

DAYLIGHTING AS A SYNTHESIS TOOL IN THE EARLY STAGE OF AN URBAN-SCAPE DESIGN

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Abstract. This paper proposes an integrated daylighting design framework for developing optimal configurations of multiple buildings in order to achieve satisfactory visual comfort level. The proposed approach consists of the application of *Climatic envelope* and Design Rules with assorted computational tools. The envelope becomes a prescriptive zoning tool and 3D boundary of parcel design that clarifies environmentally conscious design boundary for architects to develop various building configurations. Its synthetic implementation of natural light in the design process is combined with Design Rules for optimizing the building configurations to maximize their visual comfort level. The proposed design framework is demonstrated through a real site application; Honolulu, HI and Seattle, WA where two dominant sky conditions, clear and overcast sky, are represented. The integrated framework is introduced as a design guideline for architects to develop initial building configurations that maximizes the visual comfort in the early design stage.

Keywords. Daylight design; visual comfort; climatic envelope; design rules; urban-landscape; design synthesis; configurations of buildings.

1. Introduction

Natural light is one of fundamental factors in environmental design to decide user's satisfaction with allowing basic human activities, creating spatial experience and revealing the form of a space. The replacement of electric light with the natural light in architectural design has been shown as one of the most effective ways for the reduction of energy use (DeKay, 2010, p. 36). According to International Energy Agency (IEA, 2000), current daylighting design practice is developed according to the growing need of environmental sustainability. Daylight becomes one of instrumental factors at the early stage of architectural

design process rather than just environmental analysis tool in the post evaluation process (Caldas, 2008; Rakha and Nassar, 2010).

However, the application of daylighting in the current design practice has been limited to investigate and develop a single building at a time. It hinders an overview of how buildings affect the quality of visual comfort to each other (Steffy, 2002). In his "Daylighting and Urban Form," Decay introduces the concept of *Climatic Envelope* that provides initial point of designing building configurations, allowing daylighting design as a synthesis tool to generate urban-scape (DeKay, 2010). Consequently, the study takes *Climatic Envelope* as the inception of the framework. Design rules are then developed to find optimal configurations of buildings regarding visual comfort illuminance level in specific sky and site condition with assorted computer applications such as SketchUp, Ecotect, and Designbuilder. Integrated design procedure introduces daylighting as a synthesis tool for generating urban-scape with optimal visual comfort level at the early design stage.

2. Daylighting Design Framework

Successful provision of natural light can be achieved through the interplay of natural light and building form (Reinhart and Galasiu, 2006). The proposed daylighting design framework is developed for maximizing visual comfort level in early architectural design of an urban-scape. It consists of *Climatic Envelope*, basic design rules, and procedures.

2.1. CLIMATIC ENVELOPE

Climatic Envelope (DeKay, 2010), the composite of solar and daylight envelope, deals with both direct sunlight and daylight for a full spectrum of natural light under both clear and overcast sky conditions.

Solar Envelope and *Daylight Envelope* are two representative theories regarding natural light in designing a building form. They are the product of latitude, built context, the size, shape, slope and orientation of the site. While *Solar Envelope* ensures the access of direct solar light to the site (Sarkar, 2009), *Daylight Envelope* assures adequate daylight access, ambient light to the street and adjacent buildings by shaping and spacing buildings (Brown and DeKay, 2001). In this paper, *Climatic Envelope* is employed as a 3D boundary to constrict the growth of height and width of the given site which limits building's volume growth as shown in Figure 1. Based on *Climatic Envelope* boundary condition, building volumes are adjusted. The volumes of segmented building blocks out of the boundary are reconfigured back into the building where the cut volumes came from as shown in Figure 7.

