Structural morphologies and sun transmittance control: integrated parametric design using genetic algorithms

M. Turrin  
Faculty of Architecture, Delft University of Technology, Netherlands

P. von Buelow  
Taubman College, University of Michigan, USA

R. Stouffs  
Faculty of Architecture, Delft University of Technology, Netherlands

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With specific reference to the case of modular wide span roofs, in this paper we discuss the support given by parametric modeling and genetic algorithms to performance oriented design. Performance oriented design searches for forms and materializations based on their performances. Aesthetics, structural performances and economics often dominate the design process when focusing on large roofs. However, the current increase in attention to energy-related aspects generates new challenges which require special attention. Particularly, the use of renewable energy resources needs to be confronted in the design. Based on this, structural morphology and solar energy transmittance have been selected here as key aspects.

Parametric modeling is presented as a support in the conceptual phase of a performance based design process based on its potential in generating design alternatives. This technique has in fact the capability to represent both geometrical entities and their relationships. These relationships are structured in a hierarchical chain of dependencies, established during the preliminary parameterization process. The independent properties of the model are usually expressed through independent parameters, and their variations generate different configurations of the model. After having been automatically created, the different instances of the model can be explored with respect to a given set of performance oriented design criteria. Due to the breadth of the solution space, its systematic exploration is however not possible when left to the intuition of the designer, and the integration of other computational supports is here considered to further support the design process. With respect to this, Genetic Algorithms (GAs) are here specifically discussed. GAs are cyclic search techniques which operate on generations of large sets of design solutions (populations). Operations including recombination, mutation and selection progressively shift successive generations toward solutions which perform better when evaluated with respect to a given single or multiple criteria (fitness function). Combining parametric models with a GA optimization is therefore proposed as well suited to address the creation of instances which perform better with respect to the fitness function. This potential is at the base of the ParaGen method, a design tool currently in development. By using a series of both custom written and commercial software packages, ParaGen constitutes a cycle which links three basic steps: the assignment of values to the independent parameters; the generation of the corresponding geometry; and the evaluation and selection of generated solutions based on performance. Specifically, GA routines are used to select the values of the parametric variables; parametric modeling software (e.g., Generative Components) is used to create different instances of the geometrical solution; simulation software for the analysis (e.g., STAAD-Pro for structural performances, and Ecotect for solar energy evaluations) are used to evaluate the generated instances. Two examples based on this cycle are discussed. The first example was developed as a master student
project tutored by the authors and focuses on structural morphology. The structural geometry of a dome was modeled based on points distributed along rings. The parametric variables regulated the number of rings and the number of points per ring, thereby allowing the generation of design alternatives based on different densities and distributions of the points. For each configuration of the points, segments (representing the structural bars) were generated by following either Voronoi diagrams or Delaunay triangulations. For both, the ParaGen method used a finite element analysis to determine member forces under a simulated snow load and the cycle of selection, recombination, and evaluation was used to optimize and explore the solutions. The second example is currently used by the authors for exploring a large roof with respect to thermal and daylight comfort of the spaces underneath. The covered area is subject to a risk of overheating in summer. The strategies for reducing this risk are various. In one instance, the example implements the use of ventilation for cooling on one side, and on the other side the control of the solar energy transmission through the roof. This latter is explored through the optimization process. The roof is modeled as a NURBS surface and tessellated with three-dimensional components representing the cladding modules. Based on an algorithmic pattern, each module is a combination of opaque and transparent glazed panels. By varying the density of the tessellation and the inclination of the panels, the cladding system is explored by searching for a solution that allows the maximum daylight transmission and the minimum solar heat transmission through the roof, in summertime; and the maximum daylight and solar heat transmission during wintertime.

The proposed method aims at supporting the designer in exploring wide ranges of parametric design solutions, driving the design process by performance evaluations in its early phase. Particularly, the potentials of the combined use of parametric modeling and a genetic algorithm have been shown by discussing the example of the ParaGen method. The presented examples concern structural and solar energy performances. However, the approach as well as the specific structure of the tool can further involve other performances as well. Beside the versatility of the method, the active role of the designer during the process is here recalled as a second positive aspect. Particularly, this becomes a key point both in parameterizing the geometry and in interactively driving the optimization process.

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References


