Modeling Nightscapes of Designed Spaces – Case Studies of the University of Arizona and Virginia Tech Campuses

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Abstract

This paper examines two methods for modeling the interaction between designed spaces and nighttime light pollution. Nightscapes are becoming more important because of their potential effects on energy use and sustainability, public health, ecology, astronomy, safety and security, and placemaking.

Despite its growing importance, however, consideration of the nightscape is often an afterthought in the design process. Except for engineering drawings of lighting systems and occasional atmospheric renderings of nighttime scenes, nightscapes are not depicted. Considerations for nighttime users and for energy savings through sustainable nightscape design practices are lacking. Although several factors may contribute to this omission, including a failure to address nightscape design in landscape architecture education, the lack of appropriate tools for studying the effects of various design alternatives on light pollution is a critical issue.

This study compares two methods of modeling and depicting light pollution. The case study sites are the campuses of the University of Arizona and Virginia Tech both located in the United States. The author has been collecting lighting data for both campuses for the past few years. At the University of Arizona campus in Tucson, Arizona, high-resolution nighttime aerial photographs were taken using a helicopter. By compositing these images, the nightscape of the entire campus was represented. In contrast, the nightscape of the Virginia Tech campus in Blacksburg, Virginia was modeled using a completely different method. Lighting data from approximately 2,000 sampling points on a 10-meter grid were collected on the ground using light meters. Using the ArcGIS spatial analyst tool, a comprehensive picture of the campus nightscape was acquired.

The nightscape modeling method used on the Virginia Tech campus proved to be quicker, simpler, and less expensive compared to the method used for the University of Arizona campus. Undergraduate students taking a land analysis course collected and analyzed the data and were able to model the nightscape inexpensively. Another advantage of the method used at Virginia Tech is the ability to collect data that is difficult to gather with aerial images, such as exact locations of light fixtures, surface materials used on the ground or on the buildings, proximity to buildings, existence of different types of vegetation, and overhanging trees.
1 Introduction

Although a significant portion of human activity takes place at night, little attention has been paid to the design of nighttime spaces by landscape architects, except for lighting design research. Much of this research has focused on (1) the aesthetics of lighting design or (2) the efficacy of bright lighting for crime reduction. More recently, sustainability concerns have brought attention to light pollution issues. This, in turn, has shifted the emphasis in lighting design from advocacy for brighter lights to the reduction of light pollution and energy costs. For example, in the United States, LEED (Leadership in Energy and Environmental Design) sustainable design guidelines identify light pollution reduction as an important factor for sustainability. In addition, light pollution has been shown to affect human and ecosystem health (SHAFLIK 1997, BORG 1996, BELL 1999).

Currently, one of the most common design responses to the problem of light pollution is the use of full cut-off lights in outdoor spaces (fixtures that do not emit light above the horizontal plane). Although these lights can successfully reduce light pollution, they are only one part of a comprehensive strategy of light pollution mitigation that addresses not only lighting fixture design but also a broader set of factors in the designed environment. For example, the effects of surface material reflectivity on light pollution are rarely addressed in the research literature, despite the fact that even with the use of cut-off lights, light that strikes reflective surface materials in the designed environment will still be reflected upward.

One reason for this rather one-dimensional approach to the reduction of light pollution may be the lack of methods for measuring light pollution that also provide sufficient detail about the built environment. This has hampered efforts to provide an understanding of the relationship between design elements and light pollution. More specifically, practical methods for measuring light pollution on the ground lack the detail necessary to see the relationship between the design of a space and the light pollution it produces. Over the last decade, many have studied artificial night lights using satellite imagery (ELVIDGE et al. 1997, CINZANO et al. 2000, CINZANO et al. 2001, CHALKIAS et al. 2006). However, the resolution of the images used in these studies was too coarse to correlate light pollution with space design.

As possible alternatives, this study examines two additional methods for collecting light pollution and space design data: high-resolution nighttime aerial imagery acquired using a low-flying aircraft and a ground survey method. The high-resolution imagery developed with these methods will allow an understanding of the relationship between materials used in designed spaces (and ultimately, the overall design of spaces) and light pollution.

2 Methods

This study compares two methods for modeling and representing light pollution. Both methods were developed by the author (an aerial photography engineer was consulted on Method 1) after finding that high-resolution light pollution imagery did not exist.
The case study sites selected are two U.S. university campuses: the University of Arizona in Tucson, Arizona, and Virginia Tech in Blacksburg, Virginia. The author has been collecting lighting data for both campuses for several years.

