Designing louvers toward optimum daylight performance in Indonesia: a parametric study

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Abstract. Architecture has a strong relationship with the daylight universe. It implicates further occupants' behaviour toward visual comforts, healthiness, and energy consumption. The daylight simulation in the early phase of design benefits the architect in predicting the possibilities of daylight-related target goals during the design process. A shading system is one of the strategies in approaching passive design to prevent an excessive amount of undesirable daylight intensity. This paper investigates different sun louvers shading patterns and their relation to the Useful Daylight Illuminance (UDI) in the context of Indonesia, presented by incorporating the EPW file of Jakarta. Parametric and multi-objective optimization has been used to optimize, explore, and map the design possibilities based on the louver shading component as dynamic parameters. Rhinoceros and Grasshopper, as parametric-based modelling software, were used as the primary modelling platform, while the Honeybee and Ladybug plugin were used to undergo the daylight-related environmental analysis. The design exploration iterates 2,160 design solutions with a value of dynamic parameters and the targeted UDI value embedded in each. The results show that the solution founded from iteration process has more areas of illuminance within 300 lx to 500 lx by about 15%.

1. Introduction
Daylight is coextending architecture and built environment universe. The daylight and natural ventilation become pivotal in approaching the issue of visual comfort. The strategies to set the building's right shading devices and orientation to ensure optimum daylight and natural heat should be included. What is more, to produce an appropriate amount of daylight illumination, the consideration of outside views and the physiological connection between the neighborhood and the greenery through shading devices are also required [1]. Through the right approach of the daylight strategies, it is expected to ensure visual and thermal comfort; thus, it can maintain the immune system through mental and physical experiences and eliminate unwanted infectious agent indoors [2]. To prevent the glare phenomena and filter only useful daylight that penetrates the room, louver shading has been widely used and engineered globally. Its utilization mostly based on visual comfort and energy consumption intention, and to support passive design consideration, often as a design feature to cut the direct sun radiation before hitting the
surfaces of the windows. Even though the research about the effect of shading to the daylighting [3] and energy consumption [4] has been widely discussed. However, in the context of Indonesia, the topic is still limitedly researched. In a tropical country like Indonesia, that is located in an equator line, shading is essential to prevent a glare phenomenon and large amount of solar radiation that enter the rooms. Even though the shading devices may vary according to the culture, availability, and cost preferences, the sun louvers are getting popular among multi-scale architectural and construction projects. Indonesia is a place that has a comfortable temperature throughout the year. However, thermal, and visual comfort is highly affected by sun radiation and direct sunlight. Thus, the shading becomes one of the main features of Indonesian architecture to protect from direct sunshine and also the high intensity of rain [5].

Computational architecture becomes popular in enhancing the architecture practice. It leads to the tremendous shifting in terms of the design process and how humans interpret contemporary architecture. Along with the advancement of technology and the blending disciplinary, the computation was incorporated due to its capability in handling complex calculation and challenging task that human power cannot be involved. what is more, the utilization of computational method brings the opportunity to tackle optimization and iteration of unimaginable design alternatives based on targeted performance through the automation process. The development challenges design and its data rather than form. Hence the design has to have four criteria such as complex, intelligible, unpredictable, and desirable [6]. The difference between the ordinary design processes and the computational or parametric one relies on the sequences that consisting during the process. While the ordinary or classical design process undergoes the evaluation after the design is completed, in opposite, the parametric process requires the targeted performance goals or value in the early phase of designing and creating the source code as a generator for the iteration process or a bottom-up approach [7,8].

Based on the background explained above, this paper tried to investigate the optimum daylight performance concerning the use of louvers shading given a context of Indonesia using a computational approach. This research aims to find the presumably best louver design feature with optimum targeted useful illuminance distribution inside the simulated room. The objectives are to arrange the parametric definition for the overall simulation and design explorer processes and map and analyze the design solution produced by the iteration process. The results are expected to give an insight into how the arrangement of louver shading would implicate the daylight distribution inside the room with a certain given context and analysis period and recommend which arrangement is fitted with the given condition.

