Tree Shade Optimization in an Urban Desert Environment

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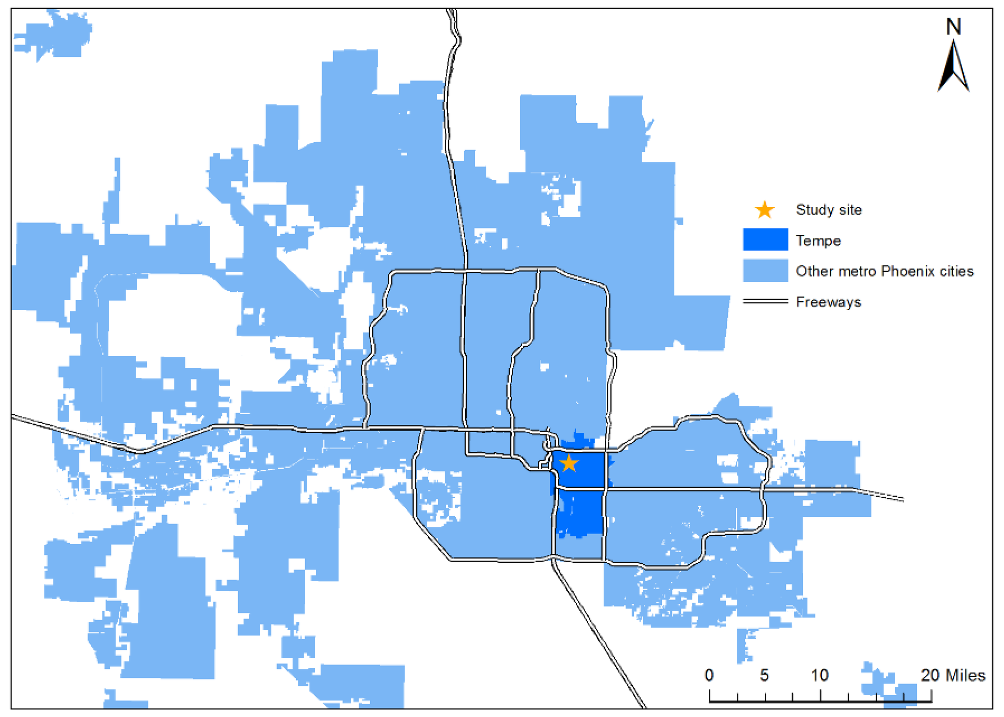
Introduction

Shade provided by trees, shrubs and other natural vegetation serves as a natural umbrella to mitigate insolation on residential and commercial buildings. In urban deserts strategically located tree shade potentially translates into significant energy and long-term cost savings as well as beneficial to human health and well-being. The goal of this research is to create and implement a new methodology to solve true 3D optimization problems by combining remote sensing (RS), geographic information system (GIS), and spatial optimization. We implement our methodology to maximize shade coverage on a single-family house in Tempe, Arizona.

Research Objectives

- Specify an integrated framework to solve spatial optimization problems in a 3D environment.
- Reconstruct 3D trees and buildings and derive tree shade for a given time of the day through remotely sensed imagery and GIS software.
- Develop a new 3D optimization model to maximize shade coverage on house rooftops and facades in a 3D environment for a single family house.
- Validate the optimal location of tree will provide better shade coverage to single-family houses in a 3D environment rather than a 2D environment.

