

# Balancing performance and aesthetic: data-driven design for fixed shading devices

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**ABSTRACT:** This paper presents a new workflow to optimize a fixed shading device to reduce thermal loads so that performance and aesthetic can be balanced while exploring various shading forms and typologies during any stage of design. The south wall of a prototypical mid-rise office building zone per ASHRAE 189.1 criteria in Albuquerque, New Mexico is studied by extracting annual hourly heating and cooling data generated by Energy Plus. This new workflow is tested against other existing methods of shading device design in terms of performance and aesthetics. The workflow presented in this paper demonstrates the optimization of fixed shading devices for cooling and heating loads without limiting aesthetic options or the shading device typology at the beginning of the process. This workflow produces iterations that perform similarly in terms of energy savings so that a designer can select a shading device based on other criteria such as aesthetic concerns or constructability issues. The user can move between different shading typologies and add their own creative, artistic interpretations, while not being required to run many simulations after each design change. This paper demonstrates a process that is more in-line with the building design process. Foundational works in the field of other shading device design methods are included to provide a point of comparison between existing practice and the proposed workflow.

**KEYWORDS:** Shading Device, Aesthetics, Thermal Loads, Optimization, Design Process

## INTRODUCTION

A survey of mostly European architects reported that 82% of respondents indicate solar energy aspects were important in their architecture practice, while at the same time 72% rated themselves as poor or very poor in using advanced tools. Most respondents preferred graphical design methods and tools with user-friendly design interfaces (Kanters, Horvat, Dubois, 2014).

Many designers aspire to holistic goals not dissimilar from the sentiment expressed by Peter Zumthor in *Thinking Architecture*, "Form and construction, appearance and function are no longer separate. They belong together and form a whole" (Zumthor, 2015). Designers, like Zumthor, are not looking to merely design shading devices that perform in terms of reducing thermal loads, but also in terms of aesthetics responding to the wants, needs, and feelings of people who come in contact with the design. John Ruskin highlights this concept in the dichotomy between building and architecture in *The Seven Lamps of Architecture*, "Building does not become architecture merely by the stability of what it erects" (Ruskin, 1857). For Ruskin, what defines architecture is pushing a structure beyond mere performance and into the realm of aesthetics and culture.

The shading device is not an insignificant part of a work of architecture. Victor and Aladlar Olgay, having lived through the modern movement in architectural practice, highlight how changing building practices have created a greater need for adequate shading than perhaps ever before,

The single window, liberated by the structure, instead of remaining a fenestration becomes a window wall. Man is presented with a psychological sense of freedom, unrestricted views, and a variety of special relations. But this transformation has brought some new problems- or rather old problems in sharply enlarged magnitude of controlling the sun's radiation. (Olgay and Olgay, 1958).

The increased use of glazing in architecture has created an abundance of solar heat gain during more hours of the year. Marcel Breuer was certain that society would not give up its new conception of open architecture that the shading device would have to become the new Doric column, an element necessary to the performance of the building and with the potential to become an exterior architectural element (Breuer, 1956).

This paper critically examines existing shading device design methods in the context of this holistic mindset and develops a new workflow to facilitate solutions that balance performance and aesthetics. Performance is defined by this paper as the ability of a shading device to reduce thermal loads. Aesthetics is defined in this paper as the amount of freedom the design method grants the designer in creating the shading device geometry.

## 1.0 EXISTING METHODS

### 1.1. Climate design method

Victor and Aladar Olgyay (1958) pioneered the shading device design method that this paper calls the 'Climate Design Method'. Their method focuses on combining climate data with shading design in a graphical manner. As currently implemented first running an energy simulation for the zone that contains the window that needs to be shaded, and from this simulation a balance point can be established, which is the outdoor air temperature where thermal loads are close to zero. This balance point can be used to evaluate all hours of the year for overheated periods and overlaid onto a sun path for the location of the zone. All sun hours where the outdoor air temperature is above the balance point represent times where additional heat gain would negatively impact the overall thermal load of the zone and therefore should be shaded. The designer can select from a range of shading typologies, each with a different shading mask. The goal is to match the best shading mask to the sun path with hours that need to be shaded overlaid. The shading mask guides a designer to select a shading typology and allows the designer to size that typology to respond to total thermal loads in a zone (Olgyay and Olgyay, 1958).

