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Effect of tree location on mitigating parking lot insolation

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A B S T R A C T

Urban land used for parking lots can contribute to the effect of overheating, whereas vegetation, especially high growth vegetation (trees), can mitigate this effect. Accordingly, in this paper we propose an algorithm, the inputs to which consist of predetermined parameters of a parking lot's geometry, trees and surrounding buildings, where the shadows help to mitigate the heat. The algorithm optimizes tree locations, aiming to provide maximum overshadowing of the parking lots, while leaving the useable parking area and the parking lot shape intact. The paper focuses on parameterization of elements that are important for this analysis process as well as combinatory calculations. These combinatory calculations are based on solar simulations, which are carried out, and take into account climate and geographical data. The algorithm is applied to several cases, depicting real world examples, as well as those based on design and greening instruction manuals. The results indicate that the tree locations estimated by the algorithm increase parking lot overshadowing, indicating that the algorithm efficiently decreases the negative influence of urban overheating.

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1. Introduction

Decreasing the overheating of built surfaces in urban areas has become an area of active research in the last several years. The urbanization process greatly increases surface temperature and influences the heat balance, whereas tree shade can provide effective cooling of urban areas (Armson, Stringer, & Ennos, 2012; Dugord, Lauf, Schuster, & Kleinschmit, 2014). Single storey parking lots in urban spaces represent potential overheating areas because they often occupy large urban spaces and most of the surface is covered by concrete. In addition, they are often exposed to direct solar radiation during most of the day. Multiple factors noted in literature have been found to affect the ratio of area in cities which is occupied by parking lots, and this ratio has been commonly found to be between 10% and 30% (Akbari, Davis, Dorsano, Huang, & Willett, 1992; Wolf, 2004; Willson, 2013; Kishii, 2015).

Vegetation is one of the most simple and effective ways of cooling the built environment. Urban vegetation has a great potential for the reduction of air temperature, as well as parking space temperature during the summer months (Akbari, Hashem, Dan, Bretz, & Hanford, 1997; Asaeda, Ca, & Wake, 1996). The results of various papers show that trees can reduce average surface temperature in summer months (Skelhorn, Lindley, & Levermore, 2014) and by planting low growth and high growth vegetation the higher temperatures of urban areas can mitigate even more heat (Onishi, Caob, Itoc, Shia, & Imura, 2010). Trees in the urban environment contribute to the control of overheating of the built surfaces (Dwyer, McPherson, Shroeder, & Rowntree, 1992; Merry, Siry, Bettinger, & Bowker, 2013; Chen, 2015; Pauleit & Duhme, 2000; Akbari, 2002). The possibility of reducing the undesirable effect of high solar radiation by green planting is often pointed out in scientific papers (Avissar, 1996; Taha, Konopacki, & Gabersek, 1999; Yu & Hien, 2006; Honjo & Takakura, 1991; Saito, Ishihara, & Katayama, 1990–1991; Kawashima, 1990).

Apart from the recognized benefits of trees, their location is very important because the insolation is dependent on it (Simpson, 2002). Increasing the number of trees is often not possible, so their distribution is the key to solving the problem of overheating. Computer methods for tree shadow evaluation, using meteorological data, have been used previously. The density, shape, dimensions of the crown and the position of the tree are parameters that affect the efficiency of cooling with vegetation and can prevent 95% of incoming radiation depending on the tree species (Akbari et al., 1992). In contemporary practice the rapid development of computational tools enables an interaction between 3D computer graphics, computer-aided design programs, and software tools suitable for precise solar analysis. For solar analysis and simulations of area overshadowing and the amount of solar radiation energy received on a given surface, software is intensively and widely used (Horvat & Dubois, 2012; D. Amado & Poggi, 2014).

The aim of this paper is to propose an algorithm which optimizes the location of trees on a parking lot in order to decrease overheating of the parking space surface area. The approach takes into consideration climate factors, parking orientation, surrounding buildings, tree size and parking spot location and size. The algorithm allows variation in the listed influences and is applicable to a wide variety of scenarios. It can also be used for parking lots in urban locations, combining the influence

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of surrounding building shadows, taking these shadows into account during tree location optimization. The majority of large parking lot areas overheat because of inadequate tree placement. By adequately positioning a fixed number of trees within a parking area it is possible to reduce solar exposure while leaving the useable parking area and the parking lot shape intact. The potential of the algorithm to solve a wide range of scenarios is illustrated through the analysis of overheating for several urban parking lot designs using simplified tree crowns. To evaluate the benefits of this algorithm we performed solar analyses for the summer months. We provide real world case studies in order to compare the insolation of parking lots with real tree locations to the result provided by the proposed algorithm.

