The effect of vegetation on daylight availability

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Abstract

Simulating daylight in building spaces is becoming an increasingly important task to achieve sustainable and healthy building designs. However, accurate modeling of daylight necessitates the inclusion of environmental conditions as well as accurately modeling the buildings' surroundings, including obstructions. Obstructions in the form of vegetation such as trees and shrubs can significantly impact the daylight performance. This paper presents a parametric study of the effect of vegetation on the daylight performance of the building spaces. RADIANCE is used to simulate the effect of the vegetation obstructions on the daylighting. A routine is developed to parametrically create vegetation and outputs geometric descriptions that in the rad format, so that they can be easily incorporated into the RADIANCE scene description file. The developed routine allows for parametric variations of the tree shapes and configuration so that these values can be studied. A standard office space is used and the daylight performance is assessed using a daylight climate-based metrics namely daylight availability. The results demonstrate the importance of taking vegetation obstructions into account when modeling daylight performance.

1. Introduction

The effect of vegetation outside windows has not received enough attention in the literature on daylighting. Vegetation outside windows, similar to other obstructions, can significantly affect the lighting conditions inside any space. One can spend a significant amount of time designing and modeling windows and fenestrations to achieve a specific lighting performance inside a space only to find that unplanned vegetation outside the window has affected the simulated performance. This is true with many of the outside obstructions that need to be considered when modeling and simulating lighting conditions. However, with the case of vegetation, it may be easier to model and therefore predict the effect on lighting. The correct positioning of vegetation can also improve the daylighting performance of specific designs through shading, which decreases the amount of glare and maintains desirable illumination levels inside.

Given that vegetation can affect the lighting conditions in a space, a number of questions now need to be answered, firstly, how vegetation affects lighting conditions inside the space. A number of realistic and extreme case scenarios can be considered to answer this question. Secondly, how does the plant type affect the lighting conditions? Thirdly, what is the increased computational time taken to model the vegetation and when is it warranted to model and simulated it? Fourthly, what are the best ways to account for vegetation in a simulation, i.e. what is the best way to model the vegetation (in terms of detail, reflectivity, shape, etc…) and what is the best way to simulate the effect of vegetation?

The main objective of this paper is to study the effect of vegetation on daylight performance in building spaces. In particular it may be possible to positively influence the daylight performance inside the space by correct position of vegetation outside the window. We therefore, briefly, explore the effect of trees' location, configuration and shape parameters on the daylighting performance inside a space through a parametric study. We also develop a systematic parametric simulation model that determines the effect of the tree location, spacing, and corresponding window configuration in order to maximize the daylight performance of a typical building space.

This paper is organized as follows; in the next section we present the parameters of the trees used in the study as well as the variables considered. In the following section we discuss the other parameters studied and details about the simulation. Then, we present some of the results and analysis and this is followed by conclusions and recommendations for future research.

2. Considered tree types and parameters

Our study will only focus on trees rather than other types of vegetation such as shrubs or grass. Grass or shrubs outside a window, for example, can also have an effect on the lighting inside a room. In fact, in this paper we will only study two of the most common tree shapes namely, column and round trees. Trees come in several basic shape and configurations. Once recent classification (Nystad, 2010) included Spherical, Hemispherical, Cylindrical, Tapered cylindrical, Flame, Inverse conical and Tend flame tree shapes. Another classification is shown in figure 1. We will study round and column tree shapes and their impact on daylighting.

