A Future Energy Harvesting Scenario for Georgia Tech Campus Using Photovoltaic Solar Panels And Piezoelectric Materials

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ABSTRACT

Renewable and clean energy has always been the widely discussed topic. According to Database of State Incentives for Renewables and Efficiency (DSIRE), 29 states have renewable energy standards that establish requirements for increasing clean energy usage and nine states have renewable energy goals. The questions of whether renewable energy harvesting is feasible, if it is, where are the potential places that we could establish harvesting sites and how much energy these sites are able to generate will be answered. The project will mainly discuss two types of renewable energy, which are solar energy and piezo energy. Solar energy harvesting is achieved by using photovoltaic solar panels, whose major function is to transform solar energy into electricity. In this project, the location of potential solar panel site will be discussed using ArcGIS technology. A high density of LiDAR cloud point data will be used to generate a DEM of the campus with an extremely high resolution (1 foot), which will be used for solar analysis. Other factors that might affect the location of solar panels like elevation, slope of the roof, orientation, radiation amount, etc. will also be included in this project. Piezoelectric material is a newly developed material that can harvest electricity using the pressure that has been put on it. The project will focus on roadway energy harvesting, which means the piezoelectric panels will be mostly put on the roadside to create electricity using pressure from the cars. GIS model will be created to make a road electricity

generation map for the future purpose of study. At last, the project will create a future campus electricity harvesting scenario based on solar and piezo method as well as give a final result of total annual electricity harvesting amount if these two methods are utilized in the future.

INTRODUCTION

Piezoelectric Roadway Potential

Piezoelectric materials are crystals that generate electricity when compressed or vibrated, which means mostly electricity is generated with the application of stress. These materials are all semiconductors, meaning that they are much like conventional electronics, generally constructed of Silicon or Geranium with additional elements (Energy Research and Development Division Final Project Report). Piezoelectric energy can be harvested in two ways: generating a single pulse of power using a stack of piezoelectric materials and generating a vibrating power that decays along with time using an array of cantilever or bent beam harvester. The two methods are shown in Figure.1[1].

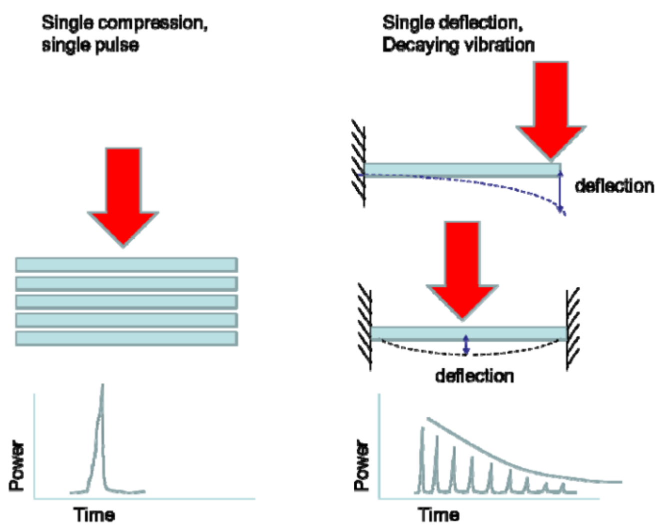

Figure.1Two ways of harvesting energy

[1] ASSESSMENT OF PIEZOELECTRIC MATERIALS FOR ROADWAY ENERGY HARVESTING

Movement and pressure are everywhere. Harvesting vibration energy from humans walking, vehicle traveling is the focus of developing future renewable energy, because this energy is cheap, easy to obtain and otherwise untapped. Researchers have found out that the full functionality of a piezoelectric device requires a compression from the outside force. The stress must be applied and then relaxed in order to general the voltage with the material.

Figure. 2[2]

Piezoelectric energy harveting can be applied to roadways and railways as Figure.2 has shown. These energy is stable and consistant compared to piezoeletric device on the ground or inside of shoes. The further discusses would be focused on roadway energy havesting.

A new bill that will implement piezoelectirc technoogy has been proposed in California in 2011. This roadway energy harvesting technology has been used in Italy and Israel. According to the report. When a car or truck passes over pavement, the pavement vibrates slightly. Inexpensive piezoelectric sensors underneath the road are applied to transfer the vibrations produced by vehicles to electricity, which can be used to power roadside lights, call boxes, and neighbouring communities. The same technology has been applied underneath highways in Israel and turned out to have great extensive application potential. It can generate 2,000 watt-hour of electricity on a 10-meter stretch of highway. Professor Haim Abramovich who is leading the project claims that one

[2] http://mfa.gov.il/MFA/InnovativeIsrael/Pages/Harnessing_power_on_highways-Feb_2011.aspx

truck can generate 2,000 volts, but to create useful electricity will require many IPEGs over hundreds of meters and a high volume of traffic. In his opinion, the power harvesing system can also be efficient on railways or runways. Italy has signed a contract to place the technology under a stretch of Venice-Trieste-Autostrada, which does not affect the vehicles travelling on the road, in terms of road “road feel”, fuel efficiency, or emissions[3]. If this project will be carried out in the future, it will generate enomous electricity for traffic lights and nearby communities. Besides the large scale application, this technology has been implemented in a variety of ways. It is not uncommon for the nightclubs to be powered by dancersin Europe, creating energy that powers the entire establishment, from the stereo to lightling. Gyms exist in which stationary exercise equipment possesses this technology in order to power the gym[4].

In general, the benefits of a roadway energy harvesting system are potentially great because of high traffic volume and a charaterastic of consistency of the volume in specific areas of states highways. Piezoelectric energy harvesting system does have many advantages over other methods. Piezoelectric devices do not require external power source, which means the only power that drives the system is the motion and pressure given by human or vehicles. Single piezoelectric device may general little energy that seem useless, however, if a large scale of application is feasible to be carried out, it might generate a enormous energy. For example, piezoelectric crystals that are placed under the surface of highway and road construction the experience the vibrations of thousands of vehicles and pedestrains a day have the potential to power the entire town and the whole community nearby. This technology has definitely been one of the worth noticing fuel exploration and will most likely be implemented into variety of technologies in the future[5].

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[3] www.energyharvestingjournal.com/articles/3128/piezoelectric-roads-for-california
[4] www.planetforward.org/iead/jump-around-taking-advantage-of-piezoelectric-energy
[5] www.planetforward.org/categories/renewable-energy

Piezoelectric Potential in Georgia Tech

Figure. 3[6]

Figure. 4 road in Georgia Tech

Georgia Tech has put a lot attention to renewable energy in recently years including piezoeletric harvesting. According to the situation of the road and traffic volume of the campus, it has a great potential of achieving piezoelectric harvesting. I-75 near the campus has the most potential for collecting pressure and converting it to electricty due to the daily traffic volume. 10th Street in the north and Northside Drive in the west are the two major streets around the campus, which have a considerable traffic volume. Great amount of energy will be generate if piezoelectric materials are imbeded under the road. Compared with the I-75 highway, 10th Street and Northside Drive, traffic volume of the roads inside of the campus are much less. However, due to the constant

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[6] http://www-old.aco.gatech.edu/conference/newcampusmap.jpg

pedestrians, private cars, trolley buses, it will still generate a considerable amount of electricity which could be used to power the buildings.

In the later part of the article, a comprehensive analysis of the piezoelectric harvesing potential will be conducted for creating a future renewable energy scenario.

Photovoltaic Solar Panels Potential

Photovoltaic (PV) is the name of method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. PV effect was discovered in 1954, when scientists at Bell Telephone discovered that silicon (an element found in sand) created an electric charge when exposed to sunlight. Soon solar cells were being used to power space satellites and small items like calculators and watches[7]. Usually, solar cells are made from silicon. A flat-plate shape provides the efficiency of converting sunlight energy to electricity.

Figure. 5[8]

The United States conducted many early researches in photovoltaics and concentrated solar power and it is among the top countries in the world in electricity generated by sun and several of the world's largest utility-scale installations are located in dersert Southwest. Many states have set individual renewable energy goals with solar power being included in various proportions. Governor Jerry Brown has signed legislation requiring California's utilities to obtain 33 percent of their electricity from renewable energy

[7] http://www.nrel.gov/workingwithus/re-photovoltaics.html
[8] https://www.google.com/search?q=solar+panel&biw=1477&bih=718&source=lnms&tbm=isch&sa=X&ved

sources by the end of 2020[9]. According to the United States Energy Information Administration, Arizona is one of the states with the greatest solar photovoltaic resource potential in the country. Governor Janet Napolitano has made Arizona "the Persian Gulf of solar energy". In 2012, Arizona had 1,106 MW of photovoltaic solar power systems and 6 MW of concentrated solar power, bringing the total to over 1,112 megawatts (MW) of solar power[10].

Figure. 6[11]

Figure. 7 [12]

Figure.6 shows the completion of Tucson Electric Power Company's Bright Tucson Community Solar Program in Arizona, which can generate a huge amount power for the community nearby. Figure.7 demonstrates a proposal of installing rooftop solar panels for free in Phoenix, a major city in Arizona. Under the proposal, consumers would save money by receiving monthly credits, and they will get a $30 credit each month for the 20 years, or $7,200 over the course of the 20-year program[13].

