A New Approach to Modeling Frit Patterns for Daylight Simulation

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ABSTRACT

With recent progress in the development of affordable and faster digital design techniques and production methods, as well as the rising demand for buildings with better thermal and visual comfort, the use of frit patterns is becoming more common. There is a great diversity of fritted materials, but there are limited highly technical solutions for evaluating the effects of using these materials. This paper introduces a custom workflow for modeling frit patterns for daylight simulation on buildings, which streamlines quantitative and qualitative daylight analysis by using parametric modeling tools such as Grasshopper3D, in association with validated lighting rendering engine Radiance. The presented method was applied to a real-world project with custom ETFE facade elements and complex geometries to explain the capabilities of the workflow.

Author Keywords

Frit, ETFE, daylight analysis, Radiance, Honeybee, performance-based design.

INTRODUCTION

As the technology of producing fritted materials has progressed over the last decade, there has been increasing desire to model the effects of using this technology in buildings. Using fritted materials changes the aesthetics of a building (qualitative aspect), as well as its thermal and daylighting performance (quantitative aspect). Generally, different solutions are used separately to evaluate qualitative and quantitative effects of using ETFE. Designers use photo-realistic rendering engines to visualize the space with fritted materials mapped on surfaces, and engineers use physically accurate rendering engines to model quantitative effects of using fritted material. The two teams therefore end up with different solutions to an identical problem. Moreover, each approach has its own way of preparing models and assigning inputs, which makes it difficult, if not impossible, to create an identical model for both platforms. This paper introduces a custom workflow developed in the 3D parametric modeling environment of Grasshopper3D with Radiance [10] as the rendering engine. The method uses a single model for design and analysis, and Radiance for both qualitative and quantitative analysis.

The workflow is used to study the effects of frit patterns on exterior ETFE pillows of the Culture Shed, a performance and exhibition space in the new Hudson Yards development in Manhattan. The building designer, Diller Scofidio + Renfro [5], included fritted pillows to mitigate excessive solar gain, potential visual discomfort as well as excessive illuminance, while keeping visual continuity between inside and outside spaces.

EXISTING METHODS

Modelling frit patterns accurately consists of two steps. First, the pattern is applied to a defined geometry and the properties of frit and base material are assigned. Second, a physically accurate engine is used to calculate light distribution in the scene. There are a number of photo-realistic rendering packages that allow users to apply image-based patterns for visualization, with simplified methods for defining the materials. These rendering packages do not use physically accurate engines. On the other hand, available interfaces for physically accurate rendering engines, such as Radiance, don't provide user-friendly solutions for image mapping, which limits their use to more technically inclined users. Currently, there are three common methods to model frit patterns by Radiance.

The first method uses a Radiance function called Perforate.cal to generate an evenly distributed dot frit pattern. Standard Radiance materials can be used for base and hole materials and the Perforate.cal calculates the position of each material on the surface based on diameter of dots and an input scale. The example below shows how the function can be used to generate a green frit pattern on a vertical surface in the XY plane:

```
void glass VE8-40_glass
0
0
3 .667 .667 .667

void trans greenfrit
0
0
7 0.370 0.502 0.304 0.010 0.15 0.222 0.000
```