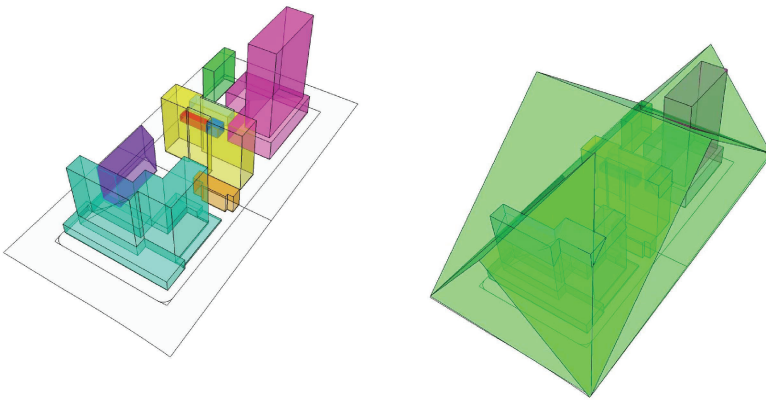


Figure 1. Climatic Envelope.

2.2. DESIGN RULES

According to “Daylighting Report” by Illuminating Engineering Society (IES, 2012), the implications of orientation, massing and building placement play a significant role in the effectiveness of daylighting. The design rules provide the guideline for orientation, form, size and placement of buildings in a given city block (Knowles, 1981) under clear and overcast sky conditions. These dominant sky conditions correspond to different natural lights; direct sunlight and daylight. While direct sun light exists under clear sky condition, daylight exists in overcast sky condition (Brown and DeKay, 2001, p. 110). Current daylighting standards including *LEED (Leadership in Energy and Environmental Design) 2002/ 2009 Indoor Environment Quality 8.1* regard sky conditions for all regions uniformly. However, as different angles of sun path impact the daylighting quality in buildings, sky conditions have significant influence to the building forms and their relations (Brown and DeKay, 2001). Therefore, lighting quality in these two sky conditions should pursue the provision of visual comfort which requires the satisfaction of the visual system and the absence of glare (Dubois, 2007, p. 8). The illuminance level for visual comfort generally ranges from 300 to 2000 lux for various tasks and avoiding glare (Advanced Buildings, 2012).

2.2.1. Orientation of Building Growth Pattern

The orientation of buildings is crucial to mitigate excessive solar access to interior environment (Knowles, 1981, p. 143). Under both clear and overcast sky conditions, the most preferred growth pattern of the buildings is EW (east-west) direction, which maximizes the southern exposure so that more diffused light can enter the inside of

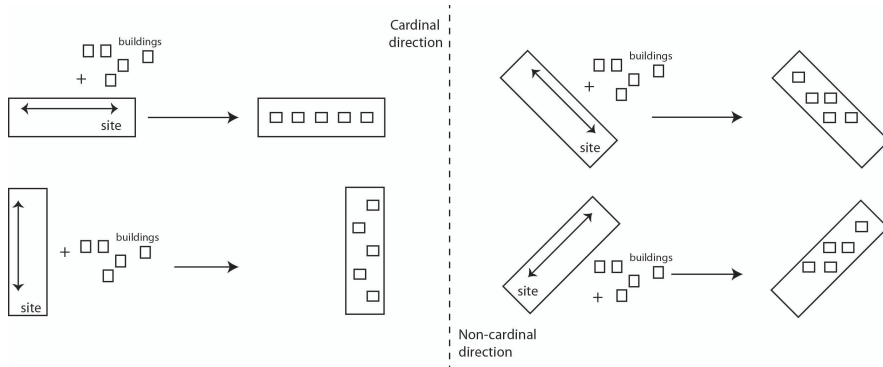


Figure 2. Buildings' general growth pattern per sites' orientation.

the building, and the potential for glare can be reduced (Hausladen et al., 2008). Depending on the given site's orientation, buildings should be situated properly. Since sunlight angle on the south facade is steep, the intensity of sun radiation is less comparing to other sides (Hausladen et al., 2008, p. 40). Therefore, maximization of the southern exposure of buildings is the key to design multiple buildings' growth pattern for minimizing the potential for glare. General growth pattern of buildings in both cardinal and non-cardinal site orientation is demonstrated in Figure 2.

