USING PARAMETRIC ENERGY MODELING TO DESIGN OPTIMAL–PERFORMANCE HOUSING UNITS WITHIN AN EXISTING FRAMEWORK

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Abstract

We face an interesting time in the evolution of the design profession. With a long history of sequential professional service delivery, we are challenged by the need for more highly integrative and productive performance-based methodologies for design exploration, concept discovery, and content application. This is clarified further by the pendulum-like cycling of design interest from the classic categories of formalist patterning to parametric form making. A fundamental conflict in this arena is the habit-of-mind in which designers approach the making of architecture as an outside-in task; establishing a form boundary and then partitioning the functional layers of each 'story' of that volume into workable circulation and staging spaces. This outside-in approach contradicts the very lessons of form-making in nature. And with the many emerging interests in biomimicry, biomorphism, and biophilia, the timing could not be better for change, specifically, that a more appropriate 21st century architecture is achievable by mimicking nature in the 'growing' of a design across scales, from cell, to organ, to tissue. To do that, an anthropometric basis of 'walking on the land' is used to set the design space; using the operational realms of Ground, Surround, and Overhead for the growth of form assemblies as an aggregation of 27 fundamental performance zones. These observations set the context for the methodological design studies described herein.

Introduction

Architectural design has romantic roots. These trace to the individual efforts of the singular designer; celebrated in the work of the great, named Masters of the field from Vitruvius to Foster. And that history is amplified in the writings of those numerous personalities, each of whom has taken a controversial stand with regard to the role of the architect and/or the content of the design mission itself. Examples related to the work reported in this paper include: (1) the writings of Habraken (1976) on the role of supports in establishing open building design and user participation methodologies, (2) the writings of Venturi (1966) who offered a harsh critique of modernism as valuing the iconic duck over the decorated shed, and (3) the more contemporary arguments by Kolarevic (2005) on the role of parametric variability in the making of form. These historic swings of architectural discourse have codified *form* as the focus of design. The study reported in this paper has used those inspirations to frame an approach by which design is codified as a *participation enterprise,* seeking evidence-based operational performance at the highest level of systems achievement. Rather than approaching design as a problem-solving reductionist activity, this approach uses the structuring of the design space as a stepping stone for design as a value-creating proposition. As advocated in the writings of Lovins, we seek optimal operational performance of the system as an effective whole. We do not seek to optimize isolated efficient parts. To borrow from the late Louis I. Kahn, nobody needed Beethoven's Fifth until it existed; the hallmark of our search.

While energy modeling for building design has been available for some time now, and has evolved from the early Trane Trace 100 punch cards to more advanced, multi-aspect programs such as IESVE and Design Builder, parametric, multi-variable optimization has only recently become fine-tuned and commercially available through the arrival of the computational power needed to support such robust endeavors. This opportunity has led to the use of optimization to develop higher performing buildings, by fine-tuning the metrics of certain building elements, such as the thermal conductivity of enclosure, and related window-to-wall ratios.

The use of parametric optimization mostly focuses on early stage, form-finding analysis (Touloupaki, 2017). Using previous experience and these early-stage parametric studies, it is possible to limit the number of iterations for a final optimization, using a process called metaheuristics (Wortmann et al., 2017).

Modeling Methodology

This study aims to apply commonly available tools to develop a framework for parametric evaluation of the sustainability of urban form developments. Most modern urban housing blocks are built on a first-cost criterion with little consideration for energy performance and occupant well-being over the operational life. This framework uses parametric methods at multiple points during the design process to help the design meet higher performance standards. The core unit for this project uses its pre-set geometry as a 'growth cell' within a larger framework of pre-ordained aggregation. The space units/margins of the 'cell' are considered through disciplined iterations to inform the next design steps for effective (not efficient) and optimal (not optimized) performance. This core unit for urban form aggregation has been patterned with sustainability and energy performance as a driving concept.

This geometry delimits the exploration in form, but also presents a scenario that is different from many other parametric frameworks which begin with form as the focus. The current framework varies the glazing, construction types and roof geometry of the base unit. One of the roof types for the base unit is an expanded living space, referred to here as "the hat." In this early work, the hat is considered separately from the base unit, and would sit atop a base unit with an adiabatic roof construction. The units are varied using the key zones of the enclosure: ground, surround, and overhead. The first variable considered is the number of window striations. As noted, that aperture layering geometry had been predetermined, and like more common parametric aperture considerations, the varying window-to-wall ratios are achieved when these windows are turned "on" or "off" in the energy modeling environment, by the algorithm. The construction sets were varied based on the ASHRAE 189.1 standard minimums and the Living Building Challenge standards. Figure 1 shows the base unit geometry and accompanying daylight factor map, and Figure 2 presents the hat unit geometry and accompanying daylight factor map.

