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A DETAILED METHODOLOGY FOR CLOUD-BASED DAYLIGHT ANALYSIS

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ABSTRACT

It is often difficult for practitioners to trust analysis software if its methods are not transparent and well-documented. The purpose of this paper is to open for review, comment and reference the methodology used within Sefaira to help those who use it and those who field requests to respond to its outputs.

This paper will document the way in which Sefaira conducts cloud-based daylighting analysis to serve non-specialist architect practitioners seeking to inform early-stage design decisions. This paper will explain how a Sefaira simulation is defined and conducted, with particular focus on the tool's unique use of cloud-computing and how the tool is optimized to support early-stage decision making.

This paper does not try to revalidate the Radiance or Daysim engines that Sefaira uses as its fundamental platform.

INTRODUCTION

Incorporating analysis into design is critical to achieving high-performance buildings. Sefaira employs Radiance and Daysim to help architectural designers assess daylighting performance as they design, thus making it easier for them to meet their projects' performance goals.

Architectural designers who seek to incorporate analysis into early-stage design do not need or want full control over every possible simulation input and setting: that much detail would be overwhelming and would incur too great a time cost. This puts Sefaira in the unique and challenging position of defining a fixed default setup that is "just right": it needs to provide an appropriate level of control over inputs and settings; it needs to simulate performance fast enough to keep up with iterative design; and it needs to be accurate enough to matter.

Appropriate Level of Control

Sefaira primarily serves non-specialist architects and designers. Control over inputs and settings must be detailed enough to support comparative analysis, and inform design decisions like siting, form, fenestration, and facade articulation. It should not, however, be so detailed as to overwhelm the user or discourage engagement with earl-stage analysis. The following illustrates the assumptions Sefaira makes about simulation definition and execution that help ensure non-specialists can engage with performance analysis.

Fast Enough to Keep Up

Evaluating multiple design decisions in a matter of hours cannot be served by a simulation process approach that by itself takes multiple hours just to set up and conduct. Defining and conducting the performance simulation must be on the order of minutes and not hours, otherwise it is not applicable to early-stage design and decision making.

Accurate Enough to Matter

The goal of building performance simulation is to inform decision-making around design. If the simulation output is not accurate or precise enough for the exercise, there is no reason to conduct the simulation in the first place.

Given the context of early-stage comparative and indicative studies, accurate enough is understood to mean that simulation outputs are consistent with those derived from other accepted methodologies. As we will see, existing accepted methods produce results that vary with each other. Provided Sefaira's variation with any one of them is less than or equal to the greatest variation among them, it should be considered accurate enough to matter for early-stage comparative and indicative studies.

Documenting Sefaira's Approach

Sefaira recently reviewed and updated a critical aspect of its default setup: the parameters used when employing Radiance's rtrace program. Sefaira sought a set of parameters that would produce results comparable to relevant and accepted benchmarks while completing the vast majority of simulations within 5 minutes.

SEFAIRA SIMULATIONS AND METHODOLOGY

Sefaira employs Radiance and Daysim to deliver each of the following sensor-based analyses:

- Point in time illuminance
- Climate-specific annual illuminance
- Direct sunlight
- Daylight factor

Each of these analyses is unique, but they do share some common inputs. Before detailing the specific implementation of each analysis, this paper will first document the common inputs that are relevant to all of the analyses.

Building Geometry

Sefaira consumes SketchUp and Revit geometry and converts it to a basic planar expression of the building. This planar expression is composed of polygons; and it is these polygons that are defined in the Radiance geometry input file. An example of a typical argument within the input file is as follows:

```
Massing polygon Model.f1
0
0
9 24.627932760511545 -9.031867057404867
0.5944949864483211 27.178111680171934 -
12.705220865242115 0.5944949864483211
24.556972052010096 -13.097203324744639
0.5944949864483211
```

This argument tells Radiance that a polygon named "Model.f1" exists in space as defiend by the nine XYZ coordinates provided, and that it should be modified with the "Massing" material. For a large model, there are thousands of these lines, because a large model is composed of many polygons.

