EXPLORING INTEGRATING DESIGNERS WITH DAYLIGHT PARAMETRIC ALGORITHMS RESULTS TO FIND OPTIMUM WINDOW–TO–WALL RATIO, SHADING DEPTH, AND SPACING: ESTABLISHING OPPORTUNITIES FOR FUTURE STUDIES

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Abstract

Architectural decision-making is a complex process. It is important for architects to create a link between their knowledge and quantitative methods. In this paper, the performance-based design process is being explored by sharing the results of the parametric simulation tools with the design team through an interactive data visualization tool. The goal is to identify a more effective process for the design team to design spaces with optimum daylight. A K–12 school with parametric window and shading was modeled in Rhino. One of the classrooms was selected for this study to find the optimum window/wall and shading design. It was simulated with Honeybee and Ladybug for analyzing illuminance level on the working area (3 ft above the floor). The variables include window-to-wall ratio, shading depth, shading spacing, and month and hour of the year. The design objectives are having the high percentage area of the space with illuminance level between 300–500 lux, and low percentage area of the space with illuminance level lower than 300 lux and higher than 500 lux. Colibri plug-in in Grasshopper is used to automatically iterate the process and save the results for the data visualization step. Design Explorer was used for interactive data visualization. The conversation between analyst and designer during the meeting helped to have a better understanding about different methods to achieve the optimal design. The methods include variable, output, and time-of-year oriented methods. This is the first step in a series of studies integrating designers with parametric simulation.

Introduction

There are many factors in the architectural design projects which make the decision-making process a complex one. These factors are aesthetic, users' needs, environmental factors, physical issues, etc. (Gercek & Arsan, 2019). An architect must decide about various aspects of a building such as form, layout, materials, etc. to meet the needs of stakeholders while his/her design has a profit for the company (Cooper et al., 2005). Quantitative methods have become a vital part of the design process. They help architects evaluate design decisions (Reinhart & Fitz, 2006). Utilizing computational simulation tools in the design process is one of the methods to provide quantitative information efficiently for architects (Reinhart & Fitz, 2006). In the recent literature review conducted by Gercek and Arsan (2019), they state that it is significant for architects to create a link between their professional experiences that they have gained from previous work and the knowledge and insight from simulation tools.

There are many tools available that provide architects with quantitative data for their decision-making. Three groups of simulation tools that play a significant role in architectural decision-making are structural, energy, and daylight simulation tools (Wortmann, 2017). Among them, daylight simulation tools have a high rate of acceptance among architects (Reinhart & Fitz, 2006). One of the reasons it is hard to evaluate and calculate the quality and the quantity of the daylight in the space through a simple equation is because daylight is being affected by various parameters such as sky type, window features, shading, etc. (Eltaweel & Su, 2017; Reinhart and Fitz, 2006). On the other hand, daylight is one of the most important aspects of people's lives which impacts their health, comfort, and productivity (Eltaweel & Su, 2017); thus, it is important to take it into account using lighting simulation tools in the decision-making process.

To simulate a building using conventional daylight simulation tools, such as Radiance, DIALux, Sefaira, etc., the designer has to change input for each variable related to every feature separately and re-run the analysis for each change. There are many features to consider in the daylight design and simulation process, such as window size, Visible Light Transmittance, shading depth, shading spacing, etc. If the goal of the simulation is to find an optimal design, it is time-consuming to change each of the features and contain all the possible combinations (Eltaweel & Su, 2017). Thus, the analyst has to significantly limit the number of combinations which he/she is analyzing. There is a high chance that the real optimum solution is not among the analyzed conditions which he/she chose to analyze, because they are not all the possible combinations considered in the simulation process. Also, in the conventional simulation process, the analyst changes each of the features semi-arbitrary. This does not provide insight on relationships of features on the final result. When there are multiple disciplines involved, the challenges and the relationships between the factors are much larger and more complicated. So it is more time-consuming, complex, and difficult to identify an optimum solution that addresses these complicated relationships with conventional simulation methods (Eltaweel & Su, 2017).

