GIS TECHNOLOGY

Shadow effect on 3D City Modelling for Photovoltaic Cells

PhD Research Proposal

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GISt Report No. 56

TU Delft Delft University of Technology

Challenge the future

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Summary

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 solve more complex problem like urban planning, disaster management, facility management etc. Such a problem is solar energy potentiality analysis and shadow effect analysis in this case is even harder. Photovoltaic cells are being popular for energy production. So many applications have been developed to know the potentiality before using this technology. The quality of the result depends on shadow effect which is very difficult to detect. 3D city models are high quality, realistic and with high details and geometries. So, 3D city models are the most practical option for detecting shadow. This paper will present a concept for detecting realistic shadows using 3D city models and getting highly accurate result of photovoltaic energy production taking the shadow effect into consideration. Levels of detail 2 and 3 CityGML data which contains roof structure, vegetation, thematically differentiated surface and texture are suitable to simulate exact real-time shadow. LIDAR point clouds are also triangulated to produce a TIN for 3D city modeling. 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 like INSEL. The recent research works in this direction has been mentioned in this paper and the need for the investigation of this approach has been illuminated.

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1 Introduction

Geo-information advancement is improving and helping to produce fully automated level of 3D urban model production. These 3D models are very high quality, realistic and include exact geometric detail. Disaster management, cultural heritage, navigation, gaming, urban planning, architecture and other sectors like this are using 3D models to solve their problems.

Our present living standard is fully dependent on energy or more precisely to say energy services. Urbanization leads to a very high increase of energy use in relatively small area. Buildings are the largest consumers of energy in cities (Santamouris, 2001). This has a huge environmental impact which is not accepted by the society of 21st century. Recently a couple of issues like global warming, green house effect, CO_2 emission, pollution etc. are being discussed a lot. And the world is looking for alternative sources of energy. Renewable energy like sunlight, wind, tide, and geothermal heat etc are solutions to that problem. As a result technologies like solar power/energy are very much popular now a day. Many researches have been done to measure potentiality of building roofs for photovoltaic cells. 3D city models are also being used for this purpose. Most of the major cities have started 3D city modeling and some of the cities already have those. Mostly 3D models are being used for visualization purpose.

Geographic location, orientation, tilt, climate condition, roof area, vegetation, neighbor buildings and shadow are the important parameters for predicting the energy production from the photovoltaic cells. Among all these factors shadow is difficult to determine. The result would be more realistic and usable if shadow effect is determined exactly. Presently some of the applications consider shadow based on assumption. Sometimes it is specified by the user as a percentage of roof area getting shadow or also defined as an hourly basis. There are also some simulating software packages and methods for considering partial shadows. The result it gives is a subject to investigate, need a lot of modification and has been explained in literature review in this paper. People spend a lot of money for photovoltaic cells and if it is placed at a wrong place where for shadow production is much lower than it was measured from potentiality analysis, they will lose money.

In this research the question that has to be investigated is, whether is it possible to measure exact intensity of sunlight/shadow effect automatically from the 3D city models. The quality of the current city models will be checked. It will also be determined that how much detailed data is minimum for calculating exact shadow. Cloud, Air quality, humidity, vegetation, texture, color, material, reflection form surrounding objects and other weather related and geographical aspects which causes, effects and controls shadow will also be investigated.

1.1 Background

Renewable energy, photovoltaic technology, 3D city modeling etc. are main concern of the research. So a brief background and history will be discussed here.

1.1.1 Renewable Energy

Renewable energy (RE) includes all energy derived from regenerative resources, which can be depleted. Therefore all RE sources are reproducible non-fossil energy sources. In other words, RE is a form of energy resource that is supplied by a natural process at a rate that is equal to or faster than the rate at which that resource is being consumed. Therefore as long as the sun is there, RE will never run out unlike other conventional sources. Before the industrial revolution RE was the only form of power available apart from labor from human and animals (Andexer, 2008).

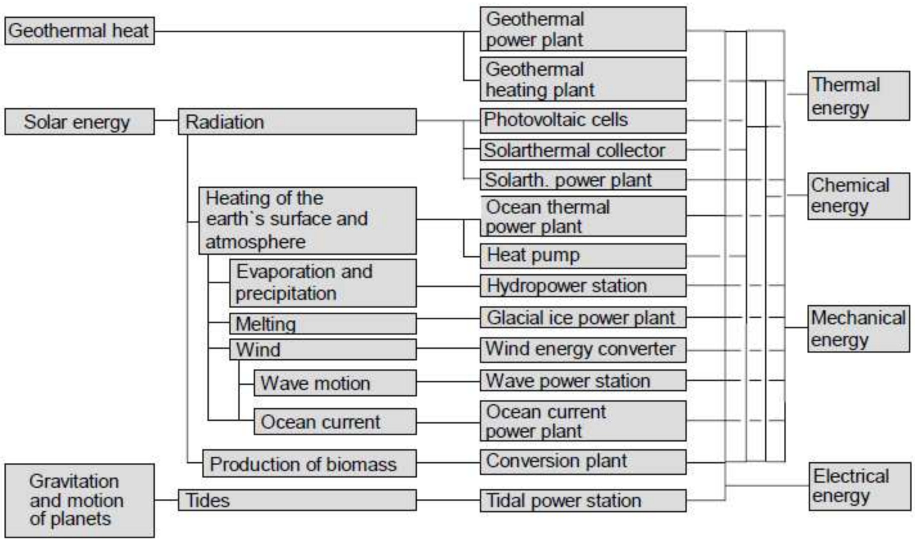

Figure 1.1: Options of using renewable energies for the provision of useful energy (Kaltschmitt et al. 2007).

There are three (geothermal heat, solar energy and gravitation & motion of planets) sources of RE which give rise to a multitude of very different energy flows and carriers due to various energy conversions process. The energy flow available on earth that directly or indirectly results from these RE sources very tremendously. Figure 1.1 represents conversions of RE to conventional energy (Kaltschmitt et al. 2007).

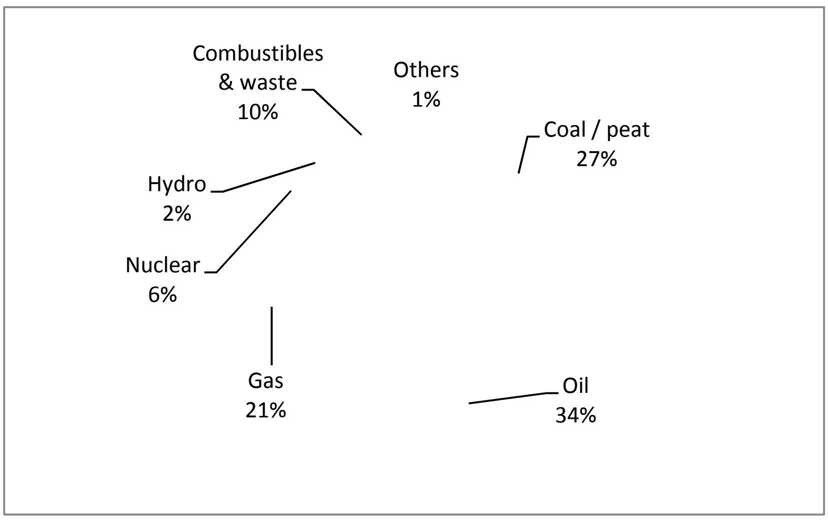

Figure 1.2: Fuel share of total primary energy supply in 2007 (IEA, 2009).

International Energy Agency of Paris has made a summary of the key energy data which is shown in figure 1.2. The major portions of energy come from coal, oil, gas, nuclear and waste plants. Sources like geothermal, solar, wind, heat, and hydro etc (others in figure 1.2) has a very small share in it. But good thing is, it is increasing. Share of these renewable resources increased from 0.1% to 0.7% from 1973 to 2007 (IEA, 2009).

