

Performative Parametric Design of Radiation Responsive Screens

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ABSTRACT: In subtropical or tropical region, shading is one of the most important design strategies due to exposure to intense solar radiation. The study addresses the need for flexible design method identified in today's architectural practice. Different workflows for coupling the parametric design with simulations of heat flow and radiation are examined. A workflow consists of tools running on modeling or simulation platform. The paper establishes three workflows, static, cross-platform and dynamic. Each workflow has similar capabilities in terms of access to simulation engines but different flow of information. Therefore, they can be employed in different design circumstances. The current investigation indicates the need for multi-objective optimization in the future.

KEYWORDS: Parametric design, façade, performance simulation

INTRODUCTION

With current industry trends in software, there is a vast selection of tools for designers to utilize. Traditionally, digital design tools in architecture follow a linear process and consequently limit possibilities for iterative modelling and exploration. In this study, a part of a collaborative project between Florida Atlantic University and BRPH (an architectural firm based in Melbourne, Florida), software packages are evaluated for their individual capabilities as well as interoperability. The project becomes an experimental model for applying and transferring knowhow and knowledge between academia, practitioners and manufacturer. The study began as a class project in Directed Independent Study (DIS). Later on, a continued effort received internal funding as a part of the Quality Enhancement Program. Future effort will be included in an elective course titled Performative Parametric Design.

The study examines designs and design methods of building skin. Like human skin, building skin can function as active thermal regulator. Heat gain and loss through building skin is governed by different modes of heat transfer. Heat gain is a major concern for cooling dominant region like South Florida. Radiation contributes roughly 20% of total thermal load through glass façade in this region.

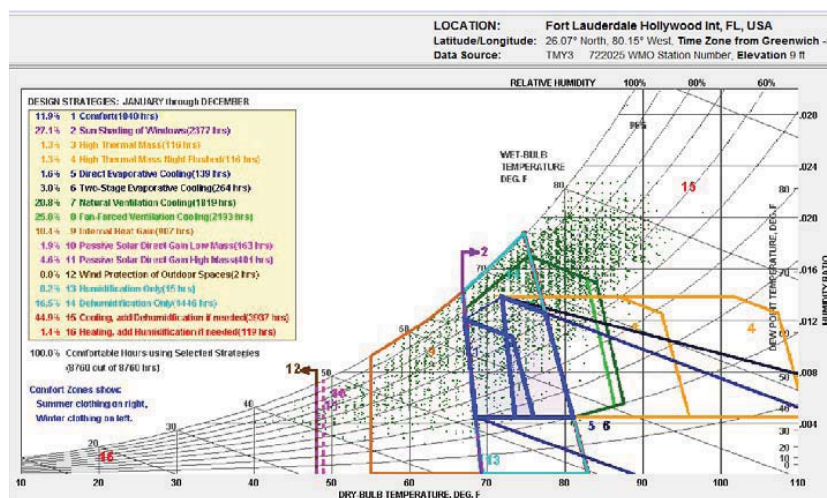


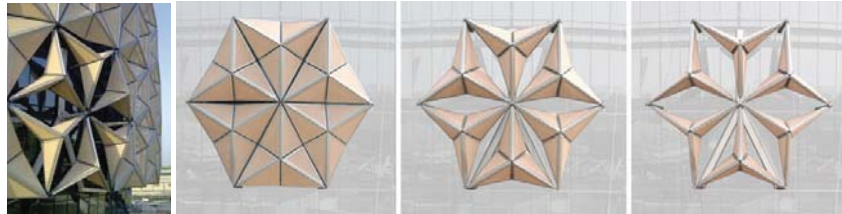
Figure 1: Psychrometric plot of Fort Lauderdale weather data

Fig. 1 shows that shading of windows is a strategy that should be applied 27.1% of the time in Fort Lauderdale, Florida according to 2005 ASHRAE Handbook of Fundamentals Comfort Model. Climate Consultant 5.4 is used to plot Fig. 1. The software recommends window overhangs and operable sunshades (extend in summer, retract in winter) as design strategies for reducing heat gain.