Others such as Elhinnawy and Abdou (2004) integrated Olgyay and Olgyay's methods into digital tools to allow for the quick application of the graphical climate method to different projects. Since this point more modern tools such as Honeybee, a plugin for Grasshopper for Rhinoceros, (Sadeghipour Roudsari M., Pak M., 2013) allow designers to replicate the Climate Design Method much more easily.

One benefit of this method is; only one simulation needs to be run to gather the data to begin design. The simulation and graphical analysis on the front end of the process actually help guide the design towards a solution that will work in terms of performance while keeping the design itself more flexible to be interpreted in creative ways. However, a drawback is this method does generalize data to fit rectilinear solutions and does not easily support more complex designs.

### 1.2. Iteration and genetic optimization method

A more recent shading design method begins with a predefined shading device form and finds an optimal design through iteration. Tools such as Sefaira, owned by Trimble, attempt to do this by iterating simple shading device typologies such as simple horizontal overhangs and vertical shading over ten or less 'steps' using only the depth parameter to create these steps/iterations. Each step is evaluated on a criteria that is output by the simulation software and selected by the user. The best performing design can be selected. The design firm Payette has done a study retroactively looking at the sizing of a louver system in one of their past projects. They created 36 iterations with the parameters, louver spacing, and depth of the louvers and created a weighted average score to combine the criteria including heating loads, cooling loads, and daylight levels to select the best performing option (Hinchcliffe, Korah, 2012).

A drawback is this method requires many iterations and simulations to be run for every design iteration. This method can be extremely difficult for someone in practice to navigate when time is limited. Genetic optimization attempts to bridge that gap by creating iterations for the designer and generating these iterations, not by running every permutation but by trying to learn with each generation of iterations to achieve the goals set in the beginning. Even with this measure, the structure of the method remains the same and often still requires a prohibitively high number of simulations. One study implemented genetic optimization to design a complex concrete shading screen, and succeeding in creating a unique architectural solution that also performed very well compared to more traditional shading forms. However, it utilized over 3000 simulations to achieve this design (Andrea, Andaloro, Deblasio, Ruttico, Mainini, 2017).

Another drawback is; changes in design become time consuming. For example, a switch to a new shading typology or the building form changes enough to impact the energy model seriously, the designer must restart the from the beginning. This makes this method extremely inflexible to changes that are all but guaranteed to occur within the normal design process. This method is capable of producing very complex and custom shading forms which could respond very well architecturally. However, if the designer has no past knowledge of shading device design, they could be led to optimizing a typology that would not function as well as another in the same situation, such as vertical shading on the south façade in the northern hemisphere as opposed to horizontal shading. This process does not help the designer make informed decisions about what form the design should take in the beginning of the process as the Climate Method does, but instead optimizes within a user-defined pool of options.

### 1.3. Cell method

This method evaluates a shade cell by cell and displays the results in a color gradient map on the shade itself. This instant graphic feedback allows a designer to understand which parts of their design contribute to reducing thermal loads, which parts increase thermal loads by blocking cells that would have had a net positive impact on the thermal loads of the zone, and which cells do not help or hinder the goal of reducing thermal loads. This feedback can be used to confirm a design is functioning or can be used to edit a design to make it perform better. SHADERADE is the basis of the tool found in Honeybee. SHADERADE takes the question of when a shade is effective and transforms it into a question of where is a shade effective by calculating the net thermal load for each cell in a volume near a specified window. This cloud of cells in mapped onto a shade that is created by the user, evaluating it for refinement (Sargent, Niemasz, Reinhart, 2011).

The initial design is not informed by project-specific data. Like the Iterate method, this method relies on the background knowledge of the designer to start with a form that makes sense for the situation and does not provide guidance before the design occurs. Unlike the Iterate method this workflow does provide quick feedback shortly after the design occurs allowing time for revision, however, this becomes more of a guess-and-check method for those without knowledge on the subject. Second, this method is constantly revising the designer's inputs which means the computer has the last word on the design. It is less of a collaboration between equal parties and more of a conversation where only the designer or the computer can speak at one time, in contrast with the Climate Method where the graphic analysis in the form of the shading mask guides the designer to create a design that performs while promoting freedom to choose a path.