(a) (b) (c) (d)

(e) (f) (g) (h)

(a) Columnar Tree Shape, (b) Fastigiate Tree Shape, (c) Irregular Tree Shape, (d) Oval Tree Shape, (e) Pyramidal Tree Shape, (f) Round Tree Shape, (g) Vase Tree Shape, (h) Weeping Tree Shape

Fig. 1 – Basic Tree Shapes (adapted from http://treesandshrubs.about.com/od/treeshrubbasics/ig/Tree-Shape/)

We are primarily interested in creating a parametric model of a tree that changes its shape seamlessly from round to column shaped. Parametric trees are ones which are geometrically modeled using specific shape parameters and which are used in generating single body polygonal models of those trees that account for natural rules of growth. Parametric trees can be generated by a variety of techniques as discussed in de Reffye, et al 1988, Felkel et al, 2002, Felkel et al, 2002b, Honda, 1971, Prusinkiewicz and Lindenmayer, 1990 and Weber and Penn, 1995. Nystad, 2010 developed an algorithm that considers the number of branch levels to be produced, the shape exponent in da Vinci's equation, a parameter to describe the upward growth tendency, and the base tree scale. Also considered in this research were various leaf parameters.

In this research however, we opt to develop our own algorithm for generating parametric trees for simplicity and due to the need for robust calculations during simulation routines. We only seek to present a preliminary exploration of the effect of tree shape on daylighting and find indications on the best tree shape (column or round) and leaf density as well as the positioning and spacing. Therefore the algorithm developed here accounts for three main parameters namely, width, height and leaf density. Inherit in our algorithm is the leaf and trunk reflectivity values.
The algorithm for generating a tree is developed in Grasshopper for Rhino and is based on generating an ellipsoid which is then sliced into different sections. Points are then randomly generated on the perimeter of those slices at various intervals and leaves are created at those points. The shape of the underlying ellipsoid and the number and location of slices and points is also parameterized. For the leaves, shapes and density are also controllable. A leaf-shaped surface is generated from 2 spline curves at a certain scale. The leaves are assigned to the points on the tree. The scale is divided into two discrete scale steps so that the scale of the leaves does not vary significantly on the same tree. Each leaf is assigned a random scale from 1.0 to 2.0 and another set from 2.0 to 3.0 the size of a base leaf size. This allows modeling trees with randomly generated sizes at two scale steps that may represent different kinds of trees or two different seasons (broad leaf trees for example versus evergreens). We are therefore able to vary the shape of the tree easily by varying the height and width of the underlying ellipsoid as well as varying the leaf density. The leaf density is a variable calculated using the following equation:

$$Density = \frac{Total\ Area\ of\ Leaves}{Volume\ of\ Tree\ Boundry} \tag{3}$$

A parametric analysis can be easily conducted now taking into consideration the location of the trees outside the window as will be described next.

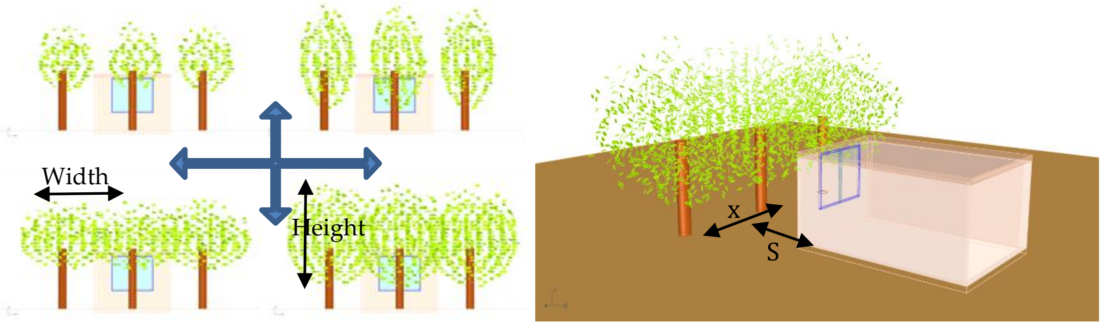


Fig. 2 – The two different shapes of trees considered and their parameters

Table 1 – The range of the parameters considered

Simulation Parameters	ab (ambient bounces)	**6**
	ad (ambient divisions)	1000
	as (ambient supersamples)	20
	ar (ambient resolution)	300
	aa (ambient accuracy)	0.1
Assigned Materials	Walls	Generic Interior Wall [Reflectance=50%]
	Floor	Generic Floor [Reflectance=20%]
	Ceiling	Generic Ceiling [Reflectance=80%]
	Window Frame	Metal Diffuse
	Window Glazing	Double Pane, Clear [Transmittance=80%]
	Ground	Outside Ground [Reflectance=20%]