In order to explore different variations of shading designs, and their effects on both radiation protection and daylight utilization, this study employs parametric design that allows parameterized manipulation of geometry to generate and populate exterior sun screen designs. They are developed on Rhinoceros (Rhino) with Grasshopper®, a visual programming tool where different plug-ins can be used to manipulate the designs and transfer data. Different plug-ins are explored to connect the parametric modeling tool with simulation software. A combination of Revit® Architecture® or Autodesk Vasari® constitute a platform with similar capabilities. Different combinations create workflows for coupling the parametric design with simulations. Platform interoperability issue of the workflows must be scrutinized in terms of compatibility and the flow of information from one plug-in or software to another.

There are multiple performance criteria in shading design. Ecotect®, Daysim® and Vasari® are simulation tools identified as candidates for performance assessment of design variations in terms of radiation exposure, daylight utilization and energy consumption respectively. All of them can be connected to Rhino through different Grasshopper® plug-ins. The paper will discuss about an approach to combine criteria into a single objective function that can be used to inform sun screen design. Response of the designs to the environmental inputs can be animated to show screen operation. The animation can also be used to visualize design optimization.

In our consideration of façade systems, we looked at precedents to identify possible actuation mechanisms (Drozdowski and Gupta 2009). The shading system developed by Aedas' for the "Al Bahar" tower (**Fig 2**) project consists of a secondary skin of 1,000 "umbrellas" that "mediate light and reduce glare" on the east and west facades, according to the architects. Such devices are necessary for thermal regulation of buildings in extreme environments.



Figures 2: Al Bahar towers responsive façade mechanism, Abu Dhabi
(Design by Aedas, 2012; image source: <http://www.designboom.com/architecture/aedas-al-bahar-towers/>)

1.0 DISCUSSION

1.1. Objectives Informed Design

The first and possibly most important objective of the project is to make informed design decisions which are based on contextual factors. The design solution(s) is a result of performance criteria that relate to the environmental conditions and is, therefore, unique to the given context. Consequently, we are interested in establishing a methodology that is parameter-driven, and not a discrete design solution. Such a methodology may then, be applied universally, adapting the criteria to match the idiosyncrasies of the given project but following the same schema that is proven to work a priori. The advantage of a process that reaches design optimization based on criteria that are case-specific is tailor-made solutions to particular problems. In addition, one could say that such a design that is a result of comfort-related simulation and analysis is an "honest" expression of architecture's response to the needs of the occupant.

Use of Parametric Design

The use of analysis to inform design decisions has been implemented in the past; our intention is to optimize the process of integrating the quantitative data derived from analysis within the design modeling process, thus establishing a seamless workflow that is both easy to apply and more efficient. Using parametric tools like Grasshopper enabled us to achieve this integrated workflow. Having established original models in

Rhino and /or Revit®, we transferred them to parametric modeling tool and subsequently linked them performance assessment engines.

Versioning

During the beginning of the last decade, architectural practitioners began to shift their interest from a visual-driven to process-driven architecture, placing emphasis on “technique”. This promoted a design methodology that relies on interdisciplinary exchange between architects and other experts, as well as a design workflow that utilizes a broad set of tools to arrive to an optimal solution. According to SHoP, “Versioning is important to architects because it attempts to remove architecture from a stylistically driven cycle of consumption”² (SHoP 2004). This notion of versioning expedites the design process and allows for a multiplicity of results that allow comparison; instead of one singular solution, the process yields “generations” of results.

The parametric workflow, as opposed to manual modeling provides a flexibility that permits the investigation of multiple solutions. The designer is able to generate “versions” of a design proposal which are slightly different to one another and subsequently test these with each other to determine the one with the optimal performance.

Developing efficient workflows that respond to technological innovations

The use of parametric design to integrate analytical results with 3d modeling reflects the current status of “digital design” and its inclination to be more integrative, linking processes through software and hardware, not only within Architecture but also between Architecture and Engineering. Being able to establish and maintain a clear mode of exchange between architects and engineers has always been important but not easily attainable. A workflow that combines modeling and analysis tools is more comprehensive and can relate to both disciplines.

Analysis of workflow

There are two possibilities to design a component that adapts to changing conditions based on real-time data capture, or design a component that is static, but whose configuration has been determined by investigating various responses to environmental conditions and selecting versions that we believe to be the most efficient under different conditions (**Fig 3**). During this project we have mostly followed the first method, where components along a surface respond dynamically to changing conditions of the pre-set parameters within a parametric workflow (see “Parametric Design” section below).

