Fixed shading device design with the performance-based-design and energy simulation

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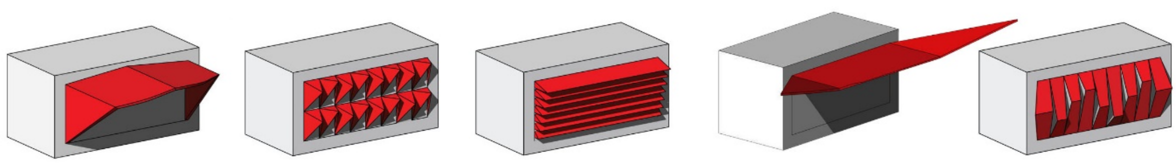

ABSTRACT

This paper presents a performance-driven design (PBD) tool developed by combining the energy analysis abilities of Ladybug, Honeybee, and EnergyPlus to inform shading device design decisions. Consider architects as the user group, the PBD workflow presented in this paper demonstrates the optimization of fixed shading devices for cooling and heating loads while providing multiple aesthetic options by not limiting the shading device typology at the beginning of the process. The PBD produces iterations that perform similarly, yet effectively, in terms of energy savings so that a designer can design shading devices based on other criteria such as aesthetic concerns or constructability issues. With a customized user interface (UI) for PBD, designers can move between different shading typologies and add their own creative, artistic interpretations while not being required to run complex simulations after each design change. This paper presents how this PBD process with new UI (PBD-UI) can be agile enough to handle frequent design changes. This method was tested by a group of architectural design students and demonstrated that the PBD-UI is more in-line with the parametric design process than traditional shading device design methods. Combined with parametric design tools and customized UI, it can facilitate more creative, innovative design solutions based on performance criteria such as reducing heating and cooling loads.

Keywords

performance-based design, energy simulation, user interface

ACM Classification Keywords

I.6.1 SIMULATION AND MODELING

1. INTRODUCTION

The performance-based design (PBD) has intrigued architects through a controlled process where prior experience is augmented by the addition of data to drive design decision-making. This design process integrates the form-making process and evaluative processes in automated systems that help design better-performing buildings. The benefit of using PBD has been concluded as "uses performance measures with actual quantifiable data and not rules-of-thumb; aims to develop a simulation model of a complex physical system; uses the model to analyze and predict the behavior of the system; and produces a quantifiable evaluation of the design." [7] In the practice of architecture, this process, defined as the PBD, is based on various generative and simulation methods. Many researchers have employed methods such as decision trees and rule-based systems to solve design problems using innovative architectural design approaches. Some of the emerging aspects in the practice of architecture involve utilizing generative modeling methods, such as the "multi-agent system to generate and evolve parametric façade panel configurations based on environmental parameters (daylight, energy consumption)" [4]. Some method focuses on the visualization and interaction of the architectural design process and the thermal environment, such as the "developing a system in which "BIM, CFD, and Augmented Reality are integrated to provide interactive visualizations." [8] The emerging methods also include trained artificial neural networks (ANNs) to predict energy consumption by "linking actual heating and electrical energy consumption data from the existing building stock to a range of design and briefing parameters." [5] Specifically, for the building components, foundational works by Victor and Adler Olgyay laid down the principles of shading device design. Works such as "design with climate" and "solar control and shading devices" form the initial effort to design shading devices that respond to the character of the project and also perform quantitatively. [3] Works such as SHADERADE: Combining Rhinoceros and EnergyPlus for the Design of Static Exterior Shading Devices look at a variant of a cell-based analysis method to create shading devices. [6]

2. CHALLENGES

The design challenge is to apply PBD principles to generate various shading devices that respond to environmental constraints and optimize based on cooling and heating load performance. It is necessary to identify the metrics by which a shading device could be judged. The question of what the shading device is optimized for is particularly relevant. A shading device needs to add to the architectural expression, but it also needs to perform pragmatically, leading to a good architecture that is also a good building. In our study, thermal conditions and visual conditions became two important metrics.

Within thermal conditions, there are thermal loads, cooling and heating, and thermal comfort. These two concepts are closely linked but are not the same. In the case of designing for thermal comfort, the goal would be to reduce peak loads so that the HVAC system can respond efficiently to changes in demand, and no change is too sharp for the system to compensate. This contrasts with a cost-centric view where any meaningful reduction in energy use, no matter what time of day, is desirable. The main difference between these two views would come in where the designer sets the threshold to determine when shading begins and ends based on the baseline energy simulation.