3. Considered layout and configurations

In order to run the parametric analysis, a typical room design was considered representing a standard office. The room dimensions were 6 meters in length, 4 meters in width and with a height of 3 meters. The other room specifications are shown in table 1. The window for the space is facing south. The spacing (s), distance between the trees (x) shown in figure 1, the width, height and density of the tree can now be parametrically varied to study the effect on the overall lighting performance of any particular design. In order to run the daylighting analysis, Diva for Rhino was used and these parameters were varied. The RADAINCE specifications and simulation parameters are also shown in table 1.

Table 2 – The range of the parameters considered

Variable	**Range**
Width	4, 6
Height	3, 5
Scale	z, 2z*
x	2, 3, 4
S	3, 4

* Where z is the leaf size.

Table 2 shows the ranges of the parameters that were considered. The values were varied and each step was considered for evaluation. We had a total of 48 different cases resulting from 2 values for width, 2 values for height, 2 values for leaf size (which is translated to density according to the number of leaves; which increases according to the width and height of the tree), 3 values for spacing between trees and 2 values for distance between the trees and room (2x2x2x3x2 = 48). However, these 48 cases were divided by the scale parameter into two different sets of 24 cases each. This was done to insure that a reasonable scaling for the tree leaves was used. These two sets of 24 cases each were then run through RADIANCE and appropriate daylighting performance measures were calculated as discussed next.

4. Results and discussion

Daylight Availability (DA) was one of a number of daylight metrics that consider the annual performance of a particular design (as opposed to instantaneous measures such as daylight factor), now commonly referred to as 'dynamic daylight metrics'. DA is defined as 'the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylit alone' (Reinhart C F & Walkenhorst O, 2001)." Daylight availability is meant to amalgamate Daylight Autonomy and Useful Daylight Index information into a single figure.

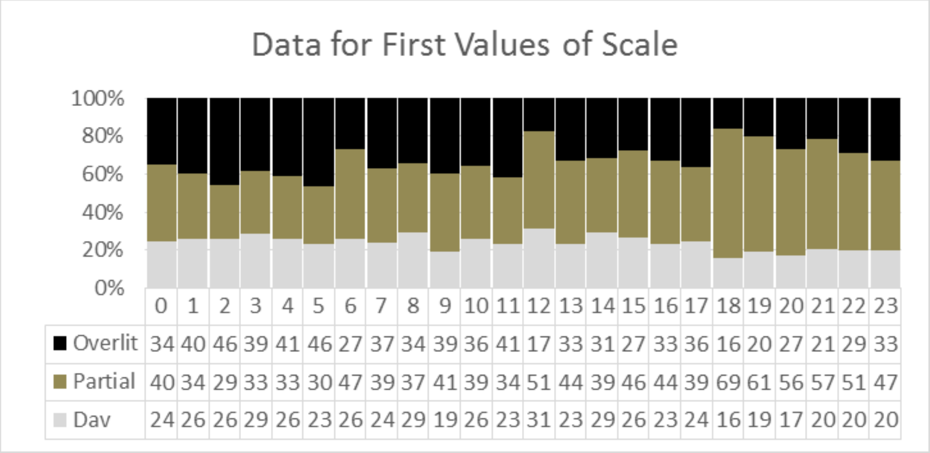
In calculating the DA, any number which is 'negative' represents 'over-lit' nodes (for example a DA value of -5% of occupied hours with 10-times the threshold illumination value). Any number between 49-100 percent represents 'day-lit' nodes (i.e. >48% of occupied hours with threshold illumination values). Similarly, any numbers 0-48 represents 'partially-lit' nodes (i.e. 0-48% of occupied hours with threshold illumination values). Table 3 summarizes this information. Therefore the Daylit, Partially Daylit or Overlit percentage for the space would be equal to:

$$DAv\ or\ Partial\ or\ Overlit = \frac{Number\ of\ Nodes\ in\ Range}{Total\ Number\ of\ Nodes} \quad (2)$$