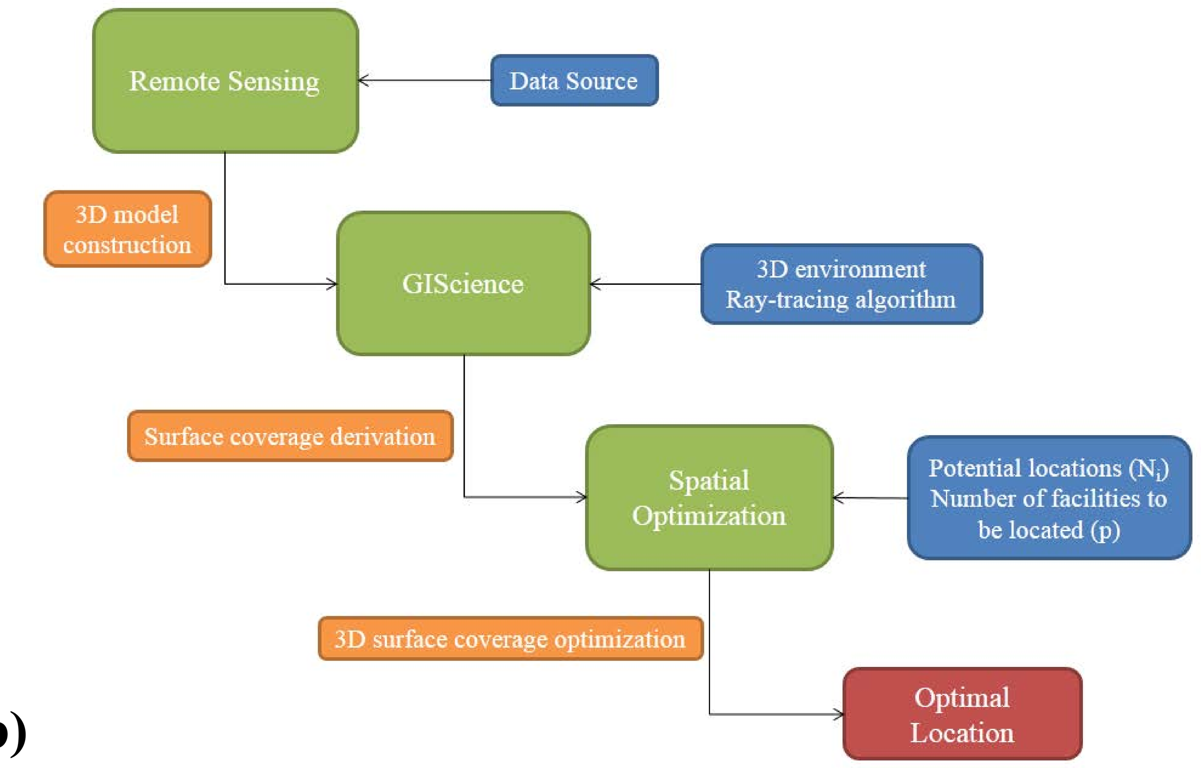
Study Area



(a)

Study site in Tempe, AZ. (Figure **(a)**)

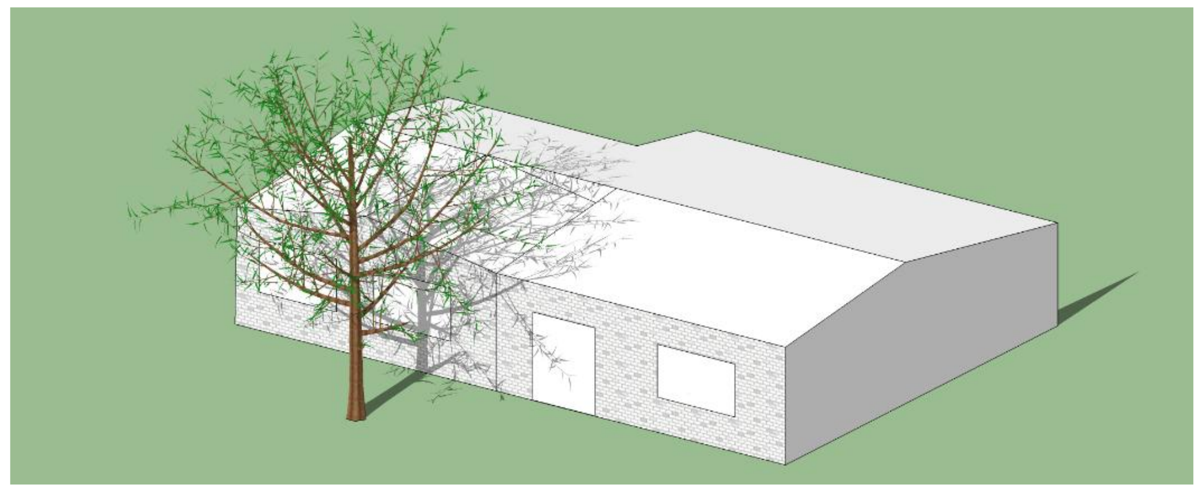
Methodology Framework



(b)

