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. The method also quantifies the error made in the estimation. Again, façades are not considered in this work. Here the influences of hourly shadow on monthly values and spacing needed between modules to avoid shadowing are taken into account. And the data used in this research was not sufficient enough which increases the demand for better quality data. The method is not applicable for medium to large scale regions, such as whole country.

This research pointed out a gap in literature on shadow consideration, fast and exact shadow detection method for energy production by building integrated photovoltaic cells on both roofs and façades, comparing current estimation for potentiality. It is also clear from other researches that the quality of data has always been an issue and there is no guidelines of which information are minimum for shadow detection. Therefore, this research has been designed to fill in this gap.

An existing method for photovoltaic potentiality analysis which doesn't consider shadow has been selected as a starting point. Solarcity3D is a student project from HFT Stuttgart. This is a Software Interface for the calculation and visualization of photovoltaic potential in city areas. It connects 3D city models and simulation engines for the calculation and visualization of potential energy yields. Parameters considered here are geographical position and orientation, roof area and pitch, climate conditions etc (Solarcity3D, 2009). This will be modified and fast and exact shadow detection method will be added and effect will be determined during this research as well as the guideline for minimum quality of data required for the calculation will also be prepared.

3 USE CASE AND AREA

This research will consider a specific area in Germany. Former military area Scharnhauser Park shown in figure 1 is an urban conversion and development area of 150 hectors 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 data was captured in first and last pulse return and classified into ground and vegetation point. Two types of data have been considered for this research, CityGML and LIDAR for accuracy. Line plane intersection method has been used initially for direct radiation. LIDAR points are suitable for selecting points on a surface from which the suns direction represents the line. For CityGML data these points needs to be extracted using surface subdivision and triangulation. But planes are represented by facesets in CityGML, which is also need for the algorithm. LIDAR points are needed to be converted into planes using surface reconstruction. So, both types of data are potential for this research.

Figure 1. Residential area Scharnhauser Park (Eicker et al, 2010).

3.1 *CityGML*

CityGML is an OGC standard open data model for storage, exchange and representation of 3D city models. Semantic and thematic properties, taxonomies and aggregations are also represented. It includes a geometric model and a thematic model (Kolbe et al., 2009). CityGML have five Levels of Detail 0 to 4 for their geometric and semantic differentiation. This is efficient for usage and data analysis for various domain applications. Coherent modeling of geometry and semantics are main principle of CityGML. At semantic level real world objects are represented by features. CityGML consists of two hierarchies: semantic and geometric, which can be different complexity. The grouping concept of CityGML allows aggregations as well. Information about appearance is an integral part of CityGML and allows for creating of very realistic models. Objects like trees, vegetation, traffic light and traffic sign etc. are represented explicitly and can be used multiple times at different locations. CityGML provides two different concepts to support the extension of generic features: generic objects and attributes, and application domain extensions.

3.2 *LIDAR*

With the increase of point densities, airborne laser scanners data becomes more suitable for 3D city models. Roof faces, road and terrain surfaces can be modeled partially in automated manner. LIDAR data can be triangulated in the x-y plane using standard Delaunay techniques to produce a TIN for 3D city modeling. Terrestrial laser scanning can create 3 dimensional 'point clouds' of thousands of data points which are collected in a matter of minutes. Advantages of Terrestrial laser Scanning are faster results, better quality results, less ambiguity, higher level-of-detail, safer data capture, unobtrusive data capture, point clouds can be conveniently used & reviewed by others for more efficient management of projects. The accuracy will depend on the type of scanner.

4 SYSTEM ARCHITECTURE

SolarCity3D is the base of this research so the shadow calculation has been integrated with its system architecture. For shadow calculation geometrical information is needed as input and semantic information serves the simulation tool. Citymodel Administration Toolkit (CAT3D) is used, to handle, manage and merge different formats of 3D Geodata, DBMS, and data schema on the server side. It provides data in different layers, which can group objects thematically for clients to query models according to needs. CAT3D framework is divided into four parts: Data Connectors, Data Format Creators, Data Mapping and Utilities (Knapp et al, 2007).

Shadow calculator gets the information from CAT3D framework and performs shadow calculation at specified time interval (per day, hour, minute) and prepares a CSV file with shadow information for each building. This file is feed into the SolarCity3D for solar potentiality analysis with the simulation engine INSEL (Schumacher, 1991). A 3D viewer is used for classified visualization of the results. And the final potentiality result with shadow consideration is also presented in excel file. Figure 2 represents the whole system architecture.