Additionally, the method has limitations that affect the possible design outcomes. The current application in Honeybee cannot support more than one window or shade surface at a time. This is due to how SHADERADE calculates each cell independent of each other, regardless of whether a neighboring cell has been shaded or not. This means any shading form or system that would be self-shading will not be accurately created under this method. Louver systems and screens, among the most common, are not supported which imposes severe restrictions of design for the user (Sargent, Niemasz, Reinhart, 2011).

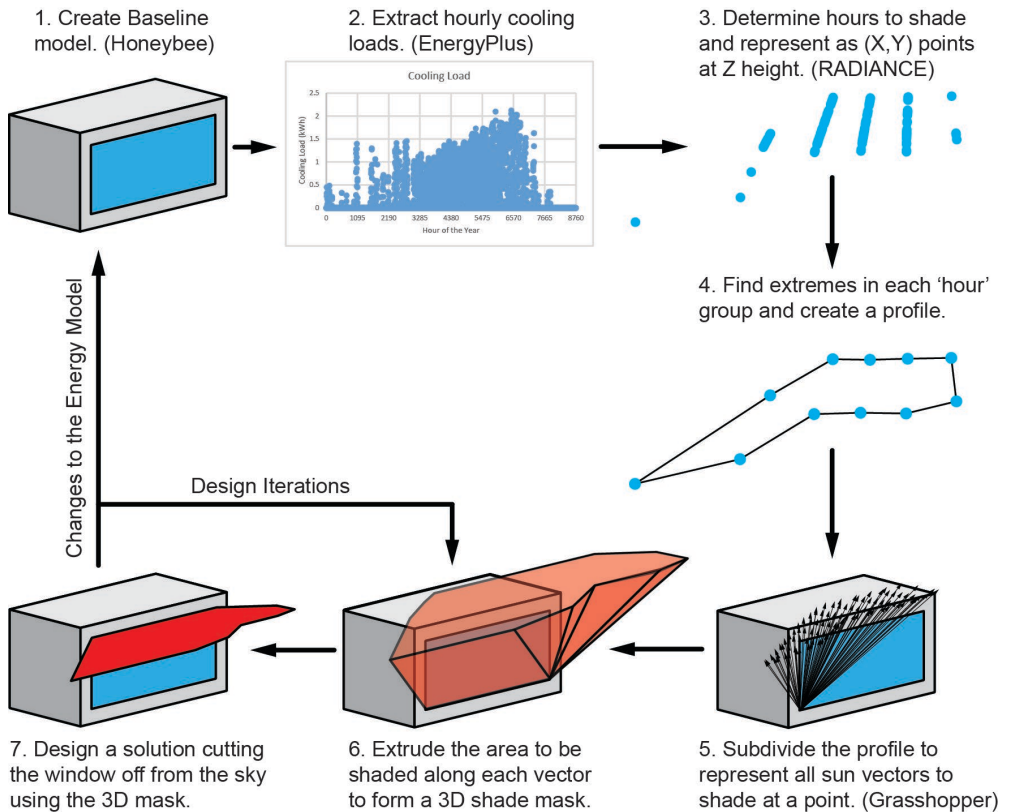
## 2.0 PROPOSED VECTOR METHOD

This workflow begins with an unshaded energy model of the zone, step 1 in Figure 1. This model 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. If there is no cooling load or direct radiation then an hour is culled from the list. A user-defined threshold is introduced to allow a designer to determine how sensitive a design needs to be towards cooling loads. If the threshold is set very low or not set at all, then most or all hours with cooling loads and direct radiation will be included in the shading mask, if the threshold is set higher only the hours with the highest cooling loads will be included. Often there exist hours with more extreme sun angles that do not contribute much to the increased cooling load in a zone and would create a larger mask without providing many benefits. Reducing the data to the highest set of cooling hours reduces the size of the mask and allows more direct sunlight to enter during times when the heating load is dominant. Determining which hours to shade occurs in step 2 in Figure 1.

