A Study on Optimizing Shading Device Configuration for Glass Curtain Wall Buildings

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Abstract. This study proposes automatic algorithm that optimizes sun shade configuration installed on the glass curtain wall facade based on the illumination data analysis of the site. The proposed optimization algorithm is to develop a data-driven design methodology to provide energy-saving potential as well as increased aesthetics with optimized sun shade configuration at the facades. Through this, it aims to expand a non-traditional design methodology in architecture that takes advantage of the potential of data-driven design and its range possibly utilizing urban data as a source of design.

Keywords: Data Driven Design, Urban Data, Optimization, Combinatorial Algorithm.

1 Introduction

The purpose of this study pursues an amalgamative architectural design methodology by manipulation of urban data. More specifically, this study proposes automatic algorithm that optimizes sun shade configuration installed on the glass curtain wall facade based on the illumination data analysis of the site. The proposed optimization algorithm is to develop a data-driven design methodology to provide energy-saving potential as well as increased aesthetics with optimized sun shade configuration of the facades. Through this, it aims to expand a non-traditional design methodology that utilizes the potential of data-driven design. Not to mention MVRDV’s datascape [1], MIT Senseable City Laboratory conducts data based researches in new understandings of urban phenomena at the urban scale [2]. Nadia Amoroso carries out a study in converting statistical city data into an innovative form of map [3]. Data Appeal, by converting the map into a multi-dimensional map, has built a new business domain that provides the groundwork for data-driven design [4]. In recent architectural field, there are heavier considerations on the energy performance of building envelopes especially enforcing sun shade devices on glass curtain wall facade to provide maximum shading. However, installing shading devices on the curtain wall facade is still considered relatively expensive even considering maintenance costs in long period so that architects and owners are still reluctant to utilize them. Therefore, the needs for more economical and efficient ways by optimizing installed areas and configuration in utilizing shade devices have been raised. In order to provide solution for this issue, the study establishes architectural example with specific requirements, and carries out the automatic design to optimize the sun shade’s formation by manipulating the analyzed data of the targeted site example which is affected by neighboring buildings. Through the automation of the optimization process, a specific methodology for a new architecture design is proposed and the comprehensive applicability to the architects is expanded as well.
2 Implementation

The proposed sun shade configuration process minimizes an objective function that represents the amount of illumination transmitted into building inside with respect to a specific sun shade configuration. Variables for the minimization problem include the placement, number, type and depth of sun shade, where the placement domain is restricted on window frames and the type number and depth of sun shade are finite. For a certain sun position, the total transmitted light into building is estimated from the geometric configuration of sun shades from neighboring buildings. The study starts with the analysis of shadow casting on the building façade set as an imaginary site in Washington, DC USA and conducted based on 4 solar terms. The study design a genetic algorithm, a search heuristic that mimics the process of natural selection, to solve the minimization problem under a limited construction cost. The study takes 4 types of general sun shade configuration into consideration with different price and performance criteria per each type. Also the study refers to the report titled ‘External Shading Devices in Commercial Buildings’ from University of Minnesota [5] for energy use technical data. More detailed study process is followings.

Step 1. Setting the designated target building volume corresponds to the legal perspective:
The range of construction that considers the legal building coverage ratio and floor area ratio of the site are used to determine the target building supposing that covered with glass curtain wall and surrounded by high-rise buildings at three sides especially large building at the south.

Step 2. Shadow analysis casted at facades with different time base: According to different times of autumnal equinox, summer solstice, spring equinox, winter solstice (1 hour increments), three orientation facades (South, East, West) shade analysis are executed to generate the status of the shadows according to each facade (Fig. 1).

Step 3. Creating surface segmentation per casted shadow at facades: The derived status of the shadows is converted into a linear data. Then the all the linear data is overlapped per each façade. The generated diagram forms the surface segmentation based on the number of overlap with consideration of including all analyzed time base which providing segmented according to the level of illuminance (Fig. 2).