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[9] David R. Baker (April 12, 2011). "Brown signs law requiring 33% renewable energy". San Francisco Chronicle
[10] Davis, Tony (February 12, 2009). "Arizona: the West's solar source". Arizona Daily Star. Retrieved 2009-05-30.
[11] https://www.solon.com/export/sites/default/solonse.com/_images/usa/Solarsystem-SOLON-TEP_550px.jpg
[12] http://www.elp.com/content/dam/elp/online-articles/2014/06/rooftop%20solar%20panels.png
[13] http://www.elp.com/articles/2014/07/arizona-utility-wants-to-install-rooftop-solar-power-systems.html

Figure. 8[14] Solar Panels in China

U.S is not the only country that has widely applied solar panels for generating electricity. China is the world's largest market for both photovoltaics and solar thermal energy. In 2013, China was the world's leading installer of solar photovoltaics reaching a total installed capacity of 35.78GW by end-June 2015[15], which covers a huge amount of total energy consumption. In 2016, China became the world's largest producer of photovoltaic power, at 43 GW installed capacity.

Photovoltaic Solar Panels Potential in Georgia Tech

Georgia Tech's research spans a wide range of advanced solar technologies, including concentrated solar, photovoltaics, solar thermal, solar-to-fuels, and thin films. Setting solar panels in campus has always been a dream to all the renewable energy researchers. According to the Solar Energy Industries Association, the amount of solar energy falling on the United States in one hour of noontime summer sun is about equal to annual U.S electricity demand. Despite the abundance of this renewable energy source, solar technologies have occupied the niche market due to the cost and lack of available infrastructures[16]. However, the reduction of cost of the materials and increase of conversion efficiency have made this dream reachable again. In addition, concerns about rising

[14] http://www.herald.co.zw/wp-content/uploads/2014/03/SOLAR-POWER-PLANT.jpg
[15] http://en.xinfinance.com/html/Industries/Utilities/2015/123224.shtml
[16] http://energy.gatech.edu/bringing-renewable-energy-sources-light

fossil fuel prices, climate change, greenhouse gases, energy security grow, solar energy has gained a huge amount attention.

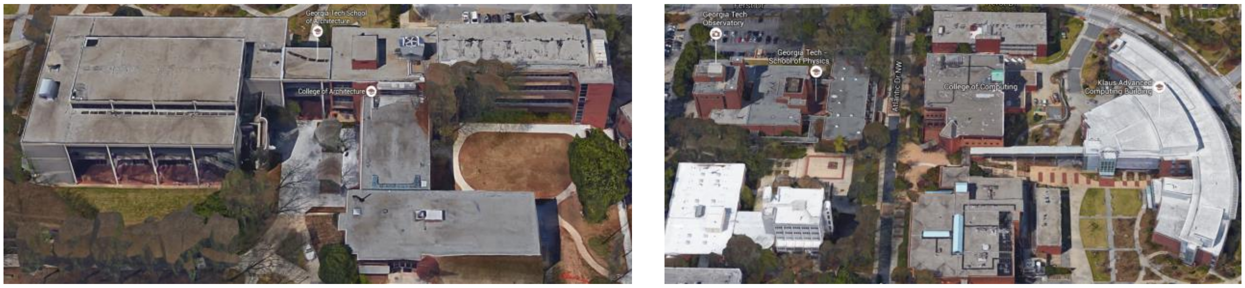


Figure. 9[17] Building Rooftop of Georgia Tech

Determining the desired suitable location of solar panel is not a easy job. There so many factors to be considered. Generally speaking, suitable locations for solar panels have specific characteristics and requirments, which vary in different scenario. For placing solar panels in campus, the location of the panels should be on the top of the buildings, which make sure the daily activity of students and vistors won't be intervened. Other factors and a comprehensive solar analysis will be introduced later.

In general, Gerogia Tech has a great potential of solar energy harvesting due to the amount of solar radiation in State of Georgia and roof numbers, roof shapes in the campus.

RESEARCH AREA

Georgia Institute of Technology is a public research university in Atlanta, Georgia. It's main campus occupies part of Midtown Atlanta, bordered by 10th Street to the north and by North Avenue to the South, as Figure 10 had shown. Georgia Tech receives plenty of solar radiation during the day time in summer, which provides the basis of solar energy harvesting. There are more than one hundred buildings in Georgia Tech campus, most of which have a desired flat

[17] From Google Map

rooftop for placing solar panels. During the daytime, Gatech is a bussy campus with constant traffic on the road. Northside Drive to the south and 10^{th} Street to the north are the most busy street in campus. I-75 to the east is not part of the university. However, it is another desired location to place piezoelectric materials due to the huge traffic volume in the highway.

Figure. 10[18] Georgia Tech Campus map

Researchers at Georgia Tech has always been focusing on how to take advantage of renewable energy and make the campus more environmental friendly. Today, Georgia Tech operates a 340-kilowatt PV system installed on Georgia Tech Aquatic Center, which was built for the 1996 Olympics. It can provide 30 to 40 percent of building's power need, which is an amount sufficient to energize 70 average homes according to the Georgia Tech Advances Solar Energy Research[19].

[18] http://geophysics.eas.gatech.edu/anewman/misc/campus-mapAVN.png
[19] http://www.gtri.gatech.edu/casestudy/georgia-tech-advances-solar-energy-research

PIEZOELCTRIC SCENARIO FOR GATECH

Introduction

Cars put significant amount of stress onto the roadways every day, one of the hot research topics is to study the potential of utilizing piezoelectric materials to harvest energy on roadways. Is piezoelectric energy harvesting really feasible to apply in the Georgia Tech campus? How much electricity energy can traffic generate? Where should we put the piezoelectric materials so that they can maximize the electricity generation efficiency? Those question will be answered in this hypothetical scenario. The basic goal of creating this scenario is to create a model that can access the potential PE energy of the roads in Georgia Tech campus, develop an interactive software that can calculate the user input traffic data into the electricity energy it can generates. Python is the major language that will be used to creating the user interface of the model and interface makes it easy for potential users to use. The final products of this scenario are the PE calculation model based on the user input traffic data, several maps demonstrating the PE energy harvesting amounts well as energy density, on each roadway in the campus. Conclusions and suggestions for the future PE energy harvesting plan will be drawn at last.

Methodology

The PE calculation is based on the efficiency of the transformation between stress and electricity. However, the stress on the materials relies on the user input traffic data, which could be gathered from two major ways: live traffic data from google or Average Daily Traffic data from GDOT. In this scenario, the road type information in Georgia Tech campus will be retrieved from the GDOT data source. TIGER 2010 Street data includes all the major roads information in Georgia. Clipping the street TIGER data with Georgia tech campus shapefile focuses to a specific campus level, which makes it easier to analyze the data. The road type information helps to set the lower and upper limit of the traffic on each road based on the experience. And the range between the upper and lower limit will be divided into five categories, which can be an interactive selection for the users. When the volume of traffic is set, the calculator will automatically calculate the pressure that traffic puts on the materials and then convert the pressure to electricity using a conversion constant, which is characterized by different harvesting systems and materials. The last step is to generate a visualized map by reclassifying the total amount of electricity generation on each road of Georgia Tech campus. The whole process is summarized in Figure.11. Variables that has been taken into account are not limited to those six. More factors will be considered and added to the model during future development.

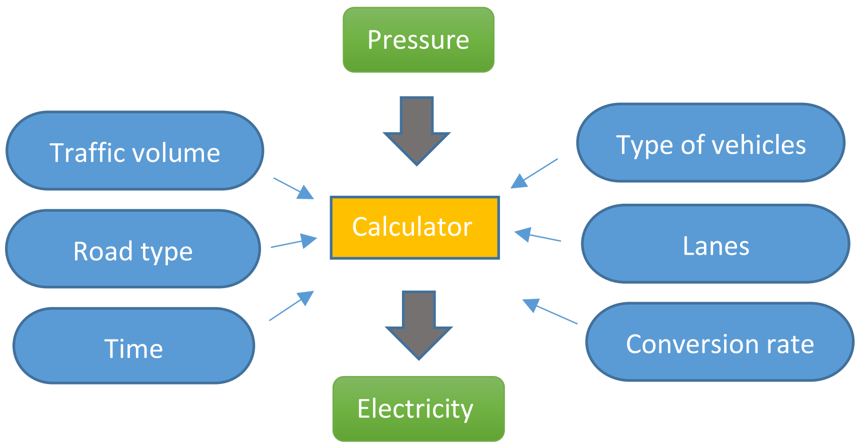


Figure.11 Flow Chart

Road types and lanes are generated from 2009 TIGER/Line Shapefiles Technical Documentation. Field MTFCC describes the characteristics of each defined road type. Figure.12 has shown only a part of the content.