However, the use of PBD, especially with energy simulation in the architecture field, is limited by a significant constraint. The knowledge threshold required to move beyond rules of thumb and gross data generalization is high, and the time required to act on that data is demanding. To properly design a shading device, an energy model representing the current design will need to be analyzed and applied to an accurately modeled and oriented design model. Architects, in practice, generally cannot devote this much time and expertise to one singular building element such as a shading device. Especially given the fact any change to the building geometry and energy model inputs will impact the thermal loads to some degree and potentially changes the ideal shading device design, invalidating previous work. Because the challenge of designing a shading device is complex, a PBD system should be flexible enough to handle the performance data in the background to free the designer to make design decisions. Because energy simulations present much more information than is necessary to those in the architectural field, this PBD tool for shading devices seeks to display only the relevant variables to the designer in a user-friendly manner while keeping the rest of the analytics in the background.

To address these challenges, our research began with defining a design method drawing on positive aspects of these PBD methods on interactive visualizations similar to the focus of BIM, CFD, and building on the principles Victor and Aladar Olgyay laid out. This method integrates energy, environmental, and other types of analysis at early design stages as the basis of PBD.

3. METHOD

Having established the goal of creating a shading device design method that produces solutions that perform and have the potential to become architectural elements, the existing shading device design methods are critically evaluated in terms of meeting performance goals and flexibility in design. Existing methods were put to the test in a baseline simulation study where the "climate design method, the iterate method, and the cell method are tasked with creating a simple overhang shading device with the goal of reducing overall thermal loads." [2] Lessons learned from these methods allow the authors to extract concepts that lead to more flexible designs that also adhere to performance goals. The more conventional shading device methods are all capable of creating designs that physically perform, however, at the cost of time and flexibility of design. The authors developed a "**vector**" method, which is embodied in a tool that takes the form of a grasshopper script relying on native grasshopper components and components from the plugins Honeybee and Ladybug, which are an interface for EnergyPlus and Radiance. The method focuses on the design and outputting sun vectors that should or should not be shaded according to different quantifiable design metrics.

This method begins with an unshaded energy model, which is used to create a shading mask to guide design exploration. The Vector Method takes inspiration from the Cell Method's specificity and, instead of evaluating every cell, evaluates every sun vector and matches the direct solar radiation passing through the window with the cooling load during the same hour. Once each hour where shading is needed is identified, the sun's position can be determined according to solar calculations through Honeybee using Radiance using the project's location to determine for all daylight hours where the sun is relative to a single point on the ground.

Once the three-dimensional shading mask is created, the user creates a solution that cuts the whole window off from the sun vectors represented in the volume. This could take the form of anything from a simple plane intersecting the mask above the top of the window or smaller tessellated shapes covering the window, each sized to shade a portion of the window during the desired time frame. Because this shade mask is in model space that can be integrated within the context of the whole project, it is easier to understand each decision's aesthetic impact while ensuring that each iteration performs to a similar degree.

This new Vector Method is explored as a function of its ability to find and alter new forms based on parameters set by the user and by the environment impacting; performance metrics, user-defined shading device rules (typologies, design decisions), window geometry, and changes to the energy model. This is to set forward the idea that solutions generated by the Vector Method are tailored to each specific condition and yet maintain a high degree of flexibility in design through user-defined goals and parameters.

Our method of PBD no longer depends on architects' intuition and personal experience to make design decisions affecting performance or requiring high levels of expertise and large amounts of time, but rather using quick feedback in the energy simulation and continuous iterations to define the design logic. This method is constructed with a graphic interface for architects and a carefully calibrated parametric modeling engine in the background. (Figure 1). Designs that create complex situations, forms, and goals that other methods find difficult to account for, can be evaluated in this new method. The elaborate design project becomes a playground for the Vector Method to exemplify its strengths over other more traditional methods. The shading devices' design is not a simple application to a preconceived building, but the Vector Method is used in conjunction with the architecture to enhance and inform the outcome. Similarly, design precedence surrounding shading device motifs and forms are essential to indicate what the industry gravitates towards and which forms this method should optimize. Design iterations are included in the application to a design project to show that this new method does not lock the user into predefined solutions but helps guide creativity to find solutions that perform.

