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GUEST EDITORIAL

Generative and evolutionary design exploration

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Expert designers, both architects and engineers, typically display a strategy of exploring design alternatives, albeit a relatively small number. Expert architects' strategy in problem solving can be denoted *breadth first, depth next*, in comparison to novices, who typically display less breadth of exploration (Akin, 2001). Although engineers' strategy is markedly different, design alternatives play a role that is as important, if not more important, than for artchitects (Akin, 2009). Where designers typically consider a very small number of alternatives in their work, this can be explained by cognitive limits, opening the door for computational support of design exploration. In particular, Woodbury and Burrow (2006) argued that exploration is a *compelling* model for designer action and that designers benefit from tools that amplify their abilities to represent goals and problems spaces, and to search for designs.

Generative and evolutionary methods have proven to be strong catalysts for design exploration, and design optimization has served as a means to assist in this exploration. Recently there is a marked move toward using optimization to aid exploration. Optimization is rarely intended to yield an optimal solution per se, instead assisting in gaining insight in the solution space, thereby reducing the size of the solution space for exploration, possibly focusing attention toward the Pareto boundary. Even at the Pareto boundary, there are a large number of solutions worthy of further exploration. Exploration and optimization together lead to a better understanding of the complexities of design issues and help designers in their decision-making process, especially with multiple-objectives problems, which is a nature of many design problems. As such, the focus of attention in generative and evolutionary design is shifting from the techniques themselves, and their direct application, to the way we are using these techniques to assist and improve the design and engineering process.

We might frame generative and evolutionary design from the point of view of a "conversation" in the sense of Donald Schön (1983); this is nothing uncommon for generative design, though it is for optimization. This type of conversation is between the designer (or design team) and the computer, and is digitally enhanced. As such, the aim is less on optimization per se and more on exploration: the results from optimization are about changing one's way of thinking more than choosing a single design and then realizing it. We can then ask the question of how these types of conversation can unfold. How do they start and where do they end? What to do with thousands of similar solutions?

The 11 papers in this Special Issue all address generative and evolutionary design exploration and contribute to the discussion of the interaction between design exploration and evolutionary design optimization.

Julian Eichhoff and Dieter Roller start off with "A Survey on Automating Configuration and Parameterization in Evolutionary Design Exploration." Focusing specifically on engineering design, they comprehensively review evolutionary design optimization approaches based on genetic algorithms (and genetic programming) addressing different design phases. Reformulating design problems as multiple-objective design optimization problems commonly reduces to parameterization, defining constants, and configuration, defining design variables, objective functions, and constraint functions. Methods from the fields of machine learning and natural language processing are reviewed to support these parameterization and configuration processes.

Herm Hofmeyer and Juan Manuel Davila Delgado, in "Coevolutionary and Genetic Algorithm Based Building Spatial and Structural Design," compare the use of a genetic algorithm with a coevolutionary method to collaboratively develop and optimize building spatial and structural designs. The genetic algorithm uses a finite element analysis method for evaluation of design alternatives. The coevolutionary method applies deterministic procedures to cyclically evaluate and improve the structural design via a finite element method and topology optimization, and adjust the spatial design according to the improved structural design and the initial spatial requirements. Both methods provide optimized building designs; however, the coevolutionary method yields

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better designs in a more direct manner, whereas the genetic algorithm based method offers more design variants.

Odysseas Kontovourkis, Marios Phocas, and Ifigenia Lambrou, in “Adaptive Kinetic Structural Behavior Through Machine Learning: Optimizing the Process of Kinematic Transformation Using Artificial Neural Networks,” examine the application of machine learning to the adaptive behavior of a kinetic structure in order to explore suitable solutions resulting in final appropriate shapes during the transformation process. Specifically, a control mechanism based on artificial neural networks is applied to optimize the complex and nonlinear transformation behavior of the kinetic structure as a result of its components’ local activation influencing each other in a chaotic and unpredictable manner.