In addition to converting SketchUp planes and Revit objects to polygons for use in Radiance, Sefaira assesses the classification of these SketchUp Planes and Revit objects as defined by the user. Specifically, Sefaira assesses if the user has classified the plane or object as window glazing: if the plane or object is *not* window glazing, then it receives a "Massing" designation; if it *is* classified as window glazing, then it receives a "Glazing" designation. These designations dictate what material will be applied to a given polygon. Note that a user can chose to designtate elements as "Ignored for Sefaira" which ensures they are not included in the simulation.

Defining and Assigning Materials

Sefaira daylighting visualization models can contain up to two materials: an opaque "Massing" material based on a plastic Radiance primitive, and a transparent "Glazing" material based on a glass Radiance primitive.

The Massing material definition is fixed and defined as follows:

```
0
0
5 0.4000 0.4000 0.4000 0.0000 0.0000
```

The five arguments in this material definition refer to the Red Green and Blue color reflectance values (in this case each equal to 0.4), the specularity (0) and roughness (0). The preceding definition, then, translates to a flat and smooth gray plastic, akin to examining a physical cardboard scale model in an open outdoor area.

The Glazing material definition is defined according to its transmissivity, *tn*:

0

0

3 *tn tn tn*

A user specifies transmissivity indirectly by designating a Visible Light Transmittance (VLT) which is applied to all building glazing. Sefaira derives transmissivity from the VLT value.

Arraying Sensors

Sefaira daylighting analyses employ sensor-based simulations, and as a result seek to array sensors across a horizontal plane offset from the floor.

A sensor has X, Y, and Z coordinates. The X and Y coordinates of a sensor are set relative to the edges of the building's floors. This is possible because a user must classify SketchUp planes and/or Revit objects as "floors" before a simulation can proceed. The Z coordinate of a sensor is set based on a discrete user input called "Workplane Height." This positive height offset is taken relative to each building floor, such that an array of sensors is present at Z = [Workplane Height] wherever there is a building floor. The typical workplane height is 30" above the floor or 1" above the highest regular task surface.

The distance between sensors is defined automatically and is informed by the building's floor area. A user can select two resolution settings: Low resolution typically results in a grid spacing of 1m-2m, while High resolution typically results in a spacing of 0.6m-1m.

Converting Point Values to Visualizations

Sefaira's sensor-based analyses deliver discrete point values (i.e. illuminance or daylight factor). Converting point values to false color visualizations (Fig. 1) demands a method for interpolating values between sensor points and assigning pixel values to illuminance or daylight factor values.

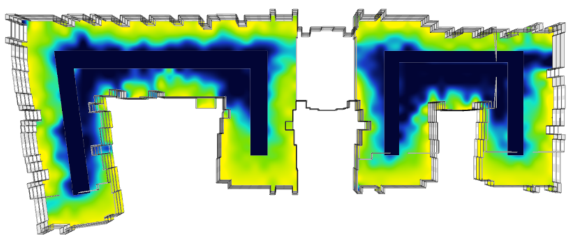

Figure 1 Sefaira Daylighting Visualization: Navy represents 0% of considered hours meeting threshold illuminance and yellow represents 100% of considered hours.

Sefaira's method for interpolating values between sensor points and overlaying the resulting set of pixels is common across all analyses.

Defining Simulation Parameters

Each of the Sefaira analyses relies on backward ray tracing powered by Radiance. Broadly, ray tracing consists of tracing the path of light from the light source to a destination in a scene and assessing the impact. In Sefaira's case, where an array of sensors is used, it makes more sense to use backward ray tracing: emit rays from a sensor and assess whether or not it finds a light source. Backward ray tracing only requires consideration of rays emitting from the sensors under consideration, rather than an infinite number emitting from a light source.