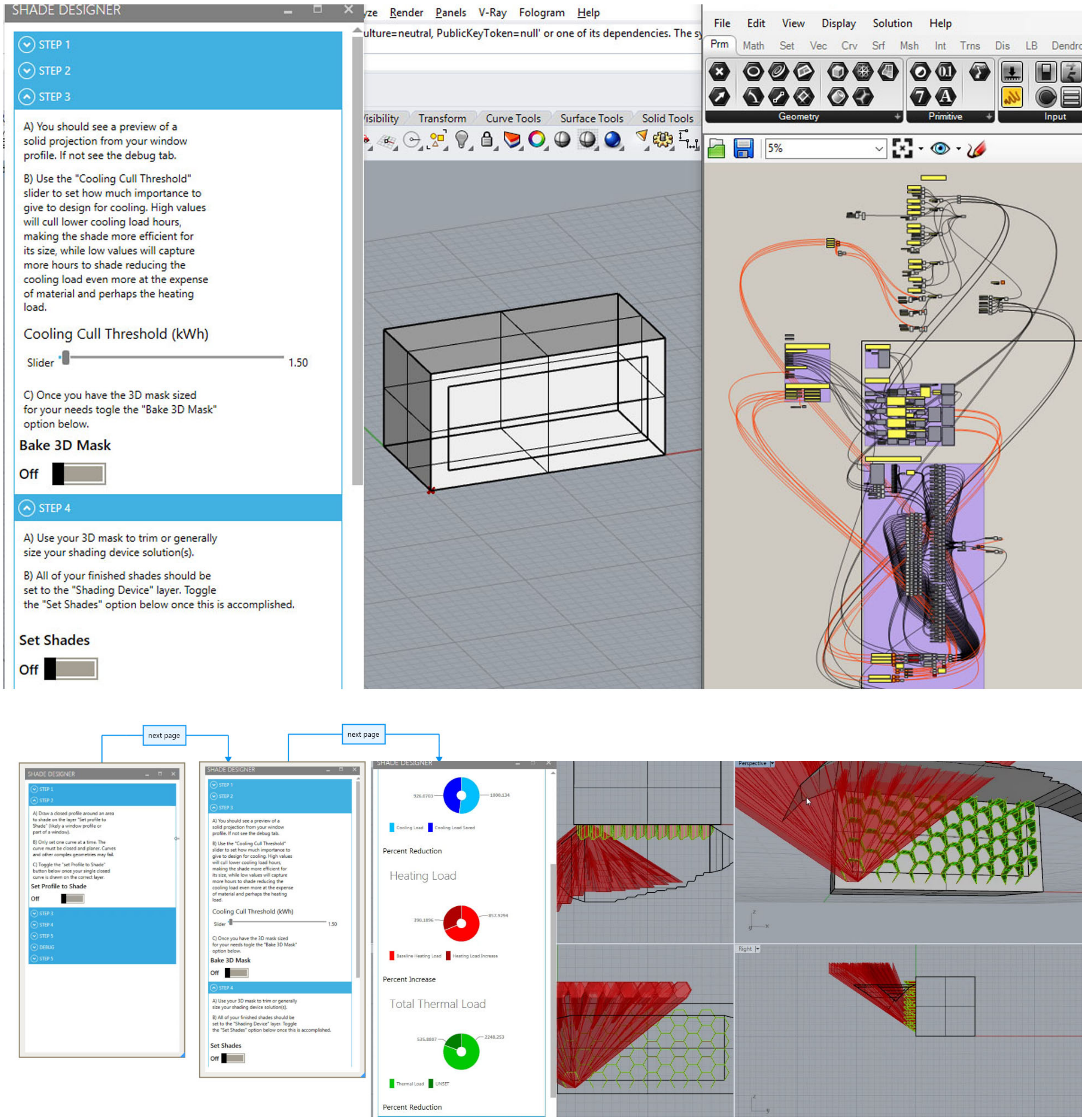

Figure 1: The new UI embedded in Rhino. The PBD method runs on a combination of Grasshopper, Human UI, Honeybee, Ladybug, and Rhinoceros as platforms to model building geometry, run simulations through EnergyPlus, analyze and filter data. Through a user-friendly graphic interface, the PBD brings that information back into the 3D modeling space to allow a design to occur.