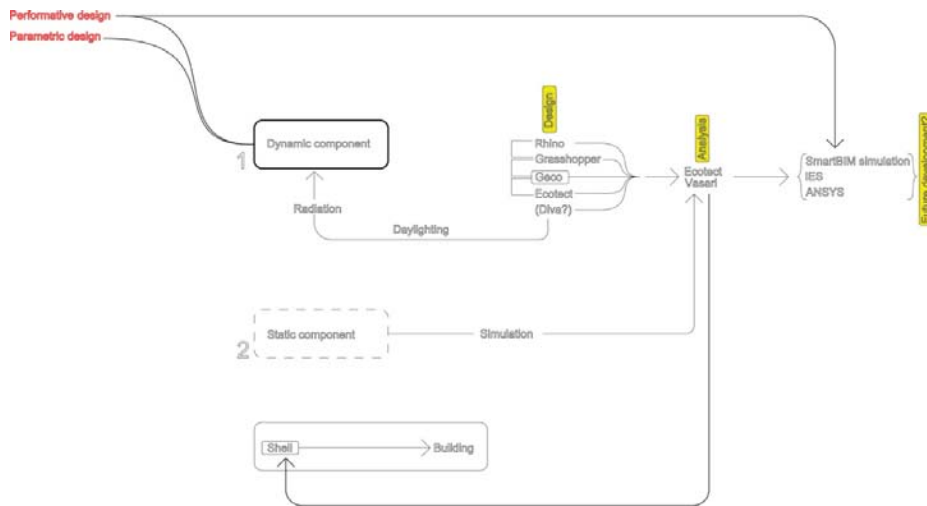


Figure 3: Workflow schema showing relationships between critical components of the project

1.2. Methodology

This investigation uses two distinct methods of software integration to achieve real time analysis, parametric surface generation, and validation of the effectiveness of these solar devices in building performance. The benefit from linking multiple platforms is the possibility to generate tested solutions in real time. These models are reacting to linked simulation, thus automating the design process to provide detailed results.

Three different workflows were developed relying on capabilities of modelling platforms. Different workflows require different sets of additional tools. They share a common objective: the generation of a reactive facade, comprised of panel systems, optimized against solar exposures for a particular location. The two processes begin to diverge when the study looks into both a static application, optimized for annual averages, and a dynamic system capable of responding on an hourly basis.

The static system provides a more direct method of optimization. Additionally the final geometry can be more directly integrated with Autodesk Revit® Architecture and other BIM components. While BIM software packages are robust in their practical applications, this study demonstrated their limitations for linking facade geometry to be updated and re-evaluated, when large changes are made to the design model. Consequently, instead of importing a dynamic file that links to the facade shape, it is rather an object on its own, listed as a shading device that cannot respond to changes in geometry without running the process again. Furthermore, spaces are not recognized as thermal spaces outside BIM software limiting the cross-platform data exchange to analyses other than thermal simulation.

However, the benefit of using static components is the use of Autodesk's built-in energy modelling. Any imported shading device from Rhinoceros®/Grasshopper® can be used directly in the environmental model of Revit®/Vasari® as a shading device. Autodesk's model can show the resulting influence of these surfaces on the building's estimated heating/cooling performance, operation cost, comfort and lighting. While not being able to achieve a variable, fully dynamic surface, the final objective of this method was validating building performance. Without validation of even a simplified system, the scope of practical application for these shading surfaces within the industry remains very narrow. Cost and feasibility are equally relevant to the success of practical application, however the system must provide an effective result in its primary purpose before other validation takes place. This method is ideal for a single, non-operable system optimized for average/cumulative annual solar shading.

To achieve a dynamic system that is updated on an hourly basis, the Rhinoceros®/Grasshopper® model is linked to Autodesk Ecotect® via a plugin called GECO³®. GECO® facilitates real-time data exchange between both software packages. The solar path can be traced/imported into the Rhinoceros® model through Grasshopper's parametric engine; changes in solar position/angle directly affect the models response. This allows for more complex panel systems or other large quantities of variable shading components to be automated and animated. However, this dynamic adaptive model is only capable of running in the Rhinoceros®/Grasshopper® environment and can only be exported to BIM models as a "baked" or finalized model. The individual panels and their variable apertures cannot support reciprocal communication between parametric and simulation tools. Therefore, the design process cannot be interactively visualized.