The Radiance program responsible for ray tracing is rtrace_dc. Daysim's program, rtrace_dc, is a modified version of the Radiance rtrace program. Sefaira utilizes both, and employs one or the other depending on the type of simulation.

The following set of parameters governing the behavior of the ray tracing calculation is shared by all simulations:

Table 1 Sefaira rtrace Parameter Values

PARAMETER	VALUE
aa	0.15
ab	This value is fixed at 0 when considering direct sun simulations, and can be set to 2, 3, or 4 by the user for all other simulations
ad	256
ar	32
as	20
dc	0
dj	0.7
dp	32
dr	0
ds	0
lr	0
lw	0.05
st	1

You will note that ambient bounces (ab) is the only parameter that changes. There are two reasons for this: first, simulations assessing only the direct component of daylight should not consider ambient light and thus set ambient bounces to 0; second, ambient bounces impact output resolution and processing time. A user may decide that low resolution and low processing time is preferable to high resolution and high processing time. In such a case, the user would select ab = 2 instead of ab = 4.

The following section details how Sefaira arrived at this particular set of default values.

SEFAIRA'S DEFAULT PARAMETERS

Sefaira sought a set of default rtrace parameters that would produce results comparable to relevant and accepted benchmarks without significantly lengthening simulation time. For the non-specialist designer in the throes of rapid early-stage design iteration, analysis speed is critically important.

Research Approach

Three buildings of various complexities were considered: a simple box, a series of stacked boxes, and a more detailed multi-level office building.

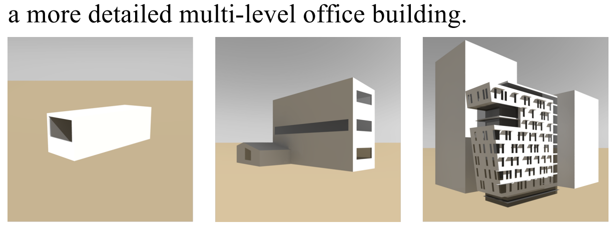

Figure 2 Study models

For each of the buildings, the research team conducted five sensor-based Radiance simulations using different sets of Radiance parameters, and estimated the illuminance at 10am on March 21. The following five Radiance parameter sets were used to estimate illuminance for each of the three buildings:

1. The proposed Sefaira parameters which have since been incorporated into the product.
2. Parameters sourced from Radiance's default "Medium" rendering setting.
3. Parameters sourced from a publicly-available Daysim 3.0 tutorial.
4. Parameters sourced from a consulting specialists' input.
5. Parameters sourced from early Radiance documentation.

Settings Summary

	Sefaira	Radiance "MEDIUM"	Daysim 3.0 Tutorial	Specialist-suggested	Radsite "Accurate"
-aa	0.15	0.15	0.1	0.15	0.15
-ab	4	4	5	6	2
-ad	256	800	1000	1024	512
-ar	32	1904	300	96	128
-as	20	128	20	2	256
-st	1	0.1	0.15	0.05	0.15
-lw	0.05	0.0001	0.004	0.000001	0.002
-dc	0	0.5	-	0	0.5
-lr	-	8	6	6	8
-dj	0.7	0	0	0	-
-dp	32	4096	512	4096	-
-dr	0	1	2	3	-
-ds	0	0.3	0.2	0.01	-
-ms	-	0.01	-	1.1	-
-ss	-	1	-	32	-
-av	-	0.01 0.01 0.01	-	0 0 0	-
-dt	-	0.1	-	0	-

Figure 3 Lists of Comparison Parameter Values

All other elements of the simulation (e.g. material properties, location, etc.) were kept constant.

