VISUALIZATION OF LAND SURFACE TEMPERATURE OF URBAN AREAS: THE CASE OF THE QUEZON CITY CENTRAL BUSINESS DISTRICT

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ABSTRACT: Geovisualization has been utilized in several studies in applications for the urban environment, as it focuses on the application of communicating scientific phenomena through mapping articles, more oftentimes in more than two dimensions. In this paper, an existing model for the calculation of the Land Surface Temperature (LST) was employed using values of Normalized Difference Vegetation Index (NDVI), Normalized Difference Building Index (NDBI), Surface Albedo (SA), Sky View Factor (SVF), Solar Radiation (SR), and Surface Area-to-Volume Ratio (SVR). In the case of the proposed Quezon City Central Business District, an increase in the surface temperature was predicted with the increase of the man-made structures in the area, in terms of the number, density, building heights, and land use. Present values were calculated, and a projection was made for the future scenario was performed using the existing Land Use Plan. A hotspot analysis and 3D visualization was utilized to observe the trends of increase in surface temperature, as well as equalization of the values

1. INTRODUCTION

1.1 Background

Geovisualization provides a tool for information display, and for the insight into the datasets behind this information. It has produced various geographical digital products, but it is not limited by excluding paper maps (Cartwright, 2004). Theories in traditional cartography have been extended as the development of technologies have progressed, and how well these new media are effective in communicating the information made by the producers to the end-users.

3D geovisualization, also referred to as landscape visualization, is an important tool for planners, as these help raise questions to the users as hoe the people can access, process and use the information that are able to model the existing complexities of the world (Pettit, 2006). Visualization has been important in the formation of well-informed decisions, but as studies in the involvement of this tool in planning, it should not be seen as one step to guide us in forming proposals, but it can be used to model existing ones.

One of the important parameters in the studies of the urban environment quality is Land Surface Temperature (LST), which is a function of multiple interrelated factors. (Villanueva, 2015) As Buttenfield (1993) and Skupin and Buttenfield (1996,1997) have utilized the technology for Environmental modelling, it is vital that we ensure that what is produced is based on a reliable information analysis.

1.2 Objective and Expected Output

In this study, along with the developments of the built-up structures in the Quezon City Central Business District (QC CBD), and the accompanying changes in the LST are to be estimated using the model created by Villanueva (2015). The existing land use plan created by the local government will be the basis of the projections and the estimations for the future scene.

The final output will be a three-dimensional urban landscape model representing the future as-built environment of the area, as well as a representation of the LST to aid the observation of its change, parallel to the growth of the structures.

The visualization will also be supported by a hotspot analysis for the analysis of the clustering of certain extreme surface temperatures.

1.3 Study Area

Figure 1. Google Earth snapshot of the project area (outlined in yellow)

The Quezon City Central Business District is a proposed growth area in the city center, bounded by three main thoroughfares- the Epifanio Delos Santos Avenue (EDSA), North Avenue, and East Avenue, covering 250 hectares. Presently, majority of land uses in the said area are Institutional, owning to the numerous government offices, as well as hospitals in the area. The business district was created by virtue of the proposal of the QC Masterplan in 2006, as mandated by then President Gloria Macapagal Arroyo's Executive Order No. 106 (QC Land Use Plan, 2011).

Aside from the institutional uses, one of the Metro's major structure is the Trinoma Mall, constructed in 2007, as well as the ongoing constructions of the Vertis North residences by Avida and the remained presence of the informal settlers. The area boosts its main road frontages and its proximity to the city center, even its full extent to become larger than the Makati, Ortigas, Alabang, Eastwood, and Bonifacio business districts (Tomoling et.al., 2012)

Figure 2. Floor Area Ratio Map of the Business District (From QC land Use Plan, 2011)

Also contained in the land use plan is a Floor Area Ratio (FAR) Map, in support of the existing city building code. The district will be a mixed-use hub and will be divided into 5 main districts: Commons, Downtown Hub, Emporium, Residences at Veterans and the Triangle Exchange. (QC Land Use Plan, 2011)

1.4 Scope and Limitation

The CBD considered in the study excludes the Veterans Memorial Medical Center area, as this parcel is excluded in the FAR Map. This map also, containing the lotting, is considered the final footprints of the map during the completion of the CBD.

Elevation values are assumed to be constant in the elevation model, and the building heights used for extrusion in the 3D model, and the computation of the factors in the LST.