A way to circumvent this constraint is by using interoperable tools within the same platform. While this dynamic model has its export limits into BIM platforms, it can still execute energy and performance calculations within Rhinoceros®/Grasshopper® for similar validation. GECO® allows Ecotect® to import geometry from Rhinoceros® and calculate building performance, thermal values, solar radiation and day-lighting separately. This allows users to perform complete conceptual design and mass modelling in Rhinoceros® with the benefit of seeing design changes in real time and make faster more informed decisions. With the exception of dynamic solar values, the Rhinoceros® model can be exported to Revit® to proceed with BIM modelling and documentation. Both processes have their limitations when used separately, but when used simultaneously in the same project they can yield similar results for design and energy modelling. Using both methods allows for cross referencing their results in order to balance the design further.

1.3. Parametric design and simulation

Static platform

An experiment on static workflow is based on Revit®/Vasari® platform. Simple models are employed. With a static system the process can begin with traditional mass modelling methods such as the provided capabilities in Revit® or Vasari®. This study uses a standard Torus geometry component in the Vasari® library (Fig 1). The torus was chosen for its continuous surface subject to variable solar exposure. The scale is chosen to model at minimum five stories, Vasari® then automates the massing of the floor slabs in the 'modify mass' tab and approximates spaces and circulation when a benchmark analysis is enabled. The analysis is executed using the provided default setting for typical construction types, materials, glazing and location.

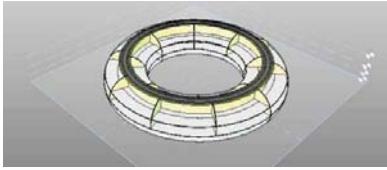


Figure 4: Torus geometry used for analysis

This baseline simulation calculates energy use intensity, life-cycle cost, emissions, heating and cooling loads, based on data from a weather station in the location selected. Additional variables considered in the calculation include floor area, exterior wall area, average lighting power, occupancy load, and exterior glazing ratio. After this benchmark is complete, another simulation model is created by increasing the exterior glazing ratio to a fully glazed façade. These two analyses show the extremes in building performance and give insights towards the direction of optimization. For example, comparing a 40% typical glazing construction to a 90% glazing construction shows a significant increase in the monthly electrical consumption. The optimization of performance can take place within this preliminary mass model by selecting the construction types and variables desired and then further investigate those in the Rhino®/Grasshopper® environment. The benchmark model selected for this study is the high glazing extreme.

Cross-platform

For this study, a triangulation pattern is selected in Revit®/Vasari® and set to full glass panels which are exported as (.dwg with ACIS solids format) for use in Rhino®/Grasshopper® as mesh geometry. Mesh geometry is imported by system default as exploded single surfaces based on the UV divisions chosen in Revit®/Vasari®. The grasshopper definition's first task is collecting all surfaces and relating these to the rest of the process as one single entity comprised of points for generating new panels. Grasshopper® has built-in capabilities to organize all point geometry of a mesh and apply an individual panel to each surface based on a standard model. The standard geometry used here is a diamond surface similar to the division created in Revit®/Vasari®; it is then divided into two smaller triangulated components. Along this division line, the aperture is created at the centre by generating two edges that symmetrically increase the space between them (Fig 5).

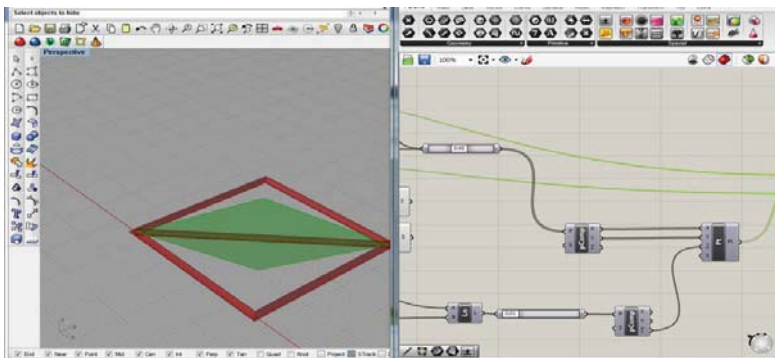


Figure 5: Aperture division in two panels (Rhinceros®) and controlling definition (Grasshopper®).