Simple Box

Note that the point illuminance values estimated in the simple box model are very consistent across all five simulations:

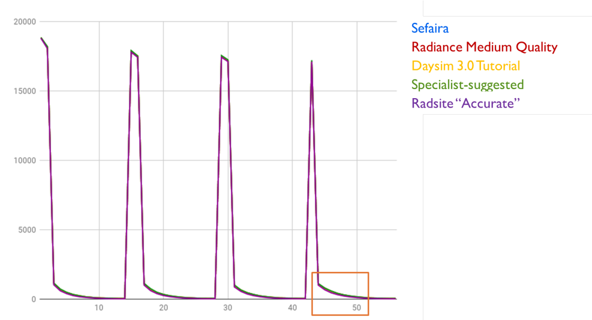

Figure 4 Box Model Point Value Comparison Graph: Y-axis is Illuminance in Lux; X-axis is the Sensor Point

This graph shows sensor point values for the whole model. Focusing on the enlarged area in Figure 5, it is clear that a small amount of variation occurs:

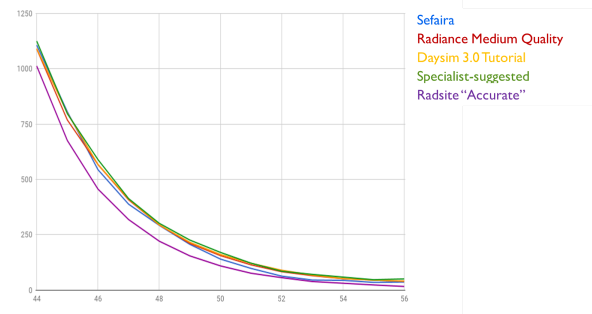

Figure 5 Box Model Point Value Comparison Graph Enlarged: Y-axis is Illuminance in Lux; X-axis is the Sensor Point

The variation is slight, with the greatest outlier being the parameters sourced from early Radiance documentation. The proposed Sefaira settings track well against the other three benchmarks.

In addition to illuminance values, simulation speeds were compared. Simulation time using the Sefaira settings was much faster than simulation times associated with the three benchmarks the Sefaira settings tracked so closely against:

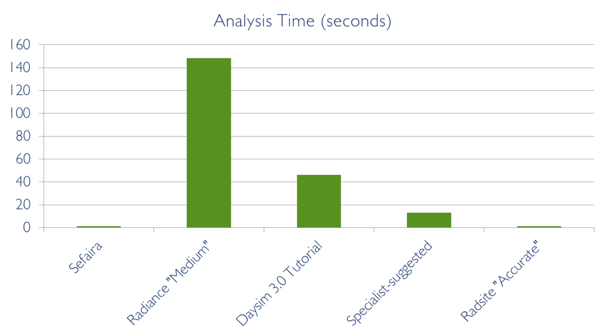

Figure 6 Box Model Analysis Time

Stacked Boxes

The stacked boxes model contains quite a few more sensors than the Simple Box, so a segment of the results is shown below to illustrate how the various groups of settings performed relative to each other.

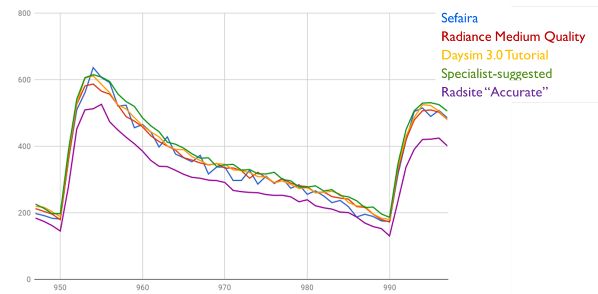

Figure 7 Stacked Boxes Model Point Value Comparison Graph: Y-axis is Illuminance in Lux; X-axis is the Sensor Point

Again, the "Radsite 'Accurate'" settings produced outlying values, while the other four tracked fairly well against each other. There was a bit more "noise" or variation produced from the Sefaira settings; this is an opportunity for further refinement, possibly associated with scene size and scene description (i.e. looking beyond Radiance parameters to smooth this variation).