All prepared visualizations are results and are based on readily available datasets, and no changes since the plan was drafted up to the present are reflected. No consultations and surveys are concluded to aid in the production of the visualization. Hardware also limits the quality of the final product in terms of resolution and playback smoothness.

2. REVIEW OF LITERATURE

2.1 Urban Areas and Temperature

Urban climate is a current subject of interest in research, and most studies involve pattern changes observations over a period of time. (Jin, 2009)

Weng, Lu, and Schubring in 2003 investigated the relationship of the abundance of vegetation and the formation of urban heat islands through the estimation of land surface temperature. Landsat image was used to calculate the NDVI, as the estimator of vegetation abundance and calculated LST from the image's thermal band was correlated.

Amiri, et.al, did a similar study, but with using the Temperature and Vegetation Index (TVX) and Land Use/LandCover (LULC), and discovered that most changes due to urbanization were observable, as low temperature-dense vegetation corresponds to a movement towards a high-temperature-sparse vegetation space.

Land cover patter and configuration and its effects in LST in urban environments. The correlation of the composition, and the configuration was examined and it was found out that the composition of the land features significantly affect the LST, most especially the percent cover of buildings. (Zhou, 2011)

2.2 Geovisualization Technologies and Applications

As emphasized by Cartwright (2004), geovisualization must include the assurance that what is in the model is a result of a reliable scientific information analysis, and aside from being an effective computer display tool, it must be one that end-users must be able to need and utilize effectively.

In 2009, Jin studied the understanding of Climate Change patterns by utilizing Geovisualization. By straying away from singular variables and exploring complex climate change in different perspectives, not just geographically but also temporal, and using multiple variables.

In a Master's Thesis, Villanueva (2015) utilized Remote Sensing and GIS in the characterization of urban environments. Conditions were characterized in terms of the thermal, vegetative and urban built form. A model for estimating the land surface temperature from NDVI, NDBI, Surface Albedo, Solar Radiation, Sky View Factor, and Surface Area-to-Volume Ratio was created using multiple linear regression.

3. MATERIALS AND METHODS

3.1 Materials

In the calculations for the creation of the 3D landscape models of the Quezon City Central Business District are the following:

- Landsat 7 ETM+ Satellite Image, Path 116 Row 50; earthexplorer.usgs.gov
- Metro Manila Building Footprints
- Metro Manila LiDAR Data
    - Digital Elevation Models
    - Digital Surface Models
- Floor Area Ratio Map; QC Planning Office

3.2 Methodology

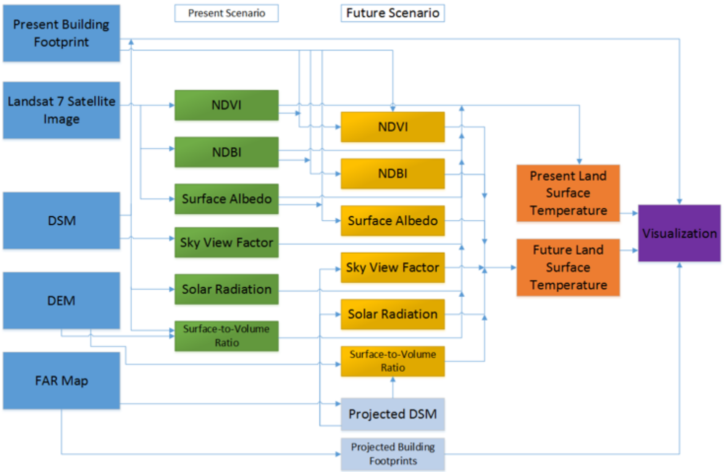

Figure 3. Processing and Geovisualization workflow

Figure 1 shows the general process for the geovisualization, starting from the raw datasets to the input to the 3D scene. In general, the process is divided into four parts: data preparation and processing, generation of datasets and LST calculation for present situation, projection of LST to the future scenario, and the preparation of the visualization in three-dimensions. This process will be elaborated in the next part of the paper.

In general, the Landsat image will be used to calculate NDVI, NDBI and the Surface Albedo. Equations 1, 2, and 3 below will describe the relationships used.

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \qquad (1)$$

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \qquad (2)$$

$$\begin{aligned} ALB &= 0.365\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4 \qquad (3) \\ &+ 0.085\alpha_5 + 0.072\alpha_7 - 0.0018 \end{aligned}$$

where α_i =spectral reflectance of the corresponding band

Sky view factor is referred to as the ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment. According to the literatures, the values for sky view factor are between zero and one, referring to the entirely obstructed and free spaces, respectively.