Once each hour where shading is needed is identified, the position of the sun 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. The Sun's altitude and azimuth angles at each designated hour can become points (X,Y) and a designated Z height above a prospective window. These (X,Y,Z) points are the same as vectors originating at (0,0,0), step 3 in Figure 1. By taking the profile of this set of vectors a flat shape a Z height that represents all solar vectors at all times that need to be shaded can be established, step 4 and 5. Extruding the profile of the window or area to be shaded along each vector and joining each extrusion results in a three-dimensional shading volume that can be interacted with in modeling space, as any other architectural element. The mask shown in step 6 takes into account the geometry of the window, orientation, and data filtered from the initial energy model to inform the size, shape, and character of the resultant shading volume.

Once the three-dimensional shading volume 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, as shown in step 7, or smaller tessellated shapes covering the window, each sized to shade their own 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 the aesthetic impact each decision makes while ensuring that each iteration performs to a similar degree.

Any update in the energy model or geometry of the shaded area feeds back directly into the generation of the shading mask to provide instant feedback to the user. Allowing the software to control more complex operations such as the generation of the mask and displaying the consequences in real time allows the designer to focus on design and not be concerned as much with the time and knowledge involved with creating and interpreting a two-dimensional shading mask. Real-time feedback was critical in helping users to understand what the implications were for various actions in creating a design through a parametric script (Maleki, Woodbury, Neustaedter, 2014). The creation of a three-dimensional shading volume is a parametric exercise, driven by hourly energy data, which needs to be understood conceptually by users. Therefore, a real-time link between design decisions on the building level and the outcome in terms of the shading mask is essential to ensure a success shading device design method in practice.



**Figure 1.** Vector Design Method Workflow.

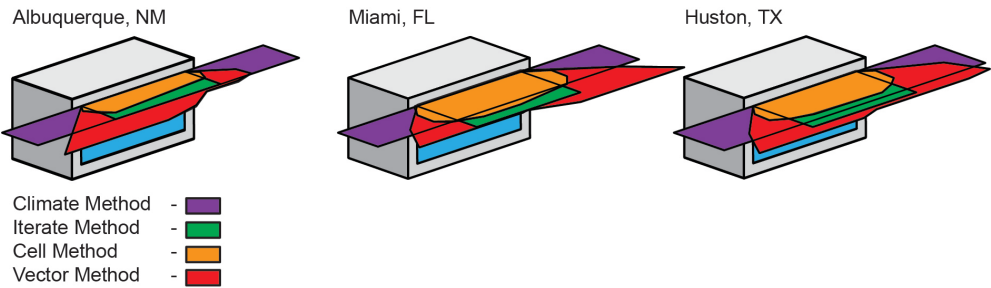
Because the Vector Method requires only one simulation to be run and the process does not have to be repeated from the beginning to create design iterations, this method is flexible for many stages of design. A simple energy model could be created during schematic design to test different shading options on different building orientations and forms to get an idea to communicate to the client about what the skin of a building could look like and what kind of energy savings they might expect. A final more complex energy model could be created towards the end of design, when the building form is decided upon, and a finalized shading device system can be designed and altered per construction and budget restrictions. The Vector Method supports quick typology selection, as the Climate Method does, form finding and quick typology sizing, like the Cell Method, without the high number of simulations like the Iterate Method.

### 3.0 COMPARATIVE CASE STUDY

#### 3.1. Performance study

To determine how the Vector Method performs in pragmatic terms, in its ability to design a shade that reduces overall thermal load, it is tested against each of the other existing design methods. This is accomplished by using Honeybee as an interface to EnergyPlus to run a baseline simulation and then, using the existing and new methods described above, create simple horizontal overhangs to reduce thermal loads as much as possible. 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. The study is run for three separate locations, in different ASHRAE climate zones to ensure the Vector Method performs as well or better in multiple situations. The Climate Method is carried out by using the 'Honeybee\_Balance\_Temperature\_Calculator'