The primary plugin that is required to initiate this process of mesh management is called Weaverbird®⁴. This Grasshopper® plugin enables the model to sort and organize the divisions of mesh geometry but more importantly contains management tools such as 'Mesh Edit' that refines the imported geometry into an organized set that comprise one refined group to be exported into Ecotect® to obtain solar radiation calculations. The object is exported as a whole via GECO® from Rhinceros®/Grasshopper® but individual panel geometry, originally exported from Revit®/Vasari®, receives its own calculation. GECO® sets up simultaneously within Grasshopper® and Ecotect® the environmental parameters based on weather files similar to the Revit®/Vasari® data. Since both software packages use the same weather files and Ecotect® calculation, the consistency of results is maintained in both project files.

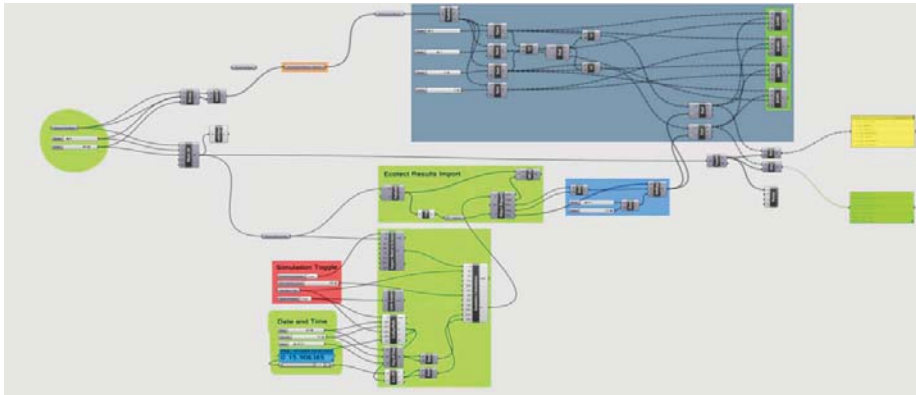


Figure 6: Overall parametric definition controlling the apertures
 The Grasshopper® definition is set up to import solar values based on a domain range and then converts this set of values to correlate with panel aperture (**Fig 6**).

Dynamic platform

This dynamic method can begin entirely in the Rhinoceros® environment. It has much wider capabilities for conceptual modelling because it is a NURBS-based system (Non-uniform rational B-spline). Users can maintain complexity in the initial design phase by including Grasshopper® definitions when creating changes in the model for iterative solutions. Once a form is selected -in this scenario, a variation of the Möbius strip⁵- the Weaverbird® plugin is essential for dividing the surface into a UV panel system similar to the automated process that Revit®/Vasari® provides. The benefit of this method is that all the modeling, surface division and analysis can be completed without any intermediate exporting across platforms. The overall process from form generation to analysis and validation can be completed in the Rhinoceros®/Grasshopper® environment via GECO® and Weaverbird® plugins. The final export of this method will serve solely for BIM models to import as a component for the documentation, as well as a Revit®/Vasari® building energy model.

After the building façade has been divided to desired parameters, the same definition components used in the static process for creating adaptable panels is used again in this method. Again the system Rhinoceros®/Grasshopper® system contains by default these components to organize the divided geometry into a point list that can reference the individual panel design as multiple surfaces, complete with access to the panel number, location in relation to the surface and its aperture values that will be accessed from Ecotect® via GECO® (**Fig 7**).

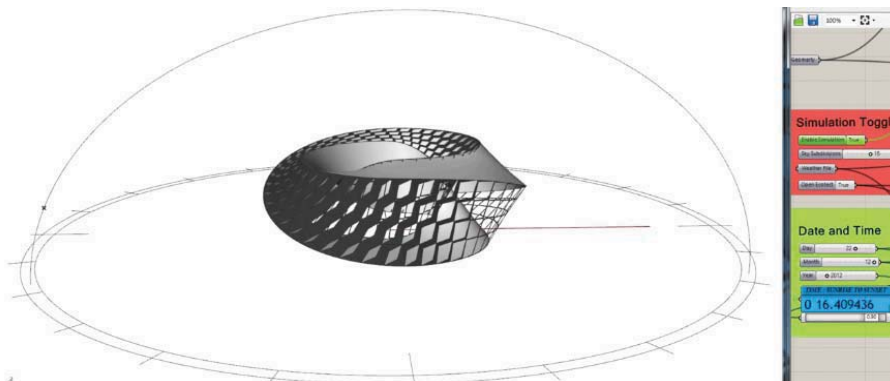


Figure 7: Möbius surface geometry used in the later stage of analysis

The similarities in both methods here is from the processing of the geometry to GECO® for Ecotect® and then finally taking the values of Ecotect® results and remapping their domain ranges to match a logical domain for controlling shading aperture, distance, rotation and any additional Euclidean transformations of individual panels. (**Fig 8**).

