

ANIMATED BUILDING PERFORMANCE SIMULATION (ABPS) – LINKING RHINOCEROS/GRASSHOPPER WITH RADIANCE/DAYSIM

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ABSTRACT

This paper describes the linking of the popular three-dimensional CAD modeler Rhinoceros with advanced daylight simulations using Radiance and Daysim. A new, highly effective design workflow within Rhinoceros is presented that directly exports scene geometries, material properties and sensor grids into Radiance/Daysim format and calculates a series of performance indicators including monthly or seasonal solar radiation maps as well as daylight factor and daylight autonomy distributions. The simulation results are automatically loaded back into the Rhinoceros scene using falsecolor mappings. Using the Grasshopper plug-in for Rhinoceros, key design parameters such as window size and material descriptions can be changed incrementally and the simulation results can be combined into an *animated* building performance simulation, i.e. a dynamic visualization of the effect of these design parameters on the daylight availability within the scene. The design workflow has been specifically developed with the architectural design process in mind, aiming to provide designers with immediate, high quality feedback all the way from schematic design to design development.

INTRODUCTION

Parametric design has become a strong trend in contemporary architectural design practice and education (Day, 2010). The term refers to a practice of digitally modeling a series of design variants whose relationships to each other are defined through one or several mathematical relationships (parameters) which then form a parametric space which may comprise dozens or thousands of related but distinct forms. An example series of forms is shown in Figure 1. Thus far, parametric design has been largely utilized for an aesthetic which emphasizes complex, continuously differentiated forms. Typical performance based design aspects that are already being considered are floor area ratios and/or other restrictions that are dictated by a site's urban topography. Given society's increased focus on energy efficiency and occupant comfort, there is now also a growing need within the parametric design community to include sustainability-related

performance aspects, most notably energy and daylighting. This paper is concerned with the latter.

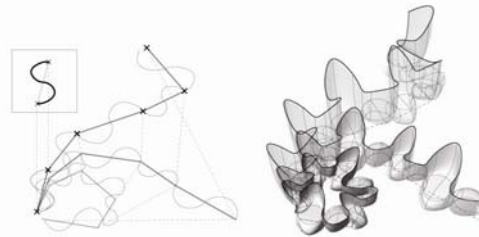


Figure 1 Example of a Parametric Design Study using Rhinoceros/ Grasshopper: A relationship is established in which points generate a line which generates a surface. Changing the position of the points results in numerous two and three dimensional forms. (design T. Shigemura 2009)

Daylight simulations have of course been around for decades and an ever-growing number of design analysis workflows exist to convert scene geometries and materials definitions from just about any CAD modeler into various daylighting simulation packages. Given that green building rating systems such as the US Green Building Council's LEED system (USGBC 2009) encourage the use of simulations, it is not surprising that design practitioners are increasingly reporting that they are using daylight simulations within their firms (Galasiu and Reinhart 2007). Many daylighting design analysis workflows involve several manual steps such as (1) exporting a geometry file to a temporary file format, (2) importing the file into a daylighting analysis program, (3) setting material properties and simulation parameters, (4) running the simulations and (5) importing the results back into the CAD program for data visualization. These workflows are hence somewhat difficult to remember for casual users who just want to do an occasional 'quick check' of how well their current design performs. The fact that several manual steps are usually required poses a real barrier for designers interested in automatically validating a large number of design variants.

To overcome these barriers and to make advanced, validated daylighting analysis methods available to the parametric design community at large, this paper

presents a new, fully automated daylighting analysis workflow using Radiance/Daysim within the Rhinoceros/Grasshopper CAD modeling environment. The paper also explores new ways of visualizing daylight simulation results for a large number of design iterations in a manner that produces significant iterations and reveals critical trends, thus helping design teams to create value for the design process. The underlying premise of this work is that 'an *informed* design decision is a *better* decision'.

Before reviewing the details of the new workflow in the methodology section below, a critical reader might stop and wonder whether there is actually a need for yet another daylighting analysis workflow that allows the users to carry out an analysis that they could ultimately have already have carried out before e.g. via export from Rhinoceros via Autodesk Ecotect into Radiance/Daysim. The reader might further wonder whether there is in fact much to be gained for design from running a very large amount of simulations of very comparable design variants.

The authors' answers to such concerns are the following: First, our personal observation is that there is already a tendency - at least in architectural education - to encumber students with many different software tools which can easily become more disruptive than productive. There is thus a notable benefit from having users operate within a single environment with which they are already very familiar. There is also the practical observation that software interoperability remains a concern and significant source of simulation errors especially for simulation novices (Ibarra & Reinhart 2009).