Timing data again showed Sefaira significantly outperforming the other options:

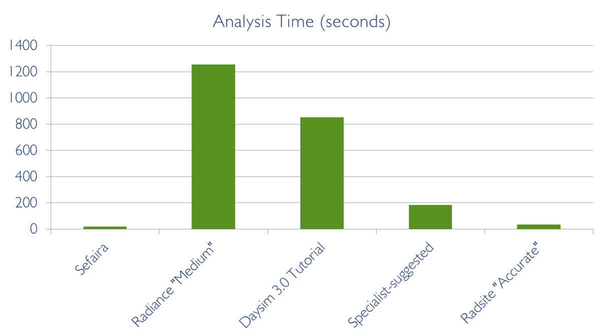

Figure 8 Stacked Boxes Model Analysis Time

Office Building

As the models grew in size and complexity, so too did the variation among the parameter groups:

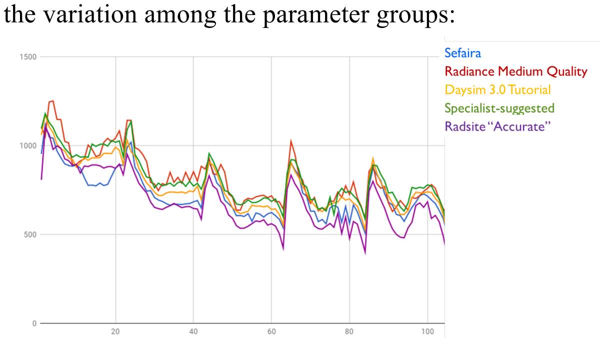

Figure 9 Office Building Model Point Value Comparison Graph: Y-axis is Illuminance in Lux; X-axis is the Sensor Point

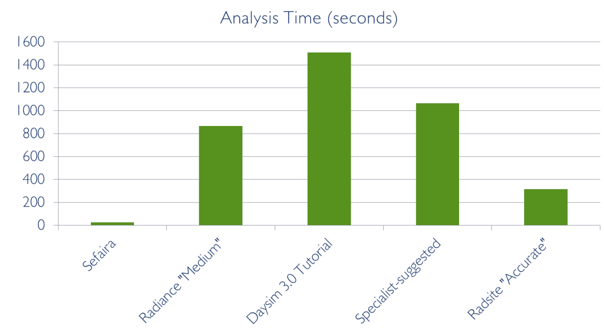

Figure 10 Office Building Model Analysis Time

The main takeaway from this third and final study was that the Sefaira settings adequately balance speed and precision: In the absence of a ground truth reference, the Sefaira setup (i.e. its group of parameters) is compared against accepted setups. The Sefaira setup's speed supports the rapid iterations present during early-stage design; and the Sefaira setup's variation with accepted setups is consistent with their variation to each other. This gives confidence to the claim that Sefaira can be used at the early stage of design to inform decision making.

SPECIFIC ANALYSES

As shown and discussed, Sefaira daylighting analyses depend upon multiple commonly derived and defined inputs; however each analysis also maintains unique requirements. The following will address the unique processes and requirements of each Sefaira analysis.

Point in Time Illuminance

Point in time illuminance assesses location-specific daylighting for a specific hour, day, and month. The simulation offers the user a choice to consider a clear sunny sky or a cloudy sky corresponding to a standard CIE overcast day. In addition to choosing the sky model, the user must define the desired point in time to consider. While a specialist user during late stage analysis may need to define a unique sky model, the choice of sunny or cloudy is adequate to support early-stage comparative and indicative studies among users who may not have the desire or knowledge to define a unique Radiance sky model.

The calculation is a basic execution of rtrace followed by an execution of Radiance's rcalc program to convert the rtrace output to illuminance values.

Climate-specific Annual Illuminance

Climate-specific annual illuminance assesses location- *and* climate- specific illuminance, derived from both daylight as well as direct sunlight (i.e. direct beam solar radiation).

