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The Development of an Algorithm for Responsive Facade Integrating Urban Data as a Source of Design

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Abstract. . This study suggests a novel design methodology for building envelope by developing an automatic algorithm that enables window openings to respond flexibly against both environmental and programmatic conditions concurrently. Moreover, the algorithm fosters a data-driven design to provide not only energy-saving potential but also dissimilar aesthetics affiliated with utilizing unitized window system that accommodates various opening size adapted to illumination levels needed at the facades. In its final, the study aims to suggest building envelope configurations based on the illumination contour from scattered data interpolation by taking shadings from surroundings and programmatic requirements together. Moreover, it expands the potential of design by manipulating the combined application of both physical and programmatic data as a source of design.

Keywords: Data Driven Design, Urban Data, Normalization, Scattered Data Interpolation, Kernel Function

1 Introduction

Currently, there are emerging needs for reconsiderations at using glass curtain wall system for a large scale building's cladding asking if there might be a better ways of claddings due to increased requests of environmental values especially energy saving. Glass curtain wall from functionalism based on machine aesthetics at 20th century has been prevailed with changing traditional function of building envelope as a climate filter [1]. However, because of tremendous energy consumption and building equipment costs today, it has become one of the biggest threats to humanity. As the self-reflection of architectural field to that, there are emerging development of new cladding system and legislation of energy saving regulations pursuant to strengthen environmental values [2]. The study's focus resulted in the design of a responsive facade which prioritize and integrates parameters which are programs and environmental considerations. Considering the casted shadow data by surrounding buildings, we estimate the optimized window placement with the designer-given program configuration on the façade. The estimation is performed through a type of scattered data interpolation with the program configuration as samples. In this context, this study focuses on the needs for new type of curtain wall which is prefabricated unitized

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system that is novel punched window wall possibly providing optimized window size and expands the bigger possibility of variation than traditional stick system.

2 Implementation

The study establishes architectural examples with specific site and programs as a mid-size headquarter building for publication company at Washington DC USA. The programs exposed on the façade include lobbies, library & book store, design studio, restaurant, conference room within the field of regular office. Several important variables were incorporated into consideration, the shadow cast from surroundings and the different illumination levels of scattered programs at façade [3]. Instead of the typical glass curtain wall façade contains universal transparent glass surface, the study proposes utilization of unitized window system with vision glass in the middle, aluminum frame around that can varies in dimensions relatively with respond to parameters to ensure optimized illumination followed by reduced energy consumption.

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. Also the target building is surrounded by high-rise buildings at three sides especially massively large building at the south.

Step 2. Shadow analysis casted at facades with different time base: According to different times of both equinoxes, summer solstice, 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 façade [4]. (Fig. 1).

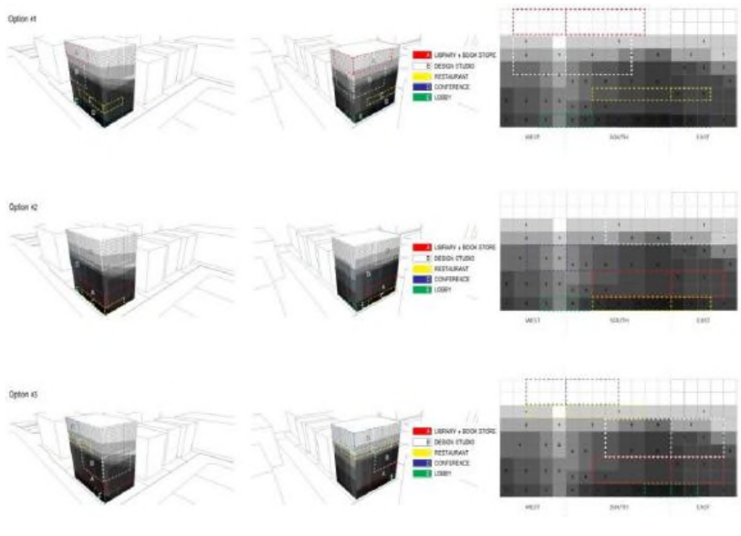

Fig. 1. Three options per program allocations over shaded areas at facades

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.

Step 4. Normalization of program illumination attributes and shadow segmentation data: The façade of the target building is segmented into several regions by the casted illumination quantities as Step 3. Each program such as lobby or restaurant requires its own suitable illumination. The shading segmentation and programmatic requirements are related with illumination; however, there is no common mathematical measure for handling two quantities in single framework. We design normalization process to manage the illumination related variables as follows:

Program requirements illumination variable, p

- 0 : middle value between maximum and minimum illumination values
- \+ : programs relatively brighter than middle value
- \- : programs relatively darker than middle value

Shading variable, s

- 0 : middle value between maximum and minimum shading values
- \+ : brighter region relatively than middle region
- \- : darker region relatively than middle region

Step 5. Defining window variables with diverse opening size by program and environmental illumination data: Our façade design system deploys unitized windows with several size types. We define the window variable on development elevation, which is affected by program and environmental illumination data, as follows: window variable w = p-s, the subtraction of shading variable from program illumination variable. For example, let's assume that library is needed to be bright as +2, i.e., p=+2 and the specific point on development elevation is somewhat dark as -2, i.e. s=2. In this case, window variable w=+2-(-2)=4 describes that a large sized window than program requirements should be established since the installation position is darker than normal illumination region.

Step 6. Scattered data interpolation of window opening sizes on development elevation: This step estimates window variable distribution on whole façade by the designer-given program placement and the shading information. Fig. 1 shows three options on the program placement; the first row describes the programs are deployed to follow shading analysis results. For the second option, the designer places the programs only by architectural planning regardless of shading results. For the third option, the programs are placed against the shading results. The design-given programs make role of interpolation samples where window variables are defined as in step 5. Then, we generate an approximation function with window variables at the sample points by radial basis function , a real-valued function whose value depends only on the distance from the origin [5,6].

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Where the number of sample points is and is appropriate weights to be determined. Linear, cubic and Gaussian functions are widely used as the radial basis function and we use the Gaussian function to guarantee the smoothness of the approximation.

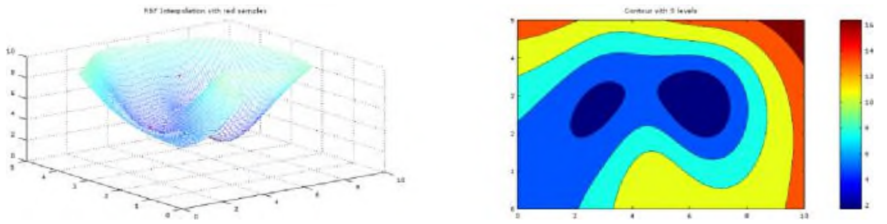

Fig. 2. Scattered data interpolation by red circle samples (left) and its contour depiction (right) for option #2 configuration in Fig. 1

Step 7. Applying the interpolated window sizes distribution to establish the unitized window system at facade: For the final step, we establish unitized windows on target building façade using the approximated windows variable distribution in step 6. The continuous window variable is segmented into the number of window types and can be depicted by contours as in Fig. 2.

3 Results

The paper proposes a novel façade design method which keeps the aesthetic value in sustainable architecture and illumination requirements of a given space program. For sustainability, we analyze shadow casted onto façade of a target building from surrounding buildings. To maximize the architectural efficiency for program assignment under shading data, we define a variable relating with window size, which is the crucial variable of this paper. For the program samples defined on specific regions, we estimate whole window size distribution which is continuous and interpolates the samples. 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. The proposed framework can also be extended to other cladding elements such as shades whose depth and types are various.

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