in conjunction with the Ladybug sun path and shading mask components to determine graphically which parts of the sky need to be shaded and to match a rectangular form to shade this area. The Iterate Method mimics the Sefaira workflow to simulate this method realistically being used in practice. The shade is assumed to be the width of the window and incrementally increased from a .30m (1') overhang to a 3.05m (10') overhang. Each result is analyzed through the same settings in Honeybee as the other methods, and the best performing option of the group of ten is selected. The Cell Method uses the 'Energy\_Shade\_Benefit\_Evaluator' in Honeybee, which was based directly on the SHADERADE process, provides the cell-by-cell analysis as well as visualizing this data on the surface of the shade using Ladybug. The simple overhang starts as an oversized rectangle and is trimmed based upon the results of the shade evaluator component to create the Cell Method solution. The Vector Method is carried out utilizing a mix of Honeybee, Ladybug, and native Grasshopper components to create a script that creates the three-dimensional shading volume as described earlier. The shading mask is used to trim a horizontal surface at the top of the window. The resulting shape is the Vector Method solution. The design solutions for each method for the three locations are shown in Figure 2 below.



**Figure 2.** Comparative Method Study Designs.

**Table 1.** Comparative Method Study

Design Method	Location		
	Albuquerque, NM	Miami, FL	Houston, TX
Baseline (Annual kwh)	2,611.3	5,222.5	3,964.3
Climate (Annual kwh)	2,084.3	3,694.9	2,903.9
% Improvement	20.18%	29.25%	26.75%
Iterate (Annual kwh)	2,073.6	3,784.0	3,011.1
% Improvement	20.59%	27.54%	24.04%
Cell (Annual kwh)	2,084.9	3,749.1	3,045.5
% Improvement	20.16%	28.21%	23.18%
Vector (Annual kwh)	2,060.3	3,676.5	2,922.8
% Improvement	21.10%	29.60%	26.27%

Table 1 shows the performance results of each design in Figure 2 compared to an unshaded baseline. Annual thermal loads are presented (kwh) and the percent improvement over the baseline.

The Vector Method performed the best in two of the three cases against existing methods and followed closely behind the Climate Method in the third case. Overall, each method was able to achieve a design that performed in a similar manner for the three test locations, however, the form that each design took was unique. The Climate Method was restricted to rectilinear forms with wide side overhangs, the Iterate Method was confined to predefined rules in the beginning of the process, and the Cell and Vector Methods created more unique geometries. Even though the typology of simple overhangs was utilized the form each solution takes is unique due to the effect of each method on the end product. This indicates that there are multiple design solutions that function to a high degree and multiple paths to achieve these

designs. This shifts the focus back to how much time is required to generate a solution and how much effort is required to create design iterations based on aesthetic criteria.

The Climate, Cell, and Vector methods all rely on setting a threshold, whether it is a quantifiable number or interpreting a graphics display, to design a solution. For this reason, user error could easily be to blame for one method overtaking the other, and it would not be right to say that the Vector Method is the 'best performing' method. However, this study does show that the Vector Method has the potential to work as well or better than existing methods in designing shades that reduce thermal loads.