1.1.2 Photovoltaics/Solar Energy

The first photovoltaic module was built by Bell Laboratories in 1954 (Knier, 2002). Photovoltaics provide a simple, reliable and elegant way of converting sunlight directly into electricity. The simplicity in use leads to modular, easily deployed system ideal for remote area power supply but now it is surfacing in an increasing variety of urban applications (Green, 2001). The range is from lining the roofs and façades of buildings and even bodies of automobile to dedicated fields of photovoltaic panels. Photovoltaics generate electricity in more than 100 countries. This fastest growing power generation technology has increased to its capacity to some 21 GW for grid-connected PV and 4 GW for Building Integrated PV until 2009. Germany is the clear leader in this field. Next in this list was Spain, Japan, USA etc. Figure 1.3 shows the share of different countries in global cumulative installed PV capacity (Sawin & Eric, 2010). According to the U.S. Department of Energy, a one-megawatt electric plant running continuously at full capacity can power 778 households each year.

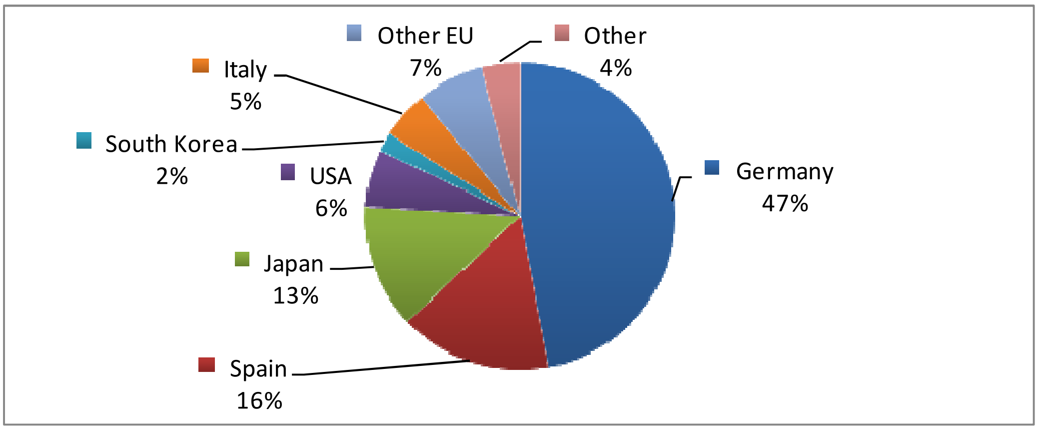

Figure 1.3: Global cumulative installed PV capacity through 2009 (Sawin & Eric, 2010).

Germany's market for PV has been supported since 2000, providing a guaranteed payment for a 20-year period for PV-generated electricity feeding into Germany's grid. Germany's PV market experienced its highest annual growth year in 2004, a 290% increase from 0.15 GW in 2003 to 0.60 GW in 2004 (Bundesministerium der Justiz, 2008). Spain also had an increase of 410% in 2007. Norway has the highest ratio of off-grid and Germany has heist ratio of grid-connected PV system (Sawin & Eric, 2010).

1.1.3 3D GIS

3D city and landscape models are now a topic of major interest and a number of algorithms have become available for the automatic and semiautomatic data collection. Aerial data like stereo images or LIDAR generates urban models using those algorithms. Tools for generation of polyhedral building models are based on constructive solid geometry or a boundary representation (Kada et al. 2006). 3D data can be organized in DBMS, retrieved and rendered by front-end application, the user remains self-responsible for the validation of the objects as well as true 3D functionality. To manage 3D volumetric objects for modeling man-made objects, natural objects and geological formation, DBMS data type *polygon* and *multi-polygon* or user defined data type could be used. Three candidates for a simple volumetric object were *polyhedron, triangulated polyhedron* and *tetrahedron*. 3D line objects means utility networks like pipeline, cable networks could be managed in DBMS using supported spatial data types *line* or *multi-line*. Though 3D point objects were rare in real world but with the advancement of the sensor technology and laser scanning techniques a large amount of 3D point data are being produced which could be organized in DBMS by using supported spatial data types *point* and *multi-point* or user defined type (Zlatanova, 2006). Although it is always better to use a specific point cloud. CityGML was developed to solve these issues. 3D GIS should be able to offer the same functionality as the traditional desktop GIS system. The progress in 3D modeling is apparent especially in the vector domain (also in field raster domain : height grid) for representing crisp objects like geometry models which are widely available and used, topological models which are investigated and some good prototypes are successfully tested, and network models which are emerging for indoor representations (Zlatanova, 2009).

3D GIS is not only used in 3D city modeling but also ecological studies, environmental monitoring, geological analysis, civil engineering, mining exploration, oceanography, architecture, automatic vehicle navigation, archaeology, 3D urban mapping, landscape planning, defense and intelligence, command and control etc (Abdul-Rahman & Pilouk, 2008).

One of the processes of generating and managing building data during its lifecycle in an interoperable and reusable way is Building Information Modeling (BIM) (Lee et al. 2006). BIM simulates the construction project in a virtual environment. The meaning of the word simulation in this context refers to a single coordinated and integrated entity containing all required information to plan and construct a building project. Virtual building implies that it is possible to practice construction, to experiment and to make adjustments in the project before it is actualized. BIM is a project simulation using 3D models of project components with links to all required information connected with the project planning (Kymmell, 2008). It covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (Wikipedia, 2010a). Borrmann (2010) have adopted the concepts of spatial query functionality for 2D space and applied them on geometric object in 3D space by developing spatial operators and algorithms. The concept was tested on 3D building models and 3D city models by a software prototype which reads-in any 3D model including building models provided in IFC file format or city models provided as CityGML file.

1.2 Study Area

Former military area Scharnhauser Park 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.

1.3 Shadow and Photovoltaic Cell

The motivation for this work came from the MSc Thesis. The title of the thesis was *Solar Panel Calculation*. The idea was to calculate the possible solar energy generation based on the area and exposure of the roof and give a prediction of the financial return when selling the energy to a utility company. The aim was to establish a web based application which would be an ideal promotion-platform as well as a mechanism to get visibility in the area of solar energy know how. The objectives were to establish a rich internet application using Flex after comparing with other similar technologies like AJAX, using Google Maps API for base map after comparing with other available map APIs, deriving Solar Radiation Data from the SSE dataset of NASA after comparing with other available data sources for radiation data, calculating the financial return while selling the energy to a utility company because Germany has a law that utility companies have to buy electricity produced by private households, implementing the application and make publicly accessible.

Figure 1.4: Problem faced during energy calculation (Alam, 2009)

As 2D image was used, the height information was missing and not considered. So the shadow causing by the height difference and geometrical difference was causing unrealistic result. In figure 1.4 two examples has been shown. There was no alternative to compensate this height effect. 3D city models can provide height information and also very details of building geometries. Why is height information so important in this case? The answer is height difference causes shadow. Then I tried to gather more information about shadow effect and solar potentiality. I found a significant gap which must be filled in the research area. My effort would be to add some more accuracy calculating the potentiality especially by solving the shadow detection problem. The purpose of this research is to suggest a new approach to detect shadow and its effect of photovoltaic system using the 3D city models.

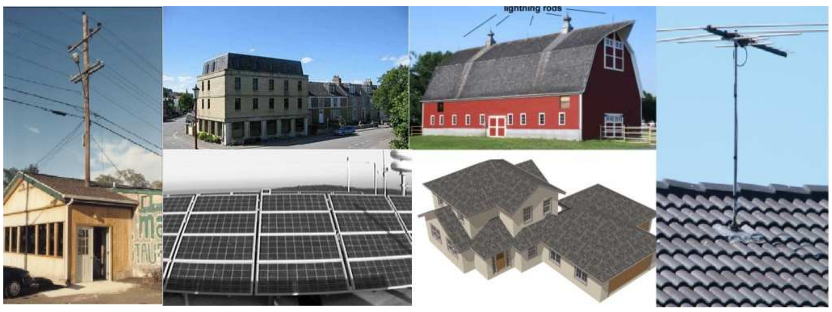

Figure 1.5: Shadow on roofs and walls which effects PV energy production.

