Making reasonable decisions for a greening plan: effects of the distribution of shading duration by building structures

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Abstract

This study aims to find out the shading effect of building structures for an effective plant design. The concept of sunlight duration for building structures is employed, and is built into a 3-D analytic model by AutoLISP and AutoCAD. For a practical concern, it might serve as a reference for plant selection and disposition in a courtyard design. This paper presents a case study of the Life Science Building in NTU. We begin with the simulation of illumination conditions on its north plaza on the spring equinox, summer solstice, autumn equinox, and winter solstice. The illumination conditions are classified into four levels: <1 hour, 1~2.5 hours, 2.5~4 hours, and >4 hours. The illumination level is compared to the actual greening condition of the bases. The result shows that the illumination conditions of the plants differ within a year in terms of the shading duration. In addition, the sunlight condition changes within a day. During the four hours before and after noon, the sun has the highest angle and the strongest light, so most foliage plants are likely to be burnt, dehydrated, or wilted. Therefore, shade-oriented plants should be arranged away from unshaded place. Finally, to save maintenance cost, it is recommended that plants with different degrees of shade-resistance should be chosen according to the computer simulated sunlight condition before they are distributed to the 32 fixed flowerbeds. Usually, the same plants are used in different areas in the planning of courtyards, which is nevertheless a questionable technique.

Keywords: computer simulation, shading duration, planting design.

1 Introduction

Illumination control is one of the crucial elements in horticultural techniques. Many physiological processes of plants are closely related to the quality,
strength, and cycle of sunlight. However, the artificial climate controlled by phytotron is radically different from the micro-climate condition around the buildings. While greening is most necessary in the surroundings of a building, these areas are, nevertheless, stressful environments to the plants. Consequently, when designing the plants, a further plan must be made to ensure the minimum sunlight on the plants, so that the cost of care and management could be decreased.

Because the areas surrounding the building have different degrees of shade and are also affected by other buildings, for a reasonable and practical standard of plant choice, the environment condition should be attained in advance.

This study simulates the shade condition by a 3D analytic model according to the shape, direction, and height of the building in a hope that it could make convenient and efficient the greening work under different levels of sunlight.

2 Levels of sunlight conditions and characteristic of the plants

2.1 Photosynthetic flexibility

Insufficiency of sunlight has a visible influence on the photosynthesis process of plants (McGree and Troughton [5]). In 1982, Bazzaz and Carlson [2] coined the term “photosynthetic flexibility” to recount the difference between sun plants and shade plants. The main point of this idea is that sun plants have apparently different degrees of photosynthesis under light and dark environments while shade plants have a consistent function of photosynthesis under different light conditions.

Actually, long-term insufficiency of illumination will hinder the stem growth (Barden [1]), fruit development (Jackson et al [4]), and budding differentiation (Cain [3]) of both sun plants and shade plants, seriously affecting the visual quality and the greening effect. To evaluate the shading effect of the building structure in a plant design program, we present a preliminary categorization in terms of the length of time when sunlight shines directly on the plants.

2.2 Levels of sunlight condition

The illumination conditions appropriate for greening are classified into four levels and compared with the computer-simulated sunlight curve of the building structure. By this approach, we could explore effectively the growth conditions and the countermeasures of plant cultivation. See table 1.

<table>
<thead>
<tr>
<th>Degree of sunlight conditions</th>
<th>1st Degree</th>
<th>2nd Degree</th>
<th>3rd Degree</th>
<th>4th Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of sunshine</td>
<td>More than 4 hours</td>
<td>4 – 2.5 hours</td>
<td>2.5 – 1 hours</td>
<td>Less than 1 hour</td>
</tr>
</tbody>
</table>
3 The development of system model

3.1 Graphics of the building shade

Possible duration of sunshine: Measure the time duration within a day when sunshine on the ground.
Duration of sunshine: Refers to the actual amount of time within a day when the sun directed shines on the ground.
Rate of sunshine: Refers to the ratio of the duration of sunshine to the possible duration of sunshine.
Declination angle: Simply termed as declination, represented by δ. The value of δ changes each day, ranging from 23º 27′ ≧ δ ≧ -23º 27′ in a year.
Hour angle: Represented by t, divided into two parts with the middlemost point when the sun is in the mid of the sky. The time before the noon is assigned + while after the noon, −.
Angle of sun-height: \[ \sin h = \sin \delta \cdot \sin \delta + \cos \delta \cdot \cos \delta \cdot \cos t \]  (1)
Angle of sun-direction: \[ \sin A = \cos \delta \cdot \sin t / \cos h \]  (2)
Calculation of time for sunrise and sunset: \[ \cos t = - \tan \delta \cdot \tan \delta \]  (3)

At the latitude degree of the base, measure the data on the appointed day in the chosen time slots. According to the testing time, establish in turn the shade model and the shade graph of each building structure.

![Sun declination angle](image1)

Figure 1: Sun declination angle.