The DA values in terms of Daylit percentage, and partially Day lit and overlit are calculated for the two different values of scale (leaf density) and are shown in figures 3 and 4. The values shown are for the entire space, they summarize the data for each case. Each case has 3 values; Daylit, Partially Daylit and Overlit. In order to determine what would be the best of these design options, we need to rank them according to a single criterion.

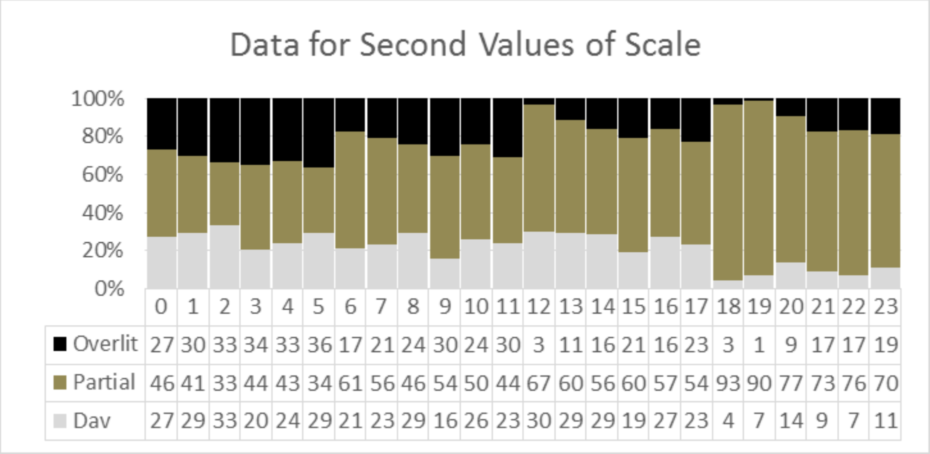
Table 3 – The levels of Daylight Autonomy Used

Indices	Range
Daylit	50% to 100%
Partially Daylit	0% to 50%
Overlit	< 0%



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
■ Overlit	34	40	46	39	41	46	27	37	34	39	36	41	17	33	31	27	33	36	16	20	27	21	29	33
■ Partial	40	34	29	33	33	30	47	39	37	41	39	34	51	44	39	46	44	39	69	61	56	57	51	47
■ Dav	24	26	26	29	26	23	26	24	29	19	26	23	31	23	29	26	23	24	16	19	17	20	20	20

Fig. 3 – The Daylight Availability Values for the first set of scale values (z)



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
■ Overlit	27	30	33	34	33	36	17	21	24	30	24	30	3	11	16	21	16	23	3	1	9	17	17	19
■ Partial	46	41	33	44	43	34	61	56	46	54	50	44	67	60	56	60	57	54	93	90	77	73	76	70
■ Dav	27	29	33	20	24	29	21	23	29	16	26	23	30	29	29	19	27	23	4	7	14	9	7	11

Fig. 4 – The Daylight Availability Values for the second set of scale values (2z)

Therefore, we used a measure that combines the three values of percentage over lit, partial Overlit and Day lit into one single measure. This measure may be more representative for ranking the design cases in terms of their daylight availability performance. Since we want to maximize the Daylit percentage and minimize the Overlit, we can divide the Daylit percentage by the Over lit percentage. This ensures that the bigger the difference, the higher is our factor since a higher nominator and a lower denominator increases the overall factor.