2.2.2. Placements of Buildings

Although given site is sometimes in the situation with difficult natural light access, the juxtaposition of buildings can mitigate the effects of the natural variation of sunlight (Knowles, 1981, p. 144). For both clear and overcast sky conditions, EW cardinal layout creates potential for good visual comfort level.

The design rules for the placements of buildings under clear sky condition are: 1) when the buildings are located on EW growth, place short buildings on the west side, 2) when the buildings are situated in NS (north-south) cardinal growth, place short buildings on the north side, 3) if the site is oriented in NW-SE direction, short buildings should be placed on NW side, 4) short buildings are better to be placed on SW side when the buildings are non-cardinally oriented in NE-SW direction, 5) compact and closed configuration of buildings work better to achieve visual comfort illuminance level in clear sky condition because the buildings can be a shade to each other which lowers the potential for glare issues and direct sunlight, 6) When the building surfaces are overlapped, it is better to have tall building surfaces face either north or south, and 7) Specific building height difference and distance have direct relationship, $d=x(h)$ where d =distance between buildings,

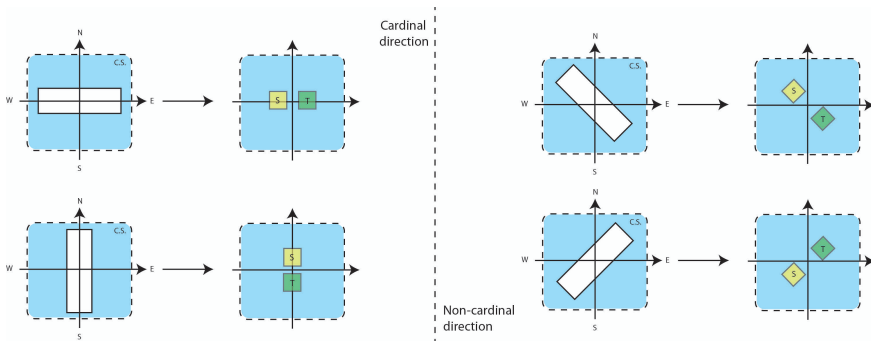


Figure 3. Basic Configurations of Buildings: Clear Sky condition.

h =building height and distance factor $x=[0.8,1.3]$ (Brown and Dekay, 2001). Based on the illuminance level ranking under clear sky, the relationship of building placements in height difference is illustrated in Figure 3.

Also, the design rules for the placements of buildings under overcast sky condition are: 1) For cardinal direction, short buildings are better to be placed in the east side when the site is in EW growth, 2) When the site is in NS growth, short buildings should be placed in the south side, 3) building location with general height difference in non-cardinal site is same for both dominant sky conditions, 4) especially in winter time, non-overlap and open layout of the buildings is preferred to maximize the sun access to short buildings, and 5) For the direct relationship, $d=x(h)$ where d =distance between buildings and h =building height, distance factor x is $x=[2.5,5.4]$ under overcast sky condition. The summary of building placements based on relatively high visual comfort illuminance level under overcast sky is shown in Figure 4.

2.2.3. Building Forms

The form of building plays a significant role to control sunlight access (Rakha and Nassar, 2010). Transformation of the building is essential to establish better environmentally fit relationship among interrelated buildings around (Knowles, 1981, p. 145). Prototypical building forms for solar design are straight, angled and stepped forms (Brown and DeKay, 2001). Stepped building forms are preferred in overcast sky condition because stepped surfaces allow sunlight to be reflected off of front horizontal surfaces that can bring indirect and diffused light into interior spaces such as light shelf effect (Brown and DeKay, 2001). Angled building form is preferred in clear sky condition with 30 degree slope. However, the degree of building slope between 15 and 60 is acceptable for creating adequate visual comfort level. Preferable building forms under each dominant sky condition are shown in Figure 5.