SpringSim-SimAUD, 2015, April 12 - 15, Alexandria, VA, USA

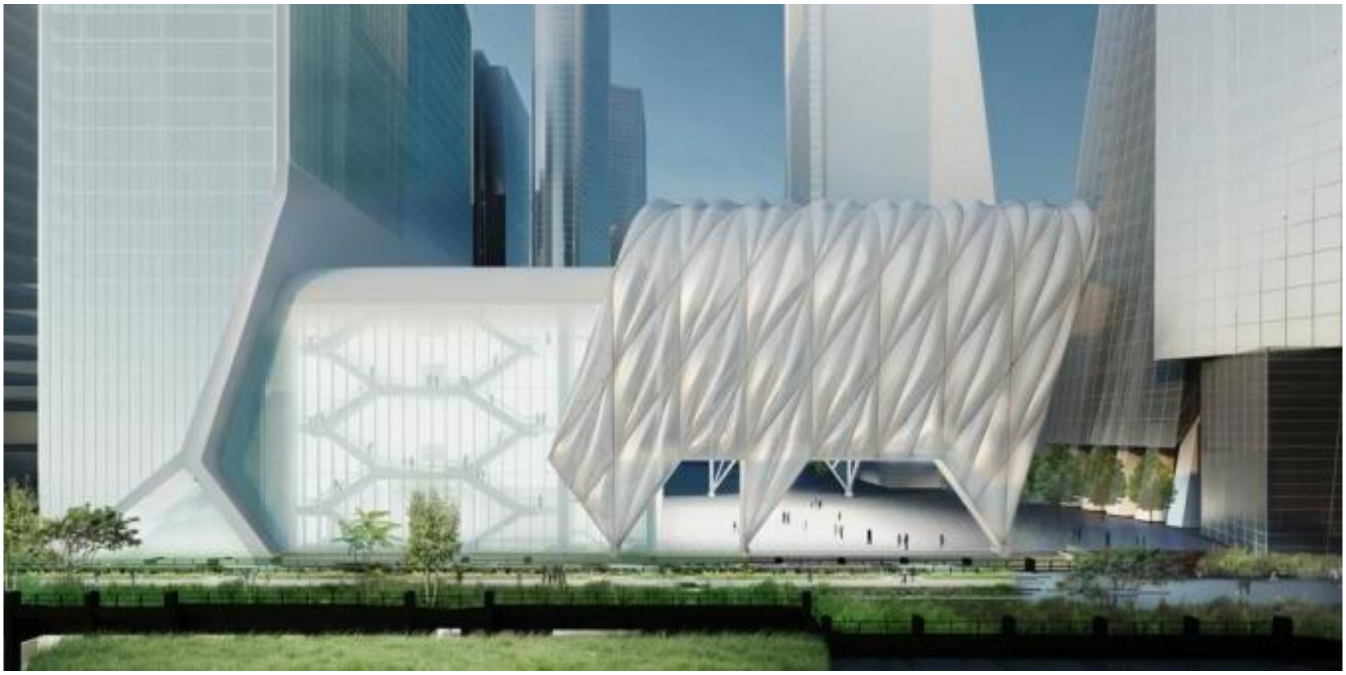

Figure 1. Culture Shed, Credit: Diller Scofidio + Renfro

```
void mixfunc frit-g40
6 VE8-40_glass greenfrit z_hole perforate.cal -s .5
0
1 .357
```

This method is usually used for planar geometries in standard planes (XY, XZ, YZ). It can be modified to generate a similar pattern in 3D and on non-planar surfaces, but the user will have limited control of uv distribution and the pattern won't be as expected on complex geometries. Moreover, the function is limited to just generating evenly distributed dot patterns and can't generate other custom patterns.

The second method used outputs of Optics [7] and glaze script [4]. Optics was developed at LBNL and was designed to evaluate properties of complex glazing units. Radiance's outputs of Optics can be processed by Optic2glazeddb to generate a format that can be used by Radiance. The results can then be used to generate Radiance renderings. Similar to the previous method, this method doesn't provide support for generating custom frit patterns.

The third method uses Bidirectional Scattering Distribution Function (BSDF) measurements for frit patterns from available resources such as LBNL Window package [8]. Window is also developed at LBNL, and is used for modeling complex glazing systems. Window has libraries for different window system components, venetian blinds and roller shades. Window can be used to generate BSDF files, including systems with frit patterns. Radiance also has a genBSDF module that can be used to generate BSDF data from a Radiance model. The main constraint of using BSDF files for this study is the limitations for visualizing the geometry, which means they can't be used for qualitative analysis [1].

THE NEW METHOD

The new method uses Rhino/Grasshopper to map images, frit patterns in the case of this paper, on test geometries and export them to Radiance for daylight analysis. The workflow is developed in Grasshopper3D, the visual programming plugin for Rhinoceros. The visual programing platform provides easy access to different stages of the analysis, from geometry generation through material and frit pattern assignment, to analysis of specific settings, such as weather file and analysis type. Patterns are visualized in Rhino and the user can modify them before running the simulation.

A number of Grasshopper plugins are used in this workflow. The Human plugin [6], developed by Andrew Heumann, is used to map images on geometries and visualize them in Grasshopper. It extends Grasshopper's ability to create and reference geometries and carries some Rhino functionality, such as image mapping, to Grasshopper. Honeybee is used to export Grasshopper geometries and their assigned materials to Radiance. Honeybee is part of Ladybug, an environmental plugin for Grasshopper 3D that connects Grasshopper 3D to validated simulation engines for daylighting and energy simulation [9]. It currently supports integration with Radiance, Daysim, EnergyPlus and OpenStudio. Finally, a set of new components is developed as an extension for Honeybee to export image patterns from Grasshopper to Radiance.

