

LADYBUG: A PARAMETRIC ENVIRONMENTAL PLUGIN FOR GRASSHOPPER TO HELP DESIGNERS CREATE AN ENVIRONMENTALLY-CONSCIOUS DESIGN

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ABSTRACT

As high performance design is becoming more desirable in the field of architecture, the need for supporting architects with environmental analysis tools is also growing. Rhino/Grasshopper is one of the most widely used platforms that are used by designers today. There are already a number of environmental plugins developed for Rhino/Grasshopper. However, Ladybug offers several advantages that are currently not offered by existing Rhino/Grasshopper related environmental design plugins.

Ladybug imports standard EnergyPlus Weather files (.EPW) in Grasshopper and provides a variety of 2D and 3D designer-friendly interactive graphics to support the decision-making process during the initial stages of design. It also simplifies the process of analysis, automates and expedites the calculations, and provides easy to understand graphical visualizations in the 3D modeling interface of Rhino/Grasshopper. It also allows users to work with validated energy and daylighting engines such as EnergyPlus, Radiance and Daysim. Integration with the parametric tools of grasshopper allows for almost instantaneous feedback on design modifications, and as it runs within the design environment, the information and analysis is interactive. The development is a free and open source; users can customize the tool based on their needs and contribute to the source code.

INTRODUCTION

The approach to the design process can produce vastly different outcomes in design and building performance. In an environmental design approach, the initial step is to identify critical environmental factors that influence building design. A clear understanding of the design problem and site environmental condition increases the possibility of making environmentally responsive design decisions in the early stages of design, even before a building form exists and a design is evaluated. In this stage, designers evaluate their decisions, not based on the result of any analysis, but based on personal judgment that stems from experience and the understanding of environmental data. An and Zofchak (2012) point out that not considering basic analysis “may lead designers to jump into

unnecessary analysis to answer basic questions.” Meaningful data visualization can assist designers in making better design judgements. With this approach, advanced studies, during the design development, can also be used to enhance schematic environmentally-conscious design options.

Currently, excluding Vasari, there is a disconnect between the platforms that run basic analyses (e.g. weather data analysis, sunpath diagram, radiation analysis, etc), and the platforms that run advanced environmental studies (e.g. daylighting simulation, energy simulation, etc.) This paper introduces an environmental analysis plugin, Ladybug, which facilitates the process of environmental design analysis during different stages of the design by integrating weather data analysis and advanced simulation in a parametric environment.

Ladybug is a free and open source environmental plugin for Grasshopper3D. Grasshopper3D, is a “graphical algorithm editor” (grasshopper3d.com) plugin for Rhino, a 3D modeling tool which is becoming an increasingly preferred modeling tool for designers, architects, and students. Ladybug benefits the parametric platform of Grasshopper to allow the designer to explore the direct relationship between environmental data and the generation of the design through graphical data outputs that are highly integrated with the building geometry. Figure 1 shows several components of Ladybug in the Grasshopper platform.

There are currently four environmental analysis tools, for Rhino/Grasshopper, available to the public (excluding Ladybug). Table 1 compares the existing environmental analysis tools for Rhino/Grasshopper based on the analysis types that they provide during the different stages of an environmental design process. As it is shown in Table 1, none of the tools provide the full spectrum of the environmental studies, and there is almost no support for weather data analysis.

Ladybug is an effort to support the full range of environmental analysis in a single parametric platform. It creates interactive 2D and 3D graphics for weather data visualization to support the decision-making process during the initial stages of design, and the components evaluate initial design options for implications to the design from radiation and sunlight-hours analyses results. It also provides

Table 1
Comparison of the existing environmental analysis tools for Rhino/Grasshopper

PROCESSES		ANALYSIS TOOLS				
		Ladybug	Heliotrope	Geco	Gerilla	Diva-for-Rhino
Climate Analysis	Analysis	✓				
	Visualization	✓	✓**			
Massing/Orientation Study		✓		✓		✓
Daylighting Study		✓		✓		✓
Energy Modeling		✓			✓	✓*

* Limited to one thermal zone

** Only daily sun path diagram

energy and daylighting modeling by using validated simulation engines such as EnergyPlus (US Department of Energy), RADIANCE (Ward, 2004), and Daysim (Reinhart and Walkenhorst, 2001).