MTFCC	FEATURE CLASS	SUPERCLASS	POINT	LINEAR	AREAL	FEATURE CLASS DESCRIPTION
L4130	Point-to-Point Line	Miscellaneous Linear Features	N	Y	N	A line defined as beginning at one location point and ending at another, both of which are in sight.
L4140	Property/Parcel Line (Including PLSS)	Miscellaneous Linear Features	N	Y	N	This feature class may denote a nonvisible boundary of either public or private lands (e.g., a park boundary) or it may denote a Public Land Survey System or equivalent survey line.
L4165	Ferry Crossing	Miscellaneous Linear Features	N	Y	N	The route used to carry or convey people or cargo back and forth over a waterbody in a boat.
R1011	Railroad Feature (Main, Spur, or Yard)	Rail Features	N	Y	N	A line of fixed rails or tracks that carries mainstream railroad traffic. Such a rail line can be a main line or spur line, or part of a rail yard.
R1051	Carline, Streetcar Track, Monorail, Other Mass Transit Rail	Rail Features	N	Y	N	Mass transit rail lines (including lines for rapid transit, monorails, streetcars, light rail, etc.) that are typically inaccessible to mainstream railroad traffic and whose tracks are not part of a road right-of-way.
R1052	Cog Rail Line, Incline Rail Line, Tram	Rail Features	N	Y	N	A special purpose rail line for climbing steep grades that is typically inaccessible to mainstream railroad traffic. Note that aerial tramways and streetcars (which may also be called "trams") are accounted for by other MTFCCs and do not belong in R1052.
S1100	Primary Road	Road/Path Features	N	Y	N	Primary roads are generally divided, limited-access highways within the interstate highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.
S1200	Secondary Road	Road/Path Features	N	Y	N	Secondary roads are main arteries, usually in the U.S. Highway, State Highway or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They often have both a local name and a route number.
S1400	Local Neighborhood Road, Rural Road, City Street	Road/Path Features	N	Y	N	Generally a paved non-arterial street, road, or byway that usually has a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.

Figure.12 MAF/TIGER Feature Class Code (MTFCC) Definitions

Table .1

MTFCC	DESCRIPTION	NUMBER
S1100	**Primary Road**	**21**
S1200	**Secondary Road**	**46**
S1400	**Local Neighborhood Road**	**263**
S1630	**Ramp**	**15**
S1710	**Walkway/Pedestrian Trail**	**1**
S1750	**Internal U.S Census Bureau use**	**4**
S1780	**Parking lot road**	**4**

Table.1 describes the detail road information in Georgia Tech Campus. Local neighborhood road is the most common road type in this area with a number 263. Secondary and primary and ramp come after. In the analysis, the four road types mentioned above will be the major scope that will be focused for piezoelectric analysis.

Analysis and Results

Using model builder in ArcGIS, a piezoelectric calculation model is created with 7 user inputs including user defined workspace, user defined boundary, traffic volume of four types of roads and conversion percentage from pressure to electricity. The model first clipped the Street data with user defined boundary to generate a study area, which reduced the size of area, making calculation easier. Then it calculated the traffic volume and generated number of lanes for each road based on traffic level selected by users. Finally, energy generation field was added to the study area shapefile and then filled with the amount of energy calculated according to an energy generation function. The whole model is presented in figure.13.

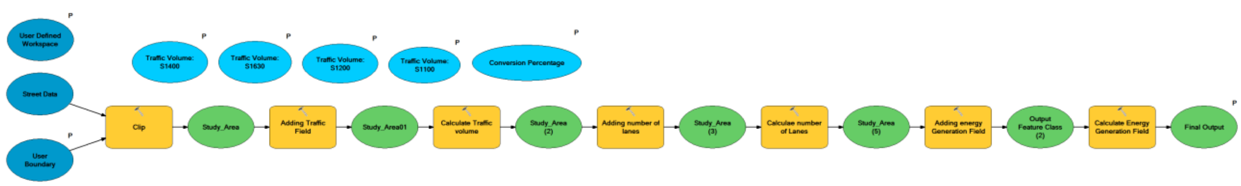
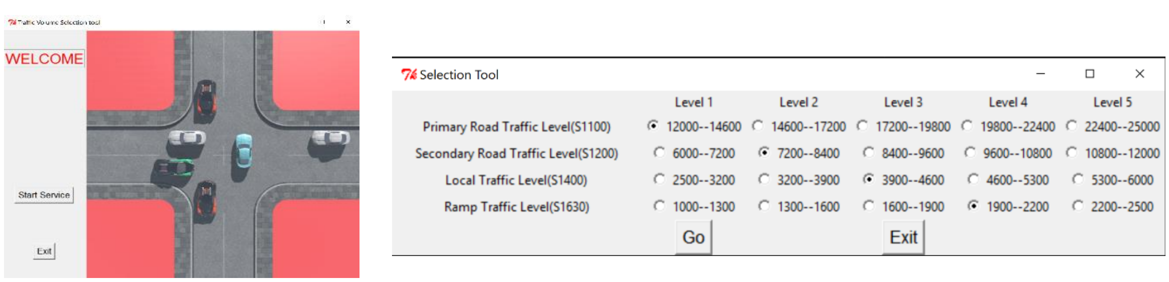


Figure.13 Piezoelectric model

The piezoelectric model created in ArcGIS only facilitates ArcGIS users. However, for the convenience of other non-ArcGIS users, a python interface was created using Tkinter as basic GUI designing tool.



(a) Welcome interface (b) Traffic volume selection tool

Figure.14 Python Interface

For the selection tool in Figure.14 (b), each road type has a minimum and maximum daily traffic volume defined by users. Then the tool divided the difference between those two numbers by five, giving five categories for users to select from level 1 to level 5. After the selection, user can select “Go” to continue or select “Exit” to exit the program. After clicking “Go”, a new interface will pop up asking for coefficient (Figure.15). The coefficient is the percentage of transforming pressure to electricity, which varies a lot due to the different characteristics of the piezoelectric materials. Then the coefficient is used for calculating the final amount of electricity the system is able to generate. The amount of electricity of each road will be a new field added to the shapefile. With reasonable display, different electricity generation ability of the roads in Georgia Tech will be categorized and shown in the map. Based on the traffic volume, average vehicle weight and pressing period on the piezoelectric material, the default conversion coefficient is set to 0.000005.

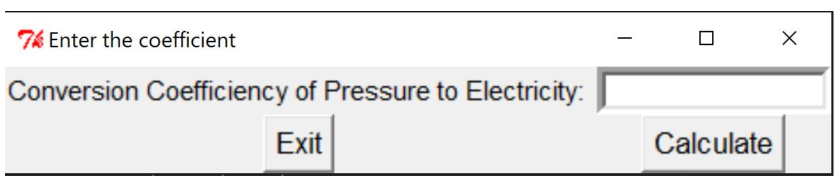


Figure.15 Coefficient interface

The electricity generation map of Georgia Tech Campus is presented below in Figure.16. The electricity generation ability has been categorized in five. From blue line to red line, the ability grows. The red lines highlighted in the map represent the roads with high electricity generation density while the blue lines represent the roads with relatively low PE generation density. The energy generation density basicly demonstrates which road is more efficient in providing pressure-transformed energy than others. Generally, highways have the highest PE energy potential per linear foot and total energy potential. 10th Street in the north, Northside Drive in the west as well as Tech Pkwy NW also have great potential for piezoelectric energy harvesting.

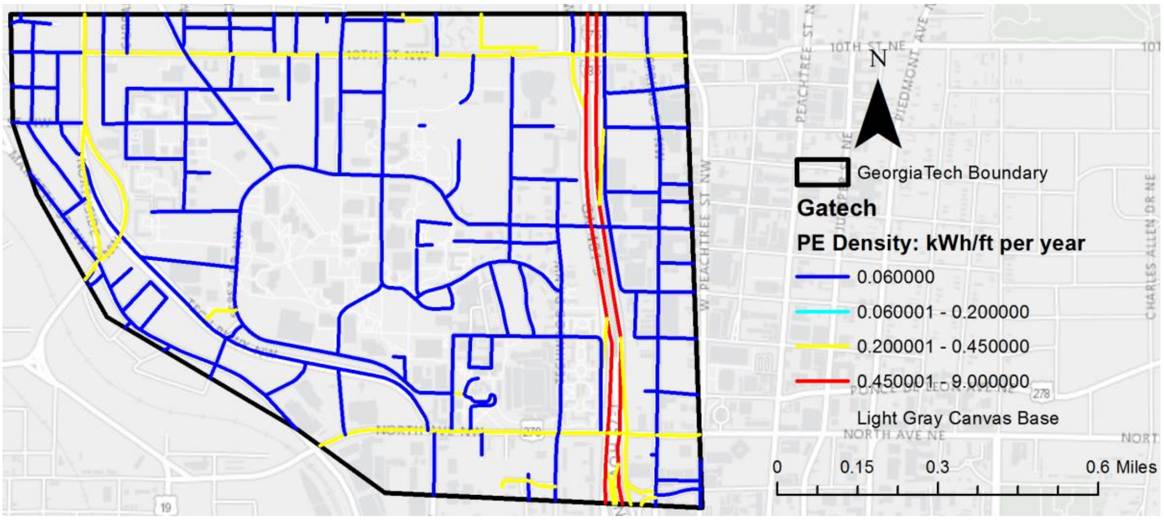


Figure.16 PE generation density in Gatech

In terms of total energy generation, it represents the total amount of energy roads can generate. The total energy generation is determined by the energy density of the road as well as the length. By multiplying energy density and the length of the road, the total amount transformed energy will be calculated. Figure.17 demonstrates the total piezoelectric energy generation distribution across the campus.