2. Methodology

2.1. General overview
This research incorporates a parametric-based computational design method [9] to calculate and explore design solutions regarding daylight performance. Figure 1 illustrates the workflow of the research. The early step started with the ideation and next followed by defining the dynamic parameters as a design variable. The parametric definition making deploys the historical data provided by Energy Plus named EPW file of Jakarta, Indonesia [10] to calculate and explore design solutions regarding daylight performance. Figure 1 illustrates the workflow of the research.

2.2. Geometry modeling
The simulated room was made to replicate a standard modular Indonesian classroom or offices. The room’s dimension is 8 m x 12 m x 3.5 m. the opening was made with approximately 40% of the glazing ratio. The shading was arranged with several dynamic parameters represented by number sliders component. The first design variable is eaves or overhang. The second is spacing between the blades, the third parameter is blade size or blade wide, and the last dynamic parameter is blade’s rotation. The model and analysis are illustrated in Figure 2, and the range of dynamic parameters as a design variable is described in Table 1.
Figure 1. Research workflow.

Table 1. Design variables.

| Parameters    | Division | Step   | Range      | Total |
|---------------|----------|--------|------------|-------|
| Overhang      | 3        | 30 (cm)| 30-90 (cm)| 3     |
| Spacing       | 8        | 5 (cm) | 5-50 (cm)  | 9     |
| Blade size    | 7        | 5 (cm) | 10-45 (cm) | 8     |
| Blade rotation| 9        | 5°     | 0-45 (°)   | 10    |
| Total iteration|         |        |            | 2160  |

Figure 2 illustrates the virtual shading devices and its component as design parameters (independent design variables) that furthermore act as a context surface in the daylight simulation process. This model does not apply any specific materials to see the general implication caused by the simulation. However, the glazing was set to have an RGB Rad material level of in average 0.5. Figure 3 shows one of the visualization results and the grid-based analysis’s value for each test point for further daylight analysis.
2.3. Context and analysis period

As environmental data supplied to the environmental analysis engine, this research uses the EPW file of Jakarta provided by Energy plus [10]. Jakarta is located at 6.2088° S, 106.8456° E. The sun position taken for the simulation is on December 21 at 12:00. The sun's position is roughly situated at an altitude of 73°, heading 180° toward the south direction [11].
2.4. Computational tools
The entire parametric system is arranged in the modeling software called Rhino 3D [12] and the conceptual parametric-based plugin called Grasshopper [13]. For the environmental analysis purposes, Ladybug and Honeybee [14] was incorporated. The plugin is allowing to import of Energy Plus Weather Data EPW for the data analysis needs. What is more, it was built to facilitate engineers and designers to conduct environmental analysis with relatively less time-consuming. Honeybee and Ladybug are integrating the well-known and established simulation engines such as Energy-plus, THERM, Radiance, Open Studio to undergo and calculate environmental phenomena by the given weather data during the design step. Figure 4 illustrates the parametric definition of the entire modelling and simulation system in grasshopper.

![Diagram of Grasshopper definition clustering](image)

**Figure 4.** Grasshopper definition clustering.

2.5. Design explorer
The design exploration process was generated by plugin software TTtoolbox with the components called Colibri. Colibri was developed by Thornton Tomasetti [15] and it allows the generate an interactive parallel coordinate plot for each step of iteration for the designer's exploration and visualization purposes [16]. Different from the Multi-Objective Optimization process where the targeted solution tends to genetically generated based on the desired targeted value, the Colibri is iterating all the total possibilities.
that exactly produced by multiplication each step from the input sliders (Genotype) and calculate the whole targeted value (Phenotype) following this process.