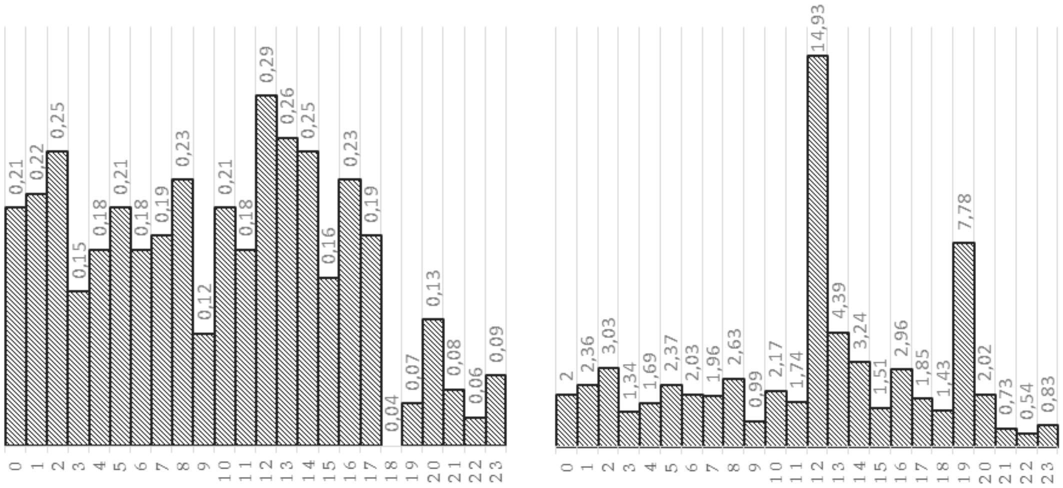
$$\text{Measure 1} = \frac{Daylit}{1+Overlit} \qquad (3)$$

Although this measure does not explicitly include the partially lit values, the percentage of the space that is partially lit is already inherit in this measure since the Daylit + the Overlit + the Partially Daylit must equal one. Therefore the bigger the difference between the Daylit and Overlit value, the higher the partially lit values. Another measure which takes the three values was also used and in this measure we penalize the high Overlit and Partially Daylit values and we reward the high daylight availability values by using the following formula:

$$\text{Measure 2} = \frac{Daylit}{Overlit * Partially\ lit} \qquad (4)$$

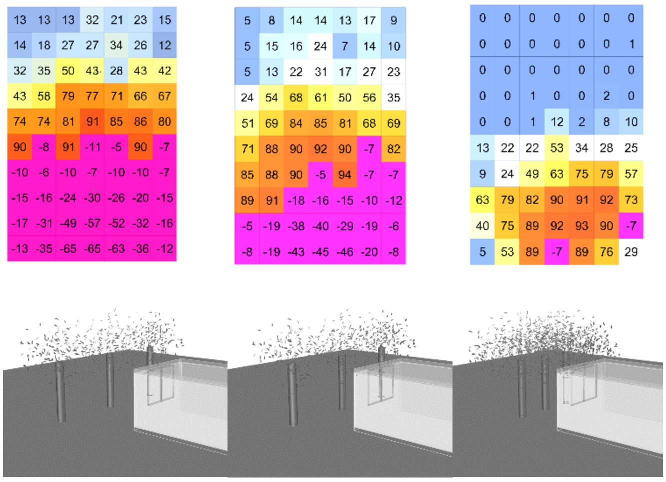
Both of these measures were calculated for the 24 cases and the results were plotted in figure 5. In figure 6, we present a comparison of some of the results from the most extreme cases in the data set. The grid values for daylight availability and the corresponding design scenarios are presented. It is evident from this data that for a simple design such as the one shown, circular trees are more favorable than column shaped trees. Also, it seems higher leaf density is favorable. This is probably due to the south-facing window. We simulated the best and worst cases with 6 ambient bounces for more reliable data and results and found improvement in the overall readings. Although we only simulated 3 conditions, which are the best case (12), the worst (5) and one in the middle (2) all for 2 ambient bounces, they have managed to maintain the same ranking within the 3 simulations.