In 2019, the authors introduced this PBD workflow at the University of Cincinnati and taught it to third-year students in the architecture design program. The students' work was evaluated in terms of performance, reduction of total thermal loads, and design flexibility. How easily the tool was applied to varying conditions and dealt with design changes throughout the process is vital. The subjective matter of whether the shading devices contribute to the architecture as architectural elements are also addressed.

PBD relies on the performance data to influence and impact the design process from beginning to end. The primary investigation focused on designing shading devices, which can be evaluated by their energy performance and further supported by continuous iterations. By utilizing Rhino and User Interface (UI) wrote in grasshopper, the authors combined Ladybug, Honeybee, and prescriptive form seeking into a user-friendly toolset called PBD-UI. Students explored several shading methods for generating designs through step-by-step guidance and fast feedback on the cooling and heating load. Students measured the performance outcome against the predefined baseline models[i]. Performance data is represented as a chart, illustrated, and processed internally with an energy simulation engine. The relationship between performance data and actual building form is simplified to examine its interactions. It is then that this design process acts as a system where the performance data is fed back to promote a new design iteration. The revised model and simulations are then processed until the desired aesthetic is obtained (Figure 2).

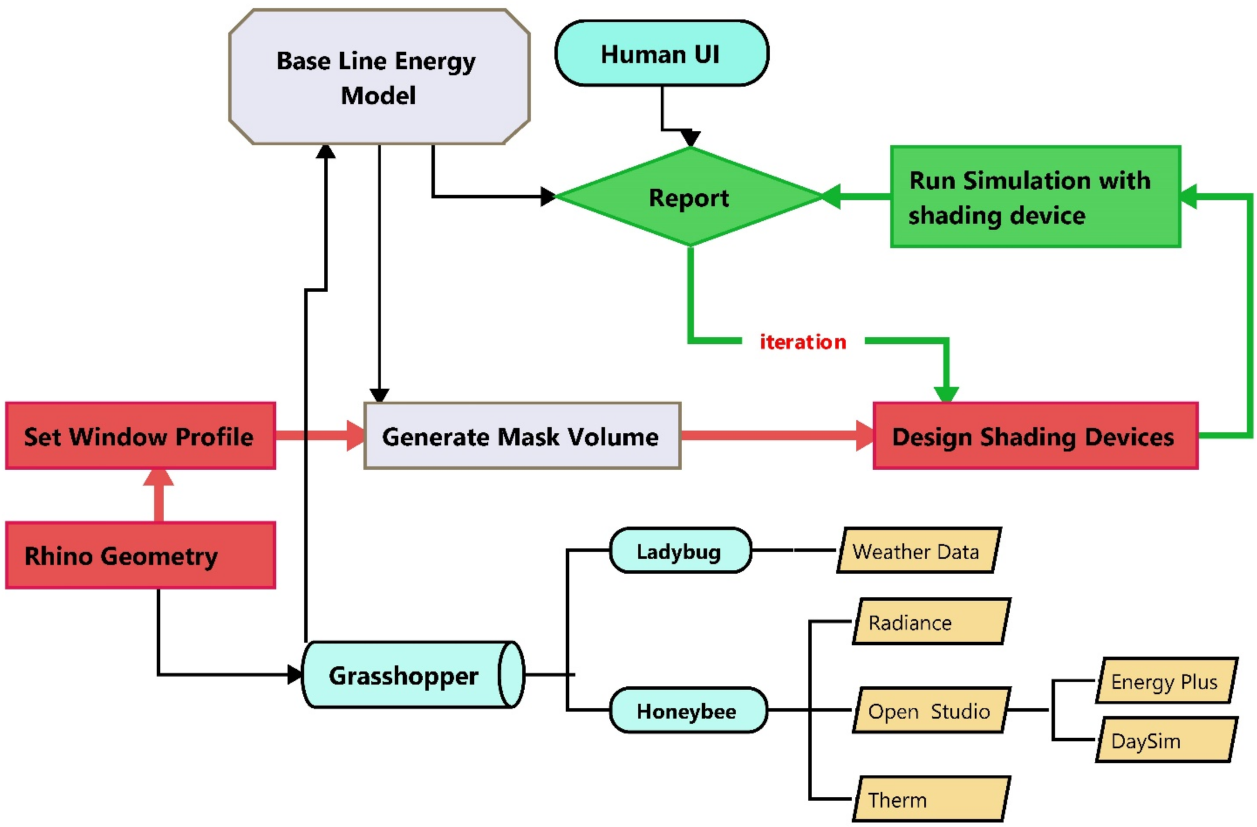

Figure 2: Diagram of our PBD-UI. The ability of this system to produce not only a final product that works but also the system's ability to fix within a design process that is not purely linear and is constantly in dialog with its constituent parts informing revisions is important. (Red = user Input; Yellow =behind scene program; Green= performance feedback.)

The authors developed the PBD-UI to optimizing a fixed shading device to reduce heating and cooling energy use so that performance and aesthetics can be balanced while exploring various shading forms and typologies during any stage of design. First, a basic wall with window opening(s) was studied by extracting annual hourly heating and cooling data generated by the whole building energy simulation program, EnergyPlus. Creating a system to organize, filter, and interpret this data provided designers with a list of all days and hours a window can avoid heat gain or invite passive solar heating. These days and hours become vectors to project a window profile forming a volume of space to be shaded by calculating sun angles at each of these times. Within this volume, typologies and opportunities to create new forms were tested. Conventional typologies such as simple overhangs, vertical shading, and louver systems were explored before moving to more innovative possibilities.