DISCUSSION

The benefits of integrating environmental analysis and building simulation into the design process have been discussed in previous studies (Weytjens et al, 2012). The limitations and issues also have been discussed in several researches on the integration of simulation into the design process, barriers and proposed solutions (Bleil de Souza and Knight, 2007, Rizos, 2007, Macdonald et al 2005, Hobbs et al, 2003, Morbitzer, 2003, Mourshed, 2003). The paper briefly discusses the main limitations and discusses the solutions that Ladybug provides for these limitations.

Existing limitation: Data-Design Disconnection

The effort to establish a single platform for design and simulation during different stages of the design has been a constant subject of development for a few years. In a recent study, conducted by Weytjens et al (2012), designers and architects agreed that the environmental design process was facilitated when analysis tools were integrated within the design

application.

The use of multiple platforms for design and simulation not only slows down the process, but also introduces interoperability issues which includes the use of multiple models and interfaces. The unfamiliar working methods of building simulation software, the complexities in geometry creation and demanding input data are the other complications.

A few modeling programs aim to bring together conceptual massing and environmental analysis within the same platform. Vasari integrates conceptual massing and environmental analysis. However, as an application based on the Revit platform, generation of complex geometry is limited and data representation is prescribed to application settings. Revit has also taken measures to incorporate conceptual massing components into the existing platform. Recently, there have been developments to include Energy Simulation as a built-in component of Revit 2014 (Kennedy and Kfoury, 2013). However, similar to Vasari, there are limitations in modeling complex geometry, and the application is generally not used for advanced form studies. There are also limitations for modeling large-scale projects such as master planning design.

Finally, an integrative graphical result visualization is critical to integrate environmental simulation in architectural design. With the exception of radiation



Figure 1 Ladybug Components

and daylighting studies, which typically map the results onto the geometry, the results are generally presented in the form of reports and/or spreadsheets. Although this form of information may be easily comprehended by simulation experts, the information usually does not easily appeal to the graphic nature of a designer's thought process. The form of presenting data is prescribed to application settings that cannot be customized for the majority of the parameters. Finally, with the exception of a few applications, the simulation data cannot be used to generate the next iterations of the design.

Proposed Solution: Integration of Design and Analysis in a Parametric Environment

More recently, parametric modeling tools have introduced a new approach to modeling and design to the architectural community. Parametric modeling, by nature, is based on data; connections and changes between different levels of data are instantaneous. This system provides multiple benefits for integrating design and analysis. The ability to visualize the environmental analysis data within the design platform allows designers to make a clear connection between the data analysis and the design.

Within the parametric platform of Grasshopper, building details, which are generated from the base geometry, remain as layers of the base data. When optimization of the base geometry, which is appropriate for environmental analysis modeling occurs, the details, which are parametrically linked, automatically update. A single model is used for both the design model and the analysis model, facilitating a smoother, more integrative and efficient workflow.

CASE STUDIES

Radiation Study

Radiation is an important factor to consider in occupant thermal comfort and energy use of the buildings. Although the amount of radiation received by a surface has a direct relationship with the orientation (horizontal angle) and vertical angle of the surface, most of the visualization methods do not address this relationship. The radiation data is usually visualized as tabular 2D graphs, averaged weekly or monthly, or 3D graphs which only show the amount of the radiation for a specific period of time.

Ladybug provides three different diagrams for radiation to address this issue: Tregenza Sky Dome, Radiation Rose and Radiation CallaLily.

Ladybug uses GenCumulativeSky (Robinson et al., 2004) to calculate the amount of radiation for different sky patches of the Tregenza Skydome and colors the sky patches based on the result; the graphic gives the user an overall understanding of the sky condition. The user can select the period of the year to visualize the sky dome.