The main problem for PV cells is shadow, no sun or bad angel to sun. Building integrated PV (BIPV) systems suffer from reduced performance level and thus lower profitability of the investment compared to non-building. Because the electricity produced by a PV module depends upon the least illuminated cell (Arizona Solar Center Inc., 2010). PV integrated into the built environment is frequently subject to partial shading resulting from: roof-landscape, hill/mountains, other buildings located in the proximity of the array, minor obstacles such as antennas, lightning protection masts, Electric poles and trees etc. shown as in figure 1.5. Shading of a single cell within a PV-module, leads to a reverse bias operation of the cell which may result in hot-spots and potential breakdown of the shaded cell (Bruendlinger et al. 2009). Research has been done to solve partial shadowing. Bypass diode (Zhang et al. 2009), maximum power point tracking, reconfiguring solar array in real time are used to minimize the partial shadowing effect on the solar array.

1.4 Related Works

Solar 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 closely criticized which helps to understand the gravity of this research work.

GTA Geoinformatik Gmbh (2010) has carried out solar potential analysis for CO_2 reduction and climate protection. They 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, shading from roof-mounted, neighboring buildings or vegetation, solar radiation on that position. But the whole process 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.

CPA Systems Gmbh (2010) has a Java based software component called SupportGIS/Java3D. This is based on modern databased powered 3D-information system which uses CityGML. It has the ability of continuous updating information of the official geobasis data. It also doesn't have a very transparent way of considering shadow during the calculation. Again it also considers the roof only so the drawbacks from the previous one are also valid for this one. Actually it is suitable more for tourism, real estate industry, town planning, exhaust mapping and simulations etc. but for solar potentiality calculation shadow have to be considered very deeply.

Wiginton et al. (2010) demonstrated techniques to merge the capabilities of GIS and object-specific image recognition to determine the available roof top area for PV installation in a large scale area applying ArcGIS extension, feature analyst and orthophotos etc. It produces an estimated potential roof area from the total roof area considering factors like shadow, other uses and orientation etc. But here façades have not been considered for PV installation and the data source also contains some errors. It uses 10 orthophotos for building extraction workflow which is expensive. It failed to carry out consistent analysis on more samples. Buildings were also outlined by hand in some case.

Solarcity3D (2009) is a student project from Stuttgart University of applied Sciences. 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 and shadow effects. The climate condition and shadow effect in this case are fully dependent upon the simulation engine which is also looking forward to have a good solution for detection shadow effects on PV module. INSEL weather and meteorological database (INSEL, 2010) use monthly mean for 12 month and for large scale but for PV module such generalized data is not sufficient to provide accurate results. It generates an hourly time series data using stochastic models of monthly means to achieve accuracy.

Dr. Baum Research e.K. (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 and Hulstrom (1981) which is very old and based on low quality data and was subject to improvement. 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 worse result for worst variant which is normal for any *bird* model. 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 in their method which uses full 3D information for both feature extraction and solar potential analysis using 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 small objects 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. Using 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) presented a methodology for assessment of photovoltaic potential in urban area using open-source solar radiation tools and 3D city models. It uses the *r.sun* radiation model from PVGIS (Šúri et al. 2008). 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) described 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 research pointed out a gap in literature for a method applicable for medium to large scale regions, such as whole country.

Castro (2007) programmed a computer tool for simulating the electrical behavior of shaded PV modules and determining the performance decrease. In his research he demonstrated the utility of ray tracing techniques for determining the shadow projections of surrounding objects. Here the system was formed with two flat surface the opposite wall and a finite section of an objective wall. Parameters considered here are sun position angles, coordinates, azimuth, inclination and dimension of the finite section and the opposite wall. Here shading of the beam radiation on to a surface is calculated through ray tracing techniques. Shading of diffuse and the ground reflected components and their respective reflections between the surrounding objects are neglected in the calculations. The algorithm takes huge time to detect shadow.

1.5 Approach

For detecting a very exact approach has been considered for hard shadows as a start up of the research. Here for a single plane shadow can be detected. Consider 3DCitymodels as input and in CityGML format (LIDAR might also be considered). Plane is normally declared as faceset in CityGML. So, the first step would be to find out each individual facesets. Second step would be to triangulate each facesets. This process is independent to each other. Then to achieve a fine resolution a 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 resolution. Then the centroid of the triangle is measured and a line towards sun's direction is imagined representing the sun's ray. Next step is to look for any intersection point lying on that line. 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 1.6 shows the steps discussed above at a glance.

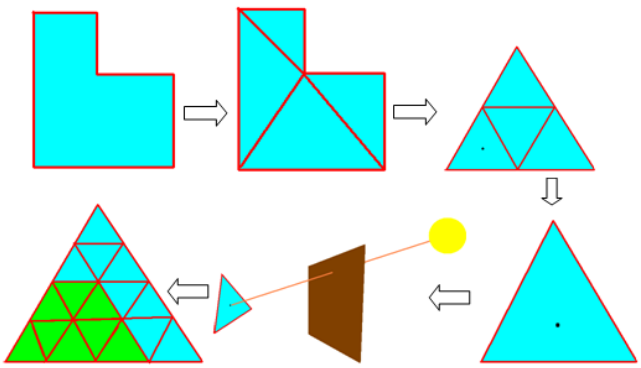

Figure 1.6: Steps for detecting shadow triangles.

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 like figure 1.7. Thus the problem with the thin triangles can be avoided and a fine result can be obtained.

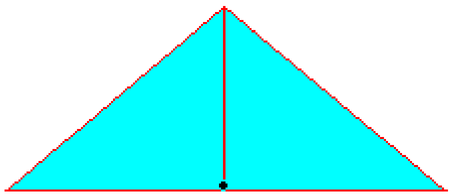

Figure 1.7: Different approach for long skinny triangles.

2 Conceptual Design

In order to get optimum output from the photovoltaic cells, consumer needs to know the potentiality of the photovoltaic cells. If consumers invest on photovoltaic cells trusting the wrong prediction, he will definitely loose huge money. An accurate technique for detecting shadow and its effect using the latest technology will eliminate this problem. I propose to research and development of such a method to determine shadow effect on 3D city modeling or point clouds for photovoltaic potentiality analysis.

2.1 Research Objective

The objective of this research is to develop an automated approach to detect shadow and its intensity for 3D city models and acquire exact output from the photovoltaic cells through a realistic simulation. During this research building semantic attributes should be investigated and structural capability of the roof or wall to hold a PV panel will also be considered. Optimization of the PV arrays will also be considered to get the maximum output. The texture and color of surrounding objects and their effect on PV because of reflection and absorption will be measured.

2.2 Research Question

To reach the research objective a long way of studying existing solutions, designing and applying new solutions, giving formal description of new solutions, running experiments and tests and comparing with existing solutions and real world result etc. must be endured. A central question with some sub-questions has been formulated have been formulated, which should be answered during the course of the research. The central question is:

Q: What is the added value of shadow consideration for energy production by building integrated photovoltaic cells comparing current estimation for potentiality? How to apply a fast shadow detection method for photovoltaic potentiality analysis for roofs and facades and what type of data is minimum for this so that some decision making can be supported?

The sub-questions which will lead to the central question are:

General Questions:

- What are the existing solutions and approaches for photovoltaic potentiality estimation and are they sufficient?
- How big is the impact of shadow on a photovoltaic array?
- Are the existing data sufficient to detect shadow?
- How fast is the algorithm and how efficient is it for detecting shadow?
- How to compare the result if it is showing the reality?

Questions related to shadow detection algorithm:

- Which parameters should be defined as the cause of shadow?
- What are the most popular approaches for shadow detection and how this approach produces better result?
- What type of output is suitable for BIPV potentiality analysis?
- What are the factors of uncertainties and how to determine the maximum negligible error?
- How shadow results can be represented (e.g. point, polygon, vector etc.)so that it gives the best output?
- How to obtain and represent degree of shadow or intensity of light?

