The reliance of insolation pattern on surface aspect

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Abstract The Sun’s radiated energy is an important source in realizing the green technology concept construction. When interacting with the atmosphere and objects on the Earth’s surface incoming solar radiation (insolation) will create insolation patterns that are ambiguous and as a result need to be investigated further. This paper explores the insolation pattern and ambiguities against topographic surfaces in the context of direct, diffuse, and reflectance irradiance. The topography is modeled from LiDAR data as Digital Surface Model (DSM) and Digital Terrain Model (DTM). The generated DSM and DTM were converted to Triangular Irregular Network (TIN) format within the Arc GIS environment before the insolation pattern could be visualized. The slope and aspect of the topography has an impact on the insolation which is the emphasis of this paper. The main outcome from the study is the insolation map and plots of relationship between the insolation and surface aspect. The findings from this study should contribute to the sustainable practices of green building technology.

1. Introduction

Sustainability planning is crucial for today civilization [1]. Its awareness through green technology concept would be seen in built environment. Malaysia being at the equator is experiencing a climate hot and humid, receiving impartial rain and summer leading to sun’s radiated energy throughout the year. Insolation has a closed integration to solar rights, solar gain, daylight potential and solar control one of the most crucial variables related to the energy consumption, day lighting and human comfort in residential buildings [2]. The pattern of insolation of the radiated energy varies from global, direct, or diffuse as it hits the topography due to different aspects of topographic orientation. There are several factors involved which affect the pattern of solar energy in spatial and temporal distribution for instances climate factors and topography [3]. Hence, this study focuses on the correlation between aspect and insolation whereby the diverse characteristic of the aspect would interact with the model of incoming solar radiation pattern.

The construction of infrastructure such as buildings must take into account the amount of incoming solar radiation (insolation) towards a sustainable practice of green building technologies [4]. Thus, solar access planning has become one of the important aspects in structures construction. An initial superior arrangement of structure built will contribute to the effective planning and decrease energy
cost. The insolation pattern limits to the direct, diffuse and reflected irradiance which used the algorithm approach from [5,6]. Thus, in order to predict the solar insolation pattern and ambiguity, this study will use the 3D Model as the focal approach on producing the model of insolation pattern towards generated 3D model. The generation of TIN through surface analyst and spatial analyst likewise the sky map, solar map, and viewshed of the surface used the Arc GIS as the processing medium. Subsequently, those results employ overlay analysis to investigate the relationship of various aspect and insolation pattern.

2. Review of Insolation Pattern and Surface Modeling

Implementation of insolation pattern analysis has been widely used in diverse application considering either atmospheric or topographic factors [4,7,8,9,10]. Various characteristics of the obstruction angles, sky opening and view factors indicators can also be examined based on the insolation pattern provided by direct, diffuse and reflected irradiance [6]. In insolation pattern investigation several factors takes into account such as the site latitude and elevation, slope and aspect of the terrain as well as the effects of shadows cast by surrounding buildings, vegetation and terrain topography [8].

2.1 Direct solar radiation

Direct solar radiation is where the solar energy reaches the Earth’s surface from the solar beam from the solid angle of the Sun’s disk without considering any interactions with particles in the atmosphere. The algorithm for the insolation adapted from Dubayah and Rich [6] demonstrate direct radiation is a function of solar zenith angle and solar beam at top of the atmosphere and varies by date. The optical depth of $\tau_0$, the irradiance is

\[
\mu_0 S_0 e^{-\tau_0 \cos \theta_0} = \left[ \cos \theta_0 \cos S + \sin \theta_0 \sin S \cos \phi_0 - A \right] S_0 e^{-\tau_0 \cos \theta_0} \tag{1}
\]

where $S_0$ is the exoatmospheric solar flux, $\theta_0$ is the solar zenith angle, $\phi$ is the solar azimuth, $A$ is the azimuth of the slope, and $S$ is the slope angle. Both $S$ and $A$ are derived from digital terrain and surface data. For clear sky conditions the spatial variability of incoming solar radiation will usually be dominated by [1].