2.6. Measurement metrics
The metrics that become a target for the grid-based daylight simulation are Useable Daylight Illuminance (UDI). UDI defines as the annual occurrence of illuminance within the range that is considered useful by the occupants. Generally, UDI is ranged between 100 lx – 2000 lx. However, Nabil (2006), classified the UDI range in some category which is insufficient with illuminance less than 100 lx, Effective with 100 lx – 500 lx, Desirable with illuminance ranged between 500 lx – 2000 lx, and exceed with illuminance value more than 2000 lx [17,18]. This research only focuses on and calculates the range between UDI0 300 lx to 500 lx [19]. Another UDI investigates in this research is UDI1. Another UDI investigates in this research is UDI1 with the illuminance below 300 lx and the UDIa with the illuminance value above 2000 lx.

3. Result and discussion
This section will describe the simulation results produced by the design exploration processes. The result and discussion are divided into three sub-sections: The comparison model, which is the simulation room without shading, the preferable UDI0 results, the unpreferred UDI0 results, the tendency, and the discussion. The value distribution map or a parallel coordinate plot is drawn to see the connection between the dynamic variables and the targeted goals.

Figure 5 illustrates the parallel coordinate plot produced by the Design Explorer TTToolbox interface. It contains 2,160 wire connections when each wire represents the design solutions with the embedded design variable values. The first four axes are the design variables: Overhang, Spacing, Blade size, and Blade rotation, with the value range, which was divided accordingly. The red dotted bubble indicates the targeted value searching area. The searching area is the range in the UDI0 axis with the highest percentage value. Figure 6 shows several samples of the result generated by the design explorer. Figure 6 illustrates the random chosen individuals among the design solutions that probably produced during design exploration. Each of the solution embeds the information of the arrangement of louver component parameters (independent variables) and the daylight objectives (dependent variable). Through this kind of visualization, the daylight distributions and design intention supply a direct feedback for the designer and stakeholder dusting the early phase of designing.
3.1. Comparison model
The comparison model was built to be a benchmarking model. This model is a simulated room model with no shading devices. The sky condition that directly hits the glazing surface is intended to give an insight into how the UDI is distributed inside the simulated room when no filter prevents direct sunlight from the outside. Figure 7 shows the visualization result of the comparison model. The picture shows that the area indicated in red, which valuing illuminance value more than 900 lx, are distributed about under the openings. The comparison model performs UDI_0 21.87%, UDI_l 44.27%, and UDI_a 1.8%.

3.2. Preferred UDI_0 result
The model with the preferred UDI_0 resulted from the exploration process is the model that performs the highest possible UDI_0 with the illuminance ranging from 300 lx to 500 lx. The targeted area percentage is the division between the grid mesh with UDI_0 and the whole mesh grid area.
Figure 8. Parallel coordinate plot of the highest UDI₀.

Figure 8 shows the Parallel coordinate plot of the highest UDI₀. The highlighted blue wire contains the combination of the design variables that resulted from the maximum UDI₀ amongst the 2,160 simulations. The solutions featured 1 value for the first variable, the overhang, which means that the length of the overhang is 30 cm, variable 2, the spacing 10 means that the interval between each blade is 50 cm, third variable, the blade size 6 means that the wide of each blade is 30 cm and the last variable, the blade orientation 7 means that each blade has 35° rotation. The combination resulted in UDI₀ 34.97%, UDI₁ 64.84%, and UDIₐ 0%. The result shows that the individual solution founded by the iteration process has more areas of of UDI₀ by about 15% compared to the comparison model. Besides, based on the simulation results, the louver removes the 1.8% of the glaring possibility from the comparison model into 0% UDI above 2000 lx.

Figure 9. Results and visualization of the solution with the highest UDI₀.