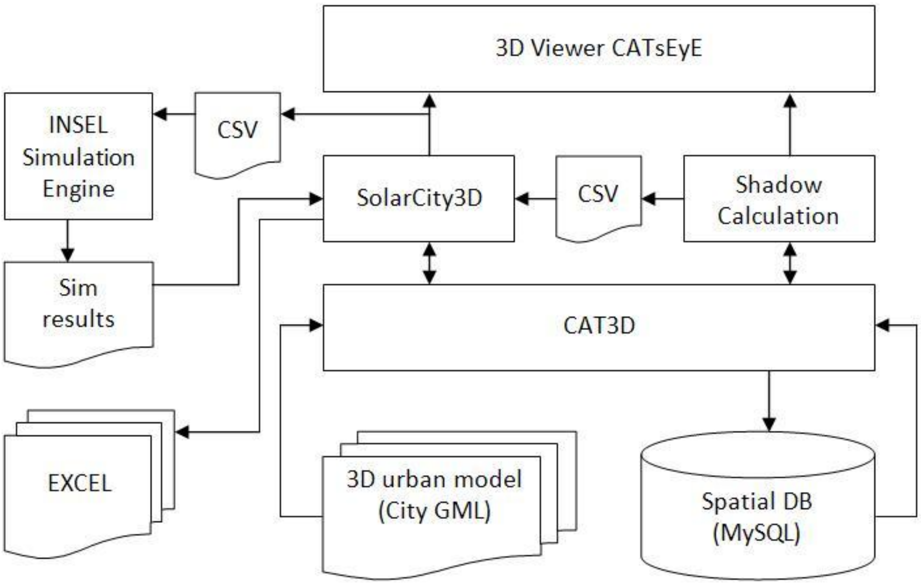

Figure 2. System Architecture

5 REAL TIME SHADOW COMPUTATIONS

Real-time shadowing technology is a key component for visualization in gaming. Most of the techniques and algorithms have been developed to give the gaming environment a solid look with hard shadow, soft shadow, physically correct shadow, direct and indirect occlusion etc. (McGuire et al, 2003) has develped a set of algorithms for hard shadow using stencil buffer and shadow volume geometry. They used the point in polyhedra method with the algorithm. The algorithm was developed for point light source. (Dimitrov, 2007) has introduced cascaded shadow maps for directional light like sun to fix the aliasing problem by providing higher resolution of depth texture near the viewer and lower resolution far away. *Volume Light* (Nvidia, 2008) is another technique to consider the scattering effect of light for small particles in air interacting with light beam. (Mayers, 2007) applied variance shadow mapping technique for soft shadow. A query is applied after rendering the depth from the viewpoint of light to texture which containt the fragment of light. (Sainz, 2008) introduced multiple depth buffer based ambient occlusion technique using *ray-marching* and a new hybrid method called *tangent tracing*. Piece-wise linear approximation of the horizon integration has been done here for efficient occlusion contribution. (Luebke & Parker, 2008) used ray tracing for reflections from curved surface, refractionsn and accurate shadows using CUDA and GPU. These works are followed for real time shadow detection for this research. All the works are gaming and visualization oriented, so they have different considerations for near and far object and focus only on objects within view frustum. But the principles used there can be used to get shadow information for the whole study area. The output of these works is pixel oriented. But for this research the information required is per point or per triangles after fine triangulation for desired resolution. Therefore the algorithms have to be modifiedand for using the principles and focusing the output requirement.

6 PHOTOVOLTAIC CELLS AND SHADOW EFFECT

Photovoltaic cells effectiveness depends mainly on amount of incident sunlight and its intensity. The amount of electricity generated by photovoltaic cells is proportional to the intensity of sunlight only until the entire photovoltaic module is exposed to the sun, but this does not happen simultaneously. In a module photovoltaic cells are connected in series. Dart or shadow significantly reduces the performance. The weakest link cell in the chain limits the amount of energy production. The amount of power loss also depends on the size and darkness of shadow. 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.