2.2 Diffuse solar radiation

Diffuse radiation scattered out the solar beam by gases and aerosol including dust, particles, sulfate, and etc. The actual calculation of diffuse radiation on a slope is complex and need some degree of approximation, thus [6] assume the diffuse radiation coming from the sky is isotropic. The other factor of diffuse is sky view. Sky view factor $V_d$ can be calculated that gives the ratio of diffuse sky irradiance at a point to that on an unobstructed horizontal surface. In theory the diffuse flux should be calculated by multiplying the view factor in a particular direction by the amount of diffuse irradiance in that sector of the sky, and integrating over the hemisphere of sky directions. This is computationally complex and storage intensive because it requires the calculation of $V_d$ and diffuse irradiance for each sky sector and for each grid point. As Dubayah and Rich [6] assume that diffuse irradiance is isotropic, only one view factor is associated with each grid location thus the diffuse irradiance is given by

\[
V_d = F_d \tau_0 \tag{2}
\]

where $F_d \tau_0$ is the average diffuse irradiance on a level surface at that elevation, and $V_d$ varies from 1 (unobstructed) to 0 (completely obstructed).
2.3 Reflected Solar Radiation

Reflected solar radiation is the solar beam which reflected from terrain and benefits in mountainous areas. It describe by [6] as

\[ C_t F^\uparrow(\tau_0) = C_t R_0 F^\downarrow \tau_0 \]  

(3)

where \( F^\uparrow(\tau_0) \) is the amount of radiation reflected off the surface with an average reflectance of \( R_0 \).

The sky view factors and viewshed can be combined together in order to improve the estimation of reflected radiation [11]. Hence the total irradiance is

\[ R^\downarrow(\text{slope}) = [V_d F^\downarrow(\tau_0) + C_t F^\uparrow(\tau_0) + \mu S \text{oe-}\tau_0/\cos\theta_0] \]  

(4)

where, \( V_d \), \( C_t \), and \( \mu \) are all derived from digital elevation data and all vary spatially. The diffuse radiation and direct radiation will vary spatially with elevation as \( \tau_0 \) is a function of pressure.

3. Methodology

The methodology for this study consists of three phases which are 3D model reconstruction, investigation on insolation pattern and interrelation of aspect and insolation pattern. DTM and DSM generated from LiDAR data which is dense and accurate to perform better quality of terrain and surface modeling before area insolation map for global, direct, and diffuse performed. After the pattern of the solar radiation attained, an analysis executed to find the interrelation with aspect.

3.1 Phase 1: 3D Model Reconstruction

First and foremost, the spatial information of the features extracted as preparation for 3 Dimensional model generations. LiDAR data which used in this study which has high quality and dense, support the extraction process efficiently. After the LiDAR’s point cloud data verified, it was used to produce Triangular Irregular Network in 3 Dimensional Analyst tool in Arc GIS environment. In this phase, two type of 3 Dimensional Model constructed which are Digital Surface Model and Digital Terrain Model. The quality of LiDAR data obviously assist in providing better visualization of these models. Thus, the procedure proceeds with the raster conversion as to fulfill the necessity of insolation investigation in the next phase.

3.2 Phase II: Investigation on Insolation Pattern

The output from the first phase is used extensively in investigation of insolation pattern. In the process of this investigation, viewshed, sky map (sky direction) and solar map (sun position) calculated before further insolation pattern can be determined. The distribution then identified by plotted mean of the insolation value thus the trend for the whole year can be seen throughout. The spatial representation of insolation for DSM and DTM illustrated by the area insolation map in Arc GIS environment can be distinguished directly the pattern on study area chose. The next phase looked into the relationship of aspect and insolation pattern, the area insolation map was converted to the vector dataset to ease the process of overlay analysis between aspect and insolation pattern.