Questions related to shadow effect on BIPV:

- What is the response of PV cell to shadow?
- What kind of technologies are there to minimize the effect of shadow on PV and how to take these into account for potentiality analysis?
- How to make use of the intensity of light because the result is not directly proportional to it and vary with the number of cells in shadow of an array?

Questions related to data quality:

- What types of data are currently available and which data should be used for shadow analysis?
- How to determine if the quality of data is sufficient to detect shadow?
- Is it possible to acquire such detailed data and does it worth it in term of return from the potentiality analysis?
- How to store the information of shadow with the building information?

Questions related to accuracy and efficiency:

- How to determine if the result from the shadow detection is accurate enough to use it for PV potentiality analysis?
- How to compare it with real world data which have other effects besides shadow?
- How fast is the algorithm? How detail information can it provide for a big area?

2.3 Research Methodology

The PhD research follows the theory then involves practice and then back to theory again. Following are the summary of the methodology for the PhD research.

2.3.1 Literature Study

A PhD research must be novel. So to avoid repeated research work it is inevitable to study and follow previous literatures and works. This research includes collecting related background information for shadow detection for photovoltaic cells, collecting previous knowledge and works that have been done to detect shadow for photovoltaic potentiality analysis, and understanding the basic functions and conditions for photovoltaic potentiality analysis. So this phase will emphasis on acquiring knowledge over previous works and theories.

2.3.2 Technology espousal

Technology is the tool to solve any problem. So it is worthwhile to emphasize on technology selection and adoption. This research is focusing on shadow effect on photovoltaic cells and building integrated photovoltaic cells are of main interest so building information is very important. 3D city models are most suitable option here. So technology involved with 3D city models will be studied here. Sun is the only source of light in this case. So this shadow is dynamic and changes with time. To estimate and consider the pattern of shadow will demand advanced computing technology and hardware like GPUs. GPU related studies will be carried out in this research. To compare the result, the output must be compared with the real world data. For this purpose this output would be used with simulation for photovoltaic potentiality analysis, so previous work and knowledge on simulation will be collected. Emphasis of this phase will be acquiring knowledge on 3d city modeling, logic programming, geometric theories, database technology and simulation together with sun's radiation and photovoltaic technology.

2.3.3 Data Quality Checking

This PhD research also includes investigation of the quality of data. It has already been discussed earlier that building information is one of the ingredients, so CityGML, LIDAR, CAD, BIM, IFC etc are suitable forms of data. The format of data will be selected through the technology espousal phase. Whatever the format is, its quality has a big impact over the result of this research. Shadow can be caused by a lot of obstacles in the proximity. For example neighboring building, complex roof structure, terrain, cloud, antenna, lamp post, electric pole, lightning rods, electric wire, trees, vegetation, window or door maneuver and upcoming construction in proximity etc. might be the reason for shadow. But every detail might not be present in the current available data. So the relation between the reason and result will be deeply studied. Some things are very difficult to predict like cloud, something moves all the time like trees, something changes shape like electric wire. So different effect might take place in different seasons. Some features might be represented differently in data, for example electric wire (if data is that detail) is most likely to be represented as line geometry, which might not be very helpful for shadow detection. This phase will concentrate on the quality, resolution, levels of detail, availability and applicability of data.

2.3.4 Developments─ Shadow detection algorithm

There are a number of approach and methods for considering different types of shadow which are presently in practice. Mainly gaming, animated movies, detailed 3d architectural model etc. strongly consider shadow for mostly visualization purpose. Behavior of shadow depends mainly on light source. Quite a number of researches have been done on hard shadow, soft shadow, deferred shadow, physically correct, perceptually satisfying and robust shadows. Shadow volume technique, volume light technique, hardware shadow mapping, omnidirectional shadow mapping, variance shadow mapping, real-time ambient occlution, dynamic ambient occlusion and indirect lighting and ray tracing etc. are techniques to detect and visualize shadow. In this phase these techniques will be studied and a shadow detection algorithm will be developed through trial and error method. Some parts of the techniques may be adopted or modified and integrated with the algorithm.

2.3.5 Developments— PV potentiality analysis

The main goal of the research is to improve the current practice of photovoltaic potentiality analysis by adding a precise shadow detection technique. But performance of photovoltaic cell doesn't only depend on intensity of light. Temperature, weather condition, ventilation etc. has also impact on the output of photovoltaic cells. But these are or might be another PhD research. Here main interest is to use the output from shadow algorithm according to the behavior of the photovoltaic cells towards shadow. This is very essential for the checking results phase. Many researches have been done on photovoltaic potentiality analysis. The main purpose of this phase will be to find a better analysis method and develop and modify the shadow effect part keeping the rest as it is.

2.3.6 Developments— Building a prototype

This research problem originated from real world problem and the purpose of the research is to provide a solution for that. This makes tests essential in this PhD research. The hypothesis of the result of the PhD research will be a simulation tool providing very detail information about shadow for using with simulator for photovoltaic potentiality analysis. The task in this phase is to develop a prototype consist of user interface, framework, database, visualizer etc.

2.3.7 Checking Results

This is the last and most important part of the research. The result of a research must be authentic and trustworthy. So the result of the prototype must be checked with the real world data. For this purpose study area must have firstly real photovoltaic installation and also record of output throughout a long period of time. Secondly study area must have sufficient building information within its database. Scharnhauser park- Osterfildern, Stuttgart, Germany has such information and a small portion of electricity is delivered by existing roof top PV-systems. This might be selected as an study are for the beginning of the research.

2.3.8 Cooperation

This PhD research is such one that covers many other research fields, for instance Geomatics, Informatics, Engineering, Photovoltaics, physics, mathematics etc. So collaborations might be established with related research organizations. For instance, a cooperation with the Centre for Applied Research - Sustainable Energy Technology - zafh.net at Stuttgart University of Applied Sciences.

2.4 Scope

The research will provide a method to detect shadows more accurately. This will have a direct impact on PV potentiality prediction. At this moment most of the big cities have 3D city models or point clouds, developed countries have those models for even smaller cities. The method for detecting shadow will lead to a more realistic visualization of the city models. Not only photovoltaic energy estimation, the method can be applied for *solar water heater* also. This research demands data with high accuracy and geometric detail. For accuracy in the intensity of shadow texture, color and transparency has an impact. So the research is creating a demand for data with high accuracy, geometric detail, texture, color and transparency.

3 Research Plan

The research has been designed for four years. In 2014 the research is expected to be end with a final outcome. Most of the time will be utilized for research purpose and the rest will be used for writing the PhD Thesis.

3.1 PhD research agenda

An agenda has been proposed for the PhD Research. From Start-up to the end there are preparation phase, data collection phase, code development phase, evaluation phase, final output phase and other issues. Some of the phases are inter-related and repeated. The agenda is as follows:

3.1.1 Preperation

- Literature Review.

Literature study started from September 2010. This is the starting point of the preparation phase for the PhD research. This includes firstly, understanding the background of the PhD research (e.g. photovoltaic potentiality analysis, shadow, 3d city modeling, point clouds etc.). Secondly, studying and comparing previous and ongoing projects related with photovoltaic potentiality analysis (also projects related to the research problem) until December 2010. This took about four month. But this will continue until December 2011.

- Writing PhD Proposal.

January 2011 to March 2011 these three months were spent for writing PhD proposal. Two draft versions were submitted before writing this proposal. The feedbacks from supervisors were considered. The result is an official PhD proposal following the format of GISt reports from TU Delft which will also be published as a section report.

- Technical skill build-up.

Technical competence needed to start-up the research work will be acquired in this stage. This includes selection of software, platform, programming language, database, computer graphics etc. April 2011 to May 2011 these two months will be spent for acquiring sufficient technical knowledge to carry out this research. As four years are a very long time and technology will definitely be advanced, so additional knowledge might be acquired from time to time to remain up to date with the technology advancement.