In contrast to conventional simulation tools, there are parametric simulation tools that can be considered in the decision-making process to improve building performance. In the design practice, Grasshopper, Dynamo, and Generative Components have been used as parametric tools. There are many plug-ins which can be added to these tools that can make the parametric analysis happen and ease the holistic simulation in the decision-making process (Toutou et al., 2018). The input for the variables in these tools is not fixed, and there is a range defined by the analyst for each variable. The process of simulation is repeated iteratively for each number in the range for every variable (Nguyen et al., 2014). Because the number of iterations in the parametric tools can be a lot, and their relationship with the results are not linear, it is a time-consuming approach to find an optimal (or near optimal) solution (Wetter, 2009; Nguyen et al., 2014). Computer programming is automating the iterative procedure to find an optimum solution for a design problem. These methods are called "numerical optimization" or "simulation-based optimization" (Nguyen et al., 2104).

Wortmann (2017) states that the designers can achieve a high-performing design solution if they combine parametric modeling with performance analysis and optimization algorithms. This process can best address projects that have multiple and complicated parameters with complex relationships (Eltaweel & Su, 2017). With parametric design, there are several variables which have certain relationships with each other and the design objectives. In this way, parametric design can provide a way to find an optimum solution for the design (Eltaweel & Su, 2017). Several studies have been conducted on simulation-based optimization methods for building performance analysis by using single-object or multi-object optimization tools such as Galapagos, octopus, etc. (Toutou et al., 2018; Wortmann, 2017; Nguyen et al., 2014). There is a study that suggested integration of data visualization and architects' opinion to evaluate the final solution in this process as a future study (Palma et al., 2014).

In the literature review of optimization tools and processes, most of them focused on the optimization algorithm but the evaluations from the design team were missing in their studies. The goal of this study is to find a workflow for designing a classroom window and shading device that maximizes daylight in the space. The proposed process includes integration of the parametric daylight algorithm with the designer's decision to understand how the simulation results and designer's thought process can empower each other to achieve the goal of the design. This study is the first step in a series to explore the performance-based design process by sharing the parametric analysis results with design teams through an interactive data visualization tool and observe the interactions between the analysts and the design team in the decision-making process.

Methodology

The methods used in this paper are parametric daylight simulation, data visualization, and meeting with designers. Figure 1 shows the workflow of this study. A K-12 school building in Raleigh, North Carolina, was modeled in Rhino, and one of its south-facing classrooms was imported into Grasshopper for daylight analysis. The illuminance analysis was conducted by Honeybee and Ladybug—two free plug-ins in Grasshopper Rhino. Prior to analyzing the building, the analyst met with the architect to understand the main concerns of the simulation, and the range of variables that were to be considered and analyzed. The main variables and the outputs are shown in Table 1. The variables in this study are window-to-wall ratio, shading depth, shading spacing, and month and hour of the year.

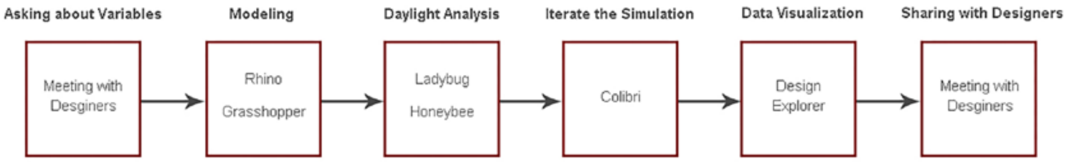

Figure 1: Workflow of the Study.

Because the proper illuminance level for a classroom is between 300–500 lux, the objectives of this algorithm are to (i) maximize the space area with illuminance levels between 300–500 lux, (ii) minimize the areas with illuminance levels lower than 300 lux, and (iii) minimize the areas with illuminance levels higher than 500 lux.

To automatically iterate the analysis and save the screenshots in the designated folder, Colibri—a free plug-in in Grasshopper—was added to the algorithm. The model was run, all possible combinations were analyzed, and the results were saved in the designated folder. There were 2,592 combinations in this study that were analyzed by this algorithm.