3.3 Phase III: Aspect and Insolation Pattern Interrelation

The minimum, maximum and average impacts of irradiance at any position in the study area coverage is indicated by area insolation map in raster based[12]. Hence, conversion of the result into vector based is needed before the investigation carried on. Then, aspect map produced using surface analyst for the next method. The same procedure of conversion applied to aspect layer for both DSM and Digital Terrain Model by spatial analysis. In order to find the relationship of insolation pattern and aspect, an overlay analysis done towards both layers that have converted into vector form in the previous procedure. The graphs of the insolation value of DSM and DTM in the context of global, direct and diffuse later plotted against various aspects.
4. Result and Analysis
The outcome of the analysis from this study helps to verify if the diverse type of solar irradiance differs from one another for DTM and DSM.

4.1 Digital Terrain Model and Digital Surface Model
DTM and DSM produced from surface analyst in Arc GIS environment is illustrated in the following figure. Figure 2 illustrates the plain digital terrain model of the study area while the rugged terrain of the images in figure 3 shows the features on the surfaces which include buildings, structures, trees, transportation network and etc. The elevation for DTM varies from 63 meters to 292 meters high whereas that for DSM varies from 63 meters to 308 meters. The difference in the high variation would affect the insolation pattern shown in subsequent result.

Figure 1. General Flowchart of Methodology.

Figure 2. Digital Terrain/Elevation Model generated from LiDAR points’ cloud data.

Figure 3. Digital Surface Model generated from LiDAR points’ cloud data.

4.2 Insolation Pattern and Aspect
Figure 4 and 5 show the plot of insolation against aspect under global, diffuse and direct radiation. It could be seen from the figure that from the overlay process, the relationship between aspect and the insolation pattern. For all the three context of insolation it can be seen that normal distribution variation of global, diffuse and direct radiation from January to December. As the diffuse and direct radiations depend on the global radiation variation the distribution share the same character of global radiation pattern. The aspect facades do contribute to the value of solar radiation as shown in table 1 and table 2. It is determined from the study that aspect from Northwest(315º), West(270º), Southwest(225º), South(180º), East(90º) and Southeast(135º) indicates higher value of insolation.
compared to aspect facing North(0°), Northeast(45°). Meanwhile the value of the irradiance for DTM is higher compared to the DSM’s. This is influenced by the absorption and reflectance on the surfaces which contain structures and natural features such as trees and water bodies. In addition, figure 6 and 7 indicates the plotted mean of insolation value from all aspect.

Table 1. The Mean Insolation Value against Various Aspects: DTM.

| Mean/Aspect | S   | SE  | SW  | W   | E   | NW  | NE  | N   |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Global      | 97396 | 91098 | 91921 | 80757 | 78064 | 69205 | 67726 | 58680 |
| Diffuse     | 21037 | 20950 | 21166 | 21020 | 20502 | 20919 | 20608 | 20630 |
| Direct      | 77321 | 71139 | 71116 | 59242 | 58833 | 46831 | 47497 | 47165 |

Table 2. The Mean Insolation Value against Various Aspects: DSM.

| Mean/Aspect | S   | SE  | SW  | W   | E   | NW  | NE  | N   |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Global      | 61637 | 56850 | 59304 | 45796 | 43885 | 32150 | 32238 | 25391 |
| Diffuse     | 11772 | 11653 | 12387 | 11815 | 11214 | 11378 | 11192 | 10860 |
| Direct      | 49692 | 45058 | 46799 | 33862 | 32547 | 20723 | 20995 | 14520 |
Conclusion

It can be concluded that modeled insolation in terms of global, direct, and diffuse is normally distributed on the surface features which derived digitally through the use of LiDAR data. The insolation pattern model and the accuracy significantly depends on the accuracy of the DTM and DSM data which derived from LiDAR used as in the computation of solar irradiance rely on aspect and slope. From the analysis performed, it is found that surface structures’ aspect facing from $135^\circ$ to $315^\circ$ would be holding higher value of insolation. Thus in can be one of the indicators in planning allocation for new structures by considering green building technology concepts.

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