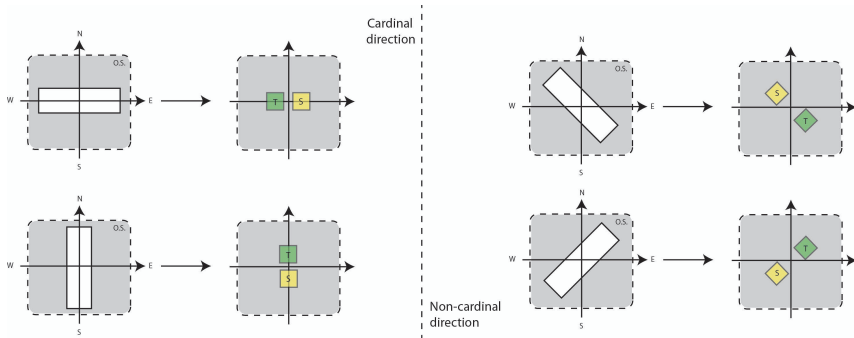


Figure 4. Basic Configurations of Buildings: Overcast Sky condition.

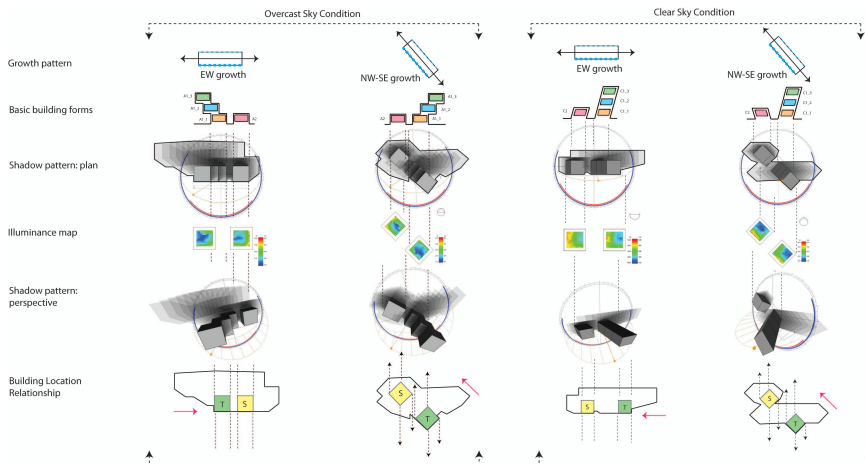


Figure 5. Building forms: Overcast Sky and Clear Sky condition.

2.3. PROCEDURE

This proposed framework requires four procedures as shown in Figure 6: 1) the application of *Climate Envelope*, 2) the decision on dominant sky condition, 3) the application of the Design Rules for the reconfigurations of alternatives, and 4) the design iteration if average visual comfort is not satisfied.

Considering latitude, dimension and orientation of the given site, *Climatic Envelope* is constructed over the target site lot. When the envelope is constructed, a part of existing buildings are cut off by the envelope's 3D boundary condition in SketchUp. Dominant sky condition of the given site is determined according to the geographical location of the site with the help of Ecotect, a sustainable building

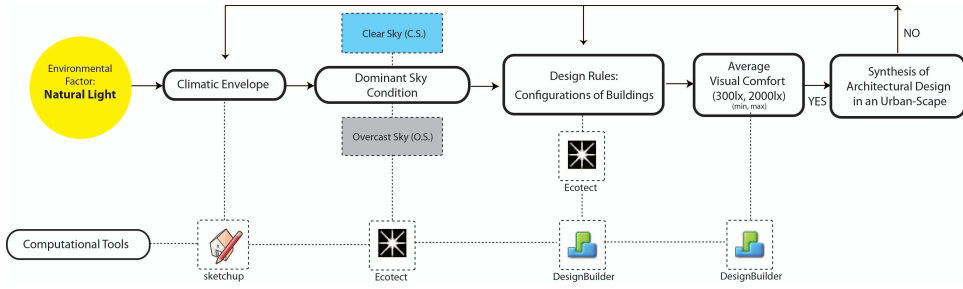


Figure 6. Framework: Synthetic Design Sequence with Natural Light in an Urban-Scape.