3.1.2 Data collection and analysis

- Building Information of study area.

Presently two types of information are being considered. 3d city models and point clouds. This will also depend upon the availability of data. For starting up the research work, city model of Stuttgart was used. As the result of the photovoltaic potentiality analysis will be compared with some real world data where there are already photovoltaic cells installed so there is no option but to choose where both the data are available. Centre for Applied Research - Sustainable Energy Technology - zafh.net at Stuttgart University of Applied Sciences has data of Scharnhauser Park-Osterfildern, Stuttgart which was already mentioned earlier, might be ideal as a study area. The data will be collected within the month of April 2011 and May 2011 for start up. The study area might always change if better data of more complex buildings and more detail information are found.

- Photovoltaic energy data collection.

This data will be required to compare the result of potentiality analysis. The energy production of photovoltaic cells in Scharnhauser Park is available. Two types of data might be used. Real time data with normal condition in different seasons with existing shadow or applied shadow (by applying additional barrier) and Average data having shadow or applied shadow (at least for some known time). Data with different type of shadow and partial shadow will be very helpful. These data will be collected at least before the end of the detection of simple shadow for direct radiation algorithm finalization.

- Data analysis.

As one of the output of this PhD research will be an assessment of minimum quality of data required for photovoltaic potentiality analysis considering shadow so both types of data will be analyzed. The quality of building information is very important here. This will depend upon the types of feature considered for shadow calculation. Impact of object like tree, antenna, electric pole, wire, doors and windows, fence etc., types of information provided for that, success in considering those object in shadow algorithm and frequency and authenticity of photovoltaic output information of the study area will be focused. After every final result of shadow calculation this will be repeated and at the end of the research a final data quality will be proposed.

3.1.3 Shadow Algorithm

- Simple and hard shadow.

Development of the shadow algorithm has already been started for simple shadow before officially starting the PhD. This only considers the direct radiation. At this moment this is operational and ready to give an output which has been integrated with the photovoltaic potentiality analysis of zafh.net of Scharnhauser Park and is to be published in the Elsevier journal of 'Applied Energy'. The algorithm will be developed further until the end of December 2011 and also whenever needed a further modification.

- Soft Shadow.

Development of soft shadow algorithm will consider the indirect radiation also. When the sun is blocked by any obstacle, only the direct radiation is blocked but it doesn't get completely dark. Soft shadow algorithm will be developed from January 2012 to September 2012.

- Exact Shadow.

Exact shadow algorithm will consider both hard and soft shadow and also reflectance, texture, color of surrounding objects. This will represent the real life shadow impression. Developing this algorithm will start in October 2012 and will take place until June 2013.

3.1.4 Potentiality analysis

Photovoltaic potentiality analysis depends on a lot of factors and shadow is one of the major factors. As there was no option for considering shadows until now so potentiality analysis tool will also be developed in a way that it can receive the information and apply it in a most appropriate way considering the devices to compromise shadow effect (e.g. diodes). This will take place after every successful development of the shadow algorithm to compare the results.

3.1.5 Evaluation

Checking results makes the PhD research more authentic, acceptable and trustworthy to all as well as helps to control the direction of research. Results of the potentiality analysis will be compared to the real world result from photovoltaic energy production from the study area. Though in the beginning the deviation will be greater than the deviation in the end, still it will help to understand which parameter have how much effect. The effect of data quality will also be very clear through every stage of checking results. The final check will take place after development of every algorithm of shadows and its effect.

3.1.6 Data requirement finalization

Quality of data plays a vital role in this research. There will always be a limit to what extent the building information as well as neighboring object information can be extracted. The emphasis of this part of research work would be to prepare a suggestion or a guideline of which kind of data have influence on the photovoltaic output. This suggestion will be prepared at different phases of research work and for different type of situation (separately for direct radiation, diffuse radiation, global radiation etc.). But a final suggestion will be prepared in June 2013 to September 2013 after all the results are checked with real world data.

3.1.7 Final demo building

Finally a demo version of the shadow simulator will be prepared. This will provide a service to calculate real time shadow as well as total and average shadow to feed in to the photovoltaic potentiality simulator and also as an output data. This final demo will be finished within December 2013. This demo will be prepared for several input and output data format like CityGML, LIDAR etc.

3.1.8 Thesis Writing

The last month of the PhD research will be spent for writing PhD Thesis. After the submission of PhD thesis the remaining time will be spent to write other articles.

3.1.9 Other Issues

There are some other issues like attending necessary courses, writing papers and articles, visiting different institutes and organizations etc.

3.2 Time Planning

A rough time planning with the above mentioned agenda have been proposed which might change in case needed. Figure 3.1 shows a full overview of the project. 70% of the total time will be spent on research work, 5% of the time for writing papers and reports, 25% of the time will be spent for other issues.

Activity/Year	2010	2011				2012				2013				2014		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Literature Review	■	■	■	■	■											
Proposal writing		■														
Article I		■														
Technical study			■													
Building Information			■													
Energy Data collection			■													
Hard Shadow Algorithm		■	■	■	■											
Article II			■													
Potentiality Analysis			■	■	■											
First Evaluation					■											
Data Analysis					■											
Paper I			■	■	■	■										
Soft Shadow Algorithm					■	■	■	■								
Article III						■										
Potentiality Analysis						■	■	■								
Second Evaluation								■								
Data Analysis								■								
Paper II						■	■	■	■							
Exact Shadow Algorithm									■	■	■					
Article IV									■							
Potentiality Analysis									■	■	■					
Third Evaluation											■	■				
Data Analysis											■	■				
Paper III									■	■	■	■				
Data suggestion Finalization												■				
Article V												■				
Final Demo Building													■			
Article VI													■			
PhD thesis														■	■	■
PhD Draft															■	
PhD Defence																■

Figure 3.1: Proposed time plan of the PhD research.

3.3 Necessary Education

This PhD research requires knowledge from several fields like photovoltaics, computer graphics, parallel programming, scientific writing, mathematics, geometry, physics, optics, geosciences, database management etc. So knowledge must be acquired in these fields. Some of these knowledge have already been gathered during the education until now. The rest of the knowledge might be gathered by studying books, research papers, journals etc. But to acquire knowledge on the other fields and also more details in all fields, some additional courses might be attended. As there is no funding for attending courses, self education and free online courses will be preferred. Many reputed universities has very nice free online courses and documentation with lecture notes, PowerPoint slides, videos and exercises etc. Massachusetts Institute of Technology (MIT) has free online open courses on computer science, physics, earth science and mathematics etc. Stanford University offers a free service called Stanford Engineering Everywhere (SEE), where they provide courses on programming methodology, linear systems, programming massively parallel processors etc. and also lots of seminars, lectures, and presentations in different fields. Physics course of Yale University, computer graphics of Indian Institute of Technology etc might also be helpful. TU Delft has OpenCourseWare (OCW) in mathematics, geomatics and informatics. Institute of parallel and distributed system (IPVS) of Universität Stuttgart, works with parallel programming. Prof. Dr.-Ing. Sven Simon of IPVS might be contacted for some courses or trainings on parallel programming. National Science Foundation of USA funded pveducation.org provides brief knowledge on photovoltaics in collaboration with Arizona State University. NASA and NREL of USA also provides information, knowledge and data on photovoltaics and earth science. Besides Stuttgart University of applied sciences also offer courses on Mathematics, Software Technology, Geoinformatics etc. Necessary courses might be attended from these departments.

3.4 Supervision

This research will be supervised by two supervisors and one co-supervisor. Prof. Dr.-Ing Volker Coors from University for applied sciences, Stuttgart and Prof. dr. ir. P.J.M. (Peter) van Oosterom from Delft University of Technology (TU Delft) are the supervisors of this research work and mw. dr. dipl. ing. S. (Sisi) Zlatanova from Delft University of Technology is the co-supervisor. The research is now mostly carried out in Stuttgart but with a bit financial support working in both Stuttgart and Delft.