Another indicator considered is the surface area-to-volume ratio. The literatures describe this factor as one of the most significant in terms of characterizing the shape-related properties of objects. If the object is more compact with lower values of this ratio, the lower is its thermal loss to the environment.

Lastly, solar radiation is significant in the calculation of land surface temperature because this computes for the amount of insolation or the incoming solar radiation received across an entire landscape at a specific location, following the hemispherical viewshed algorithm.

Finally, the land surface temperature will be calculated using the model created by Villanueva (2015) below.

$$\begin{aligned} \mathrm{LST} &= 307.721 - 2.543\,\mathrm{NDVI} + \\ &14.778\,\mathrm{NDBI} + 8.995\,\mathrm{ALB} - 1.448\,\mathrm{SVF} \qquad (4) \\ &+ 0.002\,\mathrm{SR} + 1.516\,\mathrm{SVR} \end{aligned}$$

where LST = Land Surface Temperature

NDVI = Normalized Difference Vegetation Index
NDBI = Normalized Difference Building Index
ALB = Surface Albedo
SVF = Sky View Factor
SR = Solar Radiation
SVR = Surface Area-to-Volume Ratio

4. RESULTS AND DISCUSSIONS

4.1 Dataset Preparation and Information Extraction

The Landsat 7 scene containing the project area (Path 116, Row 50) was downloaded from US Geological Survey EarthExplorer site. The image underwent radiometric calibration, from Digital Number (DN) to radiance values, which was then converted to top-of-atmosphere (TOA) reflectance. This reflectance image was then applied atmospheric corrections through ENVI's Quick Atmospheric Correction (QuAC) Module.

The subset of the Building Footprints of Metro Manila containing the Project Area was obtained, and the estimated heights of each feature were obtained from the LiDAR Digital Surface Models (DSM). This DSM was used in the calculation of the Sky View Factor (SVF) and the Solar Radiation (SR). Together with the Digital Elevation Model (DEM) was used for the Surface Area-to-Volume Ratio (SVR). The rasters followed the resolution of the LiDAR dataset, which is 1 meter.

The atmospherically-corrected images are used to calculate the indices, Normalized Difference Vegetation Index and Normalized Difference Building Index, as well as the Surface albedo, in the form of rasters with a 30 meter resolution.

The present building footprint dataset, extruded using the heights from the DSM was used in the visualization along with the calculated Land Surface Temperatures for the visualization of the present situation.

For the estimation of the future situation, building footprints were digitized from a FAR Map from the QC Planning Office, where an assumed building height of 3.00 meters was used. This was used again to extrude the shapes to a 3D model, and was converted to become a new estimated DSM, along with the DEM (terrain was assumed to be constant) for use in the SVR, SVF and SR.

For the satellite image-derived rasters, NDVI, NDBI, and SA were derived from the previous scene. A zonal statistics operation was performed for all the rasters containing buildings, so the mean NDVI, NDBI, and SA may be calculated. This mean values for these quantities are assumed to be the values also for the buildings on the second scene. A replacement of the raster values for the locations of buildings on the second scene was performed.

These new quantities were used to calculate a second, projected, Land Surface Temperature raster, draped over the projected building footprints.

4.2 3D Visualization

ArcScene was used to visualize the resulting scene in three-dimensions. Zonal Statistics were performed in the LST raster to obtain average values per building feature, and then used as symbology for each.

A hotspot analysis was performed to accompany the 3D visualization, to supplement the results and visualize where high changes and variability in temperature occur.

4.3 Results and Implications

The results of the visualization includes the present scene and the future scene of the Quezon City Central Business District, considering the differences in elevation of the buildings, the expansion of the buildings, the changes in the land surface temperature and the 3D representation of the results.