The next step is to import the generated data into the Design Explorer for data visualization. Design Explorer is a free online dashboard that was developed by Thornton Tomasetti. It visualizes the images by their variables and outputs (Figure 2). After completing the data visualization, the analyst and the designer had a meeting to review the results to find out the best solution for the classroom. This study was the first step, or in other words, a pilot study for a series of studies in this field.

Results

From our experience, there were three kinds of integrations between designers and data visualization: (i) variable oriented, (ii) output-oriented, and (iii) time-of-the year oriented. In the variable-oriented output, the designer and the analyst are discussing which variables (window/wall, shading depth, or shading spacing) are important for the designer to see the effect of it on the output. In this case, shading depth and spacing were the most important variables for the design. One window/wall assumed at this step to see the effect of two other variables on the outputs. At every step, one data from shading spacing and one from shading depth were selected to see all the outputs. By seeing the outputs together, the designer can see how the daylight distributed across the space at different times of the year and can decide which of the shadings is the best for the design. The next step is to keep the shading constant and have the window-to-wall ratio as the variable. In this way, the designer and the analyst can find the best solution for the window and shading design (Figure 3).

In the output-oriented, at first the analyst narrows down the output of the study to the best output. In other words, he/she limits the outputs to the highest values for the areas which have 300–500 lux, and the lowest values for the areas that have less than 300 lux and more than 500 lux. In this way, the variables will be filtered in a way that all of them have a good output range. After that, the designer reviews the variables and narrows down either by variable-oriented or time-of-year-oriented method (Figure 4).

Variables	Range of variables	Outputs
Win/Wall	0.4, 0.5, 0.6, 0.7, 0.8, 0.9	% of the area which has illuminance between 300–500 lux.
Shading Depth	0.3, 0.6, 0.9, 1.2, 1.5, 1.8 ft	
Shading Spacing	0.3, 0.6, 0.9, 1.2, 1.5, 1.8 ft	% of area which has illuminance less than 300 lux.
Month	March, June, September, December	
Hour	9am, 12pm, 3pm	% of area which has illuminance more than 500 lux.

Table 1: Variables in the Study.

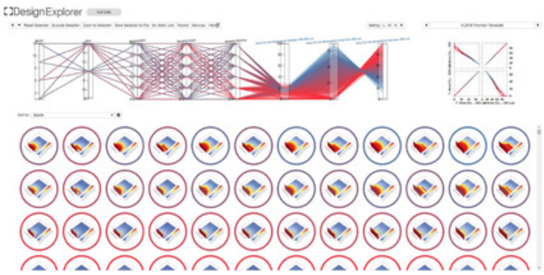

Figure 2: Design Explorer Environment.

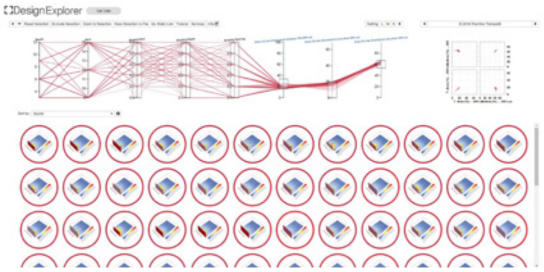

Figure 3: Variable-oriented method.

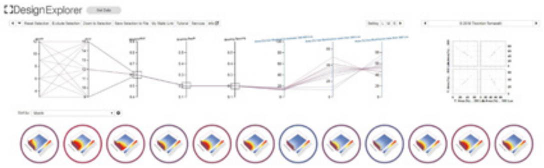

Figure 4: Output-oriented method.

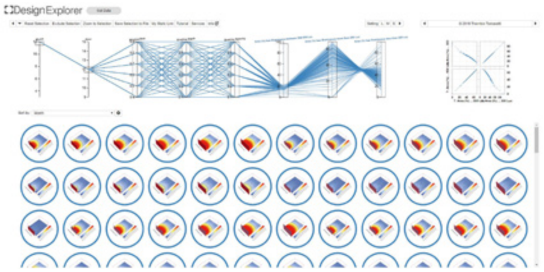

Figure 5: Time-of-the-year-oriented method.