![Coordinates of the curved line of the shadow](image2)

Figure 2: Coordinates of the curved line of the shadow.

3.2 Development of the model for building shade

a. Open DWG file; the file should be established by the “establishment of estimated figure model” function.
b. Load application program BS.lsp, load menu file BS.mnc, pop down the menu “sunlight” and choose “establish shadow model.”

c. Within the dialogue frame DCL, decide the declination, date, testing timeframe and other related variables.

d. Choose building structure; multiple choices are allowed.

e. After establishing the shadow model, press on the AutoCAD’s “3-D dynamics” command or related view command to see shadow results.

1 Decide on declination, date, and testing time
   1-0 Load DCL defining file  c:\TS\building_shadow.dcl
   1-1 Initial values of variables
   1-2 Initial values in dialogue frame DCL
   1-3 Date modified
   1-4 Inspect entered numerical value
   1-5 Modifications in angles, minutes, and seconds
   1-6 Inspection of rationality of variables

2 Establish the list of sun
   2-1 Calculate the position of the sun
   Transmit back (Date (height h azimuth A time t) (h A t) ....)

3 Choose building structures and establish shadow model
   3-0-1 Choose building structures
   3-0-2 Repeat based on sequence time
   3-0-3 Repeat based on the chosen of building structures
   3-1 Calculate roof point coordinates
   3-2 Establish list (((roof point coordinates)(shadow point coordinates))..)
   3-3 Use hatch command to draw shadow

Figure 3: Program system.
4 Discussion on methodological application and case study

4.1 Case choice and investigation

4.1.1 Major reasons for the case choice
a. The building has 13 stories, and is free from the influence of other building structure, which enables the clear and accurate observation on the shadow of the building.
b. The major garden is in the north. It has 32 fixed cement flowerbeds and several rows of plants for observation.
c. In its neighborhood, a phytotron and an experimental farm provide an accurate measuring station of relevant microclimate condition. The long-term recording is of great help for studies hereafter.

4.1.2 Base inspection and shade simulation
The Life Science Building of National Taiwan University joints the 12-meter wide Choushan Road in its north side. The circle lobby extends as an encircling winding corridor, which serves as the boundary of the major plaza. The distribution and species of the plants here are investigated, compared with the computer-simulated shading duration which calculating by 50×50 cm unit. The results are examined respectively for each section.

Table 2: Plants in the front garden of the Life Science Hall.

<table>
<thead>
<tr>
<th>Area</th>
<th>Plant name</th>
</tr>
</thead>
<tbody>
<tr>
<td>District A – Side of the lobby</td>
<td>• Alocasia macrorrhiza L. Schott &amp; Endl</td>
</tr>
<tr>
<td></td>
<td>• Asplenium antiquum Makino Asplenium nidus L.</td>
</tr>
<tr>
<td></td>
<td>• Duranta repens L.</td>
</tr>
<tr>
<td>District B – Surrounding bicycle stand</td>
<td>• Scheffera arboricola</td>
</tr>
<tr>
<td>District C – Flower bed on the winding corridor of the plaza</td>
<td>• Syngonium podophyllum</td>
</tr>
<tr>
<td></td>
<td>• Asparagus densiflorus Kunth</td>
</tr>
<tr>
<td></td>
<td>• Lantana camara</td>
</tr>
<tr>
<td>District D – Flower bed along the Choushan Road</td>
<td>• Polyscias guilfoylei</td>
</tr>
<tr>
<td></td>
<td>• Cupressus macroglossus cv.Goldcrest</td>
</tr>
<tr>
<td></td>
<td>• Ehretia microphylla</td>
</tr>
<tr>
<td></td>
<td>• Coleus blumei</td>
</tr>
<tr>
<td></td>
<td>• Melastoma candidum D. Don</td>
</tr>
<tr>
<td></td>
<td>• Impatiers wallerana</td>
</tr>
<tr>
<td>District E – Corner lot on the circle lobby entrance side</td>
<td>• Ixora williamsii cv.Sunkist</td>
</tr>
</tbody>
</table>
Figure 4: The site of the Life Science Building of National Taiwan University.

Figure 5: The shade illustrations on vernal / autumnal equinox.
Figure 6: The shade illustrations on summer solstice.

Figure 7: The shade illustrations on winter solstice.
4.2 Results and discussion

4.2.1 District A: Side of the lobby
A1. Base of the northern wall of the structure: The sun-oriented *Duranta repens* L. are planted here. From the shade illustration, it is observable that there is an obvious difference between the two ends of the plant row in terms of the sunlight conditions. At the east side close to the entrance, the shadow cast by the building stays for a long time. Consequently, it hinders the flower from displaying the unique golden color. Their leaves are sparse and the height is reduced by one-forth.