6.1 *Solar Radiation*

Air mass quantifies the energy reduction due to the absorption by air and dust while passing through the atmosphere. When sun is directly overhead Air Mass is 1. With the increase in angle from the vertical line sunlight has to pass a longer way through the atmosphere which causes reduction of radiation and increase in Air Mass. Apparent motion of the sun causes this change in Air Mass. Photovoltaic cell receives highest intensity when it gets the sunlight perpendicular to it. As the angle between the sun and the absorbing surface changes, the intensity of the light decreases. The angle between the sun and any location on earth are expressed as azimuth and elevation. These depend on the latitude, longitude, day of the year, time of the day etc. The total amount of radiation received by the module is a summation of both beam irradiance and diffuse irradiance. For getting the maximum amount of beam irradiance module is tilted according to the latitude but then it loses a portion of diffuse irradiance. Tilted module receives only a portion of the total diffuse radiation (Honsberg & Bowden, 2010).

6.2 *Photovoltaic cells*

Photon incident on a photovoltaic cell will be either reflected, absorbed or transmitted. Reflection and transmission are loss mechanism. When the photon energy is less than the band gap between the conduction band and the valence band, absorption is very week. When photon energy has just the energy equal to the band gap, light is efficiently absorbed. And when photon energy is greater than the gap, then it is strongly absorbed. Efficiency of photovoltaic cell depends on spectrum and intensity of incident light and temperature of the cell. Intensity of light incident on the photovoltaic cell affects all solar parameter. An increase in temperature also reduces the performance by reducing the open circuit voltage. Photovoltaic cells experience daily variation in light intensity. Shading of a single cell causes the current in the string of cells to fall to the level of the shaded cell and force the good cells to produce higher voltage that can often reverse bias the bad cell. Hot-spot heating occurs when a large number of series connected cells cause a large reverse bias across the shaded cells and enormous power dissipation in a small area results in local overheating and this can cause physical damage to the photovoltaic module (Honsberg & Bowden, 2010).

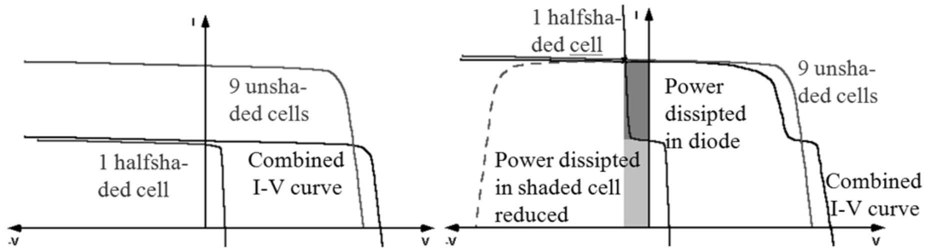

Figure 3. Comparison of I-V curve of shaded and unshaded photovoltaic cells.

To circumvent the hot-spot effect bypass diodes are connected in parallel and with opposite polarity. From figure 3 it is clear that the combined I-V curve totally depends on the shaded cell and bypass diodes reduce the effect by allowing the current from the good solar cells to flow in the external circuit rather than forward biasing each good cell. Typically there two bypass diodes in each 36 cell module. In addition to the use of bypass diodes, a blocking diode is used to prevent the current flow into shaded module from the parallel module and minimize the mismatch losses. (Honsberg & Bowden, 2010).

7 METHODOLOGY FOR BEAM RADIATION

First all the reasons for shadow must be considered and the required parameters must be determined. According to those parameters an advanced model will be developed for determining the exact shadow projected onto a surface planner or non-planner surface of a building or ground caused by any kind of obstacles including vegetation, utility features, city infrastructure, additional object except building part, chimney, lightning rod etc. The outputs will be presented in coordinates or any other usable formats as hourly basis or real-time basis which will be used in next steps to get the result. The tools will be programmed for estimating the available solar radiation (direct, diffuse and ground reflected) onto a surface shaded by multiple walls or objects mentioned above considering weather condition, cloud information etc. An optimum location and position for the PV module will be searched. In this case it would also be checked if the module doesn't lie on the surface then does it have the structural capability to hold on in case of maximum wind speed in hazardous situation. This will be Integrated with the simulation environment and an advanced simulation model will be constructed for obtaining the 3D radiation map onto a surface where the output will be a 3D city model having not only 1 or 0 type (shaded or not) but also the rank and effect of shadowing and it will be present in known usable format. An advanced model will be created for simulating the electrical performance of different type of PV arrays after shading. Time required for processing will be considered as a vital issue and will be minimized by using fastest and error free algorithm.