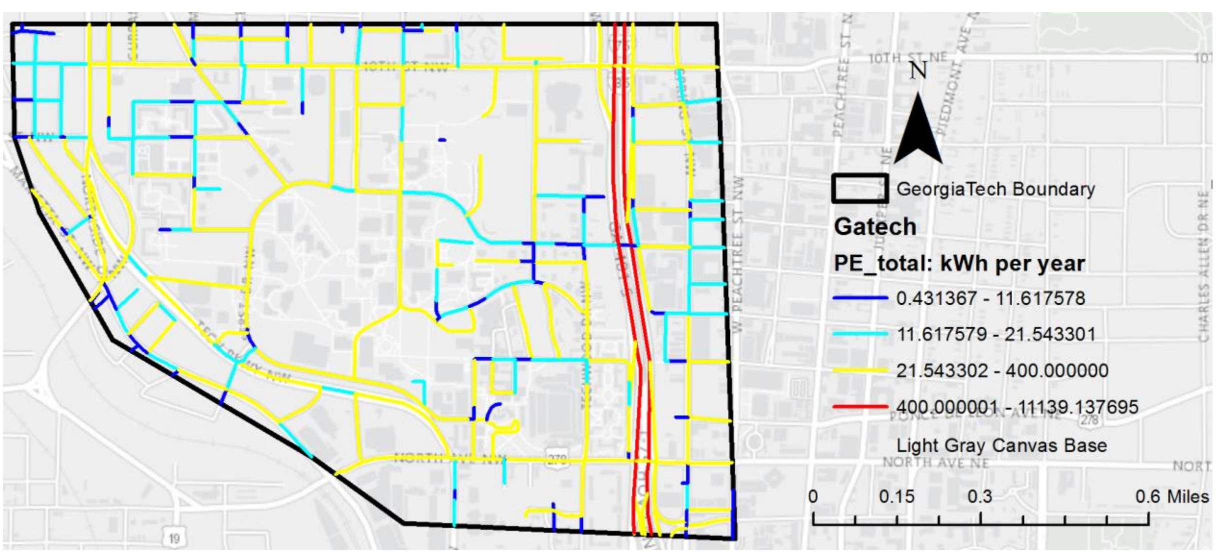


Figure.17 Total PE generation in Gatech

The total PE generation map shows how the total amount of energy that can be harvested from pressure to electricity is distributed across the campus. As the map demonstrates, highway has the most PE energy potential both in energy density and total amount of energy, which is up to 11139 kWh per year. A huge part of roads in the campus are highlighted in yellow which indicates that they are ranging from 20 kWh per year to 400 kWh per year, which is relatively lower compared to the highway. However, if they are added up, they are able to be a considerable energy source for powering lights and other small devices. The total energy generated from the piezoelectric system in the campus is able to supply hundreds of homes, which will save tons of outputs of traditional fossil fuel.

Conclusion

Mechanism energy is one of the most ubiquitous energies that can be harvested in our lives. A moving object and vibration induced by other objects can be the source of the harvesting system. Piezoelectric energy saving has a great potential in a campus scope. According to the analysis above, a number of conclusions and recommendations can be made. First of all, the analysis uses the report of LCOE (Levelized Cost of Energy) to determine a transformation rate from pressure to electricity. The calculation based on this rate gives a total amount of 100232.797723 kWh annually if all the roads are included in the energy harvesting plan. However, based on the PE density map, most of the roads in the campus are not efficient enough for transforming pressure to electricity due to light traffic. It is not wise to install piezoelectric panels, which are quite expensive right now ($215,400 – $650,000 per Km[20]), to all the roads across the campus. Highway is still the best choice for placing the panels due to the high volume of the traffic, which results in a constant high level of pressure. In addition, 10th Street in the north, Northside Drive in the west as well as

[20] http://www.energy.ca.gov/2013publications/CEC-500-2013-007/CEC-500-2013-007.pdf

Tech Pkwy NW also have a great potential as the yellow lines indicate in Figure.16. However, based on the current efficiency of the material and great cost of the system, it is not recommended to apply the system in the campus.

PHOTOVOLTAIC PANELS SCENARIO FOR GATECH

Introduction

Solar energy is an important renewable energy source that has been put much attention by many public agencies, who desire to make a difference by replacing traditional energy source with a clean and environmental-friendly source. Georgia Tech is among those agencies. At the U.S. Department of Energy-funded Solar Thermal Test Facility on the main campus, Georgia Tech Research Institute (GTRI) researchers developed a method for creating high-grade synthetic fuels with solar thermal energy. Today, a 340-kilowatt PV system is running on the Georgia Tech Aquatic Center with the ability to satisfy 70 average homes. The analysis in this part will answer a lot of questions concerning photovoltaic panels. Where to put those solar panels in the campus? What requirement must be satisfied when setting a solar panel? How much solar panels do we need in order to power the campus? How much electricity can be generated by those panels? In this part of analysis, a detailed elevation model is needed and a comprehensive solar analysis will be run using the solar analysis tool in ArcGIS. A solar analysis model for the campus will be created allowing users to specify required parameters such as percentage, period of time, rooftop, boundaries. In addition, a solar map will be created showing all the potential places for setting solar panels and a total amount of electricity that can be generated by the system will be given. Finally, suggestions as well as future plans for solar energy harvesting development are included.

Methodology

The original data for Georgia Tech campus was obtained from a light detection and ranging (LiDAR), which formed a cloud point data with high density. The cloud point data depicts a comprehensive DSM including building roofs, trees, ground, and other artificial objects. A digital elevation model (DEM) is then created using the LiDAR data, which is required in the later solar analysis.

The Suitable locations for solar panels have specific characteristics and requirements. In this study, suitable sites must satisfy the requirements below:

- Elevation requirement: the location for a solar panel must be on the rooftop
- Slope requirement: The slope should be less than 30 degrees
- Radiation requirement: the site should receive a certain amount of solar radiation (the specific number will be introduced later)
- Aspect requirement: south facing (Georgia Tech is in northern hemisphere)
- Human requirement: requirement based on building conditions and laws

In general, the study are trying to find the best location for setting solar panels, within which those requirements must be met. The summarized flowchart of the whole process is presented below:

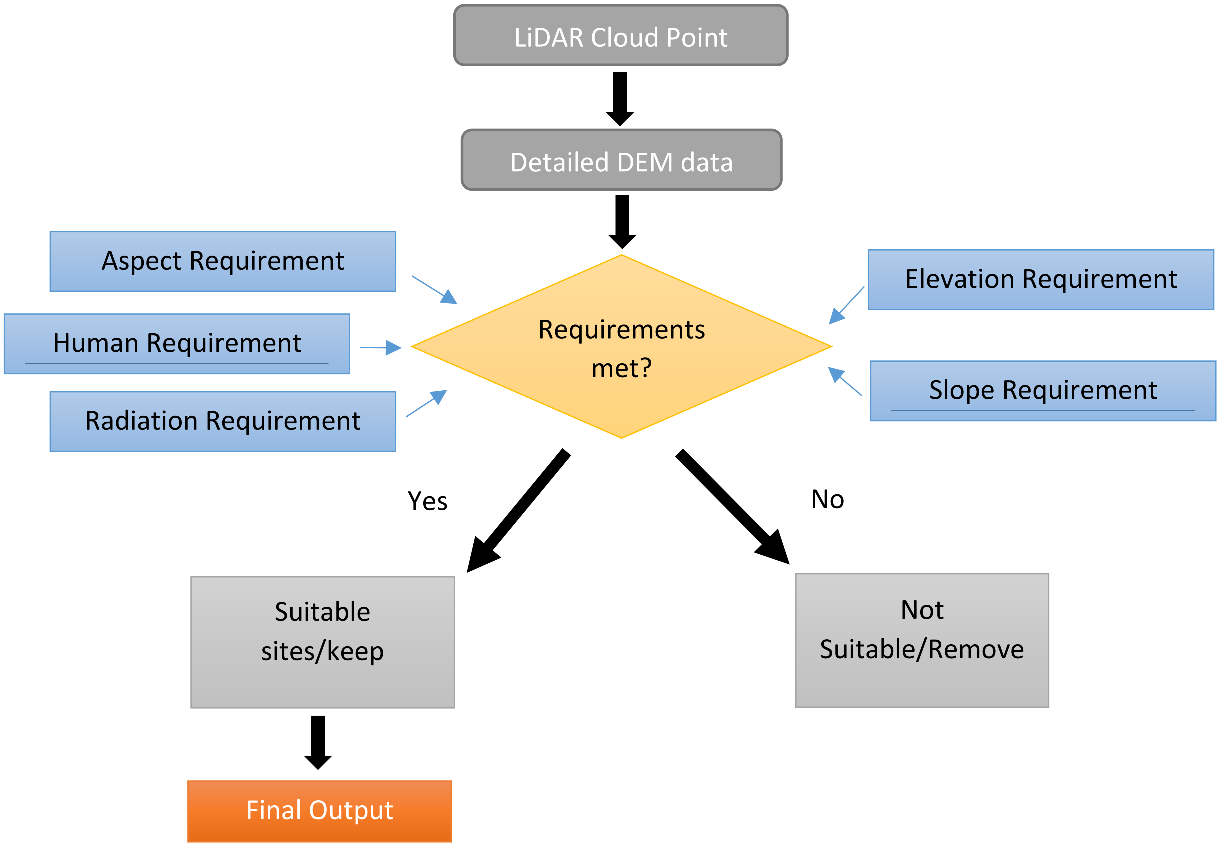


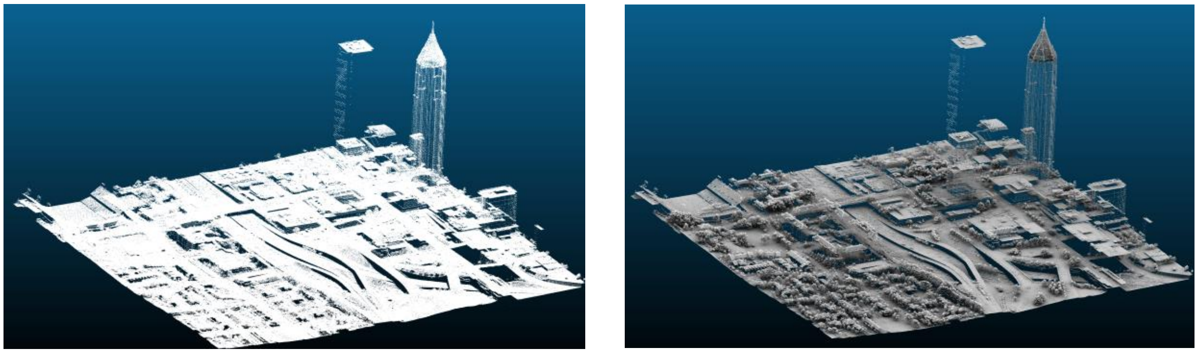
Figure.18 Process of Selecting Solar Panel Site

To find feasible locations for solar panels, all the rasters will be converted into a binary form in which a value of 1 means the locations that meet all the conditions, however 0 represents those that do not. Then all the binary rasters will be converted into a final raster and will be put in ModelBuilder to automate the output generation process. When all the requirements are met, the model will select the places that are feasible for placing solar panels as final output. If one of the requirements is not satisfied during the process, those places are removed from the final selection.

Preliminary Data

The major preliminary data using in this process is LiDAR cloud point data with a very high resolution covering the whole Georgia Tech campus. The cloud point data has 9 pieces, each of them covers part of the campus. Putting all pieces together will cover the whole research area.

Figure.19 presents the last part of LiDAR data in Georgia Tech campus using a cloud point viewer: CloudCompare.



(a) LiDAR Data 009 without shading (b) LiDAR data 009 after shading

Figure.19

Then the High density cloud point data is used to generate a one-feet resolution DEM of the campus, which will be used in the slope, aspect, solar and other analysis afterwards. High density DEM model well presents the rooftop shape, which will be extremely significant in solar analysis.

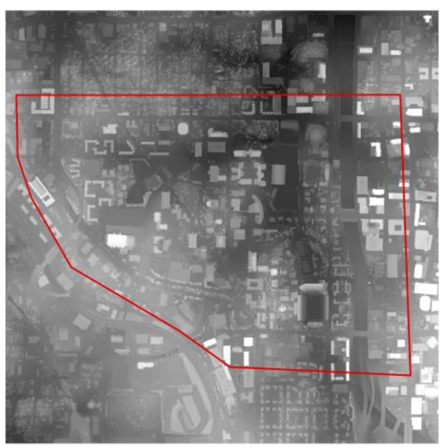


Figure.19 Campus DEM

Analysis and Results

The model basically used four binary rasters as the input to the Raster Calculator, which multiply all the raster mask to generate the final output. The 0 in the raster represents areas that are suitable for placing solar panels, while 1 represents areas that are not. By multiplying all the binary rasters, the final suitable location will have a value of 1, which means it has satisfied all the requirements. Figure.20 shows the general model of choosing locations for solar panels on the rooftop. Figure.21 represents the four input rasters, which are slope, aspect, building footprints and solar raster.

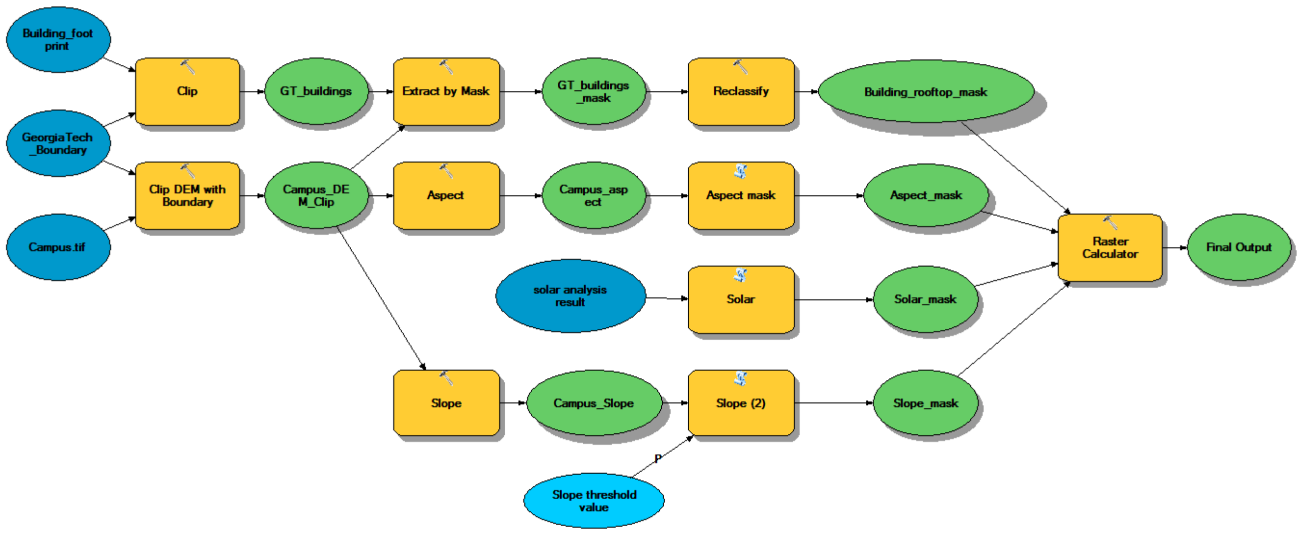


Figure.20 Solar model

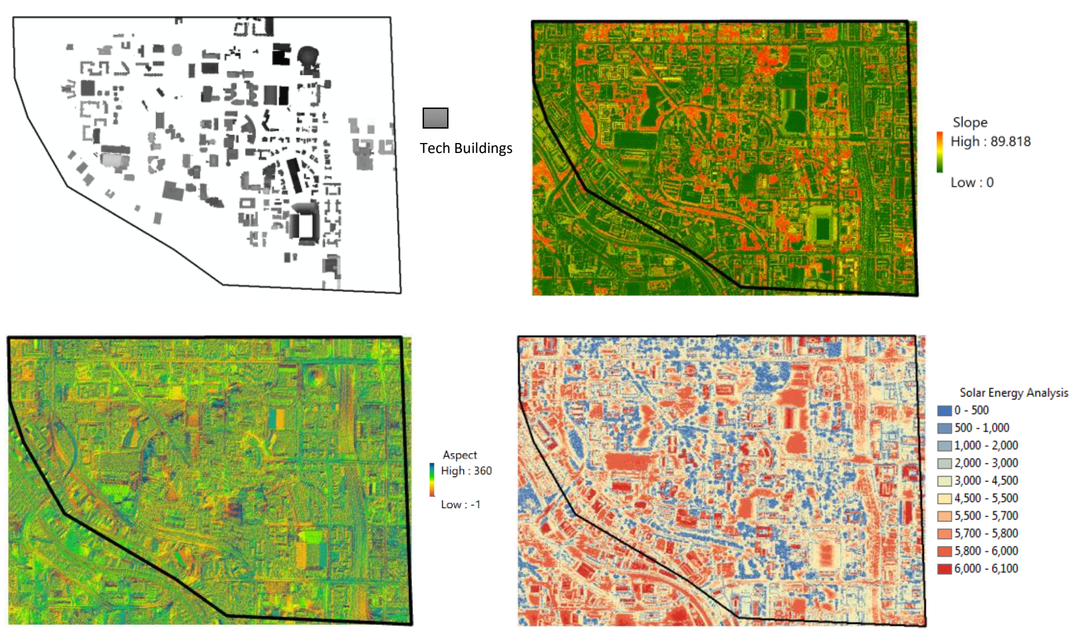


Figure.21 Buildings, Slope, Aspect and Solar Output

Figure.22 shows the binary raster mask of Building, Slope, Aspect and Solar. After integrating all the masks using Raster Calculator, the final output is shown below:

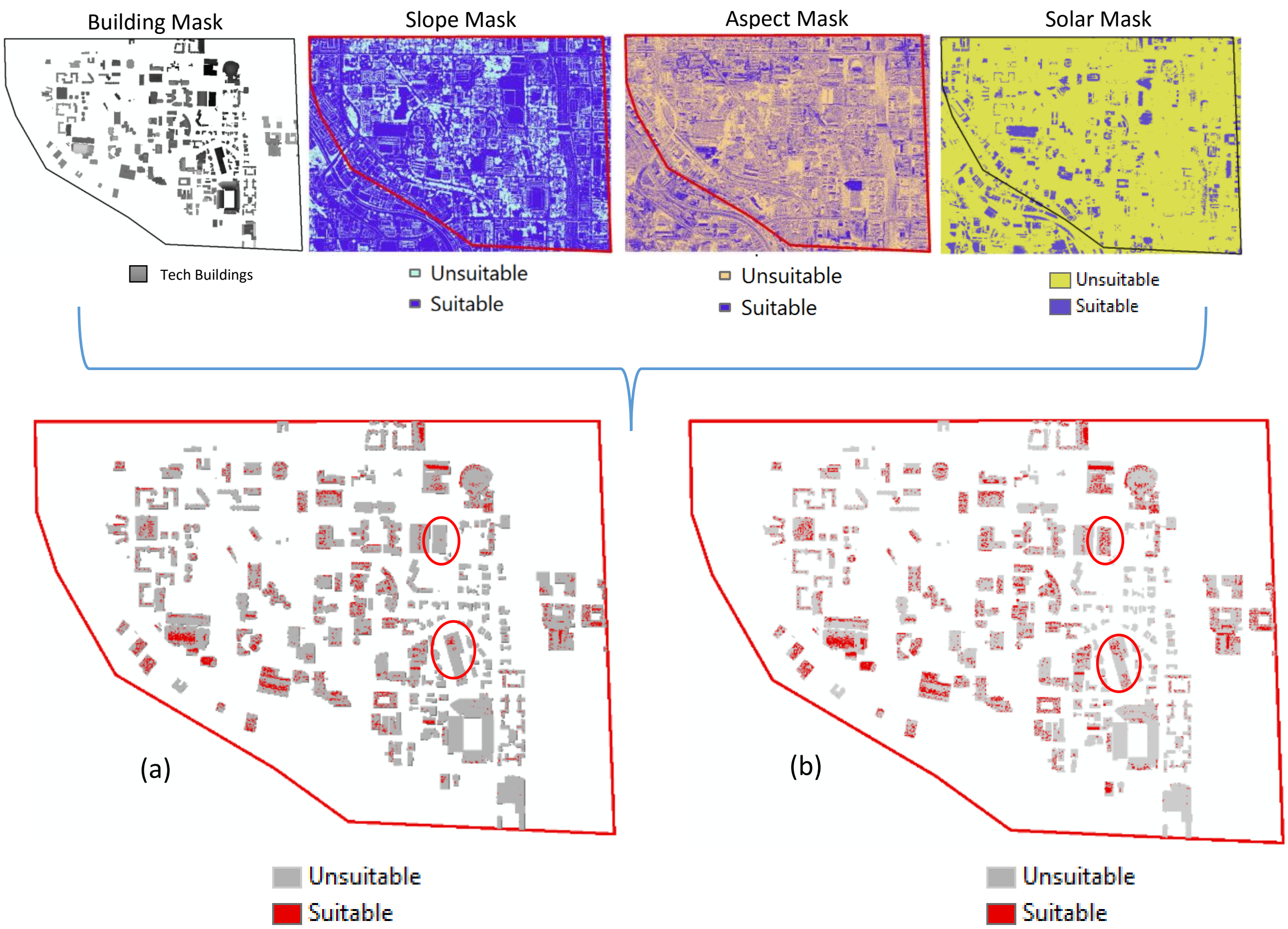


Figure.22 Buildings, Slope, Aspect, Solar masks and final outputs

Parameters varies in the two outputs. Output (a) has a degree threshold of 35 degree, which means areas with slope smaller than 35 degree will be categorized into suitable area. However, output (b) has a degree threshold of 15. As for the threshold in solar analysis, solar energy with more than 5900 WH/m2 is the desired location in output (a), while 5700 WH/m2 is required in output (b). As we can notice, there indeed exist some big differences between those two outputs. Area highlighted with red circle marked the major difference of the two outputs. Basically, the first scenario allows more slope for placing solar panels, however, it has to absorb 5900 or more solar power. The second scenario is more restricted in slope, which only allows 15 maximum degree, but with a relative lower limit of 5700 solar power. The aspect of both of them uses the same range: which are from 112.5 to 247.5 including Southwest, Southeast and South. -1 is also included in the aspect mask, which basically means flat roof.

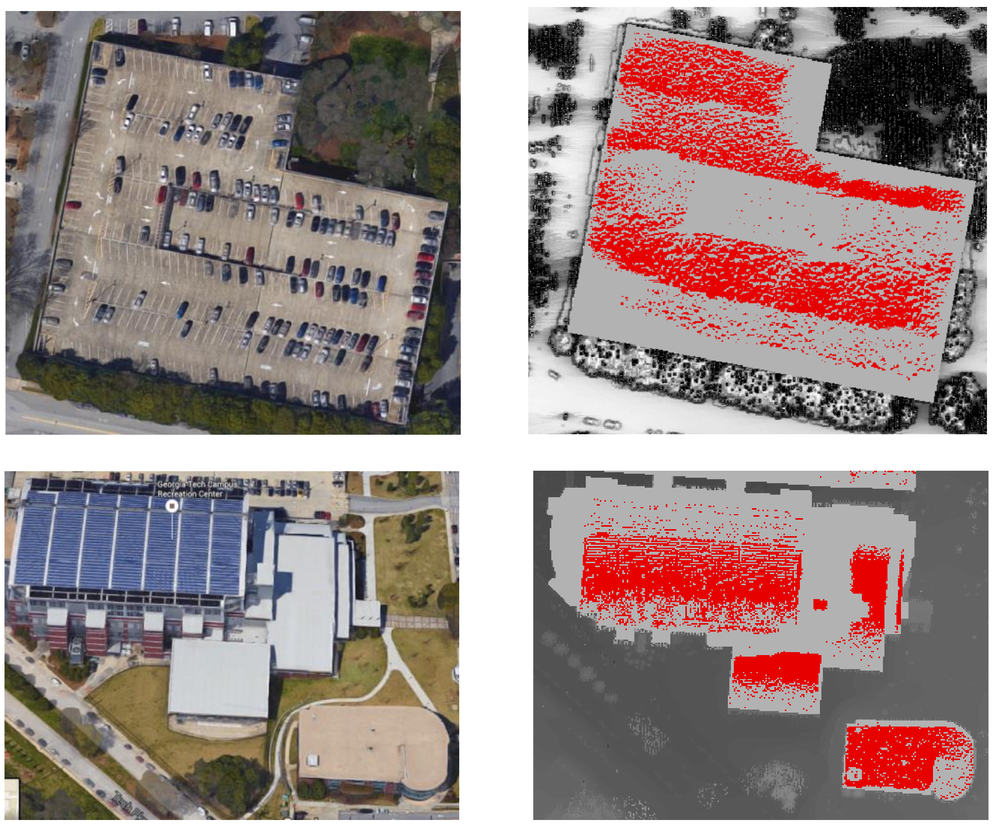


Figure.23 Result VS. Real

Figure.23 compares the results in the scenario and the actual building rooftop in real. The first pair shows a multi floor parking in Georgia Tech campus. The middle part of building is the access to the roof, which is lower than the top floor. This part will be covered by the shadow of the top during a certain amount of time in a day, so the solar analysis result recommended all the areas on the rooftop except the middle part. Campus Recreation Center is one of the solar sites in Georgia Tech solar energy harvesting program, whose rooftop has covered with hundreds pf solar panels. The result of the scenario suggested the same thing on the main roof of the building, additionally, it recommended to add more solar panels on the side roof as well.

Conclusion

The total roof top size of Georgia Tech is 4369587.45 square feet according to the extracted rooftop polygon. While based on the analysis, in the case of slope 35 as maximum and solar 5700 as minimum. The total acceptable area size is about 679065.84 square feet, which covers 15% of the total rooftop in the campus. The number of solar panels that could fit in each polygon was estimated by using the following formula: polygon area/ Solar panel size. Based on the function, a total number of 45000 solar panels are able to added to the roof in the campus using a 3 feet by 5 feet Sunmetrix solar panel model[21]. Those solar panels are able to create a huge amount of energy which can be used to power buildings and other equipment.

