Abstract. This paper describes the development of a workflow for the production of a net zero off-grid research cabin. The workflow deploys a number of affiliated parametric software packages as a form finding tool for the exterior envelope of this structure, with a focus on passive solar design as a generative formal driver. The design was required to incorporate the spatial and programmatic needs of the users in a compact, barrier free, net zero building. Simultaneously, the research question asked the designers to harness the potential of digital design in the consideration of future fabrication techniques, in order to optimize the building’s performance and the speed and quality of assembly once the project moves into construction. Parameters considered include solar exposure, external surface area, cost, fabrication, functionality, and aesthetic criteria. This project was developed by a multidisciplinary team of graduate students at the University of Calgary.

1. Introduction

Computational tools allow designers to model and simulate the effects of macro scale formal exploration and micro scale component/detail articulation throughout the design process. Within this system of design, there are a range of potential design outcomes. There are soft parameters, capable of shifting and evolving, as well as rigid constraints and solutions. A flexible approach to the softly articulated formal aspects of the design allows balance between the various objectives of the project and iterations between multiple potential solutions. Flexibility in the approach to the overall envelope allows for the negotiation of generative drivers that exert influence on this form. This paper will focus mostly on this area of the research as, at this stage, it is the primary concern. Simultaneously, the
research question asked the designers to harness the potential of digital design in the consideration of future fabrication techniques, in order to optimize the speed and quality of assembly, as well as post-construction performance.

The proposed project site is the home base for local and international researchers conducting studies of a fundamental and applied nature. The project team was given the opportunity to design a new structure to replace the deteriorating accommodations currently on site. Using passive solar design techniques as the generative driver, the proposed design for the new facility is a modern, sustainable, and multifunctional space. The design was required to incorporate the spatial and programmatic requirements of the users in a compact, barrier free, net zero building. Budget, construction techniques and site constraints were all important parameters in the development of the overall formal strategy.

2. Existing Work and Problem

In order to open the design to new possibilities, the design team employed a generative system that required “the computational specification of the principles of the formation of a design (artifact), which open[ed] up a design space for the exploration of design alternatives and variations” (DİNO 2012). This generative system was situated on a continuum between two differing modes of architectural conception. At one end of the continuum is soft form, produced through a design methodology marked by vagueness and indeterminacy, where the parameters controlling output are easily manipulated towards a specific end.

The fluid nature of this type of design process lends itself to the creation of speculative projects, such as Greg Lynn’s Embryological house, where a “rigorous system of geometrical limits liberates an exfoliation of endless variations” (Rocker 2006). At the opposite end of the continuum is a rigid design process where the final form is a direct result of specific criteria and distinct parameter ranges that constrain variation (Figure 1).
The design of buildings that make use of active and passive solar energy collection lends itself to computational logics that result in rigid form, with optimized energy performance being the primary design objective. An example of this includes the Endesa Pavilion, a rigidly articulated form created by the IAAC, in which a specific, strict set of constraints were driven through computational design tools to create a “wooden solar-tracking facade system... based on parametric modeling and digital fabrication” (Markopoulou and Rubio 2013). Other solar design work is being done to employ computational methods to drive more efficient solar designs, as shown in the work of Luisa Caldas. Caldas investigates the role of evolution-based generative design in creating sustainable and energy efficient architectural solutions (Caldas and Norford 2003; Caldas 2008). The results of Caldas’ work are architectural forms that are energy efficient compositions of highly rigid truncated and full rectangular forms. Recognizing this, Caldas and Norford identify that there is a need for “incorporating dynamic constraints into the system, so that an extra degree of flexibility is added” (2003).

Building from Caldas’ body of work, this project attempts to establish a workflow that incorporates softness and adaptability as dynamic constraints to add flexibility, culminating in the development of a computationally generated yet rigidly articulated form which is responsive to site, climate and program. The resulting workflow engages optimized solar design principles as formal drivers within a computational process geared towards the production of soft form. This workflow acknowledges the solar, aesthetic and functional performance of the architecture simultaneously, allowing for the production of a highly variable formal set that can be evaluated against these criteria. The final form integrates solar optimized geometry, the required spatial criteria, and the aesthetic and programmatic decisions developed by the design team.