The actual need and value of running multiple design variants will be further reviewed in the discussion section below but for now we justify our efforts with the simple observation that such design explorations are already becoming common practice at least in 'high-end' design. To substantiate this statement we refer to the *2009 International Radiance Workshops* event at which representatives from Arup and Buro Happold not only spoke about the need for effective means of generating and synthesizing large quantities of simulation data for their clients and the challenge of clearly and concisely communicating the results, but also showed some real world examples (McNeil, 2009 and Smith, 2009). The main difference between the parametric shoebox type simulations presented at the workshop and the Rhinoceros/Grasshopper workflow presented here is that the latter environment has been specifically designed to generate complex geometric design variations within a reasonable amount of time.

Summing up, the goal of this paper is to create a workflow that 1) is seamless with typical modeling methods, 2) uses a reliable simulation engine, and 3) yields useful visualization of results. The outcome is a workflow that incrementally changes key design

parameters such as window size, then calculates daylight performance metrics and finally combines them into an *animated* building performance simulation (ABPS), i.e. a dynamic visualization of the effect of these design parameters on the daylight availability within the scene. The workflow itself is described in the methodology section followed by an example application. The discussion further reflects on the possible significance of this workflow for design practice.

METHODOLOGY

Overview of the Workflow

Rhinoceros has recently become a modeler of choice at many North American architecture schools and in selected practices, especially those with a focus on formal design considerations (McNeel 2010). Rhinoceros is used in multiple design industries due to its ease of use and processing speed. The Grasshopper plug-in for Rhinoceros is a graphical algorithm editor that allows designers with no formal scripting experience to quickly generate parametric forms (Day, 2010). Grasshopper's usage has grown in tandem with Rhinoceros. The use of Rhinoceros and Grasshopper for the development of this workflow was born out of the popularity of the software in both traditional and parametric design environments as well as the widespread use of both among students and professionals. Additionally, at this time, other software packages do not provide the necessary components for the creation of the workflow in as smooth and fluid a manner as Rhinoceros and Grasshopper.

The new workflow distinguishes between two types of simulations: The term 'single variant' analysis refers to a daylight performance simulation that looks at one design variant at a time. A 'multiple variant' analysis refers to a series of simulations of parametrically varying designs. As described above, models generated with Rhinoceros/Grasshopper can always be used for various forms of daylighting "single variant" analysis by either using other Rhinoceros plug-ins (such as the Animation plug-in that generates direct shading studies) or by exporting the files into third party software for further analysis. As an example, in the past the second author provided detailed instructions for his architectural students of how to export Rhinoceros models for further daylighting analysis into Ecotect/Radiance/Daysim (Otis, 2009). A drawback of the above mentioned Rhinoceros plug-ins is that they concentrate on either very basic types of analysis (direct shading studies do not take the local climatic conditions into account) or are limited to visualizations with no quantitative analysis (such as VRAY animations). Currently there is a trend in daylighting analysis to promote the use of more advanced, holistic design evaluations including annual, climate-based daylighting metrics (Reinhart,