This model is a good tool for determining desirable solar panel locations. However, further development is needed so the decision making process can take into account other important factors such as costs, installing difficulty etc.

[21] http://sunmetrix.com/solar-panel-size-for-residential-commercial-and-portable-applications/

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Appendix

Piezoelectric Tool:

```
import arcpy
from Tkinter import *
import tkMessageBox
#import tkFont

global S1100_1,S1100_2,S1100_3,S1100_4,S1100_5
global S1200_1,S1200_2,S1200_3,S1200_4,S1200_5
global S1400_1,S1400_2,S1400_3,S1400_4,S1400_5
global S1630_1,S1630_2,S1630_3,S1630_4,S1630_5



S1100_min = 15000
S1100_max = 37500

S1200_min = 1500
S1200_max = 3750

S1400_min = 400
S1400_max = 1000

S1630_min = 2500
S1630_max = 6250


S1100_1 = (S1100_max-S1100_min)/5*1 + S1100_min
S1100_2 = (S1100_max-S1100_min)/5*2 + S1100_min
S1100_3 = (S1100_max-S1100_min)/5*3 + S1100_min
S1100_4 = (S1100_max-S1100_min)/5*4 + S1100_min
S1100_5 = (S1100_max-S1100_min)/5*5 + S1100_min

S1200_1 = (S1200_max-S1200_min)/5*1 + S1200_min
S1200_2 = (S1200_max-S1200_min)/5*2 + S1200_min
S1200_3 = (S1200_max-S1200_min)/5*3 + S1200_min
S1200_4 = (S1200_max-S1200_min)/5*4 + S1200_min
S1200_5 = (S1200_max-S1200_min)/5*5 + S1200_min

S1400_1 = (S1400_max-S1400_min)/5*1 + S1400_min
S1400_2 = (S1400_max-S1400_min)/5*2 + S1400_min
S1400_3 = (S1400_max-S1400_min)/5*3 + S1400_min
S1400_4 = (S1400_max-S1400_min)/5*4 + S1400_min
S1400_5 = (S1400_max-S1400_min)/5*5 + S1400_min

S1630_1 = (S1630_max-S1630_min)/5*1 + S1630_min
S1630_2 = (S1630_max-S1630_min)/5*2 + S1630_min
S1630_3 = (S1630_max-S1630_min)/5*3 + S1630_min
S1630_4 = (S1630_max-S1630_min)/5*4 + S1630_min
S1630_5 = (S1630_max-S1630_min)/5*5 + S1630_min


s = "--"
text_S1100_1 = str(S1100_min) + s + str(S1100_1)
text_S1100_2 = str(S1100_min+(S1100_max-S1100_min)/5) + s + str(S1100_2)
text_S1100_3 = str(S1100_min+(S1100_max-S1100_min)/5*2) + s + str(S1100_3)
text_S1100_4 = str(S1100_min+(S1100_max-S1100_min)/5*3) + s + str(S1100_4)
text_S1100_5 = str(S1100_min+(S1100_max-S1100_min)/5*4) + s + str(S1100_5)


text_S1200_1 = str(S1200_min) + s + str(S1200_1)
text_S1200_2 = str(S1200_min+(S1200_max-S1200_min)/5) + s + str(S1200_2)
text_S1200_3 = str(S1200_min+(S1200_max-S1200_min)/5*2) + s + str(S1200_3)
text_S1200_4 = str(S1200_min+(S1200_max-S1200_min)/5*3) + s + str(S1200_4)
text_S1200_5 = str(S1200_min+(S1200_max-S1200_min)/5*4) + s + str(S1200_5)

text_S1400_1 = str(S1400_min) + s + str(S1400_1)
text_S1400_2 = str(S1400_min+(S1400_max-S1400_min)/5) + s + str(S1400_2)
text_S1400_3 = str(S1400_min+(S1400_max-S1400_min)/5*2) + s + str(S1400_3)
text_S1400_4 = str(S1400_min+(S1400_max-S1400_min)/5*3) + s + str(S1400_4)
text_S1400_5 = str(S1400_min+(S1400_max-S1400_min)/5*4) + s + str(S1400_5)
```

```
text_S1630_1 = str(S1630_min) + s + str(S1630_1)
text_S1630_2 = str(S1630_min+(S1630_max-S1630_min)/5) + s + str(S1630_2)
text_S1630_3 = str(S1630_min+(S1630_max-S1630_min)/5*2) + s + str(S1630_3)
text_S1630_4 = str(S1630_min+(S1630_max-S1630_min)/5*3) + s + str(S1630_4)
text_S1630_5 = str(S1630_min+(S1630_max-S1630_min)/5*4) + s + str(S1630_5)

def selS1100_1():
    global S1100_NUM
    S1100_NUM = S1100_1
def selS1100_2():
    global S1100_NUM
    S1100_NUM = S1100_2
def selS1100_3():
    global S1100_NUM
    S1100_NUM = S1100_3
def selS1100_4():
    global S1100_NUM
    S1100_NUM = S1100_4
def selS1100_5():
    global S1100_NUM
    S1100_NUM = S1100_5


def selS1200_1():
    global S1200_NUM
    S1200_NUM = S1200_1
def selS1200_2():
    global S1200_NUM
    S1200_NUM = S1200_2
def selS1200_3():
    global S1200_NUM
    S1200_NUM = S1200_3
def selS1200_4():
    S1200_NUM = S1200_4
def selS1200_5():
    global S1200_NUM
    S1200_NUM = S1200_5

def selS1400_1():
    global S1400_NUM
    S1400_NUM = S1400_1
def selS1400_2():
    global S1400_NUM
    S1400_NUM = S1400_2
def selS1400_3():
    global S1400_NUM
    S1400_NUM = S1400_3
def selS1400_4():
    global S1400_NUM
    S1400_NUM = S1400_4
def selS1400_5():
    global S1400_NUM
    S1400_NUM = S1400_5

def selS1630_1():
    global S1630_NUM
    S1630_NUM = S1630_1
def selS1630_2():
    global S1630_NUM
    S1630_NUM = S1630_2
def selS1630_3():
    global S1630_NUM
    S1630_NUM = S1630_3
def selS1630_4():
    global S1630_NUM
    S1630_NUM = S1630_4
def selS1630_5():
    global S1630_NUM
    S1630_NUM = S1630_5

def Calculate():

    global coefficient
    coefficient = float(raw_input("please enter a coefficient"))

    arcpy.AddField_management("Study_Area", "PE", "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
    arcpy.AddField_management("Study_Area", "PE_total", "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED",
"")

    with arcpy.da.UpdateCursor("Study_Area",["Traffic_field","Lane","shape_Length","PE"]) as cursor:
```

```
        for row in cursor:
            row[3] = float(row[0])*float(row[1]) * coefficient
            cursor.updateRow(row)

    with arcpy.da.UpdateCursor("Study_Area",["Traffic_field","Lane","shape_Length","PE_total"]) as cursor:
        for row in cursor:
            row[3] = float(row[0])*float(row[1])*float(row[2]) * coefficient
            cursor.updateRow(row)



def Final_Exit():
    print "Exit"

def Start_Service():
    master2 = Tk()
    master2.title("Selection Tool")

    Label(master2,text = "Level 1", padx = 20).grid(row = 0, column = 1)
    Label(master2,text = "Level 2", padx = 20).grid(row = 0, column = 2)
    Label(master2,text = "Level 3", padx = 20).grid(row = 0, column = 3)
    Label(master2,text = "Level 4", padx = 20).grid(row = 0, column = 4)
    Label(master2,text = "Level 5", padx = 20).grid(row = 0, column = 5)

    varS1100 = IntVar(master2)

    Label(master2,text = "Primary Road Traffic Level(S1100)", padx = 20).grid(row = 1, column = 0)
    Radiobutton(master2, text= text_S1100_1, variable=varS1100, value=1,command=selS1100_1).grid(row = 1,
column = 1)
    Radiobutton(master2, text= text_S1100_2, variable=varS1100, value=2,command=selS1100_2).grid(row = 1,
column = 2)
    Radiobutton(master2, text= text_S1100_3, variable=varS1100, value=3,command=selS1100_3).grid(row = 1,
column = 3)
    Radiobutton(master2, text= text_S1100_4, variable=varS1100, value=4,command=selS1100_4).grid(row = 1,
column = 4)
    Radiobutton(master2, text= text_S1100_5, variable=varS1100, value=5,command=selS1100_5).grid(row = 1,
column = 5)




    varS1200 = IntVar(master2)

    Label(master2,text = "Secondary Road Traffic Level(S1200)", padx = 20).grid(row = 2, column = 0)
    Radiobutton(master2, text=text_S1200_1, variable=varS1200, value=1,command=selS1200_1).grid(row = 2, column
= 1)
    Radiobutton(master2, text=text_S1200_2, variable=varS1200, value=2,command=selS1200_2).grid(row = 2, column
= 2)
    Radiobutton(master2, text=text_S1200_3, variable=varS1200, value=3,command=selS1200_3).grid(row = 2, column
= 3)
    Radiobutton(master2, text=text_S1200_4, variable=varS1200, value=4,command=selS1200_4).grid(row = 2, column
= 4)
    Radiobutton(master2, text=text_S1200_5, variable=varS1200, value=5,command=selS1200_5).grid(row = 2, column
= 5)

    varS1400 = IntVar(master2)
    Label(master2,text = "Local Traffic Level(S1400)", padx = 20).grid(row = 3, column = 0)
    Radiobutton(master2, text=text_S1400_1, variable=varS1400, value=1,command=selS1400_1).grid(row = 3, column
= 1)
    Radiobutton(master2, text=text_S1400_2, variable=varS1400, value=2,command=selS1400_2).grid(row = 3, column
= 2)
    Radiobutton(master2, text=text_S1400_3, variable=varS1400, value=3,command=selS1400_3).grid(row = 3, column
= 3)
    Radiobutton(master2, text=text_S1400_4, variable=varS1400, value=4,command=selS1400_4).grid(row = 3, column
= 4)
    Radiobutton(master2, text=text_S1400_5, variable=varS1400, value=5,command=selS1400_5).grid(row = 3, column
= 5)

    varS1630 = IntVar(master2)
    Label(master2,text = "Ramp Traffic Level(S1630)", padx = 20).grid(row = 4, column = 0)
    Radiobutton(master2, text=text_S1630_1, variable=varS1630, value=1,command=selS1630_1).grid(row = 4, column
= 1)
    Radiobutton(master2, text=text_S1630_2, variable=varS1630, value=2,command=selS1630_2).grid(row = 4, column
= 2)
    Radiobutton(master2, text=text_S1630_3, variable=varS1630, value=3,command=selS1630_3).grid(row = 4, column
= 3)
    Radiobutton(master2, text=text_S1630_4, variable=varS1630, value=4,command=selS1630_4).grid(row = 4, column
= 4)
    Radiobutton(master2, text=text_S1630_5, variable=varS1630, value=5,command=selS1630_5).grid(row = 4, column
= 5)
```

```
    Button(master2, text='Go',font = ("Cambria, 13"), command= Start_Service2).grid(row=5, column=1)
    Button(master2, text='Exit',font = ("Cambria, 13"), command= Exit2).grid(row=5, column=3)


def Start_Service2():

    arcpy.env.overwriteOutput = True
    arcpy.env.workspace = "C:/Capstone/data.gdb"
    Streetdata = "Street_TIGER_2010"
    Boundary = "GeorgiaTech_Boundary"

    arcpy.Clip_analysis(Streetdata, Boundary, "Study_Area", "")
    arcpy.AddField_management("Study_Area", "Traffic_field", "LONG", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
    with arcpy.da.UpdateCursor("Study_Area",["MTFCC","Traffic_field"]) as cursor:
        for row in cursor:
            if row[0] == "S1100":
               row[1]= S1100_NUM
               cursor.updateRow(row)
            elif row[0] == "S1200":
               row[1]= S1200_NUM
               cursor.updateRow(row)
            elif row[0] == "S1400":
               row[1]= S1400_NUM
               cursor.updateRow(row)
            else:
               row[1]= S1630_NUM
               cursor.updateRow(row)

    arcpy.AddField_management("Study_Area", "Lane", "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

    with arcpy.da.UpdateCursor("Study_Area",["MTFCC","Lane"]) as cursor:
        for row in cursor:
            if row[0] == "S1100":
                row[1] = 8
                cursor.updateRow(row)
            elif row[0] == "S1200":
                row[1] = 4
                cursor.updateRow(row)
            elif row[0] == "S1400":
                row[1] = 2
                cursor.updateRow(row)
            else:
                row[1] = 1.5
                cursor.updateRow(row)
    master3 = Tk()
    master3.title("Enter the coefficient")
    Button(master3, text='Calculate',font = ("Cambria, 13"), command= Calculate).grid(row=1, column=1)
    Button(master3, text='Exit',font = ("Cambria, 13"), command= Final_Exit).grid(row=1, column=0)
    Label(master3, text="Conversion Coefficiency of Pressure to Electricity: ",font = ("Arial,
11")).grid(row=0,column=0)

    #entry_coefficient = Entry(master3, bd = 5)
    #entry_coefficient.grid(row=0,column=1)












def Exit2():
    print "hello"





def Exit1():
    tkMessageBox.showinfo("Warning", "You can't exit dude,you are in a presentation")
```

```
master = Tk()
master.title('Traffic Volume Selection tool')

Label(master, text="WELCOME",font = ("Arial, 20"),fg = 'red',relief = 'groove').grid(row=0)
#Label(master, text= realtime,font = ("Arial, 18")).grid(row=1)
#Label(master, text="What would you like to do",font = ("Arial, 18")).grid(row=2)

Button(master, text='Start Service',font = ("Cambria, 13"), command= Start_Service).grid(row=3, column=0)
Button(master, text='Exit',font = ("Cambria, 13"), command= Exit1).grid(row=4, column=0)

photo = PhotoImage(file='C:\Capstone\cars.gif')
label = Label(image=photo)
label.image = photo
label.grid(row=0, column=1, columnspan=3, rowspan=5)







mainloop()

# Process: Adding number of lanes
#arcpy.AddField_management(Study_Area__2_, "Lane", "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculae number of Lanes
#rcpy.CalculateField_management(Study_Area__3_, "Lane", "lane_assign ( !MTFCC!)", "PYTHON_9.3", "\\ndef
lane_assign (roadType):\\n    global RT, lane\\n    RT = roadType\\n    if RT == \"S1100\":\\n        lane =
8\\n    elif RT == \"S1200\":\\n        lane = 4\\n    elif RT == \"S1400\":\\n        lane = 2\\n    elif RT
== \"S1630\":\\n        lane= 1.5\\n    else:\\n        lane = 0\\n\\n    return lane")

# Process: Adding energy Generation Field
#.AddField_management(Study_Area__5_, "PE_Gen", "DOUBLE", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Energy Generation Field
#arcpy.CalculateField_management(Output_Feature_Class__2_, "PE_Gen", "energy_calculator
( !Lane!, !Traffic_field!, !Shape_Length!)", "PYTHON_9.3", "\\n\\ndef energy_calculator (lane, traffic,
length):\\n    global PE, energy\\n    PE = %PE_Energy_D%\\n    energy = lane * traffic * PE * length \\n\\n
return energy")
```