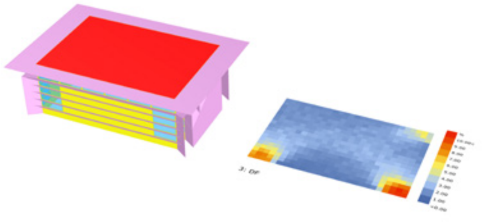

Figure 1: The base unit geometry and accompanying daylight factor map.

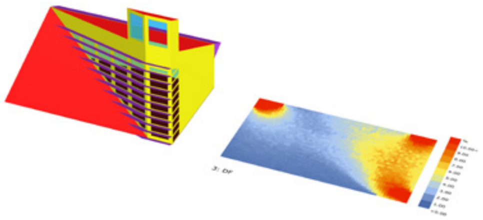

Figure 2: The hat unit geometry and accompanying daylight factor map.

These construction sets were separated by type and varied individually, so there could be a mix of construction types in any one iteration. These are all based on climate zone 5A, as the building was tested using an Indianapolis, IN, weather file. The roof geometry of the base unit also is programmed and varied, between a low-slope roof, a low-slope roof with an oculus, a low-slope roof with a pyramidal oculus, and a flat adiabatic roof meant to 'receive' the hat. Table 1 shows the initial run base unit variables and Table 2 presents initial run hat unit variables.

Input Parameter	Applicable Variables
Window Striations	6 Rows
Roof Geometries	Low slope adiabatic Low slope outdoors Low slope outdoors with flat oculus Low slope outdoors with pyramidal oculus
Wall Assemblies	Market rate R-12 Living Building R-33
Roof Assemblies	Market rate R-20 Living Building R-40
Floor Assemblies	Market rate R-19 Living Building R-27
Window Selections	Market rate U-0.42 Living Building U-0.31 Living Building U-0.29

Table 1: Initial Run Base Unit Variables

Input Parameter	Applicable Variables
Window Striations	10 Rows
Roof Geometries	Sloped roof
Wall Assemblies	Market rate R-12 Living Building R-33
Roof Assemblies	Market rate R-20 Living Building R-40
Floor Assemblies	Market rate R-19 Living Building R-27
Window Selections	Market rate U-0.42 Living Building U-0.31 Living Building U-0.29

Table 2: Initial Run Hat Unit Variables

Each of these iterations was automated using the Colibri Grasshopper Plugins, part of the TT Toolbox developed by Thornton Tomasetti. This automation 'clicks' through one option at a time, and the number of iterations multiplies by the number of variables proposed. For example, a shoe box building with three different roofs, three different walls, and three different windows would create 3 × 3 × 3 = 27, twenty-seven options. The hat unit had 264 iterations, and the base unit had 576 iterations. Each iteration is analyzed for energy performance through the Honeybee and Ladybug Grasshopper Plugins, an interface for OpenStudio and Radiance. The collected metrics for the study include total EUI, average daylight factor, and ideal air loads per unit area for cooling and heating. Using Design Explorer, a cloud-based data analysis program also created by Thornton Tomasetti, allowed for the visually accessible review of the results. The results of each optimization study were uploaded to this platform, and a range can be placed on any input variable or output metric, which eliminates those options not within these ranges, while displaying a small image of the current form. This study included a daylight factor map adjacent to the geometry. This makes it easier for the designer to find appropriate options based on the intended performance as well as other criteria.

The initial modeling pass for the base unit (Figure 3) was then used to influence a metaheuristic limitation on a further modeling pass. The team was able to place limits on the number of input variables based on output performance metrics. The two roof types with oculi were eliminated for starters because programming different ranges of roof types based on context proved too difficult. Then, an EUI limit of 60 kBtu/ft^2/yr was placed on the outputs. Then a limited range of daylight factor was applied, with a range between 2% and 4%. The total number of input iterations into the model with context was thereby reduced from 576 to 48. The number of window striations was limited to three options instead of six, and the code minimum wall option was eliminated. See Figure 4 for detail regarding the Design Explorer processing of the initial run on the base unit.