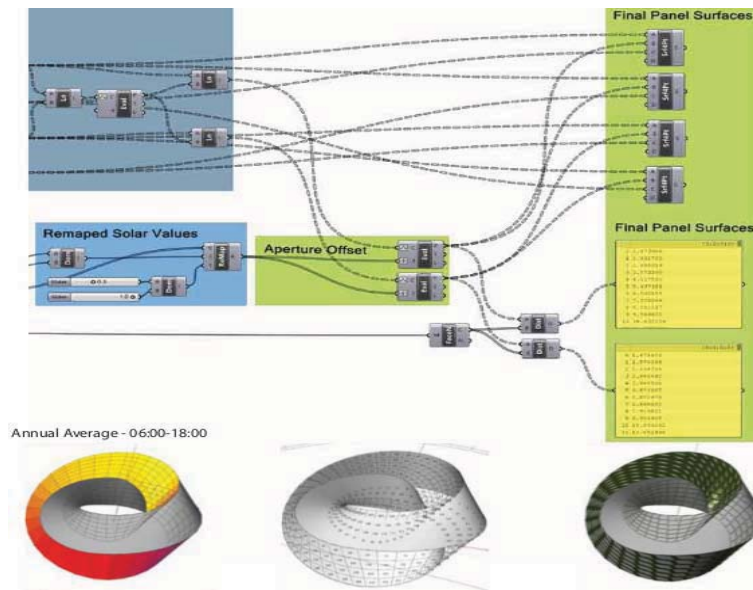


Figure 8: Definition used for the panelization of Möbius surface geometry

1.4. Results

Static platform

This method allows for Revit®/Vasari® to automate a curtain wall system by selecting the mass model and applying a curtain pattern division. In addition, the study minimizes other variables by using all glass surfaces to compare the effectiveness of the façade system. This method prevents a portion of the optimized shading device from acting on a solid surface such as an exterior wall.

Cross-platform

The model is simplified and conceptual in order to reduce simulation time. The desired final output for these panels, once applied to the imported surface, is a list of data pertaining to aperture by individual panel, individual panel dimensions, and location in relation to other panels and their position respective to surface. This data is extracted through default grasshopper components and does not require additional plugins. Detailed assembly documents can show a final product's mechanical assembly and controls with future collaboration with manufacturers.

As the simulation calculates an average annual study for this static cross-platform model, the parametric model simply calculates one aperture per panel on the overall instance of the calculation. No further action is required in modelling. Ecotect® does however provide multiple options for type of radiation study, environmental factors such as cloud cover or window cleanliness and the default parameters are used in all options to provide consistency with the Revit®/Vasari® environmental modelling. The final averaged Grasshopper® geometry is 'baked' into the Rhino file as a group and again exported as an ACIS(.sat) file type for single object import into Revit®/Vasari®, this file format prevents unnecessary mesh geometry on already simplified surfaces. This should be loaded into the existing mass model from the previous simulation and included as such in a new building performance calculation (**Fig 9**).

Dynamic platform

To take this method further, and match the process automated by Revit®/Vasari® in the static model, we use the GECO® component to export the model to Ecotect® as a mass without reactive panels and then run building performance simulation. Simulation options include energy use intensity, life cycle cost, emissions, heating and cooling loads. These available simulations are exactly the same as those available in Revit®/Vasari®. Essentially, Autodesk Ecotect® is available in both methods. It is built into the Revit®/Vasari® platform and linked to Rhinoceros®/Grasshopper®. With the dynamic method, the model remains available for output of panel information and environmental calculations as long as Rhinoceros®, Grasshopper® and Ecotect® are running. For practical applications these platforms are running the simulation at regular intervals to create dynamic data lists to inform the final constructed mechanisms of a

façade. Additionally the simulation can be run at intervals and saved to create a spreadsheet, ideally organized with variables such as time of day, panel aperture, location of panel, and panel number. (Fig 10)