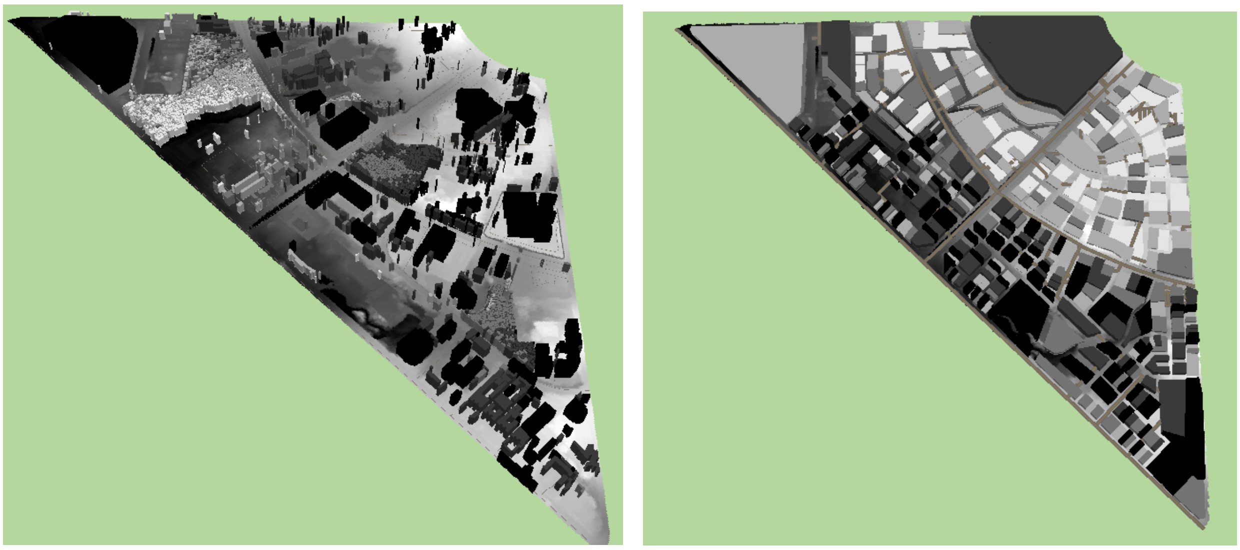

Figure 4. Current (L) and Projected (R) Buildings in the CBD

The image above shows the current buildings located in the study area. The 3D model is represented through the extrusion of the buildings according to their actual heights based on the digital surface model. The color scheme applied represents the building heights for a clearer visualization – the buildings with the darker shades refer to those with a higher elevation. The representation for the future scenario is applied the same layer scheme and design. It should be noted that the elevations of the buildings based on FAR were applied random multipliers for projection purposes.

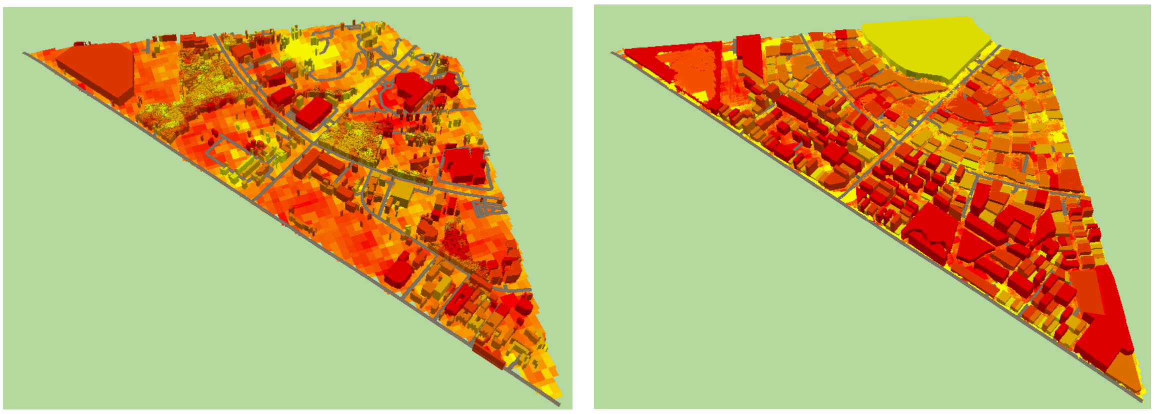

Figure 6. Current (L) and Projected (R) LST of the Buildings

This visualization for the land surface temperature of the current buildings is obtained by zonal statistics from the LST raster, and applied to the buildings. The color scheme of the buildings correspond to highest to lowest LST, with red as those with the highest values.

This visualization, on the other hand, represent the mean surface temperatures of the buildings as projected through FAR. These visualizations can easily represent the temperature and the areas with higher temperature can be easily observed for further analysis.

The differences between the present and future land surface temperatures are observed as well.