<table>
<thead>
<tr>
<th>Summer Solstice</th>
<th>SE</th>
<th>SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernal Equinox</td>
<td>SE</td>
<td>SW</td>
</tr>
<tr>
<td>Winter Solstice</td>
<td>SE</td>
<td>SW</td>
</tr>
</tbody>
</table>

Fig. 1. Shaded areas at all times for 4 solar terms per facades
Step 4. **Optimal sun shade number per types from optimization algorithm.** The study optimize shading device configuration for given marginal cost with respect to energy use data for commercial buildings in Washington DC, US [1]. Our optimization formulation considers how many shading devices are established and determines the 12 ratios $R_{ij}$ of specific shading device type as following:

$$R_{ij} = \text{ratio of } j \text{ type shading device on } i \text{ orientation}$$

$i \in \{ \text{West, South, East} \}, \ j \in \{ \text{fins, ov1, ov2, ov2f} \}$

where the shading devices include vertical fins(fins), shallow overhang(ov1), deep overhang(ov2), and deep overhang with fins(ov2f).

In our formulation, the energy saving factor $E_{ij}$ is the average value of the impact data of external shading devices on an each orientation-facing façade with a large window area in a commercial office building in Washington, DC as following:

$$E_{ij} = \text{Energy saving efficiency of } j \text{ type shading device on } i \text{ orientation}$$

<table>
<thead>
<tr>
<th>Type</th>
<th>Facade</th>
<th>fins 1,500mm</th>
<th>ov1 1,200mm</th>
<th>ov2 1,500mm</th>
<th>ov2f 1,500mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>7.0</td>
<td>18.3</td>
<td>25.3</td>
<td>30.1</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>13.5</td>
<td>22.5</td>
<td>26.5</td>
<td>32.5</td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>6.4</td>
<td>19.7</td>
<td>27.2</td>
<td>32.1</td>
<td></td>
</tr>
</tbody>
</table>

Since our determining variables are the ratios of specific shading device type and orientation, the maximum limit numbers of shading devices are given as constant variables:

$$N_i = \text{max. limit number of shadings on } i \text{ orientation} (\text{West: 225, South: 360, East: 225})$$

The unit price $u_j$ of $j$ type shading device is also constant variable and changes according to material market situation (fins: 0.5, ov1:1.0, ov2: 1.45, ov2f: 1.5)
We consider the minimum limit numbers of shading devices, which is forced as regulation in many cities and the maximum limit relating to aesthetic architecture design:

\[
\begin{align*}
\min R_i &= 10\%, \quad \text{min. limit of ratio sum on orientation } i \\
\max R_i &= 50\%, \quad \text{max. limit of ratio sum on orientation } i
\end{align*}
\]

Our optimization is formulated as a linear programming problem where maximizes the total energy saving and is restricted by two types of constraints: marginal cost \( C \) and ratio sum as follows:

\[
\max_{R_{ij}} \left[ \sum_i N_i \left( \sum_j E_{ij} R_{ij} \right) \right]
\]

such that \( \sum_i N_i (\sum_j u_{ij} R_{ij}) \leq C \)

and \( \min R_i \leq \sum_j R_{ij} \leq \max R_i \) for every \( i \)

### 3 Results

The results of the proposed algorithm is planned to be utilized to create specific architectural design based on the surface segmentation diagrams as shown in Figure 2. This can be evaluated as the implementation of an amalgamative design methodology also could be defined as a data-driven design brought about by the pursuit of objective evidence-based design practices diverging from the ideology-reliant artist-centered thinking of the past [6]. The diagram was constructed through the analysis of data that extracted through data processing, then applied as the framework for the operation of optimization algorithm. Through this, instead of a design based on arbitrary decision, the new design methodology based on data-driven design is suggested. Moreover, by proposed automation of the optimization process, the accessibility to energy-saving building design which used to be dependent on complicated post-design verifications based on technical analysis programs, only available to the limited designers is improved; and the comprehensive applicability to the architects are expanded as well. Furthermore, extension of its applicability is planned through successive researches in which actual implementation is made possible in the form a plug-in on a platform of specific programs.

### Acknowledgements

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### References

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