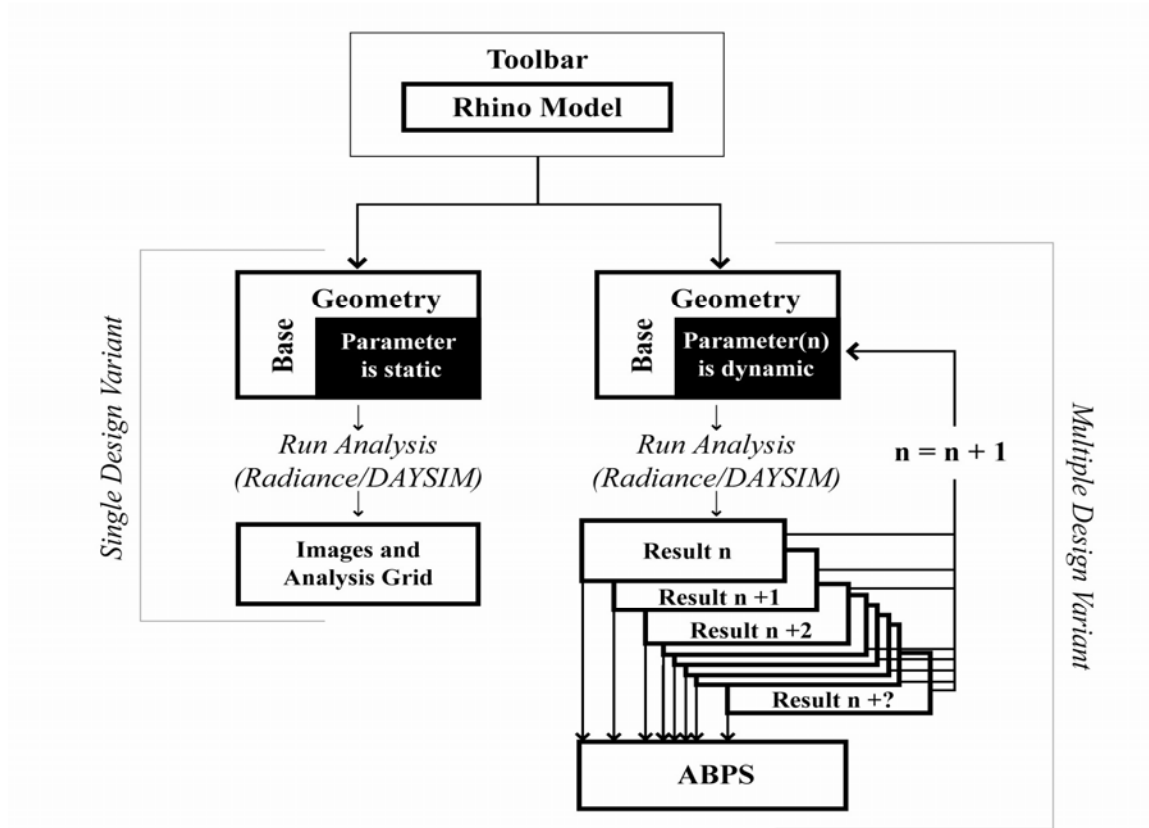


Figure 2 ABPS Workflow Diagram

Mardaljevic and Rogers 2006; Mardaljevic, Heschang and Lee 2009) and high dynamic image based glare analysis (Wienold, et.al., 2006). Previous to the work presented here, in order to analyze daylighting metrics for a “multiple variant” digital model, it was necessary to execute extensive steps, and switch between several programs in order to produce reliable results. Given the ability of parametric modeling to produce a large number of iterations very quickly, this cumbersome workflow cannot easily produce multiple variant daylighting analysis which can keep pace with the design of the digital model.

The new workflow consists of three major parts: the Rhinoceros (Rhino) toolbar, a Grasshopper file and the Radiance/Daysim engines (see Figure 2). The Rhino Toolbar can be used on its own without any Grasshopper scripting for single variant analysis. In order to conduct multiple variant analysis it is necessary to use the Grasshopper component as well. Radiance and Daysim are used as the performance calculation engines.

The Rhino Toolbar

The Rhino toolbar is a set of buttons programmed in Rhino script that can be used to setup and execute a daylight simulation. The toolbar is intended for use with Rhinoceros models, primarily consisting of NURBS polysurfaces and surfaces. It is loaded into

the Rhino interface and consists of five buttons (Project Info, Nodes, Materials, Parameters, and Metrics) intended to be used in that order (Figure 3). Each button requires user input in the form of typed input, or item selection. The “Project Info” button establishes file naming and storing conventions, and the geographic project location; the “Nodes” button asks the user to select a surface or surfaces for performance analysis and creates a series of sensor points arrayed across that surface or surfaces with a user-defined offset; the “Materials” button allows the user to assign predefined Radiance materials to layers; and the “Parameters” button asks the user to define five Radiance parameters. Finally “Metrics” provides four choices of tests to run on the given model: Image, Radiation Maps, Daylight Factor and Climate-Based Metrics (Daylight Availability, Daylight Autonomy and Useful Daylight Illuminance). The Image button produces a Radiance high dynamic range image (Figure 4), the Radiation Maps produce cumulative solar radiation maps also in Radiance HDR format (Figure 5). The Daylight Factor and the Climate-Based Metrics both generate a false-colored panel grid in Rhino which is based on the sensor point simulation data and point locations (Figure 6 and 7). In addition, previous Metric tests can be loaded by right-clicking on the Metrics button, accessing the “Load Metrics” function.



Figure 3 The Rhino Toolbar

There are several current, although not intrinsic limitations to the toolbar. The first limitation is that there are twelve available Radiance materials which can be used by the toolbar workflow. While these can be modified in their definition, additional materials cannot be added and certain properties such as name or associated layer color cannot at this time be changed. Secondly, it is currently not possible to process mesh geometries. Lastly, the toolbar does currently not support the set up of sensor point grids based on non-horizontal or non-vertical surfaces. These limitations will be remedied in the future.