This workflow was initially developed to study the effects of frit patterns in the Culture Shed retractable structure, which is covered with curved ETFE pillows (Figure 2). In this paper, Culture Shed is used to explain the workflow; however, this workflow can be applied to any building.

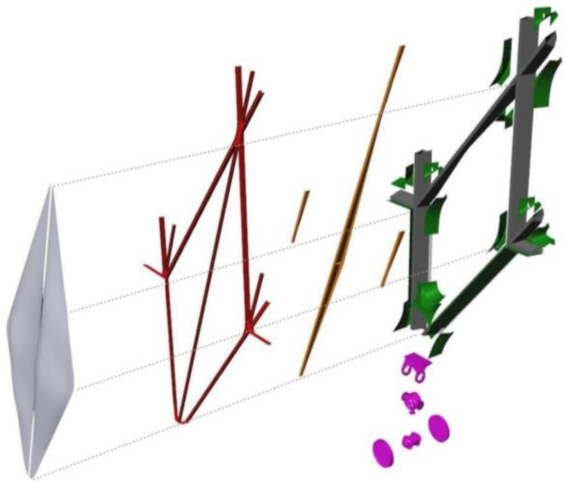

Figure 2. ETFE pillow connection to structure

The main challenge of the project was to apply several types of frit patterns to ETFE pillows with complex geometries. Each pillow is supported by steel structure. The design team was interested in studying how different frit patterns on ETFE pillows would affect daylight distribution inside the shed. The pillows have a double curvature and are defined based on the results of structural analysis. The following section describes each step of modeling the shed in more detail.

Preparing Geometry

This workflow accepts Rhino/Grasshopper's meshes and surfaces. The resulting design model can be used directly for analysis. The Human plugin, however, supports only image mapping for mesh geometries. Where image mapping is required for a surface, it should be first converted to mesh before applying the map.

Image Mapping in Grasshopper

Image mapping is already supported by Radiance, but applying accurate image mapping to multiple surfaces with different shapes and sizes needs a considerable amount of expertise and effort [2]. It is also impossible to check the mapping without running the simulations. Using Rhino and Grasshopper eases the process of image mapping and provides a real-time visualization of image mapping before running the analysis. In this workflow, Human plugin is used to apply the image mapping. This component accepts an input mesh and uses Rhino's algorithms to generate a modified mesh. Supported image mappings are shown in Figure 4.

A user can control the size of the pattern and other mapping parameters using Grasshopper sliders. Figure 3 shows how two different sizes of dot patterns are applied to multiple pillows with double curvature.