Due to the time factor, we have managed to produce quick results with 2 ab, since they take far less time (10 mins each) while using 6 ab would take around 1 and 2 hours each. The results with 2 and 6 ambient bounces are shown in figure 7, while table 4 shows the data for some of the extreme cases.



(a) (b)

Fig. 5 – A comparison based on the two combined measure (a) measure 1 and (b) measure 2



13	13	13	32	21	23	15
14	18	27	27	34	26	12
32	35	50	43	28	43	42
43	58	79	77	71	66	67
74	74	81	91	85	86	80
90	-8	91	-11	-5	90	-7
-10	-6	-10	-7	-10	-10	-7
-15	-16	-24	-30	-26	-20	-15
-17	-31	-49	-57	-52	-32	-16
-13	-35	-65	-65	-63	-36	-12

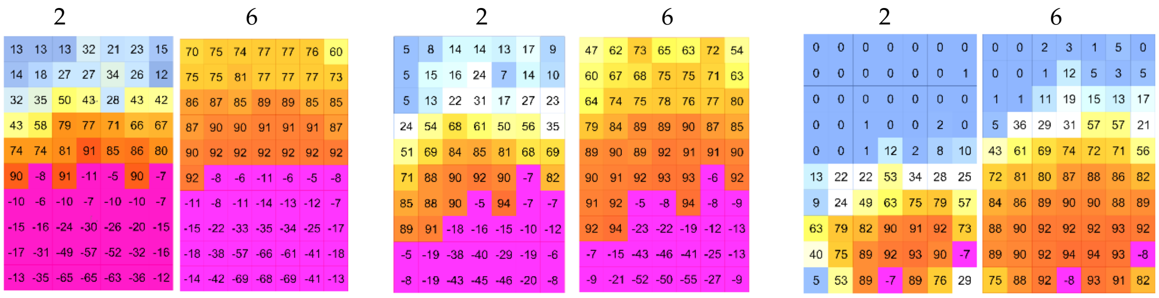
5	8	14	14	13	17	9
5	15	16	24	7	14	10
5	13	22	31	17	27	23
24	54	68	61	50	56	35
51	69	84	85	81	68	69
71	88	90	92	90	-7	82
85	88	90	-5	94	-7	-7
89	91	-18	-16	-15	-10	-12
-5	-19	-38	-40	-29	-19	-6
-8	-19	-43	-45	-46	-20	-8

0	0	0	0	0	0	0
0	0	0	0	0	0	1
0	0	0	0	0	0	0
0	0	1	0	0	2	0
0	0	1	12	2	8	10
13	22	22	53	34	28	25
9	24	49	63	75	79	57
63	79	82	90	91	92	73
40	75	89	92	93	90	-7
5	53	89	-7	89	76	29

Fig. 6 – Comparison between cases 2, 5 and 12 showing the DA Values for the standard room grid under three different cases of design

Table 4 – The data for some extreme cases

Case 2		**Case 5**		**Case 12**	
Number of Bounces		**Number of Bounces**		**Number of Bounces**	
2	6	2	6	2	6
S_R_2	**S_R_2**	**S_R_5**	**S_R_5**	**S_R_12**	**S_R_12**
2	2	5	5	12	12
WWR	**WWR**	**WWR**	**WWR**	**WWR**	**WWR**
40%	40%	40%	40%	40%	40%
Half Width	**Half Width**	**Half Width**	**Half Width**	**Half Width**	**Half Width**
2	2	2	2	3	3
No. of Leaves	**No. of Leaves**	**No. of Leaves**	**No. of Leaves**	**No. of Leaves**	**No. of Leaves**
645	645	645	645	1662	1662
Density	**Density**	**Density**	**Density**	**Density**	**Density**
0.695063	0.695063	0.359112	0.359112	0.787968	0.787968
Half Height	**Half Height**	**Half Height**	**Half Height**	**Half Height**	**Half Height**
1.5	1.5	1.5	1.5	1.5	1.5
X [tree-tree]	**X [tree-tree]**	**X [tree-tree]**	**X [tree-tree]**	**X [tree-tree]**	**X [tree-tree]**
4	4	4	4	2	2
S [tree-room]	**S [tree-room]**	**S [tree-room]**	**S [tree-room]**	**S [tree-room]**	**S [tree-room]**
3	3	4	4	3	3
DAv	**DAv**	**DAv**	**DAv**	**DAv**	**DAv**
33	64	23	51	30	59
partial DA	**partial DA**	**partial DA**	**partial DA**	**partial DA**	**partial DA**
33	1	30	0	67	39
Overlit	**Overlit**	**Overlit**	**Overlit**	**Overlit**	**Overlit**
33	34	46	49	3	3