The Grasshopper File

The Grasshopper plug-in functions by associating certain parts of geometry created within Rhinoceros or created de novo with a graphical algorithmic editor. Such geometry is previewed within the Rhinoceros viewport, and any changes to the chains of scripted graphical transformation result in an immediate visual update. One of the most intuitive and evocative components within the Grasshopper Editor is called a “slider”. The user is able to use a mouse to “slide” along a range of numerical values and get instantaneous visual feedback of the geometric effect of a changing parameter. An animation function is built into the slider which allows the user to preset a number of iterations between customized extremes. These visual iterations are stored as viewport images and can be compiled into an animation.

A two step process is followed for using the Grasshopper File on a scene containing both static and dynamic geometry and several material definitions. First, the analysis nodes, materials, and Radiance settings are established by the Rhino Toolbar as described above. Next, within Grasshopper, part of the model’s geometry is created or designated as dynamic. A parametric transformation of this geometry is specified and a slider is customized to animate this transformation. Components within Grasshopper allow custom scripts to be written in VB.NET or C#.NET. For the ABPS workflow, a VB.NET component was created which adds the scene geometry file created by the Rhino Toolbar with the new and updating Grasshopper geometry with specified material definitions. The script then runs the executable batch file with the Radiance simulation parameters and daylighting metrics selected specified using the toolbar. The results are viewed in the Rhino Render Viewport, and a screenshot captures the model geometry with the data results as a false color overlay. Animating the slider sends a sequence of transformed geometries to the VB.NET component,

which sequentially runs a Radiance simulation for each update, and the results are stored as a series of viewport images which later are compiled into an animation or flash application.

Radiance/Daysim Engine

The workflow uses the validated Radiance backward raytracer to calculate daylight factor distributions (Figure 6) and scene visualizations (Figure 4) under selected CIE overcast and/or clear skies (Ward and Shakespeare 1998) and (Mardaljevic 1995). For more advanced, climate-based daylight simulations the workflow uses the validated, Radiance-based Daysim program in order to calculate Daylight Availability (Figure 7) and other climate-based metrics on a series of sensor grids within the scene (Reinhart and Walkenhorst 2001). For annual and/or seasonal radiation maps (Figure 5) the GenCumulativeSky method is being used (Robinson and Stone 2004).

EXAMPLE

In order to demonstrate the use and results of the ABPS, the authors modeled the Zollverein School of Management and Design in Essen, Germany, designed by the Japanese firm SANAA led by Kazuyo Sejima and Ryue Nishizawa (Sejima, et.al., 2008). In particular, the building was selected because the geometry of the building allows clear display of the parametrization of various elements such as skylights, windows, and overall form.

Single Variant Results

Figures 4-7 show the four “Metrics” available in the single variant mode that are produced using the toolbar alone, without the Grasshopper/Animation portion. Figure 4 shows a Radiance visualization of the building under overcast sky conditions. The user of the workflow is encourage to always first run a Radiance visualization for quality control purposes to make sure that all elements of a scene have been properly exported from Rhinoceros/Grasshopper into Radiance.



Figure 4 Single Variant Results: Image

Figure 5 shows an annual radiation map of the building using the climate file for Düsseldorf, Germany. The image shows the annual solar radiation falling onto the surface associated with each pixel in the image. E.g. slightly over 1000 kWh/m² yr fall onto an unshaded horizontal surface (the roof). This type of data can be used for further going design analysis at the building and urban level (Compagnon 2004).

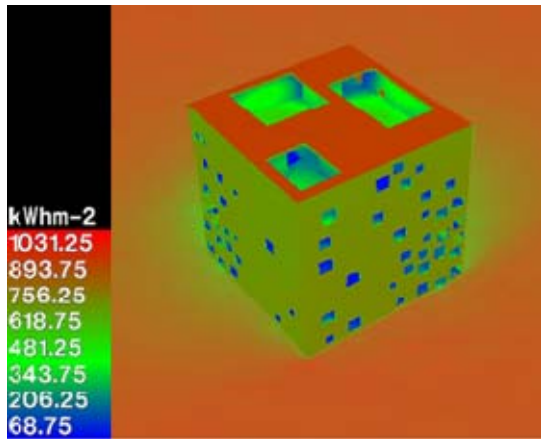


Figure 5 Single Variant Results: Radiation Maps

Figure 6 shows the daylight factor distribution on the top floor of the building, revealing that due to the skylights there is plenty of daylight on that floor.