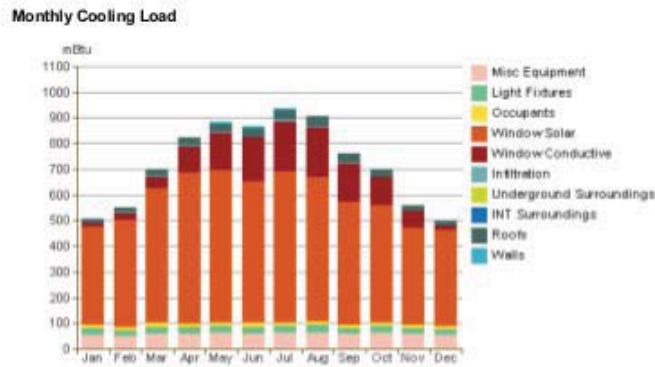


Figure 9: Graph showing monthly cooling load from toroid geometry

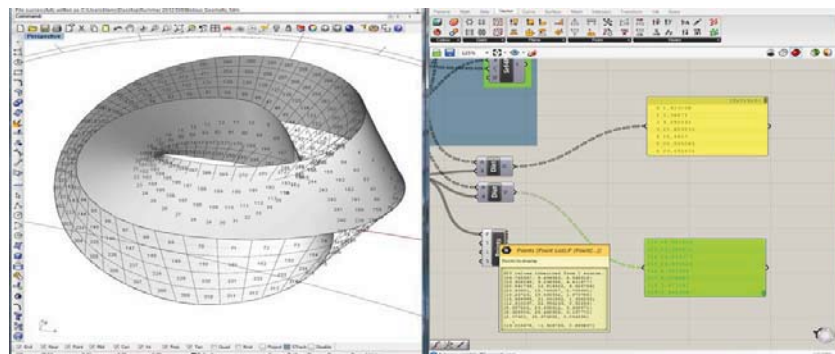


Figure 10: Panels labeled with simulation results

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CONCLUSION

This work has examined possibilities for integrating simulation and design tools to optimize performance of sunscreen designs. It explores three different workflows combining different software and plug-ins including parametric modelling and performance assessment tools. BRPH communicated to us the needs to develop digital design workflows which allow for flexibility and iterative design process while being designer friendly. The three workflows identified in the study include static, dynamic and cross-platform approaches to investigate static and dynamic screen configurations. The static platform is more suitable for simple design evaluation as it does not allow for sophisticated parametric control. The cross-platform is linear in terms of data exchange. Evaluated models cannot be imported back as parameterized model. Finally, the dynamic platform increases possibilities in both modelling and simulation taking advantage of interoperability across platforms. A combination of tools from cross-platform and dynamic platform can yield a more efficient design

workflow. We believe that both the design output and the flow of information are equally important within this investigation.

FUTURE DEVELOPMENT

The current stage of development aims to enhance the control of parametric definitions and refine the parameters to better reflect the constraints and necessities of design problems. According to **Fig. 3** this research's primary goal is to develop workflows that consider the expansion of all platforms to include more tools for performance assessment. The expansion will lead to the necessity to implement multi-criterion evaluation. Moreover, designers intend to test the current findings through hardware integration and detail construction development in a manufacturing process.

ACKNOWLEDGEMENTS

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- Weaverbird® for mesh topologies: <http://www.grasshopper3d.com/profiles/blogs/weaverbird-mesh-topologies-in>

ENDNOTES

- ¹ <http://aedasresearch.com/features/view/advanced-modelling/project/al-bahar-towers>
- ² SHoP: 2003, *Introduction*, in *Versioning: Evolutionary Techniques in Architecture*, Wiley-Academy, West Sussex, UK.
- ³ GECO® has been developed by [uto].
- ⁴ Weaverbird® for mesh topologies: <http://www.grasshopper3d.com/profiles/blogs/weaverbird-mesh-topologies-in>
- ⁵ This type of geometry was selected due to its differentiated surface orientations. Other architects have used the form (i.e. BIG's Astana National Library in Kazakhstan) and so we believe it is worth examining its performative potential.