Figure 2 shows the sky condition for Chicago during the months of June to September (cooling period) versus the months of November to February (heating period).

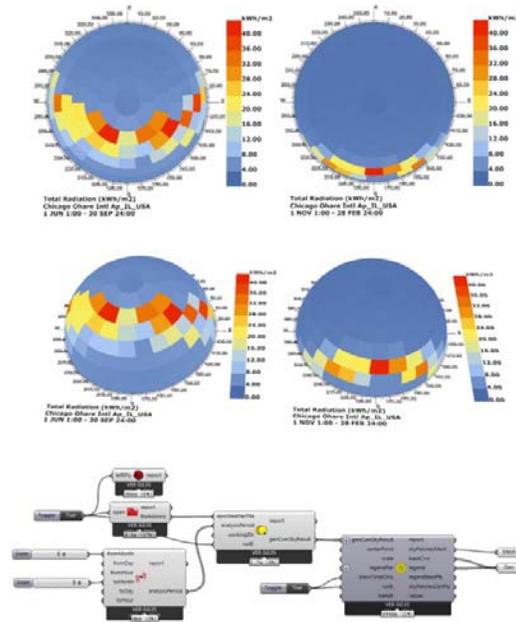


Figure 2 Sky Dome

Radiation-Rose (radRose) is a similar graph to wind-rose that diagrams the magnitude of radiation originating from different orientations (horizontal directions). The user can change the vertical angle of the surfaces and the period of time. Figure 3 shows Chicago radiation-rose during June to September (cooling period) versus November to February (heating period).

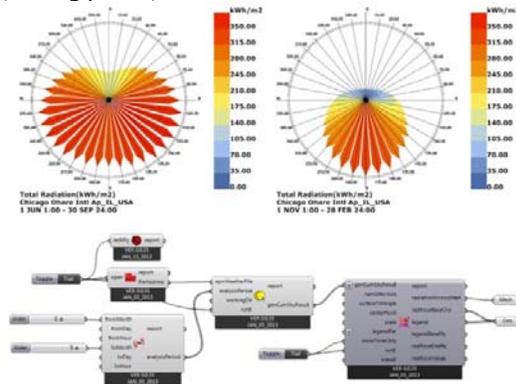


Figure 3 Radiation Rose

Finally, the Radiation CallaLily component creates a 3d graphic that maps the radiation values on a surface, for different horizontal and vertical angles, as one single geometry so that the designer can visualize the relationship between the surface orientation and the amount of received radiation on

the surface. Figure 4 shows the radiation CallaLily for Chicago; the number of horizontal and vertical angles can be customized by the user.

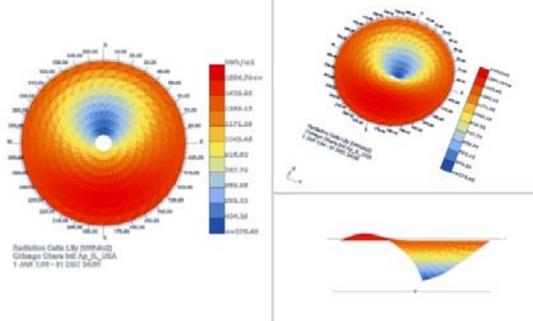


Figure 4 Radiation callaLily

Orientation Study

Orientation study is a feature integrated into the analysis components (radiation, sunlight-hours and view analysis), of Ladybug, which lets the user study the relationship between the orientation of the building and the amount of incident solar radiation or sunlight hours.

The study considers the design geometry as well as the context (Figure 5), and it is possible to run the component for a user-specified time period. The user can also input the range and divisions of the angles in the orientation study. The output is the total amount of radiation for each option, and a colored mesh of the result is produced so that the result can be referenced. Figure 5 shows the result of the study for a sample building in Chicago.

The user ran the study for orientations, of angles between 0 and 180 degrees (in 45 degree increments), to orient the building to receive the maximum amount of radiation during Chicago's heating period.