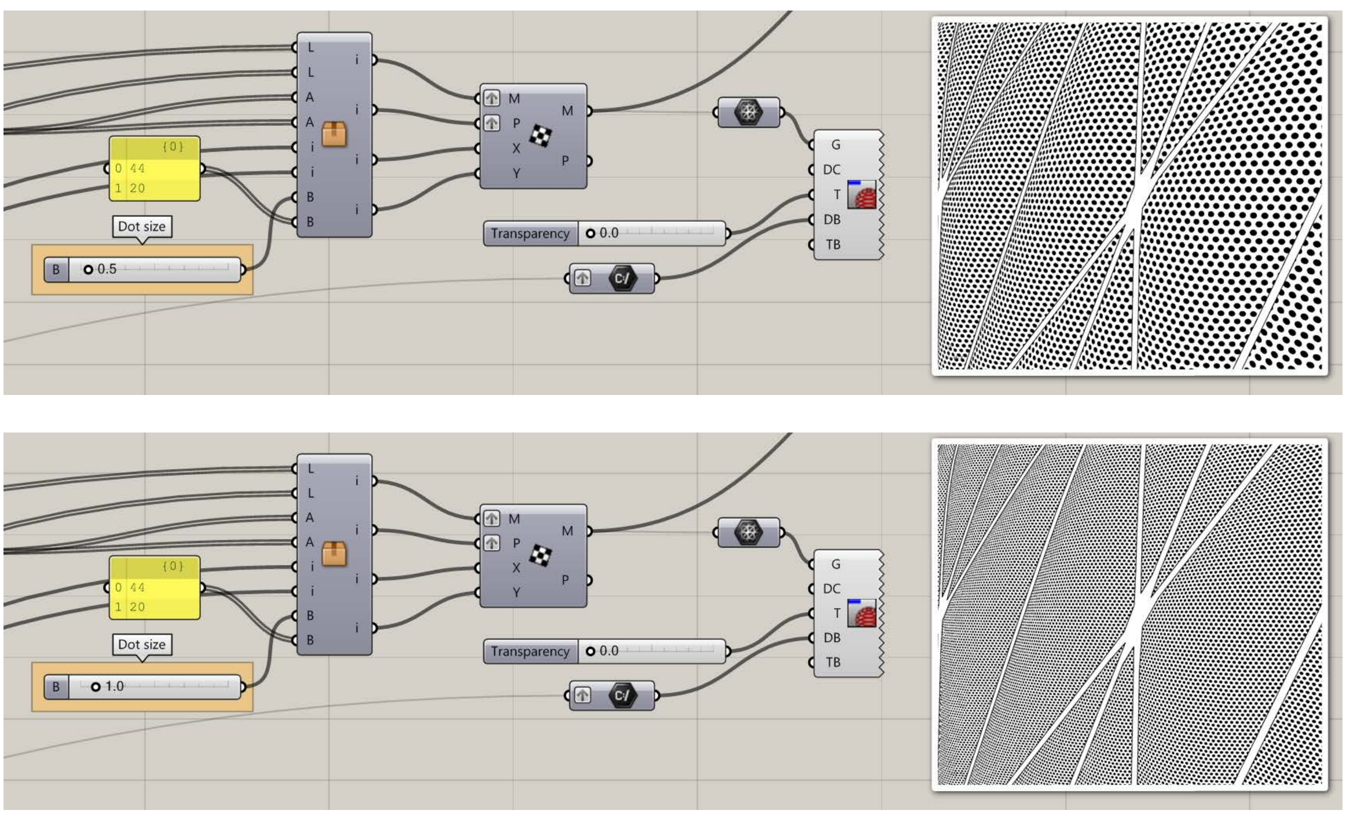

Figure 3. Real-time image mapping visualization in Grasshopper using Human plugin for two different pattern sizes

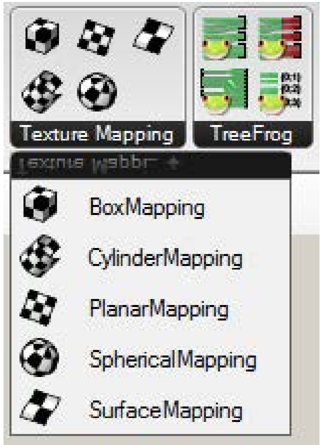

Figure 4. Image mapping options from Human plugin

Export Mapping to Radiance

A custom Grasshopper component is developed to export mesh and image patterns to Radiance. The component inputs a mesh from Human component, base Radiance material, and an HDR file of the image, and generates Radiance readable files (Figure 5).

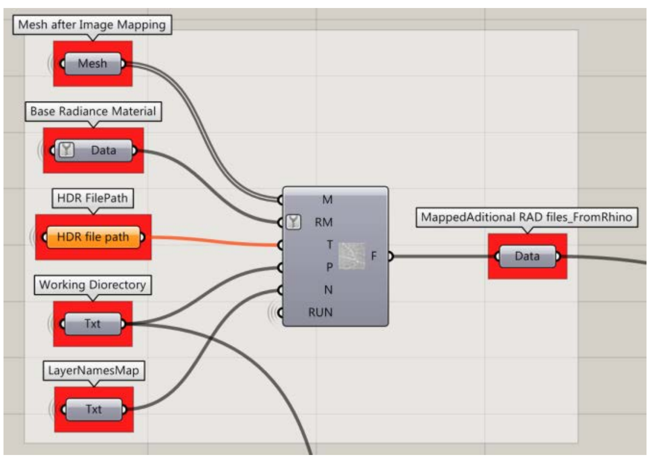

Figure 5. Export mesh and mapping from Grasshopper to Radiance. Generated files from this component will be added to Radiance scene.

In the first step, Rhino/Grasshopper meshes are exported as an .obj file. Obj is a geometry definition file first developed by Wavefront technologies. It is a simple data-format that represents the data geometry for each vertex, vertex normal, UV positions of each texture coordinate vertex and faces. In the second step, colorpict pattern is used as the modifier to create the material based on HDR image that can be applied to the surfaces [3].