A2. Corner lot besides the lobby entrance: From the two shade illustrations on vernal/autumnal equinox and winter solstice, it can be seen that the time duration of sunlight in this place is less than one hour. The ground covers planted here are mainly *Asplenium antiquum* Makino *Asplenium nidus* L. and *Nephrolepidaceae*, which favor high temperature and humidity but dislike direct sunlight. They are accompanied with *Alocasia macrorrhiza* L. Schott & Endl, which thrives even in weak sunshine. Plants here display multi-degree of greening as well as good growth.

4.2.2 District B: Surrounding bicycle stand
*Scheffera arboricola* are planted here for space boundary. It is a sturdy shrub which thrives under both bright light and shaded darkness. However, the spotted leaves of *Scheffera arboricola* should be exposed under strong sunlight in order to produce beautiful spots. Among the two bicycle stands, B2 have a higher degree of shading compared with B1.

4.2.3 District C: Flower bed on the winding corridor of the plaza
There are 29 fixed cement flowerbeds on the inner side and the outer side of the corridor pillars. 17 of them face the plaza, and are planted with lantana, a sun-oriented small shrub. The other 12 flowerbeds outside the circle are planted with *Asparagus densiflorus* Kunth combined with *Syngonium podophyllum*; both are shade-resistant plants. *Syngonium podophyllum* is a very ideal indoor foliage plant, taking only 300lux to maintain life. However, it does not react favorably to sunlight in summer. It is thus observed that *Syngonium podophyllum* in some of the flowerbeds along the road are sunburned and dehydrated whereas those near the building structure are lush and verdant.

As a whole, because the corridor extends very long, the illumination condition along the road is greatly different from that around the building.

4.2.4 District D: Flower bed along the Choushan Road
There are three flowerbeds which serve as the boundary between the plaza and the Choushan Road. D1 is planted with *Coleus blumei*, which takes strong sunlight for display of its bright color and thus serves as the index for adequacy of illumination. They are arranged with *Ehretia microphylla* and *Polyscias guilfoylei*, which are small shrubs with graceful and elegant appearance. As a whole, plants in D1 enjoy a favorable growth. As for D2, the sunshade graph has shown that it stays under the shade of the building for a long time. Also,
three tall arbors beside the flowerbeds spread out and cast their shade on this area, highlighting the shading situation of D2.

The major focus of sight on the plaza are two long-lived *Ficus wightiana* Wall. ex. Benth and a *Celtis sinensis*, who spread out their branches gracefully. The shading graph could be gained through calculations and graphics. Consequently, it has been observed that the plants in the D2 flowerbeds under the shade of big trees display poor growth and show obvious indentations. It is recommended that ground covers with high shade-resistance should be patched on this area to decrease the cost for maintenance.

**4.2.5 District E: Corner lot on the circle lobby entrance side**

According to the shading graph on winter solstice and summer solstice, the time duration of sunshine in this district is less than four hours, being the area with the longest time duration of shading due to the shadow of the building structure. During our investigation, the previously planted *Ixora williamsii* cv. *Sunkist* has been partly replaced by large pebbles to solve the problem of insufficient sunlight.

## 5 Conclusion and suggestions

### 5.1 Conclusion

In terms of the photosynthesis flexibility, shade has a greater effect on sun plants than on shade plants. For instance, the *Duranta repens* L. in this case are planted on the base of the northern wall of the structure, where shade stays all year around. If one considers using the greening standard of the fixed CO₂ volume set by the present green structure as the index, in a long-term perspective, the shading effect on the plant cultivation should be carefully evaluated for fully function of plant photosynthesis.

Besides, according to the shading condition within a day, the sun has the highest angle and the strongest light emission during 10~14 o’clock, causing sunburn, dehydration, wilting and other damages to most foliage plants. In this case study, the shading condition in district C (the flowerbeds on the outer side of the corridor) changes drastically from degree 1 to degree 4, which results in the apparently different growth of *Syngonium podophyllum*. Parts of the flowerbeds are in fact unfavorable environments for shade foliage plants.

Finally, According to the shade graph, district E is a heavily shaded area even on the most radiant summer solstice. If the minimum sunlight for plants could not be guaranteed, it is recommended that plants be substituted by rock courtyard, sculptures, patch of pictures, or water flow.

In the 1933 Conference of Agreement for Green Areas Planning in Tokyo, green area is defined as “permanent space unshaded by building structures” [6]. In fact, any effective greening plan must have taken the land typology into consideration. Generally speaking, there are different methods for evaluating the greening standard in the outer space of building structures, for example, “rate of ground cover”, “greening visibility rate”, and “greening coefficient”, etc.
However, the greening quality is also highly dependent on the effect of shade. Calculating the effect of sunlight duration decrease according to the shading condition in each direction of the building will definitely help us make reasonable decisions in a plant design program.

5.2 Aspects for further studies

This study presents a preliminary simulation of illumination condition, aiming at the understanding for the exact location of the shadow cast by the building and the time length during which the flowerbeds stays in the shade. As for the evaluation of its impact on different plants, the exact amount of decrease in sunlight strength should be further taken into accounts. Due to the personnel and budgetary limitations, it is reserved for further research.

References