design software that offers analysis for daylighting and shadow patterns. Based on the sky condition, designer would choose appropriate design rules for the site prior to synthesize configurations of buildings. Based on orientation of the site, placement buildings and building form in design rules, the cut building volumes from the result of *Climatic Envelope* are reconfigured. Reconfigured variations are transferred to DesignBuilder for verification of visual comfort levels. DesignBuilder is a software tool for checking building lighting and comfort performance. Through the procedures, Ecotect is employed for reviewing shadow patterns to understand the relationship among buildings’ height and their distances relating to the illuminance results of target buildings. If the visual comfort level of the configuration does not reach closer to average visual comfort standard, the application of *Climatic Envelope* and the design rules of the reconfigurations of alternatives are repeated.

3. Case Study: Clear Sky Condition vs. Overcast Sky Condition

The proposed framework is applied to the urban block design of two selected sites under clear and overcast sky condition. The chosen project city block is in Honolulu, Hawaii where 74% of the year is in clear sky condition. This same city block is applied in the latitude and weather condition of Seattle, Washington where 81% of a year is under overcast sky condition. The buildings in this site are conventional rectangular forms with various heights and volumes. Existing building layout is relatively closed form. Once *Climatic Envelope* is applied, the site is gone through the investigation of 1) orientation of building growth pattern, 2) placements of buildings and 3) building forms. Lastly, variation results are compared and analyzed to verify the application of *Climatic Envelope* and Design Rules in real site. Also, the illuminance resulted from the comparison between segmented building blocks and building as a whole clearly shows that a building’s size affects the relationship between buildings’ exposed surfaces and their volume

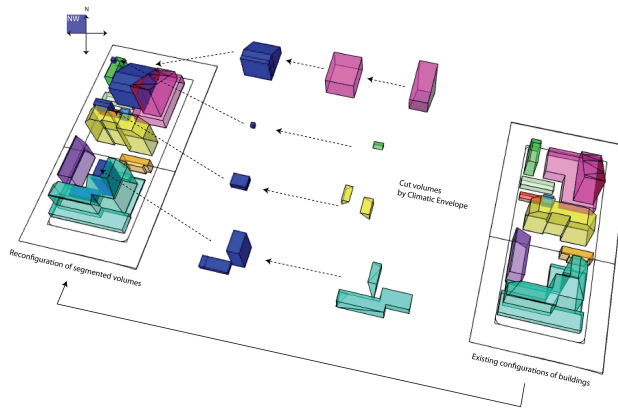


Figure 7. Reconfiguration of segmented volumes.

(Knowles, 1981, p. 145). Segmented buildings provide better opportunity for visual comfort lighting than one big mass building because of a reduced susceptibility of large buildings to external variations (Knowles, 1981). The speed of response to environmental change is much slower in large buildings than smaller buildings. Placement of segmented building blocks based on Design Rules is exemplified in Figure 7. The illuminance level differences from building size and volume changes are demonstrated in following case studies.

3.1. CLEAR SKY CONDITION

Application of *Climatic Envelope* and Design Rules provide significant reduction on building's high illuminance level by reconfiguring big building mass into smaller building sizes.

As shown in Figure 8, in the case of comparing illuminance level of existing site (min: 1701 lx, max: 4267 lx) to the illuminance level of *Climatic Envelope* applied site (min: 1285 lx, max: 3594 lx), the latter has gotten much closer to average visual comfort standard (min: 300 lx, max: 2000 lx).

3.2. OVERCAST SKY CONDITION

Overall average illuminance level in overcast sky condition is relatively lower than the illuminance level in clear sky condition because it deals with ambient natural light than direct sunlight.