Solar Tool:

```
arcpy.env.workspace = "C:/Capstone/data.gdb"
D_threshold = arcpy.GetParameterAsText(0)
in_raster = arcpy.GetParameterAsText(1)
output_workspace = arcpy.GetParameterAsText(2)

degree = float(D_threshold)

in_raster1 = arcpy.Raster(in_raster)


out_raster1 = Reclassify(in_raster1, "Value", RemapRange([[-1,degree,1],[degree,89.819,0]]))
out_raster1.save(output_workspace)
```

```
import arcpy
from arcpy.sa import *

arcpy.env.workspace = "C:/Capstone/data.gdb"
in_raster = arcpy.GetParameterAsText(0)
output_workspace = arcpy.GetParameterAsText(1)


in_raster1 = arcpy.Raster(in_raster)


out_raster1 = Reclassify(in_raster1, "Value", RemapRange([[-1.0001,-
0.99999,1],[112.5,247.5,1],[0,112.5,0],[247.5,360,0]]))
out_raster1.save(output_workspace)
```

```python
import arcpy

# Load required toolboxes
arcpy.ImportToolbox("C:/Capstone/Toolbox (2).tbx")

# Script arguments
Slope_threshold_value = arcpy.GetParameterAsText(0)
if Slope_threshold_value == '#' or not Slope_threshold_value:
    Slope_threshold_value = "35" # provide a default value if unspecified

# Local variables:
Campus_tif = "Campus.tif"
GeorgiaTech_Boundary = "GeorgiaTech_Boundary"
Campus_DEM_Clip = "C:\\Capstone\\data.gdb\\Campus_DEM_Clip"
Campus_aspect = "C:\\Capstone\\data.gdb\\Campus_aspect"
Campus_Slope = "C:\\Capstone\\data.gdb\\Campus_Slope"

# Process: Clip DEM with Boundary
arcpy.Clip_management(Campus_tif, "2222688.29667276 1371181.3681735 2229513.38341626 1376042.47918617",
Campus_DEM_Clip, GeorgiaTech_Boundary, "-3.402823e+038", "NONE", "NO_MAINTAIN_EXTENT")

# Process: Aspect
arcpy.gp.Aspect_sa(Campus_DEM_Clip, Campus_aspect)

# Process: Slope
arcpy.gp.Slope_sa(Campus_DEM_Clip, Campus_Slope, "DEGREE", "1")

# Process: Slope (2)
arcpy.gp.toolbox = "C:/Capstone/Toolbox (2).tbx";
# Warning: the toolbox C:/Capstone/Toolbox (2).tbx DOES NOT have an alias.
# Please assign this toolbox an alias to avoid tool name collisions
# And replace arcpy.gp.Script(...) with arcpy.Script_ALIAS(...)
arcpy.gp.Script(Slope_threshold_value, Campus_Slope)
```