The nightscape of the University of Arizona was modeled using aerial photography (Method 1). High-resolution nighttime aerial images were acquired using a helicopter, gyro-mounted camera equipment, and aerial imagery expert services. By compositing the nighttime images, the nightscape of the entire campus was represented.

As an alternative, the nightscape of the Virginia Tech campus was modeled using lighting data collected on the ground (Method 2). Lighting levels were collected using light meters at almost 2,000 sampling points on a 10-meter grid. Using the ArcGIS spatial analyst tool, a comprehensive picture of the nightscape was then acquired.

2.1 Method 1

The study site for Method 1 is the University of Arizona campus. This campus is fairly flat, with an average slope of about 1%. The elevation ranges from approximately 2,415 feet to 2,465 feet above sea level. The majority of light fixtures on the campus are cut-off lights.

To capture high-resolution, high-accuracy nighttime images, three flights were conducted by an Aerial Archives' photographer (June 1, 6, and 7, 2005). The first was a test flight over the Stanford University campus in Palo Alto, California on the evening of June 1. This flight was designed to identify the kind of nighttime photography most useful for capturing high-resolution nighttime images. The second and third flights were flown over the University of Arizona campus on the evenings of June 6 and 7. Visibility was excellent on both evenings, but wind direction and velocity were far more suitable on June 7 for creating the kind of imagery most useful for the study.

Imagery from the second and third flights was created using a Pentax 67II film camera mounted on a Kenlab gyroscopic stabilizer and equipped with a Pentax 105mm f/2.4 lens. The images were captured at 5,000 feet above ground. The sky was clear, and no rain had fallen for several days. Sunset was at 7:28 p.m. MST on June 7, 2005, and Astronomical Twilight (when the sun is 18 degrees under the horizon) was at 9:08 p.m. MST. The moon also set at 8:42 p.m. MST. Thus, dark conditions were maintained between 9:00 p.m. and midnight. In addition, the lighting at all campus athletic facilities was turned off in order to get the optimum result. Finally, although the data for Method 1 were collected during summer, the trees in Arizona are generally short and their leaves are small enough not to affect the readings.

2.2 Method 2

Method 2 used a ground-level survey conducted with a light meter. Lighting levels were measured along a 10-m sampling grid on the Virginia Tech campus. The total number of sampling points was 1,955 (Fig. 1).
The study area, which is a small part of the campus, is about 20 hectares (195,588 m²). Elevation ranges from 2,032 ft (619 m) to 2,084 ft (635 m). The site slope is not as flat as the University of Arizona campus but is generally under 10% slope (93% of the site). Unlike the University of Arizona, non-cut-off lights are still used.

Extech EasyView 30 Light Meters were used for the data collection (Fig. 2). Data were collected on moonless nights after astronomical twilight, when the sun was at least 18 degrees below the horizon, in order to remove the influences of moonshine and sunshine.
This resulted in a very small window of opportunity each month. In addition, the sampling points were collected only during cloudless nights. Two readings were collected for each sampling point. One was collected with the light meter pointing upward to catch direct light from the light fixtures at 30 cm from the ground. The other reading was taken with the light meter also held at 30 cm from the ground, but this time pointing down to measure reflected light. This second measurement is comparable to the data collected from the aerial method.

The same two readings were also collected for the same points during the daylight in order to calculate surface material reflectivity. Reflectivity was calculated by the ratio of downward light reading over upward light reading at 30 cm above the ground.

Other data collected for each sampling point were surface material and sky cover (%) by trees and structures. To control the influence of the tree canopy, data collection was done before or after tree growth seasons. These data were recorded on printed data sheets by observation during the daylight while reading the reflectivity of the materials. Because of the minimal number of lights located on building rooftops and access issues, data on rooftop lighting were not collected.

3 Results

3.1 Method 1

A 25-cm pixel resolution nighttime image was generated from the Method 1 data. Its resolution was high enough to study the relationship between light pollution and space design, unlike the other imagery currently used to study light pollution. For example, the DMSP (Defense Meteorological Satellite Program) OLS (Operational Linescan System)
produces a global nightscape coverage at only 2.7-km resolution. The high-resolution data collected through Method 1 enable further study, such as comparing the image with land cover types, building types, and light fixture types captured from daytime aerial photographs and site visits.