The illuminance level from existing site (min: 1408 lx, max: 3899 lx) is still very higher than any other variations. When the building forms are modified to stepped

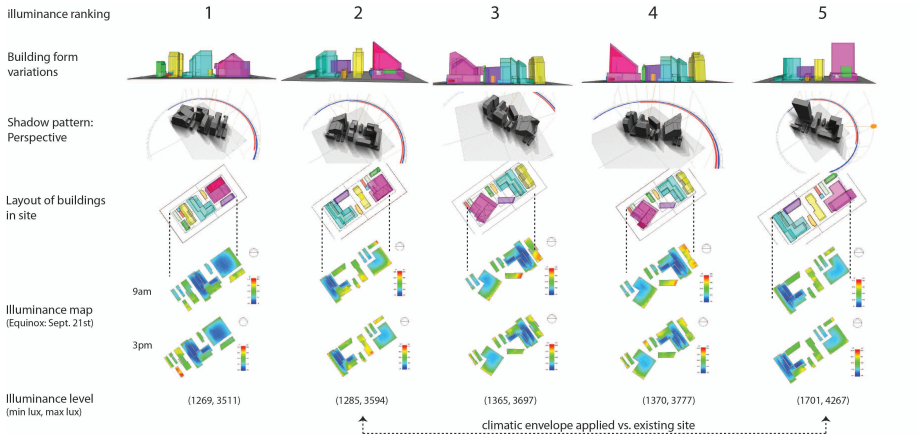


Figure 8. Illuminance Ranking: Clear Sky Condition, Honolulu, HI.

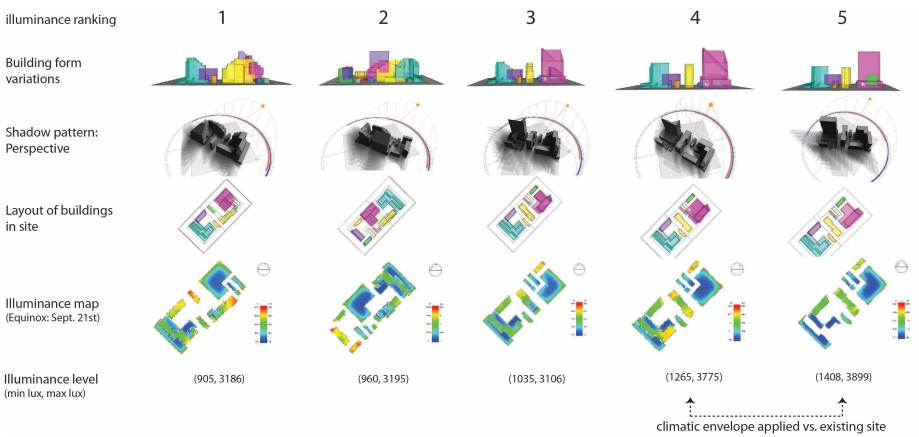


Figure 9. Illuminance Ranking: Overcast Sky Condition, Seattle, WA.

building forms such as building form variation #1, the illuminance levels of the variations has gotten much closer to visual comfort standard as shown in Figure 9.

4. Conclusion

In this paper, a synthesis-based environmental design framework based upon natural light is proposed for optimal visual comfort level at the early stage of an urban-landscape design. The proposed framework includes 1) the implementation of

Climatic Envelope as a 3D boundary of buildings in a given site, 2) basic Design Rules under clear and overcast sky conditions of the site and 3) procedures for integrating *Climatic Envelope* and the Design Rules. In this study, the daylighting performance of building is introduced as a synthesis tool for the design of an urban-scape in order to maximize its visual comfort. Furthermore, the framework has expanded the application of daylighting to the design of multiple building relations with enhancing visual comfort level from single building-focused daylighting analysis. The results of the case studies under two dominant sky conditions show that the proposed design framework allows a user to achieve significant increase of visual comfort level of the multiple buildings in the selected sites. This paper presents how architectural design can initiate the design process with daylighting as the key design driving factor. The further study will include the development of parametric modeling application based upon the design rules in order to generate various urban-scape configurations and find an optimized configuration.

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