The workflow outlined in this paper relies on the methods for introducing temporality and vagueness as described by Greg Lynn in his essay “Animate Form”. The workflow takes advantage of field conditions and point charges to produce soft, or indeterminate geometry, incorporating elements of “force, motion and time” which Lynn describes as traditionally excluded from discussions of architectural form due to their “vague essence” (2004). This project incorporates aspects of the design model proposed in Animate Form. In this case, the elements of “force, motion and time”, which animate the project and produce variation and multiple potential iterations, are the various fitness criteria and design parameters.

In 2003, Branko Kolarevic described a process called “Performative Morphogenesis”. This approach posits an integrated workflow in which “low resolution” performance simulation occurs dynamically at the
conceptual design stage, allowing the building form to be shaped by analytic computational tools (Kolarevic 2003). Until recently, the use of simulation and performance optimization tools were limited to highly specialized consultants, and typically took place after the building was designed. Today, with the evolution of parametric design platforms such as Grasshopper to include multi-objective optimization and environmental simulation plugins, this process is readily available for designers and can be implemented to augment the conceptual design workflow.

In the design of the research cabin, a multi-objective evolutionary solver was deployed both as a tool for optimization as well as a form-finding aid, along the lines of Malkawi et al.’s discussion of evolutionary-based generative processes: “The advantage of such an evolutionary approach is the creation of diverse sections of the state space that meet performance targets and increase the possibility for discovering a variety of potential solutions” (2003).

This work differs from existing work in the field through its use of animate form, a fluid and indeterminate formal system, to create a matrix of possible geometries, then driving these forms through a series of rigid requirements (in this case, solar optimization), followed by the constant refinement of these forms towards a more rigid end.

3. Investigation

The techniques employed in this workflow (Figure 2) exploit plugins designed for Grasshopper3D, a parametric extension of 3D modelling software Rhinoceros 3D. These plugins include Cocoon, an isosurface meshing tool developed by David Stasiuk; Octopus, a multi-objective evolutionary solver developed by Robert Vierlinger at the University of Applied Arts Vienna with Bollinger+Grohmann Engineers; and an environmental analysis plugin developed by Mostapha Sadeghipour Roudsari called Ladybug. The integration of multiple digital tools allows for a workflow in which a low-resolution building model is able to morph between soft forms, based on point charges and field conditions, and an environmentally optimized form, based on hard geometric constraints.
An optimal range of values based on passive solar design principles was established for length, width, roof/wall tilt angle, orientation towards south, and the floor area of the building (Figure 3). These ranges were input as number sliders into Grasshopper to create a simple, shed-like form which could then be parametrically adjusted.

This rigid geometry was then populated with randomly seeded points, which were given a variable charge (Figure 4). The resulting field condition was meshed to create a soft form, which was then tested using Ladybug to determine the total annual solar radiation falling on the surfaces.

The final stage input the objectives and genome into the evolutionary solver. The advantage of using Octopus as the evolutionary solver is that it can compare multiple objectives at once to find the most balanced solution between them. The chosen objectives were the floor area, surface area,
volume and total annual solar radiation. The gene inputs were the building length, width, height, roof/wall tilt angles, orientation from south, and the number and seed of the point charges generating the soft form.

As the evolutionary algorithm ran, it continually iterated through variations of form (Figure 5). The response of each iteration to the drivers varied, from the optimization of a single parameter at the expense of others, to a best-fit balancing of all input parameters. The algorithm was allowed to run for ten generations, after which time the variation was limited to a narrow band of optimized values.

The Octopus interface charted the range of potential forms on a 4D graph (Figure 6). This allowed the designers to quickly sort through the hundreds of generated forms, investigating clusters which had developed similar “mutations,” eliminating outliers and unusable variations and finding areas where objectives were balanced within optimal “sweet spots.”

The resulting forms were selected and culled to a matrix of optimized forms with potential for further development (Figure 7). The metrics of material and labor efficiency, assembly, ease of construction, and overall budget became considerations as the form was edited based on the formal, aesthetic and programmatic preferences of the design team in response to site conditions and physical limits, such as maximum height and floor area.
The geometry of the form was refined within these limits to suit the predetermined program requirements. An entry vestibule and a roof overhang were added to protect against excessive glare and solar gain in the summer. The final, edited form was then re-evaluated to analyze its solar performance. The form selected from this secondary workflow was the one that best met the performative criteria for function, solar energy production, buildability and aesthetics, and provided a conceptual model for further design development.