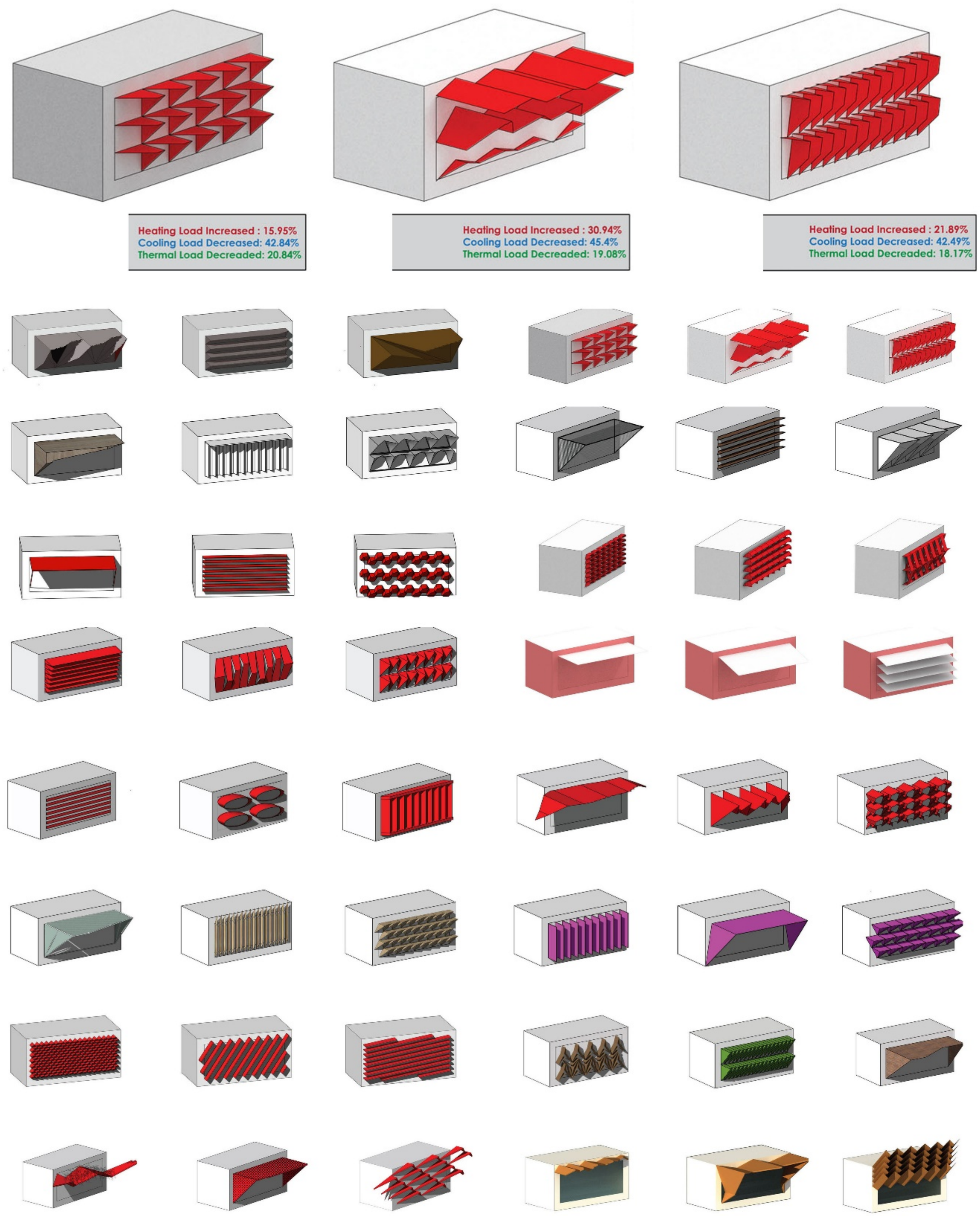

Figure 3. Student projects. Variations could include different typologies such as simple overhangs, hoods, screens, and louvers. One could experiment with angling typologies in section or elevation to see the desired effects and fast feedback. Most iterations performed within several percent of each other in terms of total thermal load reduction. Meaning this method offers iterations that perform while permitting flexibility in design. Student projects from the University of Cincinnati.