The advantage of our approach over alternative approaches (such as microclimate or computational fluid dynamics (CFD) models) is the ability to analyze large number of different combinations in order to optimize greenery in the parking lots. Integration of Rhinoceros, Grasshopper and Ecotect, which we used in this paper, allows fast processing, powerful modelling capabilities and visual feedback of performance simulation results (Shi & Yang, 2013). In addition, compared to ENVI-met, Rhinoceros allows ease of 3D modelling and higher resolution of visual representations of the built environment. A single simulation of a scenario used in this paper lasts less than 30 s. A comparable simulation using ENVI-met may take up to a week, depending on the resolution used (Egerhazi, Kovacs, Takacs, & Egerhazi, 2014). In CFD models like ANSYS in similar applications, a single simulation lasts about 15 min (Dixit & Gade, 2015). Because of the time consuming process of running a large number of necessary simulations these approaches are not practical for estimating the optimal locations of trees on parking lots.

2. Methodology

The algorithm proposed in this paper estimates the optimal location for any given number of trees on a parking lot in order to decrease insolation, with the trade-off that trees occupy otherwise usable parking space. The algorithm methodology may be described as follows (Table 1). Each point in the table is elaborated upon.

i) For the first phase any 3D modelling software can be used to create a model. The model includes parking spots and surrounding buildings. The buildings cast shadows which have an influence on the parking space overshadowing. The model can be generated or imported into Rhinoceros, a computer aided design (CAD) software, to provide the digital environment for the parametric analysis.
   Afterwards, geometry referencing is performed in Grasshopper (a visual programming language, Rhinoceros plug-in). In this way the model geometry is prepared to be used and parameterized. Then, all feasible tree positions are determined. The tree is modelled in Grasshopper in order to include the necessary tree geometry characteristics in the analysis process.
ii) In the second phase, using programming language GHPython within Grasshopper, a list of tree position combinations is created, with predetermined number of trees populating certain parking spots. The final list of combinations is selected with respect to tree size and parking spot dimensions.
iii) The third phase refers to the solar simulation implementation, based on the final list of combinations. The simulations are performed in Ecotect, which is a software for solar analysis. Any climate data/meteorological data or different period of the year and period of the day can be considered for simulation in Ecotect. It calculates average daily insolation per square meter of parking surface, taking into consideration the geometry of trees and surrounding buildings, if any.
iv) The fourth phase includes exporting numerical results of solar radiation from Ecotect to Grasshopper, in order to detect an optimal result, which corresponds to an optimal location of trees on a certain parking space.

The flow of data between the different software within the proposed method is shown in Fig. 1.

Table 1
The algorithm methodology.

i) Geometry	Input geometry: –Parking spots –Buildings	Rhinoceros
	Referencing geometry inputs	Grasshopper
	Parking spot centres (possible locations of trees)	Grasshopper
	Input tree parameters: –Crown geometry –Height	Grasshopper
ii) List of combinations	Input: –Number of trees	GHPython
	All possible combination of trees	GHPython
iii) Solar analysis	Input climate data/meteorological data and time data: –Weather file –Period of the day –Period of the year	Ecotect
	Solar simulations (calculating the average daily incident solar radiation) for all combinations of trees	Ecotect
iv) Numerical results	Detecting optimal solution (location of trees)	Grasshopper

3. Algorithm

The aim of the proposed algorithm is to estimate the location of trees that provides maximum overshadowing of parking lots during the chosen period. Using the algorithm the location of a pre-defined number of trees which provides optimal overshadowing for a given parking lot is found without decreasing the useable parking area and without changing the parking lot shape.

3.1. Geometry

The parameters for the algorithm include the following geometry: geometric characteristics of parking space, surrounding buildings and trees. These parameters are user-defined.

Geometric characteristics of parking space are:

- parking lot shape,
- number of parking spots,
- parking spot dimension and
- orientation

The buildings surrounding parking lots may significantly influence parking space overshadowing and results. Geometric characteristics of buildings include base shape and height. Input data can be created in any CAD software, as long as it can be imported into Rhinoceros in order to provide the digital environment for the parametric study. The geometry of parking spots and buildings is referenced, which means that parking spots use planar surfaces parameters and buildings use solid form parameters in order to be used in Grasshopper.

In Grasshopper, parking spot centres are determined, respectively, by using a Grasshopper component that detects the centre point for any polygon shape. These centres represent a group of points, marked with numbers from 0 to n - 1. Each point represents a potential tree position.

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