### 3.2. Design iteration study

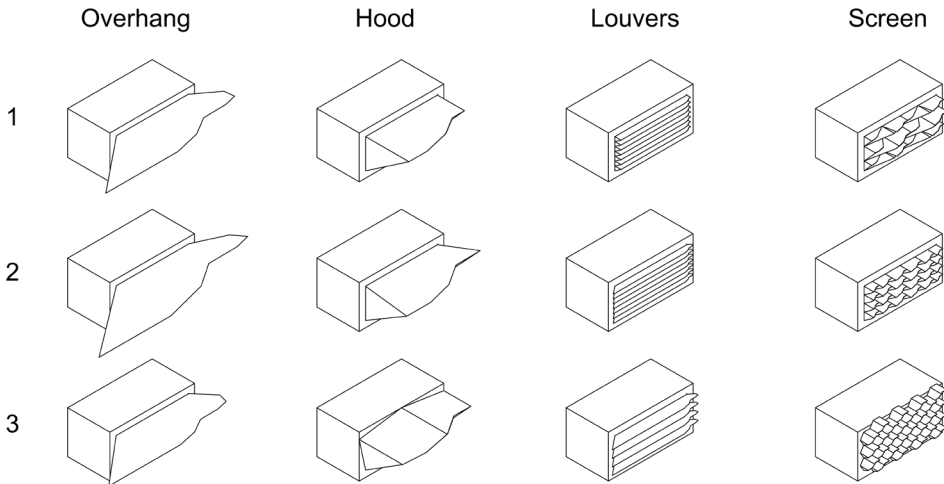
To study the aesthetic potential of the Vector Method, the Albuquerque baseline model is used, and twelve different design options are created and evaluated using only the Vector Method, as shown in Figure 3. It is impossible to create an aesthetic that could be agreed upon by all to be objectively better than another. In that light, demonstrating that the Vector Method can quickly produce unique design iterations leaves the potential for each designer to decide for themselves what is aesthetically pleasing for their project. Overhangs, hoods, louvers, and screens are iterated and simulated.

**Table 2.** Vector Method Iteration Study

Iteration	Thermal Load (Annual kwh)	% Improvement Over Baseline
Baseline	2,611.3	-
Overhang 1	2,060.3	21.10%
Overhang 2	2,029.9	22.26%
Overhang 3	2,092.7	19.86%
Hood 1	2,087.6	20.06%
Hood 2	2,070.7	20.70%
Hood 3	2,114.8	19.01%
Louvers 1	2,061.5	21.06%
Louvers 2	2,074.6	20.55%
Louvers 3	2,047.0	21.61%
Screen 1	2,128.8	18.48%
Screen 2	2,100.0	19.58%
Screen 3	2,107.8	19.28%

Table 2 includes the annual simulation results for all of the iterations generated by the Vector Method shown in Figure 3. Annual thermal loads are given (kwh) and the percent improvement over the baseline is provided.

All iterations from Table 2 show between an 18.48% and 22.26% reduction in thermal loads. Variation in iterations is likely due to how the Vector Method is only addressing direct sunlight and is attempting to create a binary list of shade hours. Each hour is either assessed to be 100% shaded or not, which means different typologies and forms might create different hours with partial shade. Despite these shortcomings, shades were able to be altered at the designer's discretion without significant sacrifices in performance. The Climate Method can move freely between most typologies, but cannot account for irregular forms such as screens and complex geometry such as non-rectilinear forms. The Iterate Method requires too many simulations to adequately explore this many typologies and variables to be feasible in practice. The Cell Method can help to evaluate many options (aside from self-shading typologies) but can only evaluate what the designer creates, meaning each iteration is not guaranteed to perform similarly if changes between iterations are drastic enough.