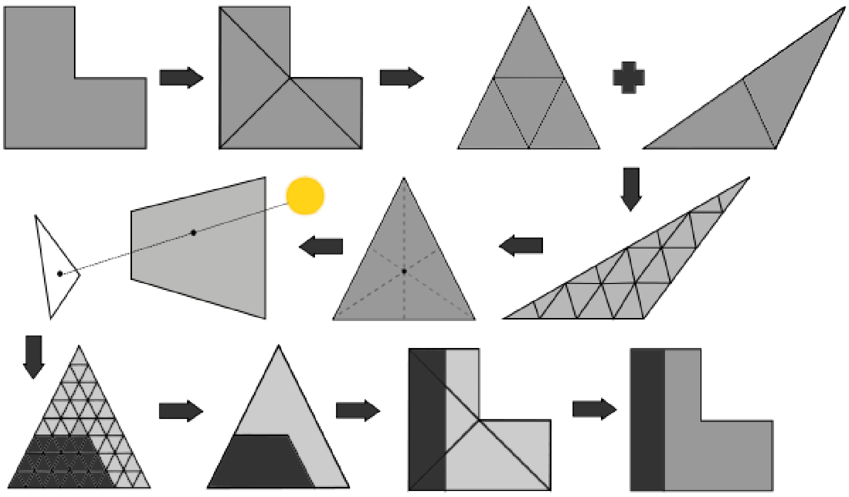

Figure 4. Steps involved in shadow detection.

The model will be applied to the PV array of the real world situation and results will be analyzed. Necessary modification of both the algorithm and the model will be made simultaneously. The report will be written sequentially with the progress of the work. For detecting shadow a surface subdivision approach has been developed. Here for a single plane shadow can be detected. 3D city models represented in CityGML format will be used. In CityGML , the building geometry is modeled as a set of polygon surface categorized as *ground*, *wall* and *roof* surface in LOD2. Each surface consists of a set of polygons. The algorithm consists of several steps. The first step is to read these sets of polygons. Second step is triangulation of each polygon. This process is independent to each other. Then to achieve a fine resolution each triangle is further triangulated. The middle point of each side is connected and thus the triangle is divided into four smaller triangles, the process is repeated until the length of the smallest side is larger than the desired resolution. Then the centroid of the triangle is measured and a line towards sun's direction is imagined representing the sun's ray. 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. If any intersection point is found then the triangle can be declared as a shaded triangle and joining the shaded triangles together will help to find the shadow polygon on any faceset. One thing should be kept in mind that this can only work with direct radiation for diffuse radiation another approach must be considered. Figure 4 shows the steps discussed above at a glance. But the process may face problem with thin triangles. So, for triangles with very narrow angles triangulation can be done by dividing the triangles according to the longest side. Thus the problem with the thin triangles can be avoided and a fine result can be obtained. The line represents the direction of beam radiation to a point. It might intersect with more than one plane but this will not affect the intensity of light. The transparency of the obstacle in this case has an impact. 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. This gives information about just an instant. With the movement of sun the shape of the shadow and intensity of light will change. This will cause variation in energy production.

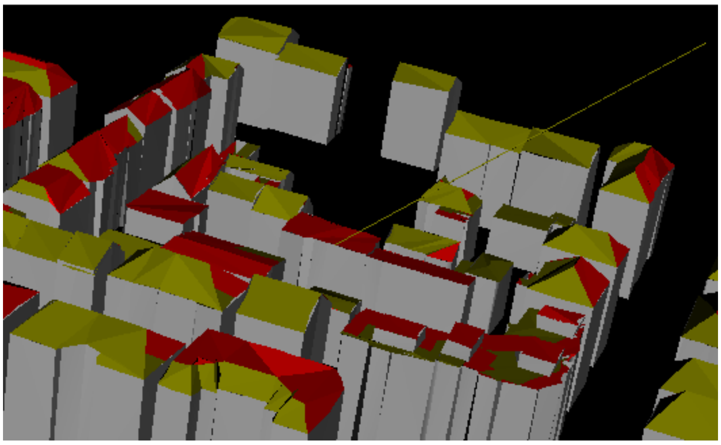

Figure 5. Steps involved in shadow detection.

Figure 5 shows the result after applying algorithm to a sample city model in the morning when sun has a small elevation angle. The red area on the roof represents the access to beam radiation and the remaining roof area doesn't get beam radiation. The algorithm was only applying on the roof and with a bigger resolution to get just an overview. Further research will consider other factors and more accurate shadow with fine resolution

8 CONCLUSION

A general problem has been introduced for using 3D city models to estimate shadow effect in solar potentiality analysis. The parameters for photovoltaic energy prediction, solar energy parameters and facts have also been mentioned. We have discussed about technologies involved to represent 3D city models. 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 and LIDAR point clouds, which is minimum for solar energy potentiality estimation.