Sun Path

Sun-path is one of the most useful and informative diagrams that has been used for several years for environmental analysis however it is most commonly shown as a stand-alone graphic. Ladybug creates an instance connection between the sun-path and hourly weather data by allowing the user to overlay any desired hourly data on the sun-path.

Additionally, the sun-path component allows the user to filter the sun positions, based on any desired condition, for the overlaid data. As an example, the user can plot the sun-path for hours of the year when the temperature is more than 18°C and the global horizontal radiation is more than 630 Wh/m (Figure 6). This option can ease and expedite the process of shading design as an example. In a typical approach the designer should:

1. Find the cutting days based on temperature, heating degree days and cooling degree days, or other shading design index
2. Find the location of the sun for the cutting days
3. Calculate horizontal shadow angle, and vertical shadow angle
4. Calculate the shading geometry

The sun-path component in Ladybug, however, facilitates the process by combining the first three steps (above). The user simply connects the hourly data, and writes a conditional statement.

The sun-path component provides the resultant sun-vectors as an output. The user can use these vectors to design the shading in Grasshopper. Since there is no limitation for the type of the input hourly data, the user can test several shading options based on different methodologies. Figure 7 shows an example of using the sun-path component to automate the shading design process based on temperature and global horizontal radiation.

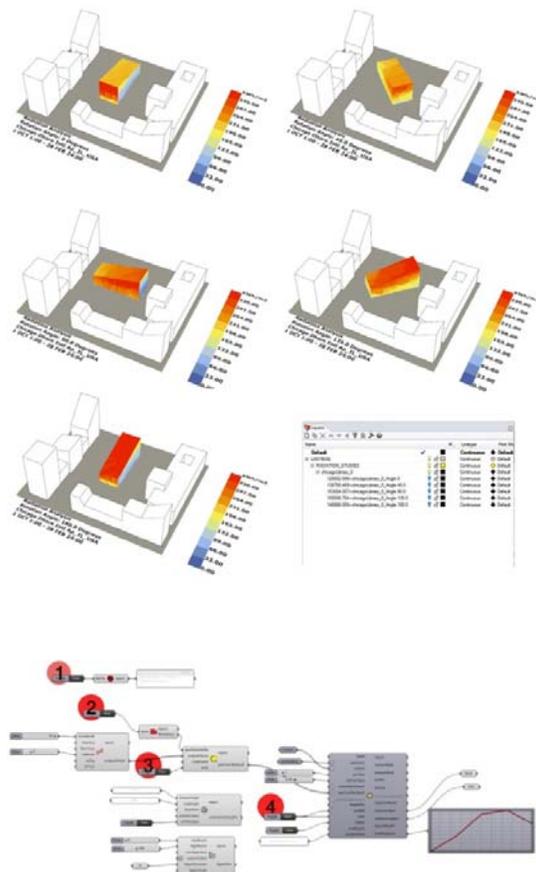


Figure 5 Orientation study and the radiation results for each orientation angle (organized by layer), and the graph of the radiation values in the Grasshopper canvas

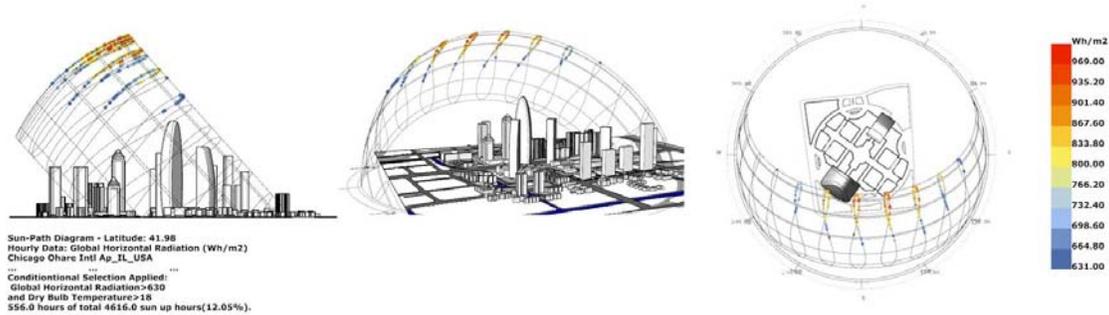


Figure 6 3D sun-path diagramming the hours of the year that the temperature is more than 18°C and the global horizontal radiation is more than 630 Wh/m