Methods 1 revealed that 8.8% of the total study area is influenced by lights (Fig. 3). The remainder of the study area did not register any signature. Of the total lighted area, parking-related areas represented about 25% and pathways 18%. Materials for both the parking areas and pathways were concrete, which has a relatively high albedo. The brightest patches in Fig. 3 are parking structures.

**Fig. 3:** University of Arizona Campus Captured with Method 1. Brightest areas are parking-related areas with bright concrete surfaces. Most of the campus is served by cut-off lights.

### 3.2 Method 2

Method 2 resulted in a ground-based light pollution map. Through a spatial analyst tool in ArcGIS, the sampling point data was converted to raster data in order to show the light pollution distribution. Downward- and upward-lighting maps were created (Fig. 4). Although these data, based on a 10-m grid, are spatially coarser than the data collected through Method 1, they provide better spectral information. For example, it was possible to record the light readings upward and downward during the day and at night.
As in the image generated from Method 1, the brightest areas in Fig. 4 are parking-related. The difference is that some of the asphalt-covered parking is brightly lit here whereas the concrete-covered parking is brightly lit on the University of Arizona campus.

**Fig. 4:** Virginia Tech Campus Captured with Method 2. Top left image shows downward dings and top right image shows upward readings. Bottom image shows reflectance of ground materials.
4 Discussion

Both methods 1 and 2 provide detailed understandings of the campus nightscapes. Having said this, however, each method has its advantages and disadvantages.

4.1 Ease of Acquiring Data

It is easier and possibly faster to acquire an aerial image of light pollution than to collect ground data. However, post-processing of the aerial image to correct for errors took a long time. In addition, because the work had to be done by professional consultants, the researcher had less control over the data processing.

In contrast, it took many hours to collect light readings for the sample points in Method 2. However, once this process was completed, it was less time consuming to compile and construct the light pollution images. Furthermore, the researcher had complete control over data collection and processing. Finally, the cost for Method 2 was significantly lower than for Method 1.

4.2 Completeness of Data

In terms of the completeness of the data collected and its usefulness in studying the relationship of light pollution to the built environment, each method has its advantages and drawbacks. Method 1 provided a dataset that covered the entire campus, but it could provide only a relative brightness map. In other words, the map reveals only the relative brightness of a pixel compared to the other pixels in the image, rather than absolute brightness values for each pixel.

Method 2 provided an accurate reading (in foot candles) of sampling points, but the coverage was limited to the sample points. Brightness over all other areas had to be interpolated. Thus it was difficult to compare land cover types against light coverage or against lighting fixture types. Although this paper does not report the additional data, the same types of readings (upward and downward lights at night and during the day) were collected at the light fixtures. When combined with the sampling point data, this will provide a more complete sampling of the study site.

In terms of providing the most complete data, a combination of methods 1 and 2 would be ideal, provided that the data could be collected at the same time. It would be unrealistic, however, to expect to collect all 2,000 sample points in one night. If the methods are combined, the number of sample points has to be greatly reduced to be used as ground-truth data.

4.3 Canopy Cover

Unlike Method 2’s ground readings, the aerial photography used in Method 1 cannot read light under trees and structures. Because light is reflected off of tree canopies and overhead structures, these factors need to be considered.
5 Conclusion

To date, no efficient models for representing nighttime scenes exist. This paper presents two attempts to model nighttime light pollution and explores the advantages and disadvantages of each. Both methods provide high-resolution images of nighttime lightscapes that were previously unavailable. Previous nighttime images were of very low resolution and, thus, not suitable for study of relationship between light pollution and designed spaces. The methods developed in this study to model nightscape are not expensive, although Method 1 costs more than Method 2. These methods can be used to model the effectiveness of various light pollution reduction measures in sustainable design.

With the high-resolution images developed in this study, the author was able to make a preliminary analysis on some aspects of the relationship between light pollution and the built environment. For example, the models indicated that light pollution reduction cannot be efficiently achieved through the simple adoption of cut-off lights. Rather, the materials used on the ground and walls affect light pollution because of their reflectivity. American sustainability criteria (LEED) do not cover the ground conditions of lights. The criteria do not provide enough guidance to reduce light pollution. Lights need to be adjusted for different materials used on surfaces.

Further study is needed on the reflectivity of various materials. Although low-reflective materials are preferred for light pollution reduction efforts, the thermal characteristics of materials must be considered. Darker materials that do not reflect as much light tend to heat up and may contribute to the urban heat island effect. The next phase of this study is to examine these thermal and reflective characteristics of materials.

References

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