Abstract

Design exploration is a creative process that consists of the incremental generation of design candidates. Supported by digital means or not, the process handles the ill-structured nature of design and allows creativity to flourish through diversity of design candidates. This research proposes a design framework for the generation of variant bar network topologies in static equilibrium which facilitates the conceptual structural design exploration. Named PEER (Policy-based Exploration of Equilibrium Representations) the framework:

- incrementally grows and transforms networks of bars within specified geometric domains;
- maintains their static equilibrium at every intermediate transformation step;
- is built around a parametric policy – a course of actions - controlled by a choice of four, explicit or abstract, rules;
- is not constrained to precedent or recursing topologies and/or geometries;

Structural design space exploration is achieved through the generation of schematic, early-stage static equilibrium representations which are indicative, but not deemed optimized, force flows. As such, they are valuable as first design inspirations, prior to comprehensive structural analyses and form refinement. The transformation policy operates on given loads, is free from maximum valency limitations and unbound to specific topologies and geometries. On the contrary, the network's topology is not known a priori, but it is defined during the decision-making design process and constitutes the main output of the exploratory process.

PEER transforms interim networks of bars, whilst the network maintains static equilibrium at every transformation step. Precisely, each transformation results in the introduction of a new node, some bar elements in tension and/or compression and a few interim internal forces. The number of interim forces decreases while the number of bars increases and the entire process ends when no interim force exists anymore, which is always achievable due to the retention of static equilibrium throughout.

Contrary to other approaches and thanks to the incremental growth of topologies, PEER opens the generative design black box. While the process can be fully automated, it also lets the designer interrupt, redirect, or backtrack to previous transformations, at every intermediate step of the transformative process. Additional control is granted to the designer through the combinatorial choice of rules.

The genetic algorithm's stochastic nature matches well with the concept of exploration and the provision of multiple design alternatives. The design space exploration capability of the presented workflow is therefore further augmented by coupling it with interactive genetic algorithms, operating for the course of a single, or multiple, policy-based transformation(s). Via the interactive user interface, the designer selects the mutation and crossover parents based on aesthetic or performance criteria – though optimization is out of the research scope – and steers the exploration process according to personal preferences.

Policy-based incremental design and interactive genetic algorithms can provide designers with infinite alternative design candidates. Consequently, they efficiently boost design space exploration, and their combination ultimately provides a new design workflow for conceptual structural design. Its capacity to unveil numerous, unprecedented, maybe unexpected, but statically valid, structural forms is illustrated through planar and spatial application studies.

KEYWORDS

Design space exploration, structural design, static equilibrium, bar model, topology, conceptual design, generative grammars, evolutionary design, policy-based design.