**Figure 3.** Design Iterations Using the Vector Method.

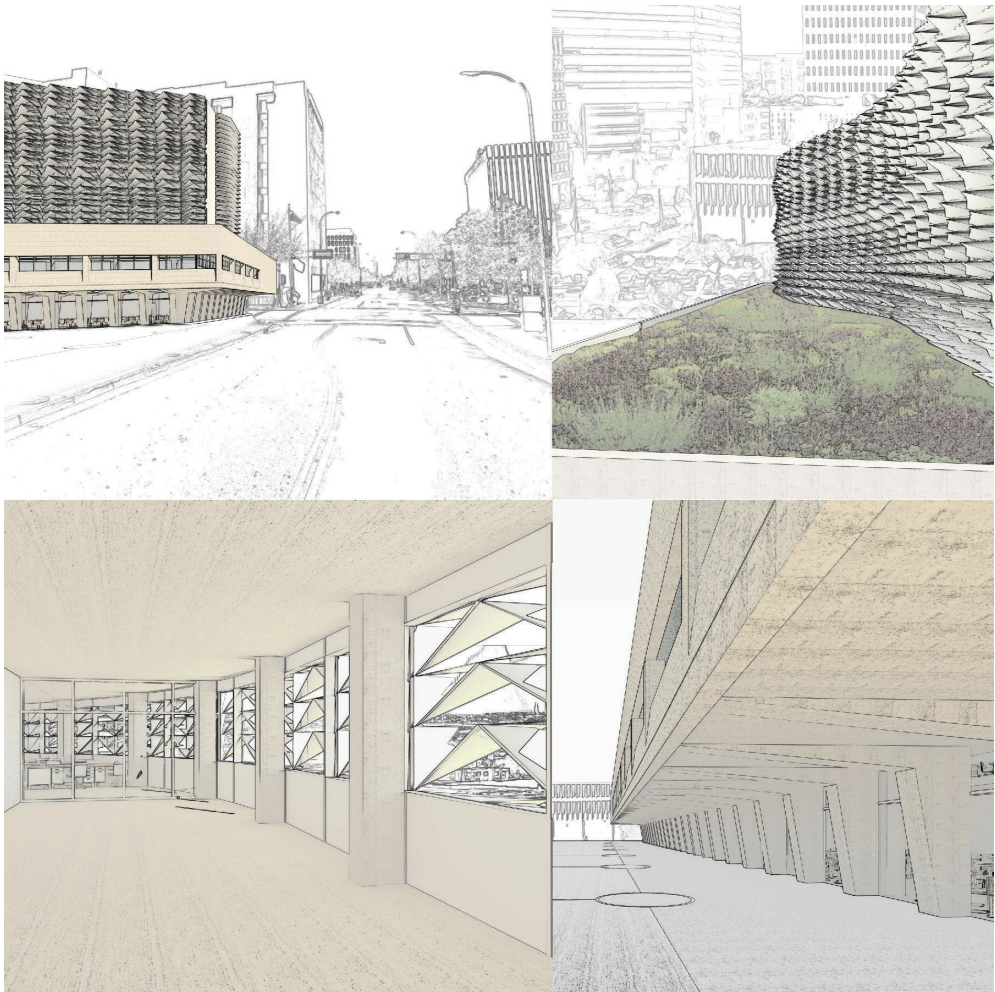
#### 4.0 VECTOR METHOD DESIGN APPLICATIONS

In the Practice of Architecture, baseline models can only prove so much before decisions must be made branching out to multiple variables involving physical context, building program, personal taste, and more. Figure 4 show a potential design solution for an office building located in the parking lot just north of Civic Plaza in Albuquerque, New Mexico. The south side of the office 'block' utilizes a triangulated screen generated by a Grasshopper script using the Vector Method, similar to screen 1 from the study above. The screen creates an interesting dynamic for users inside the space and creates a textured effect for people passing by the project. The ground level is comprised of commercial programs and uses the Vector Method to generalize how far the building should extend above to shade the ground level programs. This creates a sheltered walking space for pedestrians as well as allowing the building to perform better. This is only one example of the Vector Method being applied to one theoretical project, however, this example highlights the potential for this method to account for user experience and the creation of space that many find central to the practice of architecture. One can see how the different iterations in section 3.2 could lead to many fruitful design iterations that could change the character of the project completely.

#### CONCLUSION

The Vector Method improves upon existing shading device design methods by offering freedom to explore aesthetic options through design while holding the designer accountable to performance criteria. This adherence to performance and freedom to explore aesthetics holds the designer closer to the ideals of what makes an object into an 'architectural element'. The creation of a three-dimensional shading mask from hourly energy data mimics the intent of the original two-dimensional shading mask used in the Climate Method by Olgyay and Olgyay, allowing designers to switch between and size shading typologies freely while also informing the designer about which typologies will work best in their unique case. The three-dimensional mask improves over the two-dimensional version by existing in modelling space in the context of the building being designed, relating to an interface and workflow that designers are more familiar with. The parametric connectivity between the building geometry and properties to the generation and display of the shading mask mimics other successful parametric design systems including the Cell Method. As seen in the studies above, the Vector Method is capable of producing solutions that perform on par with existing design methods as well as producing a wide range of design options that perform to a similar level. The Vector Method ensures performance to a high standard while leaving the end solution ambiguous for the designer to define.





**Figure 4.** Design Applications of the Vector Method on a Test Building.

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