3.5 Reporting and Meetings

Regular meetings, conference and reports will be arranged for the PhD research. The types and purpose of these meetings and subject of the report has been described below.

3.5.1 Weekly discussion

A short discussion will take place with supervisor in Stuttgart reporting advancement of previous week and tasks will be assigned to follow the agenda for current week. A short summery of the discussion will be prepared and delivered to all the supervisors. Comments from supervisors in Delft will be considered at the discussion on the following week.

3.5.2 Semi-monthly Report

After every two weeks a short one page report will be prepared and delivered to all the supervisors with the weekly discussion report. This report will help to keep the direction of the research in track and also will help while writing the final thesis. The report will be more like a history record.

3.5.3 Monthly Conference

Once a month, there will be a telephone/skype conference with all the supervisors. The flow of work, direction of research, achievements etc. will be discussed there. Dates will be fixed after discussing with the supervisors. In this conference the preparation for journal publication and conference proceedings will be guided. No additional report will be prepared for this meeting but a protocol might be maintained.

3.5.4 Quarterly Report

Every three months a quarterly report will be prepared. This will contain the summation of the semi-monthly reports and also the intermediate results. This will be prepared in such form that it can be delivered for a publication. Although two publications a year has been assumed as minimum but if the quarterly report comes up with some evident result that might be considered to modify for publication after a green signal from the supervisors.

3.5.5 Semi-Annual Meeting

Every six months a meeting (in person) with the supervisors in Delft will be organized. A PowerPoint presentation will be prepared for that meeting. This might be presented also in lunch meeting of OTB, TU Delft. The meeting dates might also be fixed according to conference proceedings where all the supervisors might be available.

3.6 Involvement in other projects and educations

CityDoktor3D is a project to develop methods and metrics for quality management of virtual city models with the use of modules and experience of data verification and repair data in CAD environment (HFT Stuttgart, 2010). Currently a half-position in CityDoktor3D project is helping to carry on this research work.

4 Deliverables

The main deliverables of this research are journal articles, conference proceedings, method for detecting shadow effect on PV and finally PhD thesis.

4.1 Articles

Scientific writings will be prepared and published in well-known journals (e.g. Applied Energy; Computer, Environment and Urban System etc.) during the research period stating the intermediate status and findings of the research work.

4.2 Conferences

Conference proceedings will be attended and both oral and paper presentation will be contributed. Roughly one or two conferences per year will be attended. It is not still clear exactly which conferences will be attended but some related conferences are as follows:

- ISPRS (International Society for Photogrammetry and Remote Sensing) is an international NGO for development and advancement of knowledge research and education in Photogrammetry, Remote Sensing and Spatial Information Science (ISPRS, 2010).
- UDMS (Urban Data Management Society) has organized international symposia at various locations in Europe to provide a forum for people to discuss new approaches, to consider new technologies, and to share practical experiences in urban data management (UDMS, 2010).
- 3DGEOINFO is a joint ISPRS workshop on 3D City Modeling and applications.
- AGILE is the Association of Geographic Information Laboratories for Europe. Its mission is to promote academic teaching at the European level and to facilitate networking activities between geographic information laboratories at the European level.
- GIScience is the international conference which brings together leading researchers from all discipline to reflect the wide spectrum of scientific areas.

4.3 Other types of results

Besides these some other types of results will also be provided through research like developed algorithm, suggestion for data quality, a tool for detecting shadow and measuring effect on PV etc.

4.4 PhD Thesis

Finally a regular PhD Thesis will be written for the doctoral defense.

Annex

Photovoltaics cells

Photovoltaic is the direct conversion of sun's radiation into electricity at atomic level by absorbing photons of light and releasing electrons (Knier, 2002). PV cells are made of special materials called semiconductor (SolarServer, 2010), such as silicon (Toothman & Aldous, 2000). This thin semiconductor is specially treated to form an electric field, positive and negative on different sides forming an electrical circuit (Knier, 2002). This flow of electricity is which is further used for household purposes or provided to the grid. There are many types of photovoltaic cells according to material used. Efficiency differs for different types of PV cells. Table 1 shows efficiencies of different type of PV cells.

Table 1: Efficiencies of solar cells (Kaltschmitt et al. 2007)

Material	Type	Efficiency (%)	
		Lab-oura-tory	Industrial Manu-facturing
Large Scale Production			
Silicon	monocrystalline	24.7	14.0-18.0
Polysilicon, simple	polycrystalline	19.8	13.0-15.5
Amphorous silicon, simple	thin film	13.0	8.0
Tandem 3 layers, amphorous silicon	thin film	14.6	10.4
Small Scale Production			
MIS inversion layer (silicon)	monocrystalline	17.9	16.0
Concentrator solar cell (silicon)	monocrystalline	26.8	25.0
Tandem 2 layers, amphorous silicon	thin film	13.0	8.8
Gallium indium phosphet /Gallium arsenide	tandem cell	30.3	21.0
Cadmium-telluride	thin film	16.5	10.7
Copper indium di-selenium	thin film	18.4	12.0
Pilot Production			
Silicon on glass substrate	transfer technology	16.6	-

o Sun and Its Rediation

Sun is the main source of energy. Sunlight supports every life on earth. Every year earth receives 174 peta-watt of energy, 30 percent of which is reflected and the rest is absorbed by clouds, oceans and land (Smil, 1991). The portion of radiation that passes through the atmosphere and directly hit the ground is direct radiation. On the other hand the portions of radiation that experience reflection, refraction, absorption, scattering and deviated from straight line but hit the ground are diffuse radiation (Lillesand et al. 2008). Both direct and diffuse radiations are converted into electricity by PV cells.

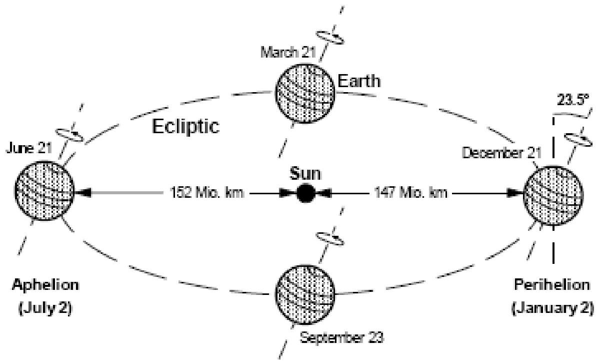

Figure 1: Orbit of earth around the sun (Kaltschmitt et al. 2007).

Earth spins around its axis which is not perpendicular to the orbit. Earth currently has an axial tilt of 23.44° (Mathews, 2010). The apparent movement of earth around the sun thus causes variation between day and night. These are the reason for angle variation of sun's ray hitting the earth's surface during different time periods in day and different day in season. Figure 1 shows earth's position on the orbit while moving around the sun. Quaschning (2003) has defined some parameters to calculate the radiation incident on a surface. Those are angular height of the sun, sun's azimuth form north, surface azimuth from north, surface tilt, zenith and surface normal. Beside these some other factors also influence the calculation like air mass index (Quaschning, 2003), clear sky insolation, cloud information, air temperature etc (NASA, 2009).

o PV System

PV systems are like any other power generation system. Equipment used are a bit different but the principle of operation and interfacing with other electrical system remains the same. PV array produce electricity using sunlight but for conduct, control and distribute/store a number of other components are required (FSEC, 2010). At present there are two type of PV system according to functionality and required components: standalone and grid-connected.

o Standalone PV System

Solar cells can produce energy only during the day time but electricity is also needed at night. So the extra energy produced during day time must be stored in the battery for using at night. For controlling the chargeability so that it does not get over charged a charger controller is used. The energy stored in the battery is DC current but normally household demand is AC current. An inverter is used for converting the current. So a standalone PV system thus consists of solar cells, charger control, batteries and inverter (Toothman et al. 2000).

o Grid-Connected PV System

Batteries increase the cost for PV system which can be omitted in grid-connected PV system. A grid-connected PV system consists of PV array, surge protector varistors, PV breakers, power inverter, service distribution panel (see reference for detail) and connection to external utility service entrance etc (Wenham et al. 2007). The function of grid-connected PV system is very simple, buy electricity when needed and sell when you have extra.