REFERENCE

Alam, M. N. 2009 Solar Panel Calculation. Behr, F. J. et al. (ed.), *AGSE 2009: Applied geoinformatics for society and environment*; 103(2009). 48

Dimitrov, R. (2007, August). *Real-time Shadow algorithms andtechniques.* Retrieved May 11, 2011, from Nvidia: http://www.nvidia.de/object/doc_shadows.html

Dr. Baum Research e.K. 2009. Shadow Analyzer. *Dr. Baum Research.* [Online] Dr. Baum Research e.K. [Cited: December 11, 2010.] http://www.drbaumresearch.com/prod38.htm.

Eicker et al. 2010. Large scale integration of photovoltaic in cities. *ICSU 2010: International Conference on Sustainable Urbanization*; *Proc. intern. symp., Hong Kong, 15–17 December 2010*. Hong Kong: ICSU.

GTA Geoinformatik Gmbh. 2010. *Solar Potential Analysis.* Berlin : ISPRS 2010. Company Presentation.

Hofierka et al. 2009. *Assessment of photovoltaic potential in urban areas using open-source solar radiation tools.* [ed.] A.A.M. Sayigh. 10, s.l. : Elsevier Ltd., March 31, 2009, Renewable Energy, Vol. 34, pp. 2206-2214.

Honsberg, C. & Bowden, S. 2010. Welcome to PVCDROM. *PVEDUCATION.ORG.* [Online] [Cited: December 11, 2010.] http://www.pveducation.org/pvcdrom.

Izquierdo et al. 2008. *A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations.* [ed.] Y. Goswami. 10, s.l. : Elsevier Ltd., April 16, 2008, Solar Energy, Vol. 82, pp. 929-939. ISSN: 0038-092X.

Joachem, Andreas, et al. 2009. *Automatic roof plane detection and analysis in airborne LIDAR point clouds for solar potential assessment.* 7, s.l. : MDPI, July 2, 2009, Sensors, Vol. 9, pp. 5241-526.

Schumacher, 1991. *Digitale Simulation regenerativer elektrischer Energieversorgungssysteme*, Dissertation, Universität Oldenburg.

URL:www.insel.eu.

Kasten, F., & Young, A. T. 1989. Revised optical air mass tables and approximation formula. *Applied Optics* 28(22): 4735-4738.

Knapp et al. 2007. Improve public participation in planning process by using web based 3D models for communication platforms. Schrenk et al. (ed.), *REAL CORP 2007*; *Proc. intern. symp., Vienna, 20–23 May 2007.* Vienna: REAL CORP.

Kolbe et al. 2009. CityGML. *OGC.* [Online] August 20, 2008. [Cited: November 15, 2010.] http://www.opengeospatial.org/standards/citygml. OGC 08-007r1.

Luebke, D., & Parker, S. (2008). *Interactive Ray Tracing with CUDA*. Retrieved May 11, 2011, from Nvidia: http://www.nvidia.de/object/doc_shadows.html

Mayers, K. (2007, January). *Variance Shadow Mapping*. Retrieved May 11, 2011, from Nvidia: http://www.nvidia.de/object/doc_shadows.html

McGuire, M., Hughes, J. F., Egan, K. T., Kilgard, M. J., & Everitt, C. (2003, November 6). *Fast, Practical and Robust Shadows.* Retrieved May 11, 2011, from Nvidia: http://www.nvidia.de/object/fast_shadow_volumes.html

Memar Consultants Inc. (2008, August). *Sun-Shadow Study*. (Memar Consultants Inc.) Retrieved December 11, 2010, from Memar Consultants Inc.: http://www.memarconsultants.com/Pages/Services/SunShadowStudy.html

Nvidia Corporation. (2008, January 15). *Real-time shadow algorithms and techniques.* Retrieved May 11, 2011, from Nvidia: http://www.nvidia.de/object/doc_shadows.html

Sainz, M. (2008). Real-time depth buffer based ambient occulusion. *GameDevelopers Conference.* San Francisco: Nvidia.

SolarCity3D. 2009. Solar Potential Calculation and Visualization based on 3D CityModels. [Poster]. Stuttgart : HFT Stuttgart, 2009. Student Project.

Tereci, A., Schneider, D., Kesten, D., Strzalka, A., Eicker, U., (2009), Energy Saving Potential and Economical Analysis of Solar Systems in the Urban Quarter Scharnhauser Park,