2

13	13	13	32	21	23	15
14	18	27	27	34	26	12
32	35	50	43	28	43	42
43	58	79	77	71	66	67
74	74	81	91	85	86	80
90	-8	91	-11	-5	90	-7
-10	-6	-10	-7	-10	-10	-7
-15	-16	-24	-30	-26	-20	-15
-17	-31	-49	-57	-52	-32	-16
-13	-35	-65	-65	-63	-36	-12

6

70	75	74	77	77	76	60
75	75	81	77	77	77	73
86	87	85	89	89	85	85
87	90	90	91	91	91	87
90	92	92	92	92	92	92
92	-8	-6	-11	-6	-5	-8
-11	-8	-11	-14	-13	-12	-7
-15	-22	-33	-35	-34	-25	-17
-18	-38	-57	-66	-61	-41	-18
-14	-42	-69	-68	-69	-41	-13

2

5	8	14	14	13	17	9
5	15	16	24	7	14	10
5	13	22	31	17	27	23
24	54	68	61	50	56	35
51	69	84	85	81	68	69
71	88	90	92	90	-7	82
85	88	90	-5	94	-7	-7
89	91	-18	-16	-15	-10	-12
-5	-19	-38	-40	-29	-19	-6
-8	-19	-43	-45	-46	-20	-8

6

47	62	73	65	63	72	54
60	67	68	75	75	71	63
64	74	75	78	76	77	80
79	84	89	89	90	87	85
89	90	89	92	91	91	90
90	91	92	93	93	-6	92
91	92	-5	-8	94	-8	-9
92	94	-23	-22	-19	-12	-13
-7	-15	-43	-46	-41	-25	-13
-9	-21	-52	-50	-55	-27	-9

2

0	0	0	0	0	0	0
0	0	0	0	0	0	1
0	0	0	0	0	0	0
0	0	1	0	0	2	0
0	0	1	12	2	8	10
13	22	22	53	34	28	25
9	24	49	63	75	79	57
63	79	82	90	91	92	73
40	75	89	92	93	90	-7
5	53	89	-7	89	76	29

6

0	0	2	3	1	5	0
0	0	1	12	5	3	5
1	1	11	19	15	13	17
5	36	29	31	57	57	21
43	61	69	74	72	71	56
72	81	80	87	88	86	82
84	86	89	90	90	88	89
88	90	92	92	92	93	92
89	90	92	94	94	93	-8
75	88	92	-8	93	91	82

Fig. 7 – The results with 2 and 6 ambient bounces

5. Conclusions

Tree parameters studied were reflectivity of tree leaves, density of leaves and tree size. A parametric study was conducted using a fixed tree type and variable parameters, which include tree dimensions, leaf density, spacing and distance from window. It demonstrates that vegetation can affect the lighting conditions in a space to a significant degree. For a simple rectangular south-facing window, round trees are more favourable with a higher tree density and a relatively close spacing with a relatively small distance from the window. It is possible to determine a relatively good solution in reasonable simulation time, by considering a basic tree model such as the one described in this paper. Future recommendations include studying more tree types and various other design parameters as well as better parametric tree models account for other tree morphological aspects.

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