Finally, a Radiance mesh file is generated using the material and the Obj file. This mesh can be added to the Radiance scene using Radiance's mesh painting and will carry all the geometrical and material data. The following lines is an example of the Radiance file:

```
void colorpict dots_image_pattern
7 red green blue ./pattern/dots.hdr . (2.11*(Lu-floor(Lu)))
(Lv-floor(Lv))
0
1 1

dots_image_pattern glass dots
0
0
4 0.980 0.980 0.980 1.400

void mesh painting
1 InteriorPillow.msh
0
0
```

Preparing Radiance's Scene and Run Analysis

Up to this step, surfaces with mapped patterns are exported in a Radiance-compatible format. For the rest of the scene, Honeybee standard components can be used. Honeybee supports creating Radiance materials in Grasshopper and the user can assign them to surfaces or meshes as desired. These geometries can be exported to Radiance next to the files that are prepared in step 3. Figure 5 shows the process of putting the study together in Grasshopper. The component-based organization of different actions and the possibility of grouping related components together and tagging them makes the workflow clear and easy to understand.

In this case study, except for ETFE pillows, generic materials are assigned to the rest of the surfaces in the model.

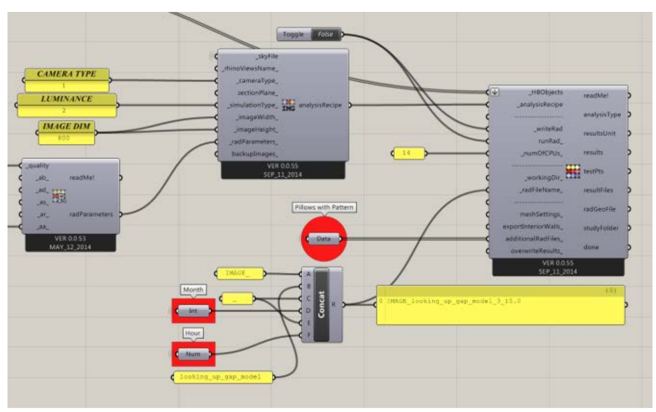

Figure 6. Putting the scene together to generate an image-based analysis using Honeybee. The generated files in step 2 are added to the scene as additional Radiance files (additionalRadFiles_).

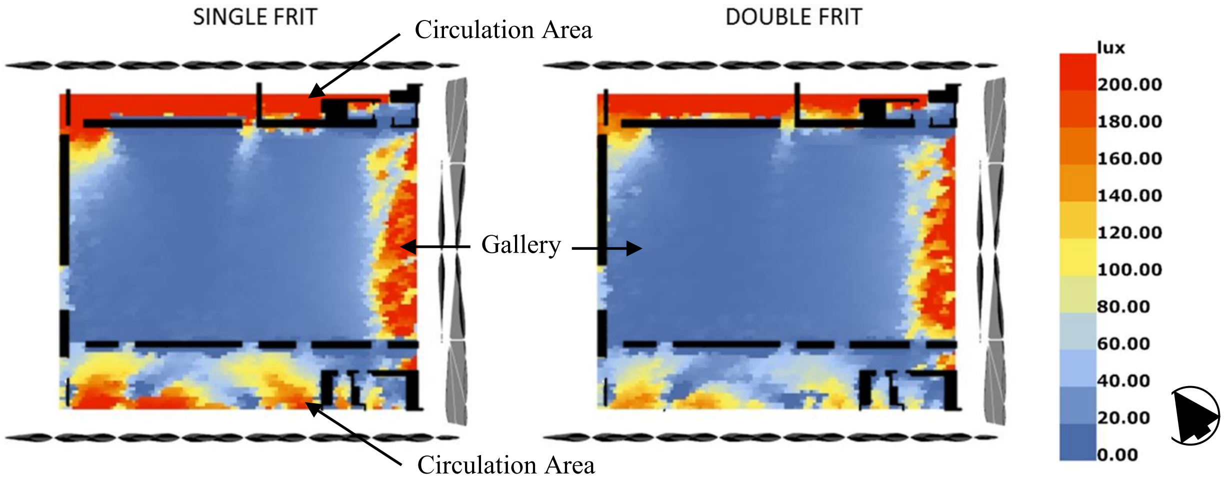

Figure 7. Illuminance levels inside the gallery. Frit only on the outer side of pillows (left). Frit on both sides of pillows (right), 3rd floor gallery, March 21, 9 a.m.