State-of-the-art Technologies

The state of the technologies used or suitable for this research work is described here. For authentic calculation height information is essential which is available through 3D city models or LIDAR data. CityGML is one option for considering 3D city models and LIDAR technology which provides point cloud is also suitable for this research because the approach for detecting shadow is point based. For roof area LIDAR data represents better result whereas for façades there is a lack of information but implied because of height difference. Java has been chosen over other platform for application development and operation. CAT3D toolkit which is based on java has been used to handle manage and merge data. CityServer 3D has also been explained here which might provide input data and also be helpful for its services. For minimizing operating time for the algorithm GPU programming has been considered which is now mostly used for gaming pc. The key factors of these things, which might be helpful for this research work, have been explained here.

o CityGML

CityGML is an OGC standard open data model for XML based format for storage, exchange and representation of virtual 3D city models. Semantic and thematic properties, taxonomies and aggregations (DTM, Sites, Vegetation, Water bodies, Transportation facilities, Land use, City furniture, Generic city objects and attributes etc.) are also represented here with the geographical appearance of city models. CityGML models have class definitions. Modularization has 11 thematic extension modules and is applied to have subset according to specific information need. It includes a geometric model and a thematic model. First one includes geometrical and topological properties of spatial objects and second one uses geometry model for different thematic fields like DTM, vegetation, waterbodies etc (Kolbe et al. 2008).

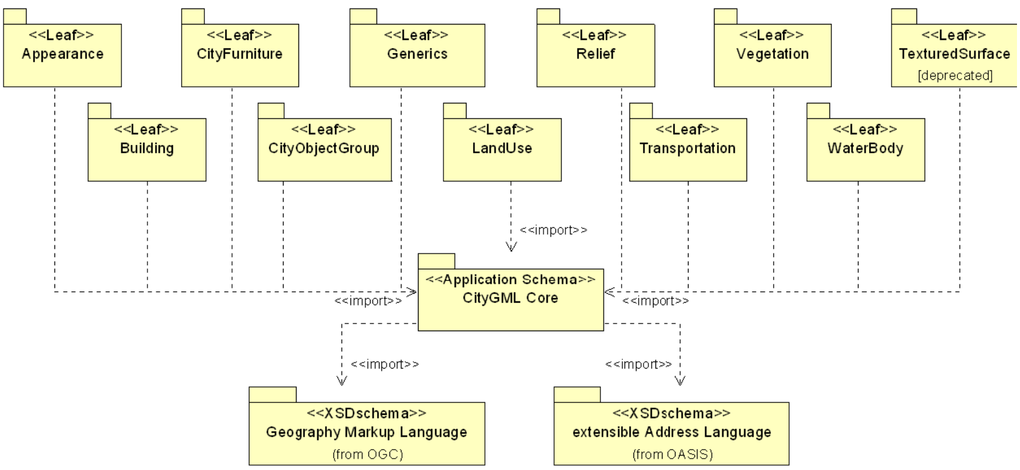

Figure 2: Separate Modules of CityGML (Kolbe et al. 2008)

Figure 2 shows the UML package diagram of the separate modules of CityGML and their dependency. *CityGML core* module defines the basic component of all

CityGML data model which comprises abstract and non-abstract base classes. It imports XML schema from GML and OASIS. *Appearance* module provides the mean to model appearance of CityGML features. It has deliberate impact on all thematic extension modules. *Building* module allows for the representation of thematic and spatial aspects. *CityFurniture* module is used to represent city furniture objects like lanterns, traffic signs, advertising columns etc. *CityObjectGroup* provides grouping concept for CityGML. *Generics* module provides generic extension which should only be used if appropriate classes or attribute are not provided. *LandUse* module allows for the representation of specific land use. *Relief* module allows for the representation of terrains. *Transportation* module is used to represent transportation feature like roads, tracks, railways etc. *Vegetation* module provides thematic classes to represent vegetation. *Waterbody* module represents the thematic aspects of river, canal, lakes etc. *TexturedSurface* module allows for assigning visual appearance properties like color, transparency and texture (Kolbe et al. 2008).

CityGML have five Levels of Detail 0 to 4 for their geometric and thematic differentiation. This is efficient for visualization and data analysis. Figure 3 shows visual impression of different LODs. LOD0 is two and a half dimensional DTM. LOD1 is building block with flat roof. LOD2 has differentiated roof structure, thematically differentiated surface and vegetation etc. LOD3 contains high resolution texture detailed vegetation and transportation. LOD4 provides interior structures (Kolbe et al. 2008).

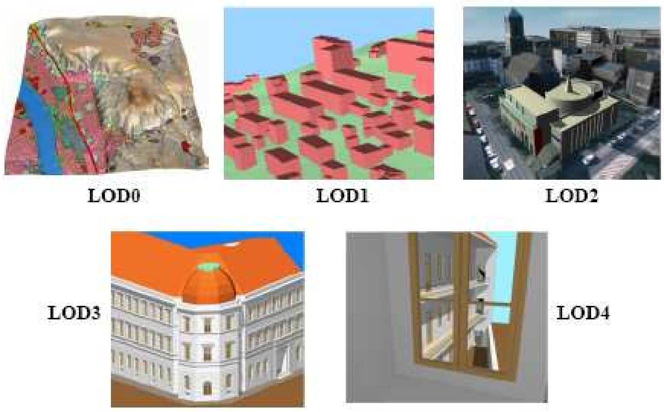

Figure 3: Five levels of detail (Kolbe et al. 2008)

Coherent modeling of semantics and thematical properties are main principal of CityGML. At semantic level real world objects are represented by features. At spatial level geometry are assigned to features. So it consists of two hierarchies: semantic and geometrical. 3D building models are often constructed from 2D footprint or architectural model, which may cause the 3D object float over or sink into the terrain. To avoid this error TIC is used which denotes exact position where the terrain touches the 3D object. Terrain Intersection Curve (TIC) consists of two closed rings: one ring representing the courtyard boundary, and one which describes the building's outer boundary. External information and unique identifier are specified as Uniform Resource Identifier URI. The grouping concept of CityGML allows aggregation and representation of arbitrary city object which may contain other group members also. Information about appearance is an integral part of 3D city modeling. Shape like trees, vegetation, traffic light and traffic sign etc. are represented by prototype which are used multiple times at different locations. CityGML provides two different concepts to support the exchange of data for universal topographic information model which are generic objects and attributes, and application domain extensions. For introducing new classes to existing classes ADE (Application Domain Extension) are used (Kolbe et al. 2008).

o LIDAR

Light Detecting and Ranging (LIDAR) was developed by NASA in 1970 and has been commercially used since the early 1990s (Bartels & Wei, 2008). A LIDAR transmits coherent laser light at various visible or NIR (Near Infrared) wavelengths as a series of pulse to the surface from which some of the light reflects day and night. LIDAR can penetrate tree canopy (returns are obtained from tree tops, from within trees and from the ground), shallow water bodies (for water depth) etc. LIDAR operates normally from aircraft platform (Short, 2010).

A LIDAR data acquisition system consists of three elements: Laser Range Finder (LRF), Global Positioning System (GPS) receiver and Internal Navigation System (INS). Distance between the instruments and the point on the surface are measured by calculating the time required by the laser pulse to hit the receiver. X, Y and Z are calculated using the GPS and INS. The problem with LIDAR is its inability to detect more than one point at any position. So LIDAR data are often referred as 2.5 D. It forms point cloud because of its irregular distribution. There are at least two types of echoes recorded by LIDAR system: the first echo and the last echo shown in figure 4 (Bartels & Wei, 2008).