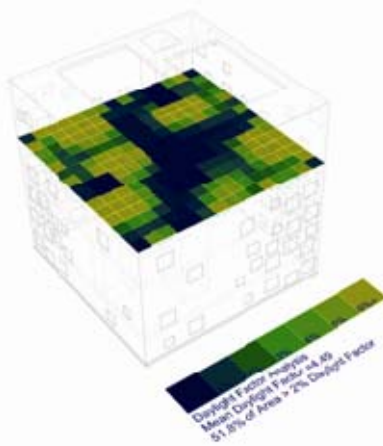


Figure 6 Single Variant Results: Daylight Factor

Figure 8 shows the daylight availability distribution on the top floor of the building. Daylight Availability is a hybrid of previously suggested climate-based metrics that captures an annual supply and oversupply of daylight in a single figure (Reinhart to be published in 2010). Assuming that the target illuminance in the building is 500 lux and that the hours of occupancy are weekdays from 9 AM to 5 PM, the figure shows the percentage of the occupied time when at least 500 lux are provided by daylight. The color code used goes from blue (low)

to green (high) and reaches saturation when the daylight autonomy reaches at a point reaches at least 50% of the maximum daylight autonomy value within the scene. The green area thus corresponds to the 'daylight area' whereas blue indicates a shortage of daylight. Finally, a test is run how often the illuminance at a point is more than 10 times the target value of 500 lux. If this occurs more than 5% of the occupied time the point is *over lit* and the area is turned red. Figure 8 shows that the three large skylights lead to too much daylight on the top floor assuming that office work is performed on those floors and that no shading device has been installed.

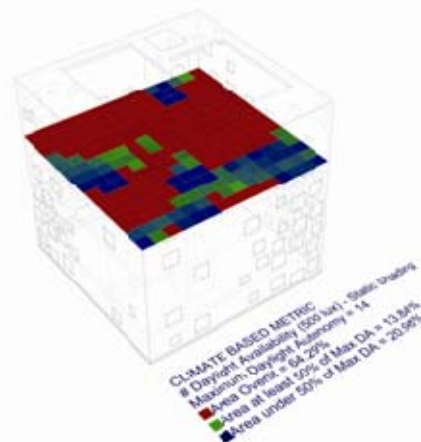


Figure 7 Single Variant Results: Daylight Availability

Multiple Variant Results

When the Grasshopper portion of the ABPS is added, multiple variants are produced and the end result is an animated simulation. Below, Figure 8 shows stills from this animation, while the animation in its entirety can be downloaded from www.gsd.harvard.edu/research/gsd-square/ABPS.html. The animation shows the effect of different skylight and window configurations on the daylight factor and daylight availability throughout the five floors of the building.

DISCUSSION

The development of this workflow has produced several new questions worthy of further attention.

Accessibility

The authors intend to publicly release the toolbar during the summer of 2010. So far it has been used and tested in-house in several courses and architectural studios at the author's home institution. Both students and studio instructors have found the toolbar useful for its ability to be run within Rhino. Interest has been piqued especially for the ability to use the toolbar in impromptu ways to check, revise and check the performance of a design.