Drastic and distributed change in temperature can be observed when the projected buildings are applied. This can be used in analysing the areas for development, taking into consideration the urban heat effect, among other environmental considerations.

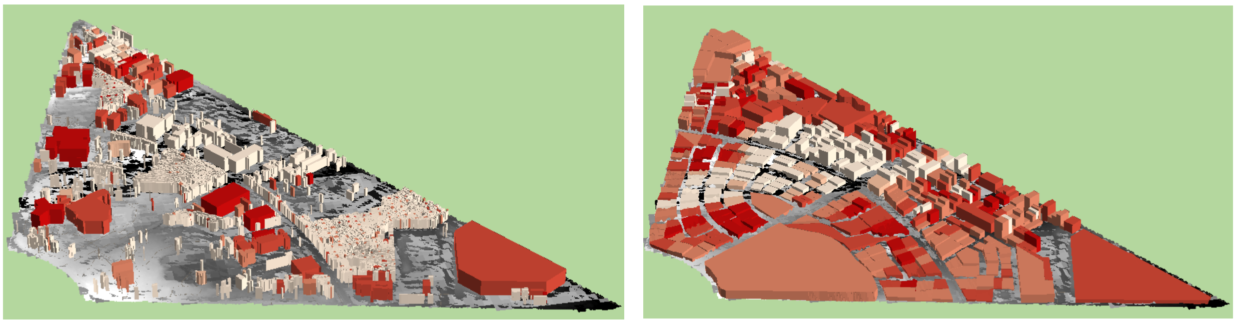

Figure 7. Differences in LST

The analysis of the results show that in the current layout of the buildings and their respective building heights, the areas with the highest surface temperature include the Administration Building of the Philippine Science High School.

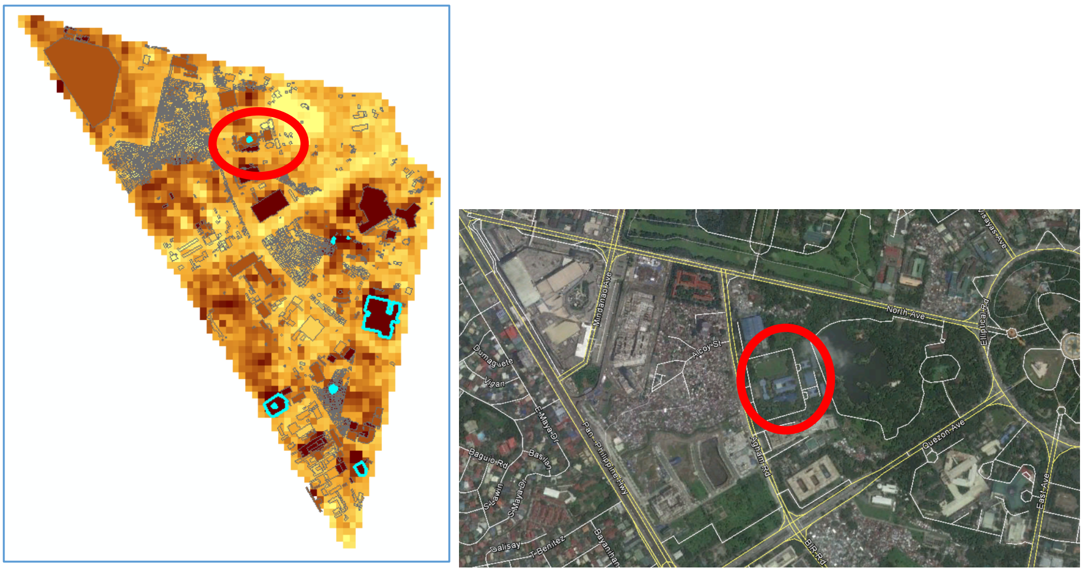

Figure 8. Buildings with Highest LST

The future scenario, on the other hand, has a higher distribution of buildings with higher surface temperatures, with the vicinity of the Department of Public Works and Highways having the highest.