Setup is automatic per the preceding sections: an ambient bounces (ab) value of 0 is automatically applied to the calculation of direct beam radiation, while the user-defined ab value of 2, 3, or 4 is applied to the annual daylight calculations.

The analysis uses Daysim's rtrace_dc program, which uses daylight coefficients to accelerate calculations that consider solar positions and weather conditions for every hour of every day of the year.

Direct Sunlight

Similar to the direct component within the annual illuminance calculation, the Direct Sunlight analysis considers only direct beam solar radiation. Unique to this analysis, however, is the user-defined time period: users can assess the presence or absence of direct beam solar radiation for a single day, or over the course of multiple days. Also, unlike the annual simulation which bases illuminance magnitude on weather file readings, the Direct Sunlight analysis assumes a clear sunny sky.

Daylight Factor

Daylight Factor is very similar to Point in Time Illiuminance, but maintains the following differences:

- Rather than a clear sunny sky, Sefaira assumes a uniformly overcast sky for Daylight Factor.
- Sefaira uses Daysim's ds_dayfactor program rather than Radiance's combination of rtrace and rcalc. This is done to leverage Daysim's ability to consider ranges of time beyond a single date and hour. Tests showed that results are consistent between the two methods; and using Daysim is convenient as requisite input header files can be prepared to serve daylight factor as well as annual illuminance.

EMPLOYING CLOUD COMPUTING

The goal of this paper is to publicly document how Sefaira's technology works. So far it has examined the common and unique aspects of Sefaira analyses. Next it will examine the technical solution (i.e. cloud-computing) that drives these fast simulations.

Process

The most computationally expensive component of Sefaira's simulations is backward ray tracing, either via Radiance's rtrace program, or Daysim's variant, rtrace_dc.

Sefaira uses batching (i.e. breaking extensive arrays of sensors into smaller groups) and parallelization (i.e. using multiple computational actors simultaneously) to complete the high number of requisite ray tracing calculations very quickly:

Batching: Sefaira considers groups of sensors, not entire arrays. Imagine the second floor of a large office. A sensor array that covers the entire floor would likely consist of many hundreds of sensor points. Now imagine if that single array of sensor points was divided into smaller arrays based on the floor boundaries of various rooms (conference rooms, private offices, etc.). Sefaira consumes these groups rather than the entire array because assessing a small group of sensors takes less time than assessing a big group of sensors.

Parallelization: Sefaira uses multiple processors at once. By assessing small groups of sensors simultaneously on multiple remote computational actors (i.e. parallelization in the cloud) Sefaira can do more in less time compared to using a single local machine. Given the context of a non-specialist user seeking simulations on the order of minutes and not hours, this speed is critical to support their engagement with building performance analysis.

Note that cloud computing serves all elements of the computational pipeline, not just ray tracing. Every step from converting input geometry to Radiance geometry and material information through producing visualizations based on point illuminance values happens in the cloud.

Impact

Speed of setup (i.e. providing sound default simulation parameters) and speed of calculation (i.e. batching and parallelization on multiple remote computational actors) makes performance simulation accessible to the non-expert designer seeking to inform early-stage design-decisions with actionable data. The impact, then, is better building design and greater overall industry engagement with building performance simulation.

CONCLUSION

This paper has documented how Sefaira conducts cloud-based daylighting analysis to serve non-specialist architect practitioners seeking to inform their early-stage design decisions.

Because Sefaira balances speed of setup and speed of simulation against complexity of operation while maintaining defensibility, it is a viable option for designers seeking to inform their building designs with performance analysis.

This public documenting of how Sefaira's technology works, should help users and specialists feel comfortable with Sefaira information, whether they are creating it or consuming it.

ACKNOWLEDGMENTS

We appreciate all the feedback and support from a wide range of Sefaira customers (too many to mention) which has helped inform and guide the development of rendering parameters in Sefaira.

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