Visualizing Results

Once analysis is completed, the results will be saved in a local folder. Based on the type of analysis, the results will be available as rendered images or imported back to Grasshopper using different Honeybee components. It can then be visualized as colored geometries. Several parametric studies have been done for the project to study different densities and radius for the frit patterns for interior and exterior spaces for two different placements of the shed. Since exploring the results of the study is out of the scope of this paper, a selection of the results is presented in the following.

Figure 7 shows illuminance levels inside the gallery in the second floor for two different combinations of frits on the pillows once the shed is retracted over the building.

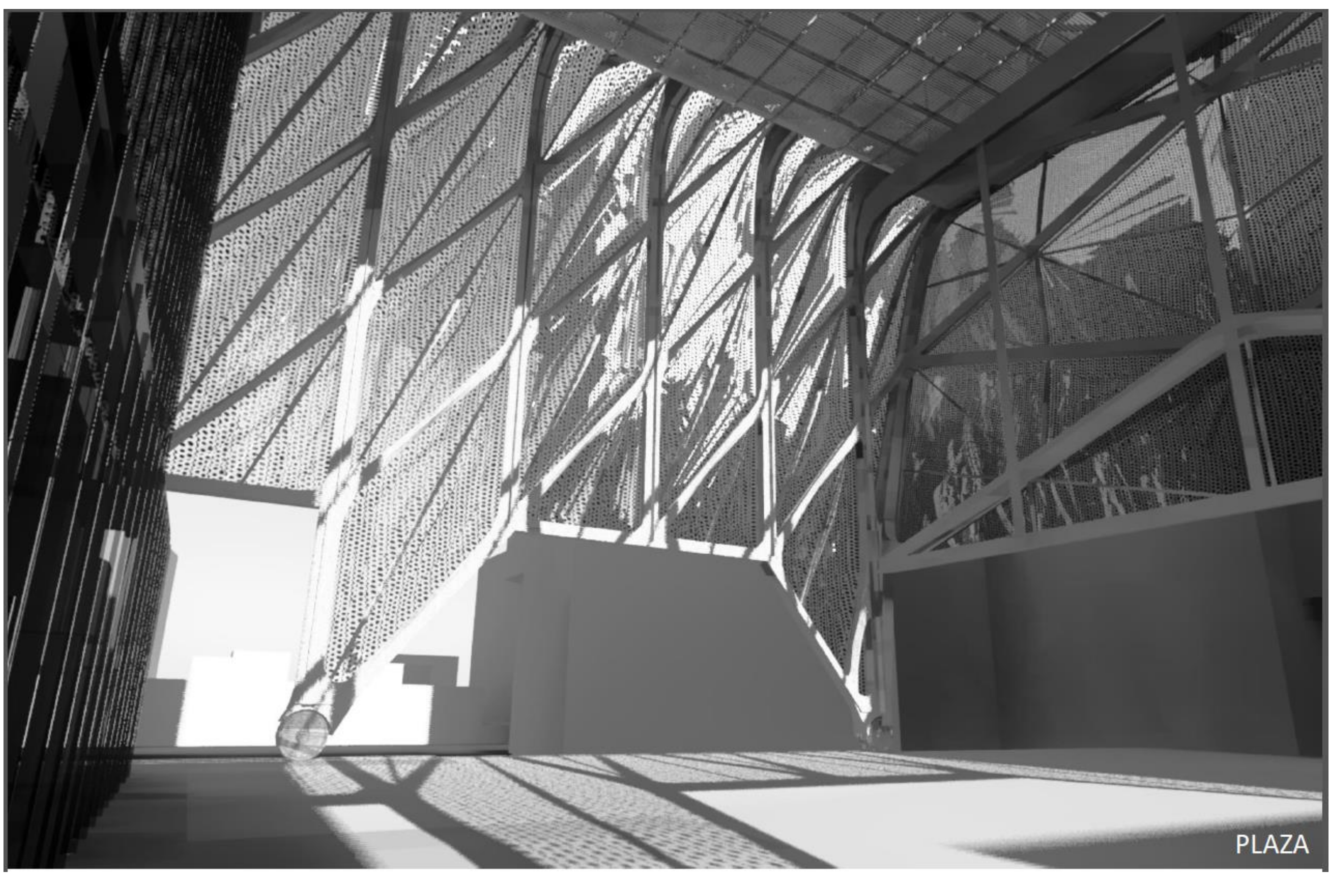

Figure 8. View from inside the plaza.