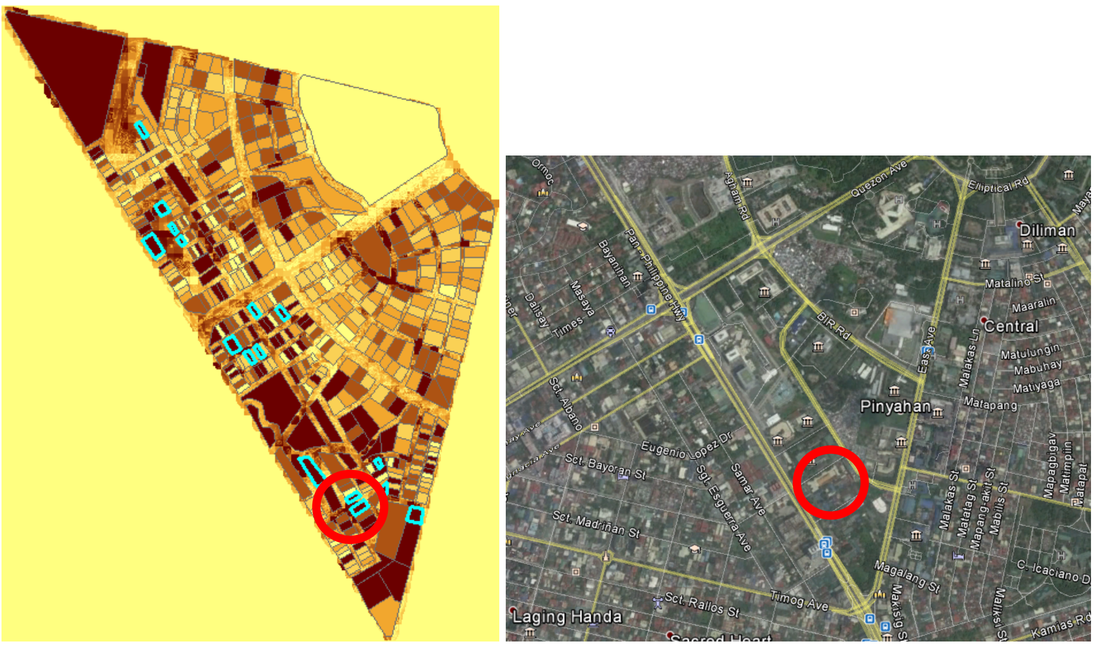

Figure 9. Buildings with Highest LST for Future Scenario

The graphs below show the range of values of the land surface temperatures as computed by the methodology.