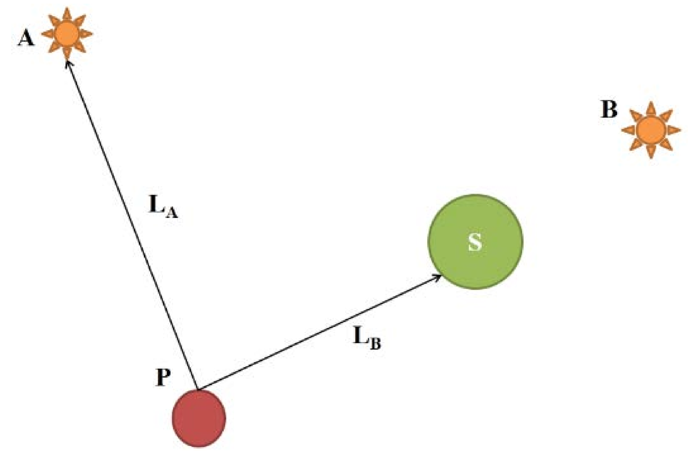
Figure **(b)** demonstrates the methodology framework for this research. It combines RS, GIS and spatial optimization to seek the optimal location of trees.

Results

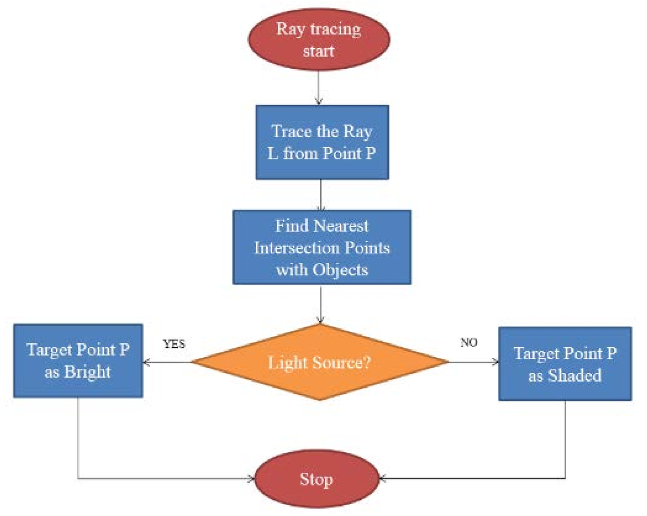


(c)

The 3D tree and building models are reconstructed as figure **(c)**. Digital surface model derived from LIDAR point clouds contributes high resolution elevation data for detailed construction of buildings and trees.



(d)



(e)

Shade derivation is conducted by ray-tracing algorithm as figure **(d)** and **(e)**.

Maximize:

$$\sum_i w_i \left(\sum_d \sum_t C_{itd} \right)$$

Subject to:

$$C_{itd} = f(g_i, X_j, h(t,d), j \in N_i)$$

$$\sum_j X_j = 1$$

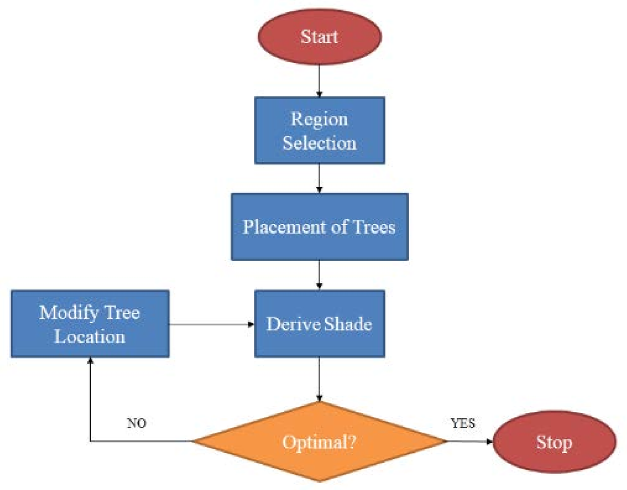
$$X_j = \{0,1\} \ \forall j$$

$$C_{itd} \geq 0 \ \forall i, t, d$$

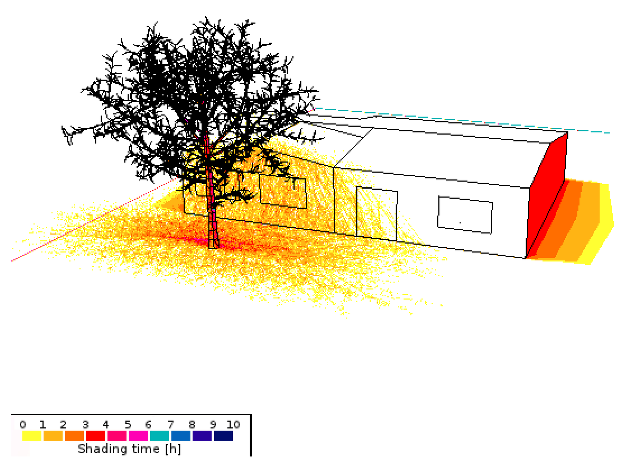
i = index of 3D surface components (roof = 1, façade = 2, windows/door = 3);
j = index of potential tree locations;
d = index of extreme heat summer days;
t = index of extreme heat hour in a day d;
w_i = weighting of surface component i;
g_i = area of surface component i;
C_{itd} = amount of surface component i covers on time t and day d;
p = number of facilities to be located;
X_j = 1 if tree located at potential site j, 0 otherwise.

(f)

Optimal location of the single tree is decided by spatial optimization model **(f)**.



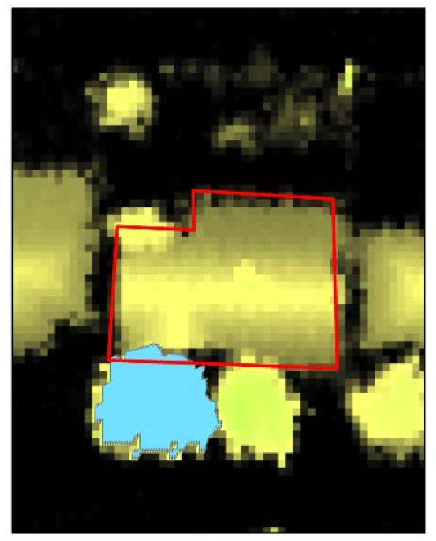
(g)



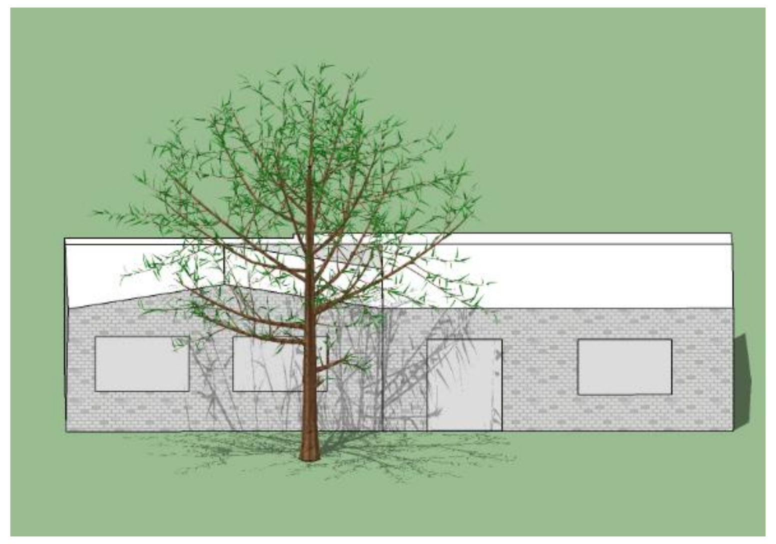
(h)

Figure **(g)** shows up the procedure for locating trees around the residential households. Optimal shade coverage intensity is shown as figure **(h).**

2D/3D results comparison



(i)



(j)

Figure **(i)** and **(j)** show tree shade derivation results from 2D and 3D environment at 2pm, August 15th. In the 3D environment, façade coverage can be successfully evaluated.

Conclusions

We propose and test our new framework combining RS, GIS and optimization to solve location-modelling problems in a 3D environment. We demonstrate and implement our new framework to maximize tree shade on a single-family house in Tempe, AZ, USA. Results show wisely relocating trees can improve shadow efficiency of a single-family house during summer months. Within the optimization process, we show how to differentiate spatial coverage on a 3D structure by calculating the shadow coverage on different house surfaces including windows and doors, facades and rooftops. Solving tree shade coverage optimization in a 3D environment will provide more convincing results than in a 2D environment.

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