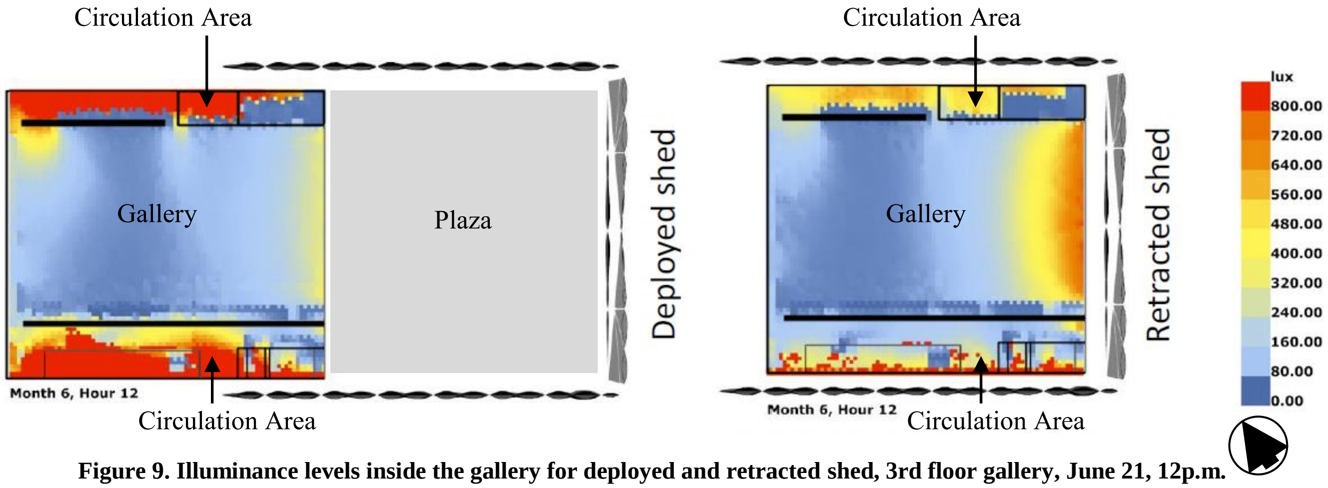

Figure 9. Illuminance levels inside the gallery for deployed and retracted shed, 3rd floor gallery, June 21, 12p.m.

Figure 8 shows a rendering from inside the plaza area when the shed is deployed. Figures 9 shows illuminance levels inside the gallery for different configurations of the shed.

CONCLUSION

The paper presents a workflow that marries parametric modeling and physically accurate rendering engines that provide an integrated, flexible approach to streamlining modeling and analyzing frit patterns qualitatively and quantitatively.

The workflow allowed the team to explore a wide range of solutions in a short time, and provides the desired results to the design team in a timely manner to help with making design decisions based on daylighting analyses. This method makes the process of studying frit patterns accessible to designers and allows the findings to be integrated early in the design. By doing so it helps designers and engineers achieve a high-quality, high-performance design.

The parametric modeling environment of Grasshopper3D provides flexibility and control of input parameters. It also helps automate the process so multiple studies can be run after setting up the model. Radiance serves as a single platform rendering engine that can achieve accurate results for both qualitative and quantitative analysis.

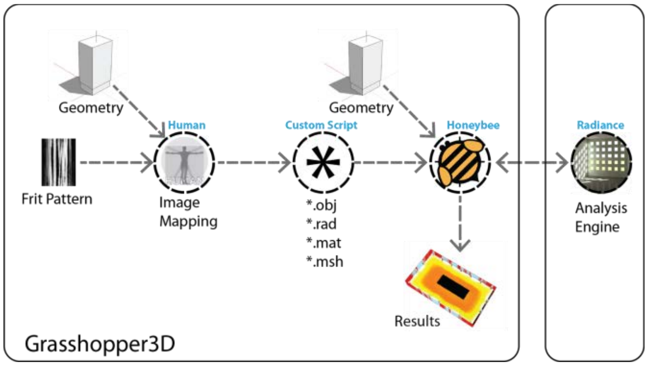

Figure 10. Simulation Workflow

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