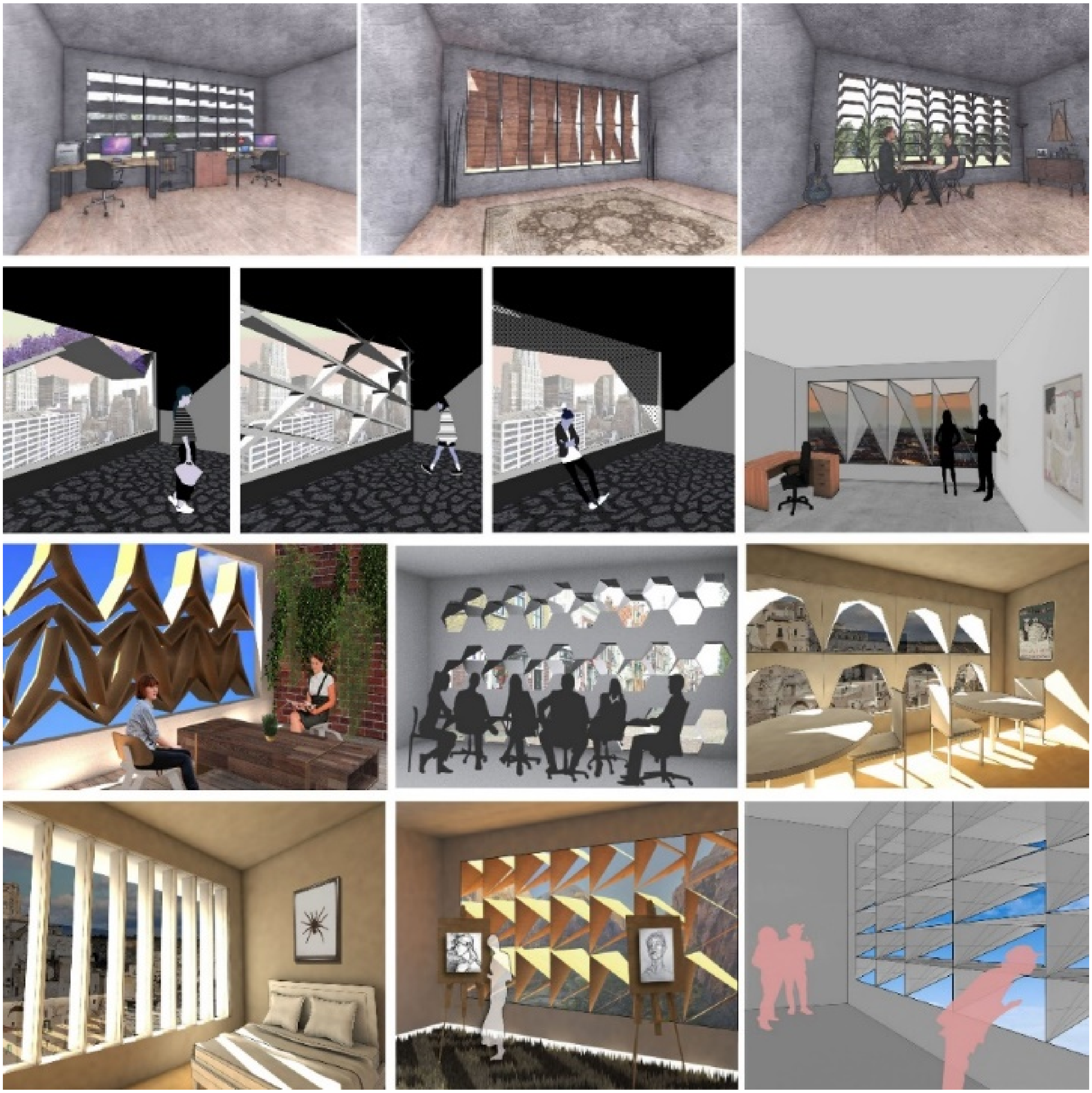

Figure 4. Creating custom shade profiles and letting profiles that do not match a window is also an option. Screens could be composed of a wide range of shape and size openings and tessellated to make unique or random patterns. Typologies can be mixed louvers with horizontal overhangs or hoods combined with louvers. Despite multiple typologies being designed in different ways, each iteration performed similarly, allowing the designer to define the character of the space using the shading device in their own manner. Student projects from the University of Cincinnati.

The performance analysis became the driver for a set of iterations. An energy report was used to evaluate the position and size of shading elements, shape of openings, or other facade elements by directly manipulating geometries in Rhino and observing its impact on the energy model. The tool is also tested by graduate students in the Architecture program at the University of Cincinnati, and feedback is collected and analyzed. Feedback led to the development of more effective user-friendly interfaces allowing the process to become more widely accessible. This aims to evaluate the success of the PBD-UI in making shading design more accessible to designers within the design process they are already comfortable with.

4. CONCLUSION

The research goal is to create a graphic interface that drives a design tool solving many issues relating to usability and flexibility in design that occur in the PBD. We observed the PBD-UI's ability to create various performing iterations, to allow real flexibility in design. Multiple design iterations that all used the PBD-UI are compared to determine if design decisions based on other architectural factors aside from energy performance can be considered without compromising thermal performance. The PBD-UI is a flexible parametric tool/process that keeps a designer adhered to performance goals while permitting freedom in design. The tool provides instant feedback as a wide range of parameters are changed as the design evolves. Parameters on window geometry, energy model inputs, user-defined shading rules, and user-defined metrics directly impact the formal expression of the final shading device design while keeping the design accountable to performance goals.