4. Results and Discussion

The workflow presented provides the designer with an opportunity to define a set of soft parameters and a range within which a number of potential solutions can exist. The designer’s role involves selecting between various iterations of emergent soft form and subsequent editing towards a more rigid form. The result is a building envelope whose geometry is optimized for the collection of solar energy, while also balancing the optimal ratios for passive solar heating and floor area demanded by the cabin’s program. This form provides a model for further testing and refinement.

The form is optimized for solar collection across its southern faces through surface area, orientation, and tilt angle. This provides an opportunity to embed a building integrated photovoltaic [BIPV] system (Figure 8) which is advantageous from budgetary, environmental, and aesthetic standpoints. As demonstrated in Figure 9, a BIPV system has the potential to provide an estimated 8,092 kWh of electricity per annum. The division of one southern face into an easterly and a westerly face, a result of mutation within the form finding process, further increases overall solar optimization, providing a higher daily and yearly consistency of generation. This analysis demonstrates that a workflow which allows for indeterminacy can generate positive results which could otherwise be overlooked in a prescriptive design process.
Figure 8. Cross section through BIPV system

Figure 9. Final form in situ solar/electrical analysis

Inserting floor area and building volume into the workflow as design parameters establishes the overarching programmatic and functional aspects of the design as drivers of the soft form iterations, and provides a functional result. Selective culling of forms ensures an appropriate volume and floor space, allowing for a plan capable of meeting the internal barrier-free requirements, hosting the required number of personnel, and meeting the need for occupant comfort (Figure 10). The optimized envelope provides a unique geometry that, when expressed on the interior, creates an engaging atmosphere.

Editing and refining the form is also paramount to maximizing its balance and efficiency for prefabrication, transportability and budgetary requirements. Through a rigorous editing and evaluation process, complex geometries can be simplified to a more rigidly articulated form without loss of performance or the essence of the soft form that produced it. The amount
of editing and simplification can vary greatly across projects, depending on a variety of factors including construction costs, techniques, and overall buildability.

While the workflow was successful in the production of a unique envelope, optimized for a high degree of solar efficiency, opportunities remain for the development of a more robust process. The workflow, with the employment of Octopus as the evolutionary solver, has the potential to include a greater degree of analysis within the generation of soft formal iterations for refinement, including structural analysis and a more robust modelling of site conditions that contribute to the overall solar performance of the project. Additionally, the evolutionary solver does not account for building details that are heavily influenced by the changing form of the project, such as wall/roof connections.

Figure 10. Floor Plan

5. Conclusion

The project provides an originating point for several discrete branches of research, including the potential for future post-occupancy research into the behavioral and energy performance of the built form, and comparative analyses of cost data between the outputs of this project’s workflow and more traditional methods of solar optimized design. In addition, opportunities for refining the developed workflow exist. These range from more accurately calculating the effects of site context and shading within the solar analysis of the generated forms, to the definition of building details that necessarily need to adapt with each formal iteration, to the inclusion of further analytic potentials such as the structural efficiency of each formal output. This increased analytic potential programs a greater degree of performance optimization into the conceptual design of the project, further
exploring the potentials of computational generation outlined by Kolarevic (2003) and expanding the range of virtual forces that can contribute to the formal generation of the project (Lynn 2004).

Further research in this area would need to examine construction processes for comparative analysis between projected and actual data, investigating whether construction optimization was achieved through the current iteration of the workflow and developing strategies for improvement based on these findings. In addition, the workflow needs to be further refined in order to relate more directly to questions of buildability, including differences in materiality, structural performance and efficiency of construction. The current workflow is successful at the creation of soft forms containing embedded rigid logics, but the rigid logics contained in these forms are currently limited to energy efficiency and solar optimization. There remain opportunities for the inclusion of more generative criteria in the early stages of the workflow, programming further information into the form itself as opposed to manually editing the resulting form to consider such criteria.

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References