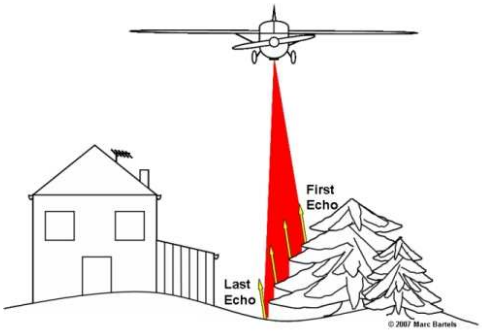

Figure 4: Airborne LIDAR data acquisition (Bartels & Wei, 2008).

LIDAR data can be triangulated in the x-y plane using standard Delaunay techniques to produce a TIN for 3D city modeling. There are two ways to extract object from point cloud. First one is to find out folding axis of the roof and second one is to identify planner segments and connect them to form the final surface model. Building block identification method (see annex) can separate high elevation data from low elevation data. Rebecca et al (2007) has defined two methods to reconstruct roofs. For the simple roof, first one is used where each interior triangles has an associated vector normal after triangulation. Noise in the data can cause irregular surfaced roof like figure 5. For complex roof normal vectors are projected onto a unit hemisphere (Tse et al. 2007).

Figure 5: A clustered simple roof created by noisy data (Tse et al. 2007).

LIDAR calibration is not a transparent process (Habib, 2009). System manufactures provides a range of expected accuracy to derive the point cloud. For example, Optech Inc. provides horizontal accuracy of 1/5500xaltitude; 1sigma and elevation accuracy <5-20 cm; 1 sigma in its high resolution digital camera ALTM 3100EA (Optech Incorporated, 2010). Airborne LIDAR has a wide range of application like pipeline, transmission line or highway and railway corridor surveys, urban environments (e.g. Telecommunications planning work), flood plain surveys, Urban mapping, Forestry (mapping of tree canopies), Archaeology, Seismic exploration, Coastal zone surveys, and Oil and Gas etc (Merrett Survey Partnership, 2010a). The QA procedures of LIDAR systems are established prior to the mapping mission and include flight planning, setup the GNSS base station, selecting appropriate time for the flight mission to assure optimal satellite availability and calibrating the system. QC check is usually conducted by checking the compatibility of the LIDAR footprints in the overlapping strips (Habib, 2009). The laser data allows higher automation in creating the models but slow down the process editing complex building (Gülch et al. 2009).

Another way of LIDAR data acquisition is Terrestrial laser scanning. This is also called High Definition Surveying (HDS) or ground based LIDAR, this technology 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. Currently there are a number of Terrestrial laser scanners like Optech, Trimble, Lica Geosystem, Riegl, Faro, Isite, Zoller+Fröhlich and InteliSum etc (IAEG, 2008).

o Java

Java is an object oriented platform independent programming language originally developed by James Gosling in 1995 at Sun Microsystems which is now subsidiary of Oracle Corporation. This was developed as a core component of Sun Microsystems' Java Platform. Java applications are typically compiled to bytecode that can run on any Java Virtual Machine regardless of Computer Architecture. The original and reference implementation Java compilers, virtual machines, and class libraries were developed by Sun from 2005 to 2007 (Wikipedia, 2010b). The goals of Java language was to make it simple, object oriented and familiar, robust and secure, architecture natural and portable, high performance and interpreted, threaded and dynamic (Oracle, 2010a). A Comparison of Java with other Languages is shown in Annex A2. Java Platform has two components: Java Virtual Machine and Java Application Programming Interface (Oracle, 2010b). A Java Virtual Machine (JVM) enables a set of computer software programs and data structure for the execution of other computer programs and scripts (Wikipedia, 2010c). The API provides the core library with functionality of the Java programming language. It offers a wide array of classes ready for use in any application.

o CAT3D Toolkit

CAT3D Toolkit is developed by Bogdahn (2007) 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. The architecture shown in figure 6 is modular and can easily be extended (Knapp et al. 2007).

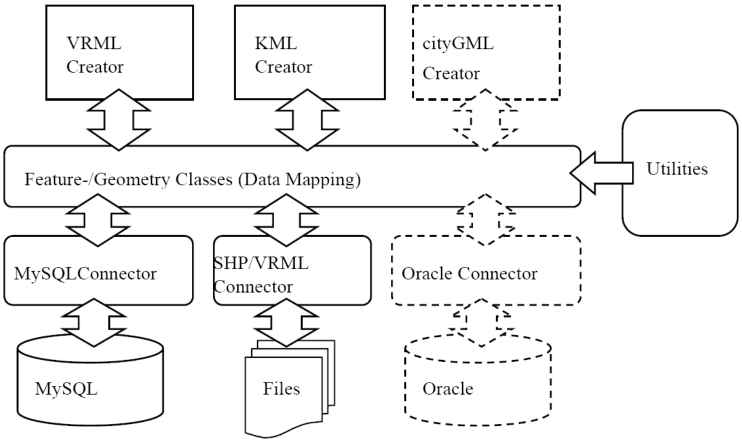

Figure 6: CAT3D Architecture (Knapp et al. 2007).

CAT3D architecture is divided into four parts: Data Connectors, Data Format Creators, Data Mapping and Utilities. The data connector modules are used to access different kind of data sources and to implement the logic of the data schema. Additional capabilities like spatial extensions can be encapsulated in the data connector. There is no direct connection to the data source. The consistency of the data can be tested inside the connector before writing in to the database. Data mapping layer defines several classes to model object features and geometries which build a general structure for data that is used by all components in the framework. It also enables exchange of modules due to special requirements and new components without interfering with the existing part of the framework. Utility module can also process data stored in data mapping layer, merge data from different sources in the mapping level, integrate data into the dataset but all these processing is done in the mapping level. Data Format Creator module generates output format, based on internal mapping formats and can be used with different applications. The format creator just provides the reserve transformation as the connector module. The module for different formats can be exchanged quite easily and any combination of data connectors and format creators can be used to build a suitable dataset (Knapp et al. 2007, Ganitseva, 2010).

o Graphical Processing Unit

> *"GPUs have evolved to the point where many real-world applications are easily implemented on them and run significantly faster than on multi-core systems. Future computing architectures will be hybrid systems with parallel-core GPUs working in tandem with multi-core CPUs." (Dongarra, 2010).*

The Graphics Processing Unit (GPU) is used in scientific and engineering computing. GPU and CPU works together in a heterogeneous co-processing computing model. Sequential part runs on CPU and GPU accelerates the intensive computation. It has a massively parallel architecture called CUDA (Compute Unified Device Architecture) which consists of hundreds of processor cores. GPU hardware manages the 10s of 1000s of simultaneous threads launched by the developer and schedules it. *Fermi* is a latest CUDA architecture which is optimized for scientific applications. Its key features are 500+ gigaflops of IEEE standard double precession floating point hardware support, L1 and L2 caches, ECC memory error protection, coalesced memory access and so on (NVIDIA, 2010).

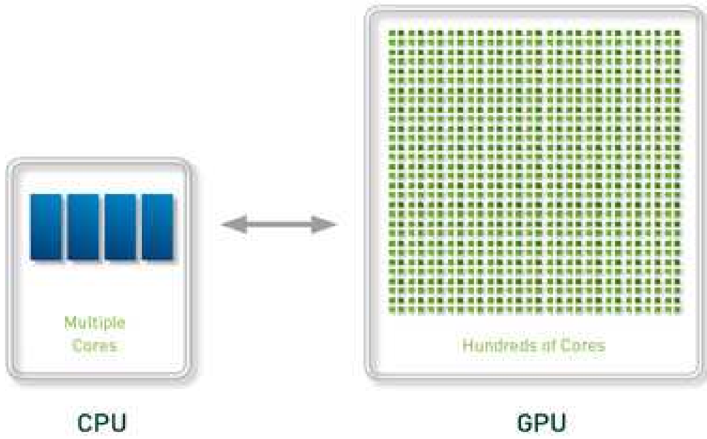

Figure 8: Comparison of CPU and GPU (NVIDIA, 2010).

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