Optimum solar form finding using Multi-Objective optimization

One of the other advantages of development inside Grasshopper/Rhino is the potential to benefit several other developments in the Grasshopper community. As an example Octopus (Vierlinger et. al, 2013) is a multiple objective evolutionary algorithm for Grasshopper.

Integrating Ladybug with Octopus allows user to easily setup and run a multiple-Objective performance form optimization inside Grasshopper. Even recently to run a performance driven optimization study takes fair amount of scripting to connect several platforms (author's paper, 2013). Figure 8 shows an example of form optimization to maximize the amount of solar radiation during the heating period and minimize the amount of radiation during the cooling period of the year, and how the one of the optimized option on the Pareto line found by Octopus. The user can explore between the several possibilities and select the preferred trade-off. Considering that typically, several simulations run during optimization studies, Ladybug was developed to benefit from multiple CPUs running the studies, therefore, intensive studies could be executed in an acceptable amount of time.

CURRENT DEVELOPMENTS

As mentioned before, the ultimate goal of Ladybug is to provide the full range of building environmental analysis in the parametric platform of Grasshopper

by providing links to validated Energy, Daylighting and CFD simulation engines adjacent to weather data analysis components. Honeybee is the extension of Ladybug which extends users' ability to work directly with Radiance, Daysim, and EnergyPlus. Butterfly is the other under development extension which allows users to work with OpenFoam and run CFD simulation. The paper discusses Honeybee in more details here and discusses the development of Butterfly under the future developments section.

Honeybee

Similar to Ladybug, Honeybee is designed to run the analysis on building masses but for more advanced studies (Figure 9). The workflow is designed for designers so similar to many other tools many of the values are set as default however despite other similar tools user can overwrite all the default inputs. There are 4 main steps to run an analysis in Honeybee.

1. Preparing simulation geometry:

Honeybee automates the process of intersecting the masses, and finding adjacent surfaces, and user only should provide floor heights and program of each space. Honeybee subdivides the mass into several units and assigns construction set, schedules and internal loads for each space based on the program.

The user, then, provides the percentage of openings for each orientation. Honeybee calculates and adds the openings to the geometry based on the percentage of the opening. Energy and daylighting simulation

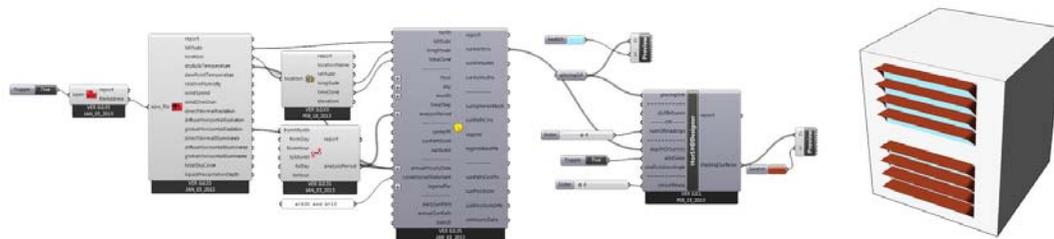


Figure 7 Sun vectors, derived from the sun path based on the user desired condition (temperature > 18 and horizontal radiation > 630 Wh/m)