Sean Ahlquist, Dillon Erb, and Achim Menges develop a heuristic evolutionary algorithm for generating and exploring differentiated force-based structures, aiming at an “Evolutionary Structural and Spatial Adaptation of Topologically Differentiated Tensile Systems in Architectural Design.” The algorithm is weighted toward design exploration of topological differentiation while including specific structural and material constraints. In an application to a specific complex tensile mesh, the evolutionary algorithm, in combination with a mesh grafting method, is shown to produce emergent and highly differentiated topological arrangements that negotiate the specific relationship among a desired maximal mesh density, geometric patterning, and equalized force distribution.

Brian Simmons, Matthias Tan, Jeff Wu, and Godfried Augenbroe, in “Determining the Cost Optimum Among a Discrete Set of Building Technologies to Satisfy Stringent Energy Targets,” present the development of an optimization methodology for selecting the lowest monetary cost combinations of building technologies to meet set operational energy reduction targets. Starting from a design outcome, the optimization algorithm searches the discrete combinatoric space of properties of market-available building technologies by maximizing the calculated energy savings divided by the additional cost over a baseline solution. When compared to prescriptive methodologies, the optimization algorithm is shown to be more cost effective and generically applicable given a palette of building technology alternatives and their corresponding cost data.

Roya Rezaee, Jason Brown, Godfried Augenbroe, and Jinsol Kim offer an “Assessment of Uncertainty and Confidence in Building Design Exploration,” noting that performance assessment at early stages of building design is complicated by an inherent lack of information on the design and the uncertainty in how a building design may evolve to a final design. They propose an initial quantification of such uncertainty associated with building energy performance, develop a method for informing decision makers of the risks in early design decisions under this uncertainty, and apply the method to two case studies of building design using two different energy modeling tools: a simplified and a detailed model.

Patrick Janssen presents “Dexen: A Scalable and Extensible Platform for Experimenting With Population-Based Design Exploration Algorithms.” The platform is scalable to allow computationally demanding population-based exploration algorithms to be executed on distributed hardware within reasonable time frames, and extensible to allow researchers to easily implement their own customized toolkits consisting of specialized algorithms and user interfaces. A case study demonstrates how evolutionary exploration methods can be applied to a complex design scenario without requiring any scripting, using a multicriteria evolutionary algorithm toolkit to explore alternative configurations for the massing and façade design of a large residential development.

Zhouzhou Su and Wei Yan propose “A Fast Genetic Algorithm for Solving Architectural Design Optimization Problems,” addressing the issue of computing time in architectural design optimization using genetic algorithms when building simulation techniques are involved. Utilizing architecture-specific domain knowledge, they combine offline simulation with a divide-and-conquer technique to effectively improve the run-time in architectural design optimization problems. They apply this to a case study of a nursing unit design to minimize the nurses’ travel distance and maximize daylighting performance in patient rooms.

Thomas Wortmann, Alberto Costa, Giacomo Nannicini, and Thomas Schroepfer, in “Advantages of Surrogate Models for Architectural Design Optimization,” additionally address the issue of understanding a complex design problem. Specifically, they propose a surrogate-based optimization approach using a mathematical surrogate model that interpolates from data relating design parameters to performance criteria. Designers can interact with this model to explore the approximate impact of changing design variables and, thus, gain a better understanding of the design problem. The approach is applied to two architectural daylight optimization problems.

Rodrigo Velasco, Rubén Hernández, Cesar Diaz, and Nicolas Marrugo move the designer/user center stage in “Notes on the Design Process of a Responsive Sun-Shading System: A Case Study of Designer and User Explorations Supported by Computational Tools.” Computational simulation procedures are employed to explore configurational possibilities that provide high performance solutions to the light requirements of covered spaces. Taking advantage of the dynamic nature of the system, a further approach of control supported by fuzzy logic is implemented at the operative state.

Finally, Tiemen Strobbe, Pieter Pauwels, Ruben Verstraeten, Ronald De Meyer, and Jan Van Campenhout, in “Toward a Visual Approach in the Exploration of Shape Grammars,” present a visual and interactive way to support the exploration of design alternatives in a creative design process. Considering a rule-based, shape grammar approach, their focus is on the representation of the design space and its exploration, and on supporting several design space exploration amplification strategies, specifically, the generation of alternatives, interactive navigation, the backup of design states and paths, and the recall of these design states and paths.

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