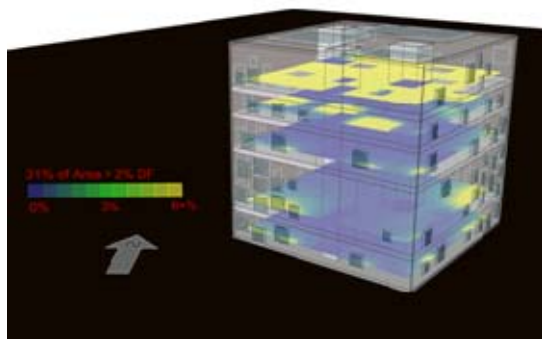
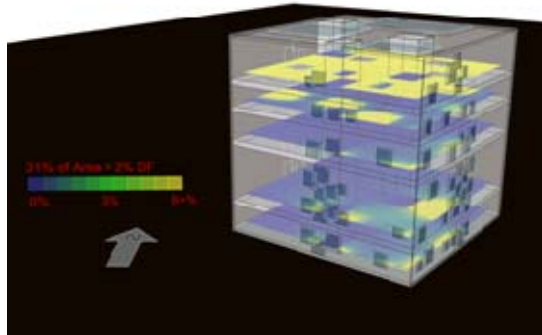
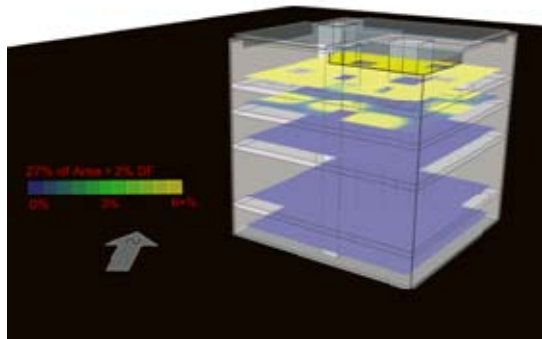
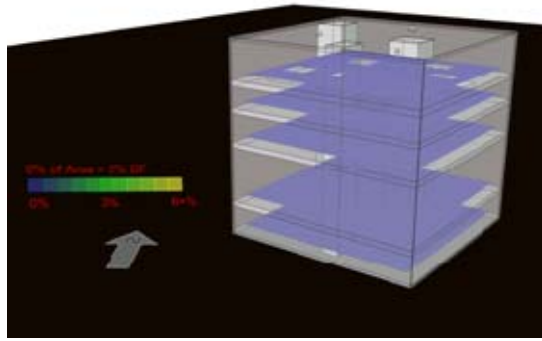


Figure 8 Multiple Variant Results - Series of standstill images of a parametric daylighting study of the Zollverein Essen.

Early Analysis

Another area of interest to this topic is the trend in architectural design to calculate performance metrics during the early stages of the design process when critical changes to siting or footprint are easier to make. Barriers to usage often have the result that small and large firms either leave the sophisticated modeling of environmental metrics until too late in the design process, or they neglect it altogether (Galasiu and Reinhart, 2007). Tools which are easier to use and that produce quick feedback are therefore ideal for promoting analysis at early stages of the design process when decisions which most affect daylighting are usually made. A sufficiently flexible tool should not limit analysis to this phase of design, but would allow analysis from schematic design through design development.

Automation

The workflow presented here, and other parametric analysis tools bring to debate the question of whether the evaluation of a design based on parametric analysis results in the 'automation of design'. In fact, the authors would like to stress that the addition of performance metrics to the parametric design process does not at all imply that there has to be a single, ideal performative solution which will reveal itself during the process and which consequentially 'has' to be used by the designers. In other words, it is not a foregone conclusion that environmental constraints will drive the form. Instead, it is, of course, up to the design team how to work with the results of an animated building performance simulation. Some designers might be inclined to use ABPS as a formgiver for their designs. Others might use it to understand how a sensitive building form reacts to certain performance metrics. Whatever the decision may be, parametric analysis usually measures one or more variables' impact on one particular metric. It is unlikely that the best choices economically, environmentally, aesthetically and programmatically will coincide with any optimum point for that metric. Even when multiple parameters are considered, the "solutions" reveal more about the parameters themselves, their linear prioritization or weighting in a cross-matrix, than a singular solution. Despite the automation of parts of the process, the selection of parameter variables and the ultimate weighing of aesthetic, environmental or economic trade-offs has no foregone conclusion, and requires the critical evaluation and consideration of intelligent designers.

Another point is of course that it is up to the designer to define parametric spaces for an ABPS and that other, even better design variants might have revealed themselves had a different set of parameters been selected. Even the most advanced computerized design workflows are ultimately just drawing aides.

The purpose of the above discussion is not to undermine the enhanced value for design that the new workflow can provide, which is to visualize a

conceptual envelope which otherwise would be more or less abstract. Through the workflow, limits and points of inflection are granted form with precision and this can provide the critical basis necessary for design decision-making.

CONCLUSION

By simplifying the process of performance analysis, increasing the speed with which reliable simulations are produced, and delivering a comprehensive visualization in the form of an animation, the workflow presented here dramatically contributes to the increased ability of designers at a variety of levels and stages of design to perform useful daylighting analysis. The workflow streamlines the interface between the design and the environmental analysis, bringing the analysis tools to the native modeling software Rhino, significantly decreasing barriers to usage. The creation of a new type of workflow such as this also presents several new questions about the benefits and costs of widely available tools and the use of parametric performance analysis in design. While it is not possible at present to forecast the implications of this tool on use and dissemination of understanding of daylighting in buildings, its development represents a significant step towards the production of tools which seamlessly unite the parametric design process with performance analysis.

ACKNOWLEDGEMENT

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