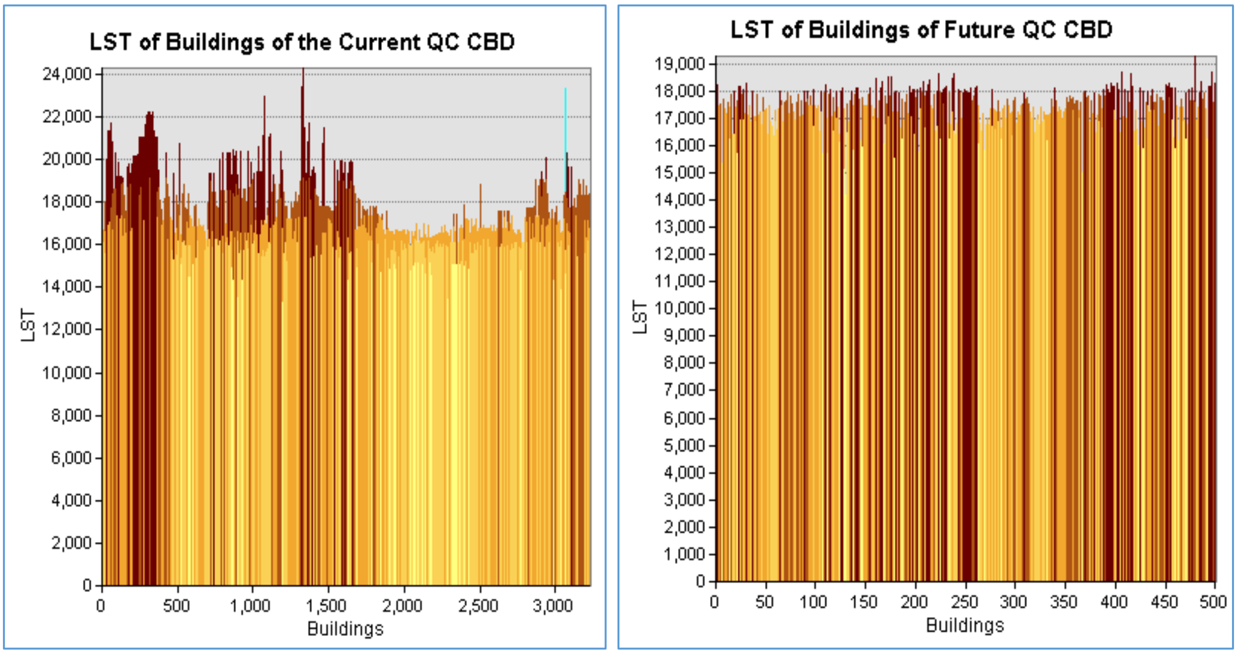

Figure 10. LST Values of the Current (L) and Projected (R) Buildings

It can be observed that though the LST of the future scenario is distributed over a larger range of buildings, the general LST of the CBD experience a decrease in magnitude. This can be accounted to the projections involved using FAR and other datasets used in the computations.

Further analysis included initial hotspot analysis to determine where the concentrations of the high surface temperatures can be located.

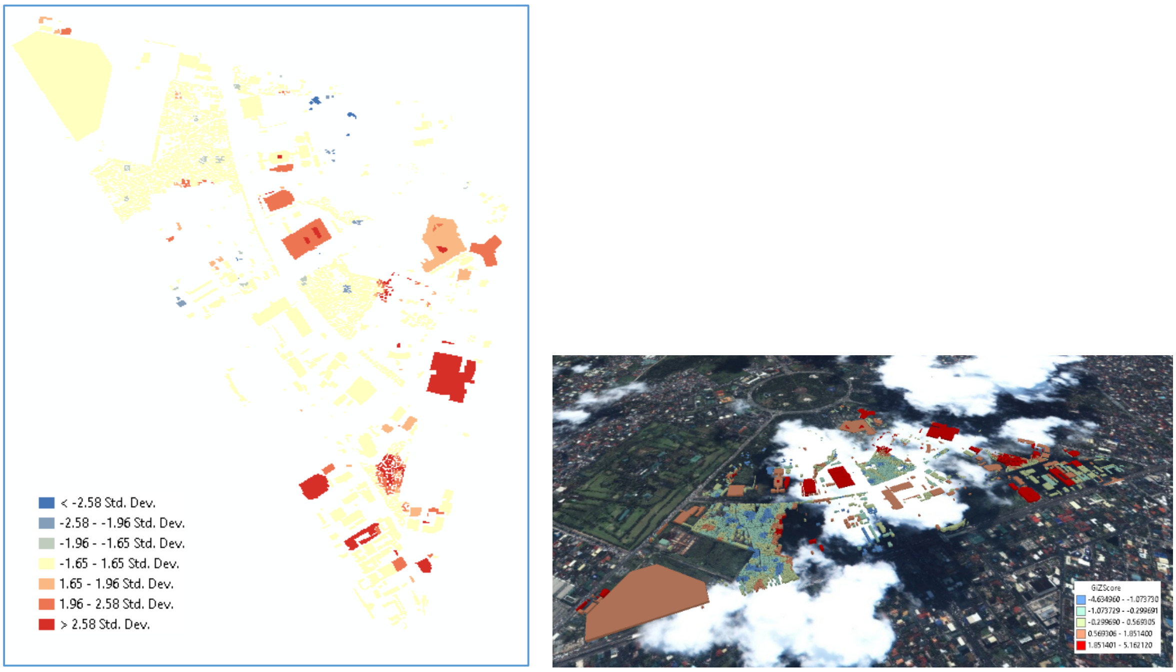

Figure 11. Hotspot Analysis for LST of Current Buildings

For the future scenario, the hotspot analysis is not as significant because of the distribution of values.

Figure 12. Hotspot Analysis for LST of Future Buildings

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, the development of the built-up structures in the study area and their accompanying changes Land Surface Temperatures are quantified using an existing model and then visualized. Factors contributing to the surface temperatures were also individually quantified, for the present and future projected scenarios, prior to the computations.

Generally, it has been observed through the visualization which structures have the highest temperatures, as well as the overall trends. When compared to the present situation, temperatures across the study areas have equalized, but at the same scale having high values.

5.2 Recommendations

Land surface temperatures may be correlated with the Urban Heat Island effect. Further refinements on the methods of projecting the building features for the future scenes, as well as the DEM assumption for computations can be explored.

The cognitive and intuitive effects of these visualizations and their consequent implications on the personal views of the stakeholders, residents, and the general public of the study area may be studied as an extension.

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