The time-of-year-oriented method is useful when the designer has limited time, and/or he/she wants to design the shading based on the peaks of the year. In this method, the analyst narrows down the time of the year to 12 pm noon in both the winter and summer, so that the designer can use variable-oriented or output-oriented methods to find an optimum solution for the design (Figure 5).

In this study, we haven't compared the results of these three approaches of the integration to see if the results of them will be different. The next step and future study will be to compare the results and how the designers will evaluate each of the approaches in their decision-making process.

Discussion

The architectural decision-making process is complex due to many factors that should be considered (Gercek & Arsan, 2019). Quantitative methods have become a vital part of the decision-making process, as they assist architects in evaluating their design decisions (Reinhart & Fitz, 2006). It is significant that architects create a link between their experience and the knowledge they gain from the simulation tools (Gercek & Arsan, 2019). Among three main categories of simulation tools that include structural, daylight, and energy, daylight simulation tools have the highest acceptance rate among architects (Reinhart & Fitz, 2006; Wortmann, 2017). In conventional daylight simulation tools, such as Radiance, DIALux, etc., the analyst has to enter the variable in every simulation. It is time-consuming and the analyst cannot analyze all the possible combinations of variables especially if the project is complex (Eltaweel & Su, 2017). In contrast, in parametric tools such as Grasshopper, Dynamo, etc., the input for each variable is not fixed. The simulation process is repeated iteratively for each input in the range for each variable (Nguyen et al., 2014). There are several studies that have been conducted to use optimization algorithms to find an optimal solution for the design (Toutou et al., 2018; Wortmann, 2017; Nguyen et al., 2014). The gap in their study is missing the designer's input in the optimization process, which is the focus of this study.

The goal of the current study is to find a solution for designing a window and shading for the classroom in a K–12 school in Raleigh, North Carolina, to improve daylight in the space. The proposed process includes integration of the parametric daylight algorithm with the designer's team to understand how the simulation results and designer's thinking process can empower each other to achieve the goal of the design which was the gap in the current literature review. The methods used in this study includes parametric daylight simulation, data visualization, and meeting with designers.

There are three approaches to integrate the designers with the parametric simulation algorithm and data visualization dashboard: (i) variable-oriented, (ii) output-oriented, and (iii) time-of-year-oriented approach. In each, the designer or the analyst initiates narrowing down the data differently. In this study, we haven't studied the difference between the results of these three approaches, which is the next step of this study.

This study is the first step in the series of our research and practices toward integrating parametric simulation and data visualization with the designer's decision making. Our hypothesis is that this process can help the designers have a better understanding about how different variables impact the output of the analysis. Also, it can help the designers and analysts have a common language to discuss simulation results and the variables in a more efficient way. This common language can be led toward a mutual decision made by designer and analyst to improve environmental conditions of the project. The next step of this study is to compare three approaches mentioned in this paper and their results. Also, following steps of this study is testing other variables such as the orientation of the building, dimension of the classroom, the width and height of the windows, and the angles of shadings. Other outputs such as Annual Sun Exposure (ASE) will be analyzed in the next steps. In this way, the designers will have more options to choose their variables for the daylight simulation to be integrated in their decision-making process.

Conclusion

It is important that architects create a link between their previous experiences and the knowledge gained from the simulation tools (Gercek & Arsan, 2019). The main purpose of this paper is to explore integrating designers' decision-making process with parametric simulation tools to find an optimum window-to-wall ratio, shading depth, and spacing for a classroom in a K–12 school in North Raleigh, North Carolina. Honeybee and Ladybug have been used for parametric illuminance analysis, Colibri used for automatic iterative analysis and saving process, and Design Explorer used for data visualization. The analyst had a meeting before and after the process to understand the concern and variables of the project and share the data with the designer.

There were three approaches found in this process to achieve the optimum design for window and shading: (i) variable-oriented, (ii) output-oriented, and (iii) time-of-the-year-oriented methods. This study is the first step in the study series to integrate designers and parametric simulation tools. In the next steps, the results of these three methods will be compared. Also, different variables and outputs such as window dimensions, classroom dimension and orientation, and Annual Sun Exposure will be added to the algorithm.

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