Figure 9 shows the solution with the highest UDI₀ value. The illuminance is valuing 300 lx to 500 lx represented by the gradation bluish color to yellow. It can be seen that considerable amount of the value is distributed from the spots under the windows to the almost center area of the room. However, the number of UDI₀ is reversing the number of UDI₁ to split 100% tested area. The picture shows that the illuminance with a value below 300 lx spread towards the corridor and in every spacing under the windows. What is more, the insufficient amount of illuminance valuing below 100 lx is occurring in the areas mentioned above.

3.3. Unprefered UDI₀ results

The unprefered solution that performs the lowest value of UDI₀ produced not in a single solution. Figure 10 shows the parallel coordinate plot of the lowest UDI₀ in the UDI₀ Axis, the wire shows multiple connections corresponding 0 value of UDI₀. The multiple selections highlighted in this plot indicates the multiple solutions with a different combination of dynamic design variables resulted in 0% UDI₀. This phenomenon is considerably caused by the dense louver configuration that blocks the skylight. The blocking could be formed by the dense spacing combined with the blade's wide size and its rotation angle.
3.4. The tendency
Unlike the typical design approach that evaluates several completed design solutions to get the tendency. In contrast, design explorer incorporates the bottom-up approach to search the targeted solution based on the target goals set during the ideation phase. It is complicated to see the clear tendency from a considerable number of individual results produced by multiple combinations of the design variable. However, in the design explorer platform, the tendency can be identified by dragging the area along the axis and the wires that are corresponding the value within the plotted area will be highlighted.

Two tendencies for the highest and the lowest UDI₀ has been shown in Figure 11 and 12. The blue wires that represent the solutions with maximum values of UDI₀ highlighted by dragging the search area along the UDI₀ Axis show that the maximum UDI₀ corresponded by mostly rotation angle more than 4 (20°), spacing more than 2 (10 cm), and blade size below 7 (35 cm). The first variable, overhang, contributes almost the same. The red wire that represents the lowest UDI₀ solutions shows that there is a balance combination among the variables causing the low percentage of UDI₀. However, there is no combination of blade size 2 (10 cm) and blade rotation 0 (0°) result in 0% UDI₀.

3.5. The limitation of the research
The study is limited to the investigation of the louver shading geometry toward the distribution of Useful Daylight Illuminance (UDI). It does not include the definition of specific materials and uses the Grasshopper component's material, except the glazing is set to have 0.5 transmittances. Direct sun is
excluded from the simulation. The metrics only use single time simulation different from Annual Sun Exposure (ASE) or Daylight Autonomy (DA). The simulation also does not include the building orientation. Considering the limitation of the hardware, the simulation uses large size of the grid test point. A smaller grid size would possibly come up with a more accurate calculation. The thermal comfort and energy consumption are not in the scope of this research.

4. Conclusion

The research addresses the methodological gap in configuring louver shading devices for the design, given the context of Indonesia. The different louver configurations directly implicate the distribution of the daylight inside the simulated room. The design variables in the MOO processes included louver components (i.e., Overhang, spacing, blade size, and rotation) to generate the daylight metrics Useful Daylight Intensity (UDI) through parametric daylight simulation and optimization using weather data of Jakarta has been presented. The results show that a specific configuration of louver shading produced from the MOO performs the best fit optimization value objective for the given context has been revealed. Besides, the data shows the relation tendency between design parameters and the daylight objectives. Based on the results, it is clear that the proposed methodology can be used to achieved optimization, in this context, the relationship between shading toward daylight performance. The significance of this research is the establishment of a design exploration platform to investigate and find the best fit solution of shading device to be applied in the Indonesian context. Having informed a range of design solutions and the tendency between parameters and the daylight objectives, designers and stakeholders, for instance, from the manufacturing company, can be benefited in terms of decision-making processes considering the design aspect of louver shading devices in a particular context to bring the intention of environmentally architectural consciousness that proven to have a positive contribution to the operational occupied working hours, human health and energy consumption. Therefore, parametric design in designing louver shading devices in investigating daylight performance is worthyly considered.

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