Using PBD-UI to visualize the impact of 3D shading masks keeps the user consistent in achieving the goals they set for themselves while keeping the exact form the design takes flexible. Sticking to the goals rigidly through a parameter system can be an excellent way to ensure quality. Being able to see changes immediately helped a user connect their actions directly to shading in the project. Changes to parameters such as window geometry, the orientation of the zone, changes in the energy simulation, and others need to reflect directly to the generated form.

The authors believe that architects do not need to apply the engineering level simulation to define in the early design stage. The PBD-UI allows architects to quickly evaluate the model until it reaches the desired performance levels. The use of energy simulation to control a shading system is just one of many approaches for informing design decisions. Seeing the impact of design decisions and identifying problems early on, such as finding out vertical shading alone will not adequately shade a southern-facing window, can help a designer troubleshoot the situation. It will help them reevaluate their chosen typology before getting too embedded in the process. The authors are continuing explorations around how the PBD-UI approach can be used for innovative design beyond formal assumption and aesthetic experimentation.

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Source code available at
https://github.com/DAAPUC/shadingdevice

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[i] The baseline consists of a single zone 3.05m x 6.10m x 3.05m (10’ x 20’ x 10’) with one south facing window 5.18m x 2.13m (17’ x 7’). The baseline uses the default closed office schedule and ASHRAE 189.1 envelope assemblies.