With these limited input variables, the 48 higher performance options were placed into a second Grasshopper script that placed the base unit within the fundamental context of 27 thermal zones in this urban block framework (Figure 5). This model ran 1,296 iterations, 48 high-performance units located in the 27 thermal zones of the building. The result of this is a large, data-filled Design Explorer environment, wherein the designer can limit either input or output parameters to pare down the choices. One of the input categories is a zone number, allowing the user to select the zones to examine (Figures 6 and 7). For the base application in these 'context runs,' a mechanical system of localized water source heat pumps with ground source heat rejection was applied for space conditioning. An ERV served as the ventilation source for the unit.

Modeling Results

Five separate modeling setups were run, and the results of the first four models determined the input parameters for the final optimization in context. The initial runs were performed with the base unit running through 576 iterations, all variables considered and multiplied. The first pass at the hat tuning was 264 iterations with all the variables considered. The base-unit-in-context run considered 1,296 options.

Conclusions

At this time, the study has verified the value of performance-based parametric studies structured by pre-ordained aggregate order. In this modular framework of the urban housing blocks, the aggregation can be strategically managed—for the performance impact of increased complexity from the variation of each individual unit or "cell." The rapid, simplified-result analysis tool allows for a range of performance goals to be selected, and optimal settings selected, enabling variations to flourish in each cell, based on its location and function in the aggregation.

Nonetheless, there are some limits to this method. The front-end programming of the study can be quite complicated, especially in regard to changing the pre-ordained form. It is also difficult to switch between groups of geometries that are made up of multiple different parts, such as a new roof assembly with skylights.

With the data of the base unit in the context of the 27 zones, the designer can select the optimal units for a specific location in this aggregation. The aggregation of the units at this time can be predetermined by the design team, whether based on a site constraint for the needed floor area, or other criterion approach.

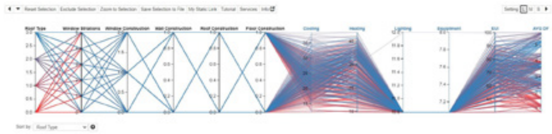

Figure 3: An image taken from the Design Explorer environment, showing the total runs of the base unit. Note, the input parameters are on the left in black and the output data is on the right in blue text.

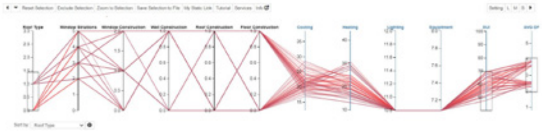

Figure 4: An image taken from the Design Explorer environment, detailing the limited ranges placed on the base to pare down the number of iterations in the context model.

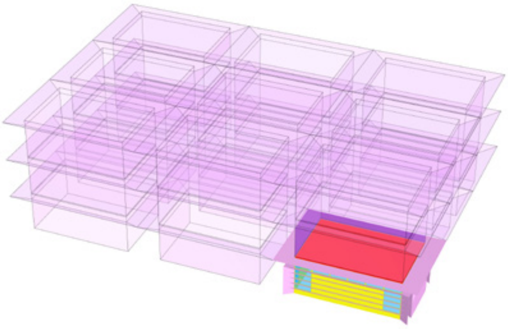

Figure 5: The base unit (yellow and red) placed in Zone 3. The 26 context units can be seen in translucent pink. The 27 zones come from each location's different exposure to the outside environment.

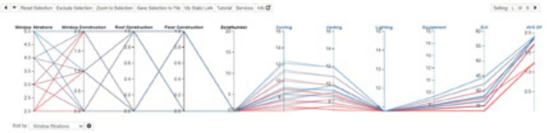

Figure 6: Design Explorer of base in context run. This image shows the options produced with Zone 1 selected.

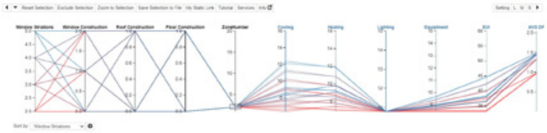

Figure 7: Design Explorer of base in context run. This image shows the options produced with Zone 2 selected.

The next step in this research project will be to automate the 'growth' of aggregated units, with each one being tuned for its location. That way the computer-generated collage of units would reflect the biomimicry goals of the study; much in the spirit of the 'form' of a tree 'growing' toward the sun. This success could offer a new method for enabling building form to be determined by effective whole system performance, and in turn yield a more sustainable built environment. Even with a self-aggregating system, the work of this study still can be useful at the cellular level of the building. If need be, the "cells" of the building can be "muscled up" to meet holistic and fine-scale energy performance goals, without changing a finely tuned aggregation.

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