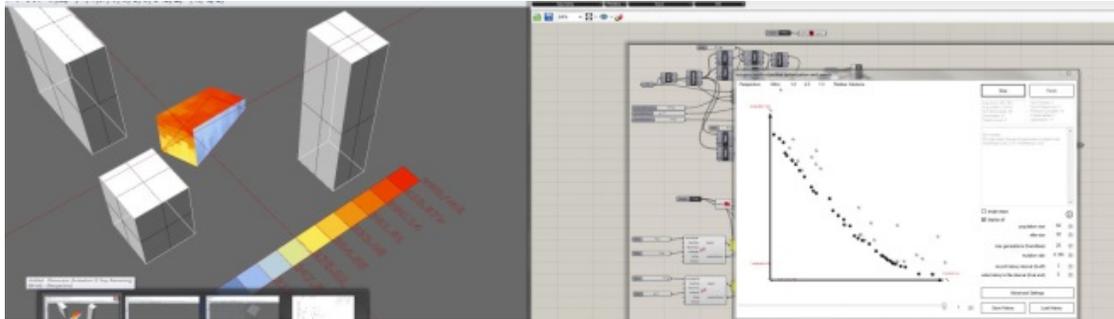


Figure 8 Form Optimization using Ladybug and Octopus

can be then be run for the geometry (Figure 10).

2. Check the input file:

Many of the current available tools are only exporting the geometries from design environment to simulation files and read the result back, however ladybug provides a two way import/export connection so user can import back the simulation file and visualize it in Rhino/Grasshopper environment before executing the simulation.

3. Run the simulation(s):

After setting up few inputs user can run the simulations from Grasshopper (Figure 11). For the energy simulation, users should provide a path to the weather file, desired outputs, working directory and project name. Users can also add context geometries as shading objects.

For daylighting simulation user should provide test surfaces or test points and overwrite radiance detailed such as number of bounces, sampling, etc. A path to the weather file is also needed as well as working directory and project name.

By default Honeybee uses an identical geometry for both energy and daylighting studies, and extracts material properties for daylighting simulation from the EnergyPlus construction. This technique simplifies the process and avoids possible user input errors. Advanced users can overwrite the default

values, and can add more details to the daylighting model for more accurate studies (e.g. adding wall thickness, or internal partitions, etc.)

4. Visualize the results:

Honeybee re-imports the results of energy and daylighting simulation visualization for daylighting and energy simulations so users can map the results with the geometries. Honeybee provides few unique visualization components which allow users to explore the results in several different ways. The paper discusses Daysim result reader as an example. Two different components are available to import the data. One component calculates typical outputs of an annual climate based daylighting analysis, such as Daylight Autonomy and Daylight Availability. However, users can customize several parameters such as working hours, minimum and maximum threshold, and the period of the study. The other component imports and visualizes the hourly values from the annual study so users can access real time values for any hour of the year, and potentially identify the problematic hours of the year to generate appropriate design solutions. Figure 12 shows both components.

FUTURE DEVELOPMENTS

Ladybug is currently available on grasshopper3d.com/ladybug mainly as a weather data analysis component. Honeybee will be released soon



Figure 9 Honeybee Components

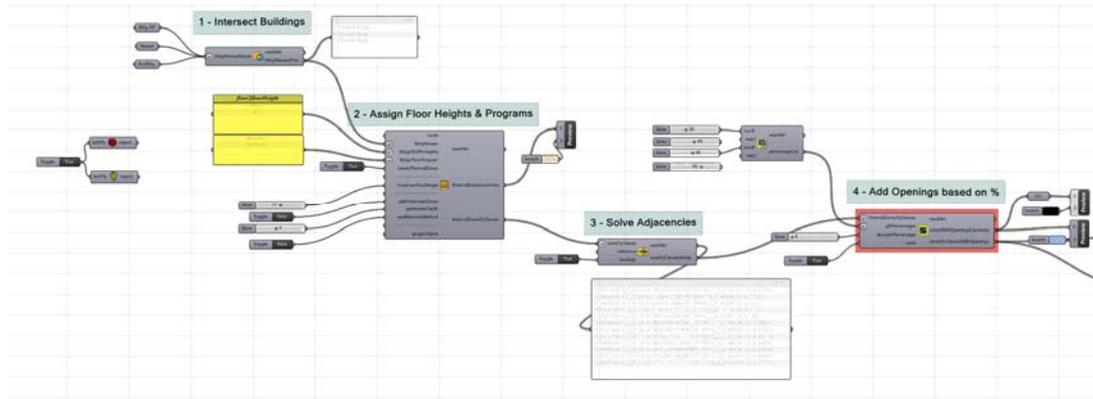


Figure 10 Preparing Simulation Geometry

which will extend the functionalities of Ladybug for advanced energy and daylighting simulation. In the longer plan the first author started the development of another new extension, Butterfly, in collaboration with EFRI-SEED project (2013). Butterfly will connect Ladybug to a web-based CFD simulation platform. OpenFoam (OpenFOAM® Foundation) is used as the solver and Butterfly reads back the results to Grasshopper for visualization.

There is also a plan to connect Honeybee to JESS (2013). JESS is a software tool that runs EnergyPlus simulations on remote server for faster and more number of runs.

Finally, as open source development has been an essential facet to Ladybug. In the perspective Ladybug will be available as an API so more developers can develop their own extensions for Ladybug. The new generation of designers are not only involved in building design, but are also contributing to advancements in technology and developing new skill sets, which include visual scripting and coding. Providing open source products allow designers, programmers, and students

to contribute new ideas, and to customize tools for specific needs. Due to the unique period of the time that we are experiencing that, one the one hand, environmental issues are a serious problem for the planet, and on the other hand Internet introduced new ways of collaborative effort for a better world, it has been increasingly important to not only share the final product, but to also share the code.

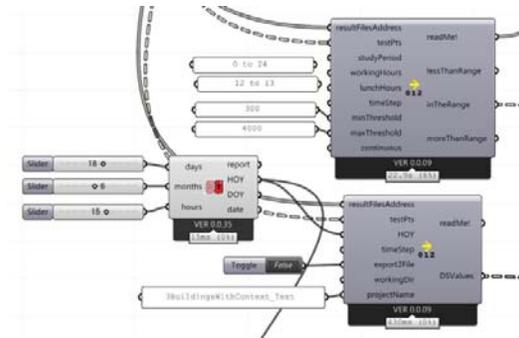


Figure 12 Daysim Read Result Components

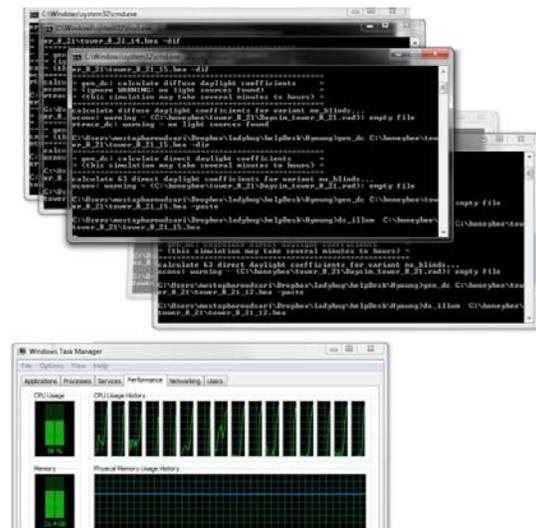


Figure 11 Running Annual Daylight Simulations in Parallel

CONCLUSION

The workflow limitations of the past are no longer a barrier for today's designers as parametric tools provide designers an integrative design platform, and through the collaborative mindset of the design community, the potentials for further development is limitless.

To encourage an environmentally-conscious design workflow, it is becoming increasingly essential to bring the analysis tools to the designer's environment. The free and open nature of Ladybug democratizes environmental analysis tools, fostering the advancement of environmentally-conscious designs. Environmental information becomes a design generation tool through Ladybug's parametric diagrams, giving designers an instantaneous feedback on the effects of design modifications. A unified interface provides accessibility and convenience to users, promoting building designs that are

environmentally-responsible for today and for the future.

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